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# PGE CLIMATE CHANGE RESOURCE PLANNING STUDY

## October 26, 2022

Portland General Electric

IRP Roundtable

Portland General Electric

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**1. Review of Climate Change in Pacific Northwest IRP Planning**

2. Climate Change Modeling & Applications to Resource Planning

3. Incorporating Climate Change into PGE’s IRP Framework

4. Recommendations

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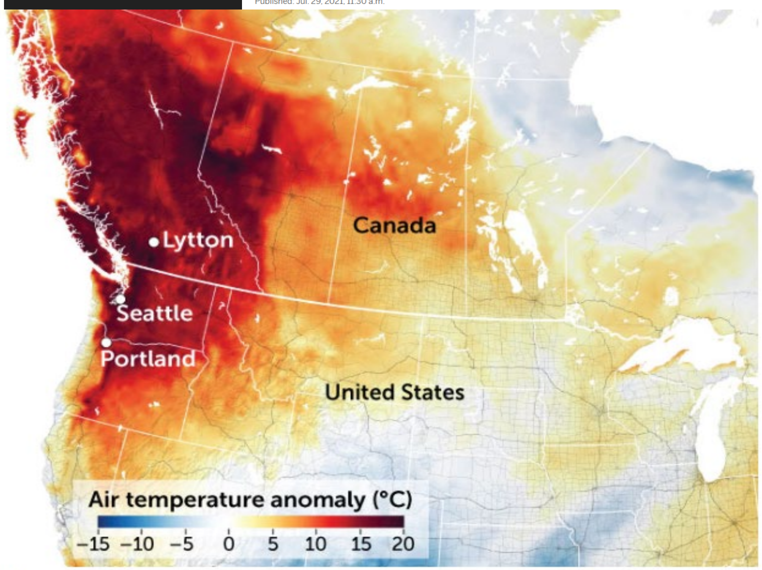
# Observable Climate Change Effects

OREGONLIVE The Oregonian

**PGE customers twice broke electricity usage records during June heat wave**

Published: Jul. 29, 2021, 11:30 a.m.




June 29, 2021 temperature compared with the 2014–2020 average for that day

- **PGE Peak demand reached 4,441 megawatts on 06/28/21**.
- This heat event is currently estimated to occur only once every 1000 years (1.2°C of global warming). [1]
  - Would occur roughly every 5 to 10 years in a future world with 2°C of global warming [1]

> *"The Pacific Northwest episode was so extreme that it did not fit our standard modeling approaches. To put this into human terms, this event should not have been possible."*
> – Flavio Lehner, Cornell Professor in the College of Agriculture and Life Sciences, discussing June 2021 Pacific Northwest heat wave.



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[1] https://www.worldweatherattribution.org/wp-content/uploads/NW-US-extreme-heat-2021-scientific-report-WWA.pdf

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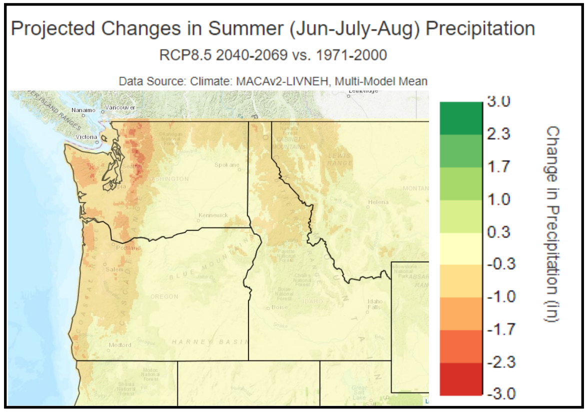
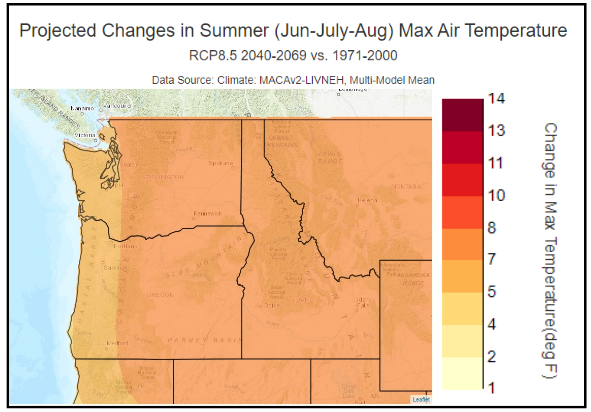
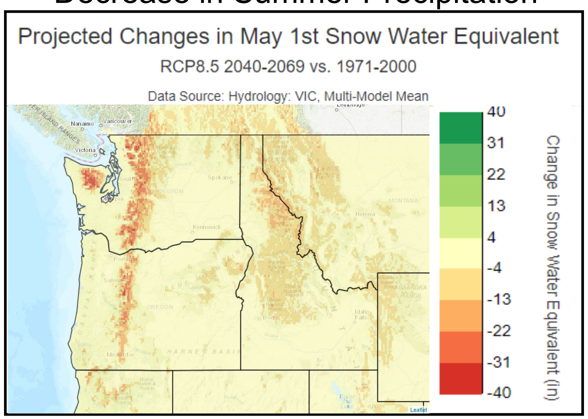
# Climate Change Impacts in the Pacific Northwest



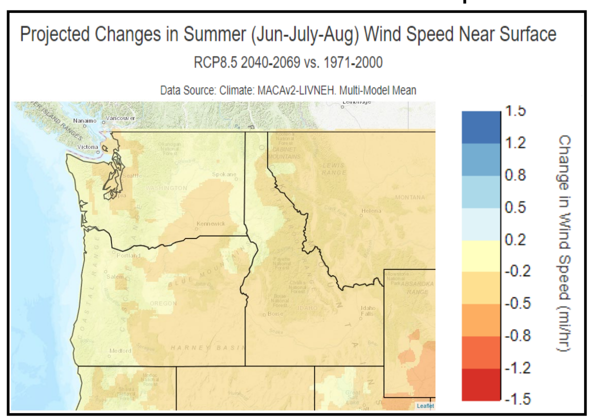

Decrease in Summer Precipitation




Increase in Summer Peak Temperatures




Decreasing Snowpack Entering Summer




Decreasing Average Wind Speeds

**Climate change will have a wide range of impacts beyond temperature increases [2]:**

- Additional impact on precipitation, snowpack, windspeed, solar radiation, vegetation, wildfire risk, sea rise, and more.
- Climate impacts will vary by season and region
- Projected changes influenced by emission scenarios used (RCP4.5, RCP8.5) and climate models selected





[2] https://climate.northwestknowledge.net/IntegratedScenarios/

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# Climate Impacts on the Power Grid

**Energy Demand**

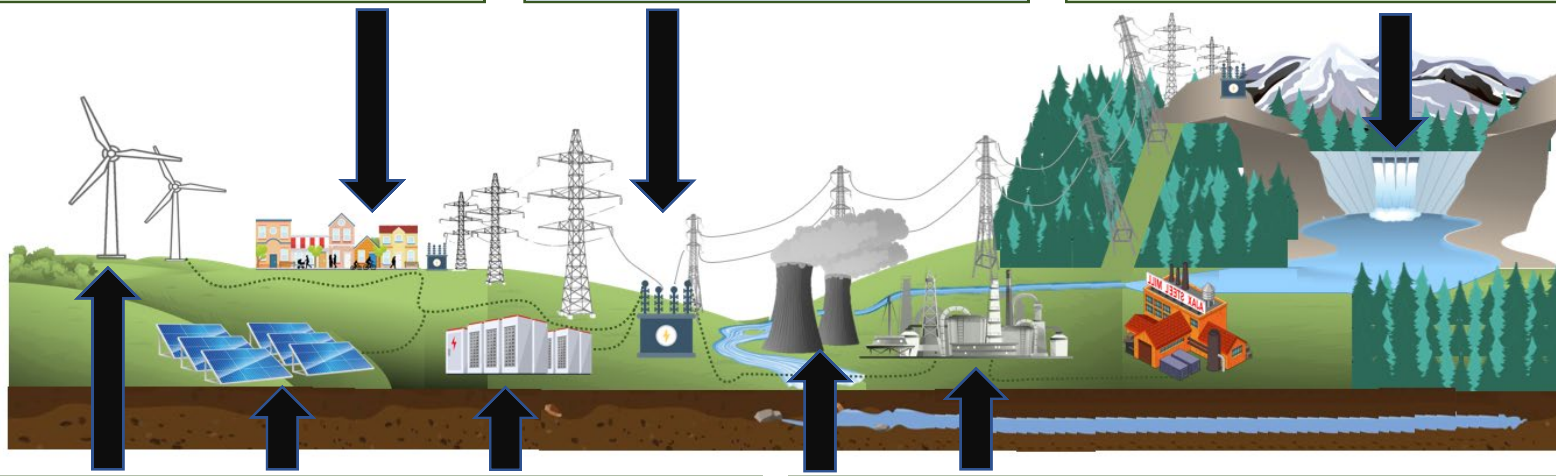
- Higher summer temperatures drive increasing cooling demand (electric)
- Higher winter temperatures reduce demand for heating (electric, gas)

**Electric Transmission**

- Increased heat reduces TX capacity
- Extreme weather (storms, wildfires) can cause additional forced outages to TX and substation infrastructure.

**Hydro Power**

- Earlier snowmelt shifts peak production earlier in the year.
- Drought and reduced runoff reduce power production.



**Renewables & Storage**

- Shifts in wind speeds and patterns impact wind generation.
- Increasing solar radiation and temperatures impact solar generation.
- Warming temperatures can impact RT efficiency of storage.

**Thermal Generation**

- Higher air and water temperatures reduce fuel conversion efficiency and cause nameplate capacity deratings.
- Reduced water availability for cooling can lead to shutoffs (FOR).

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# PNW Utility Review of Climate Change Impacts - I

| Utility | Source | Load & Gen Climate Risks in IRP | | | Notes: |
|---|---|---|---|---|---|
| PGE | 2016 PGE IRP – Climate Study | Electric Demand | Solar Gen | Thermal Gen | Climate change scenario analysis of load forecast based 20 CMIP5 models from the Oregon Climate Change Research institute Report (OCCRI). Hydro streams and wind impact were also reviewed in OCCRI report. |
| | | Hydro Gen | Wind Gen | Storage | |
| PSE | 2021 PSE IRP | Electric Demand | Solar Gen | Thermal Gen | PSE used three NPCC and BPA climate models to create future temperature and load scenarios. |
| | | Hydro Gen | Wind Gen | Storage | |
| Avista | 2021 Avista IRP | Electric Demand | Solar Gen | Thermal Gen | Avista used three state-level NPCC climate forecasts to create a climate scenario for load and hydro. |
| | | Hydro Gen | Wind Gen | Storage | |
| PacifiCorp | 2019 PacifiCorp IRP | Electric Demand | Solar Gen | Thermal Gen | PacifiCorp uses a climate forecast from a 2016 US Bureau of Reclamation study to create a climate scenarios for load and hydro conditions. Discussion on potential impact to solar/wind. |
| | | Hydro Gen | Wind Gen | Storage | |
| NorthWestern Energy | N/A | Electric Demand | Solar Gen | Thermal Gen | Public comments in IRP process regarding incorporating climate change. No references in 2020 IRPs. |
| | | Hydro Gen | Wind Gen | Storage | |
| Idaho Power (An IDACORP Company) | 2021 Idaho Power IRP | Electric Demand | Solar Gen | Thermal Gen | References BPA RMJOC climate study. Models a "climate change scenario" with an increased demand forecast associated with extreme temperature events. Climate scenarios used not explicitly discussed. |
| | | Hydro Gen | Wind Gen | Storage | |
| Bonneville Power Administration | RMJOC I & II (2010-2018) | Electric Demand | Solar Gen | Thermal Gen | Joint study with Army Corp where 80 climate scenarios were used to investigate impact on PNW hydro. |
| | | Hydro Gen | Wind Gen | Storage | |
| Seattle City Light | 2016 IRP | Electric Demand | Solar Gen | Thermal Gen | Used 20 climate models to determine impact climate change on hydro and load. |
| | | Hydro Gen | Wind Gen | Storage | |

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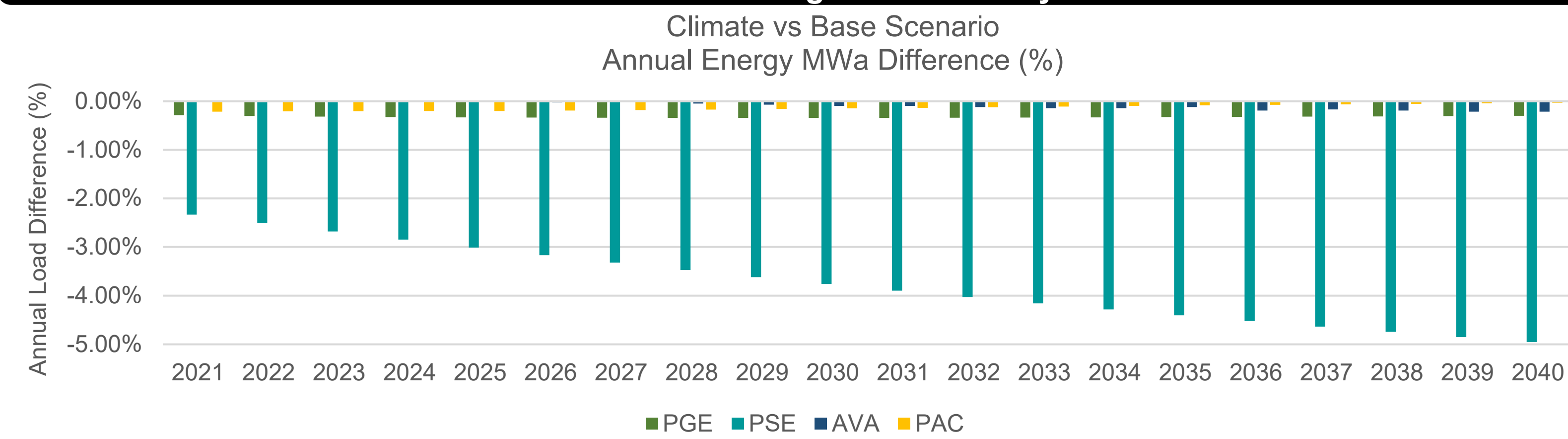
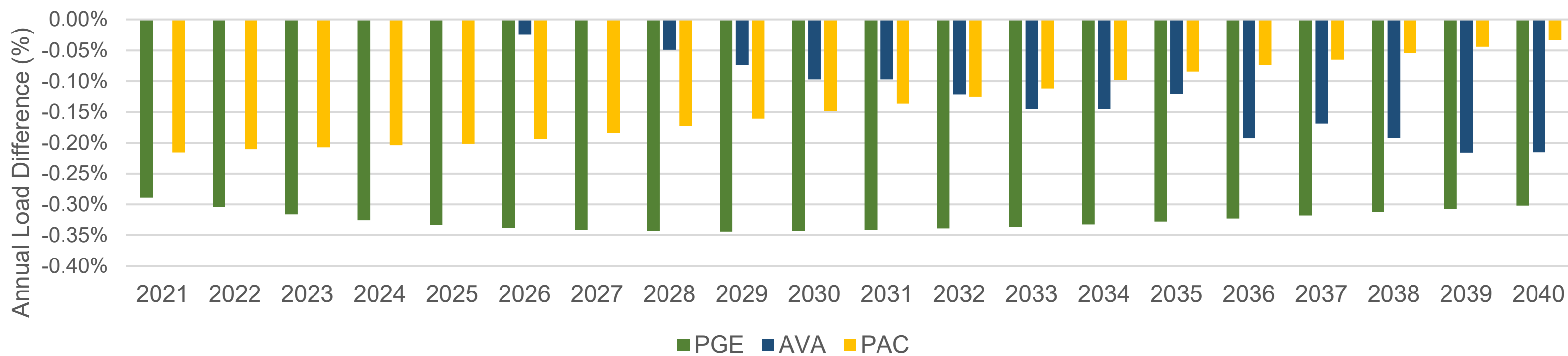
# PNW Utility Review of Climate Change Impacts - II

**Load modeling of climate change not apples to apples, but still informative.**
**2030 Annual load forecast 1% lower on average in PNW utility climate scenarios than base.**




NOTE: **PGE values based on 2016 IRP study.** PSE values based on 2021 IRP (does not include 2023 IRP workshop material).



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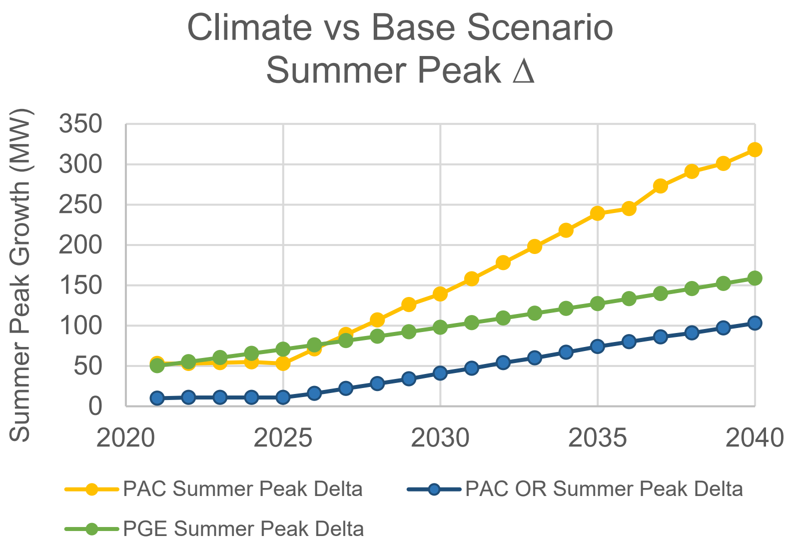
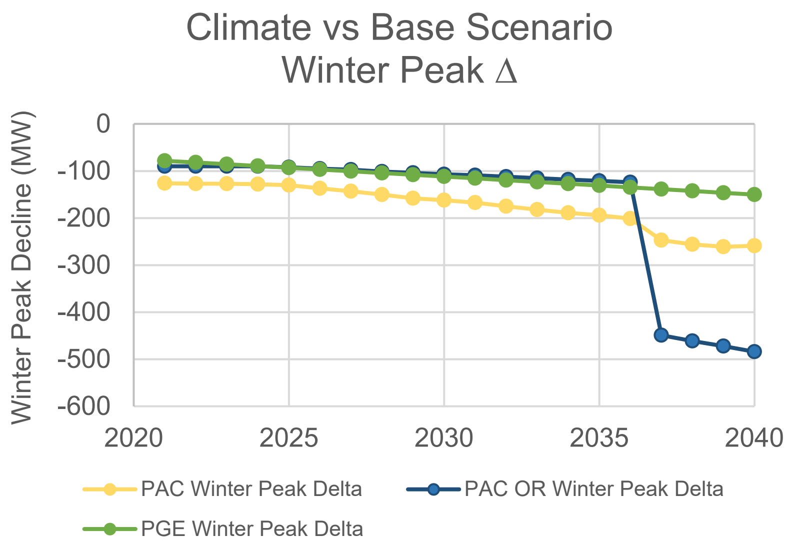
# PNW Utility Review of Climate Change Impacts - III

**Seasonal shifts in Oregon peak demand observed in PGE and PacifiCorp climate sensitivity scenarios (despite different set of climate ensembles utilized).**

- **Compared to 2030 base case, PAC and PGE summer peak increases by 2.7% and 3.9%, respectively.**
- **Compared to 2030 base case, PAC and PGE winter peak decreases by 1.3% and 2.7%, respectively.**



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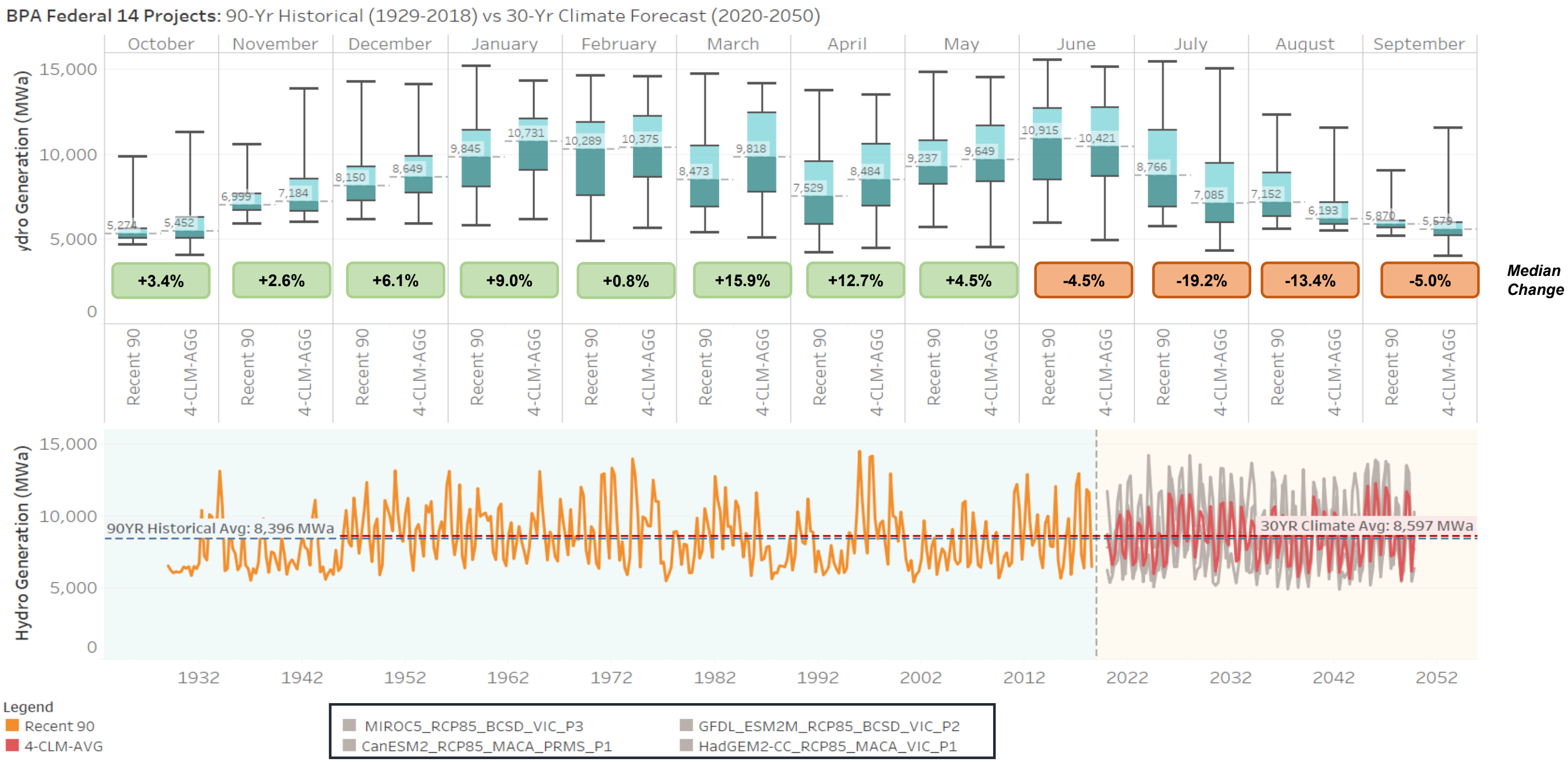
NOTE: **PGE values based on 2016 IRP study.** PAC values based on 2019 IRP study.

# PNW Utility Review of Climate Change Impacts - IV

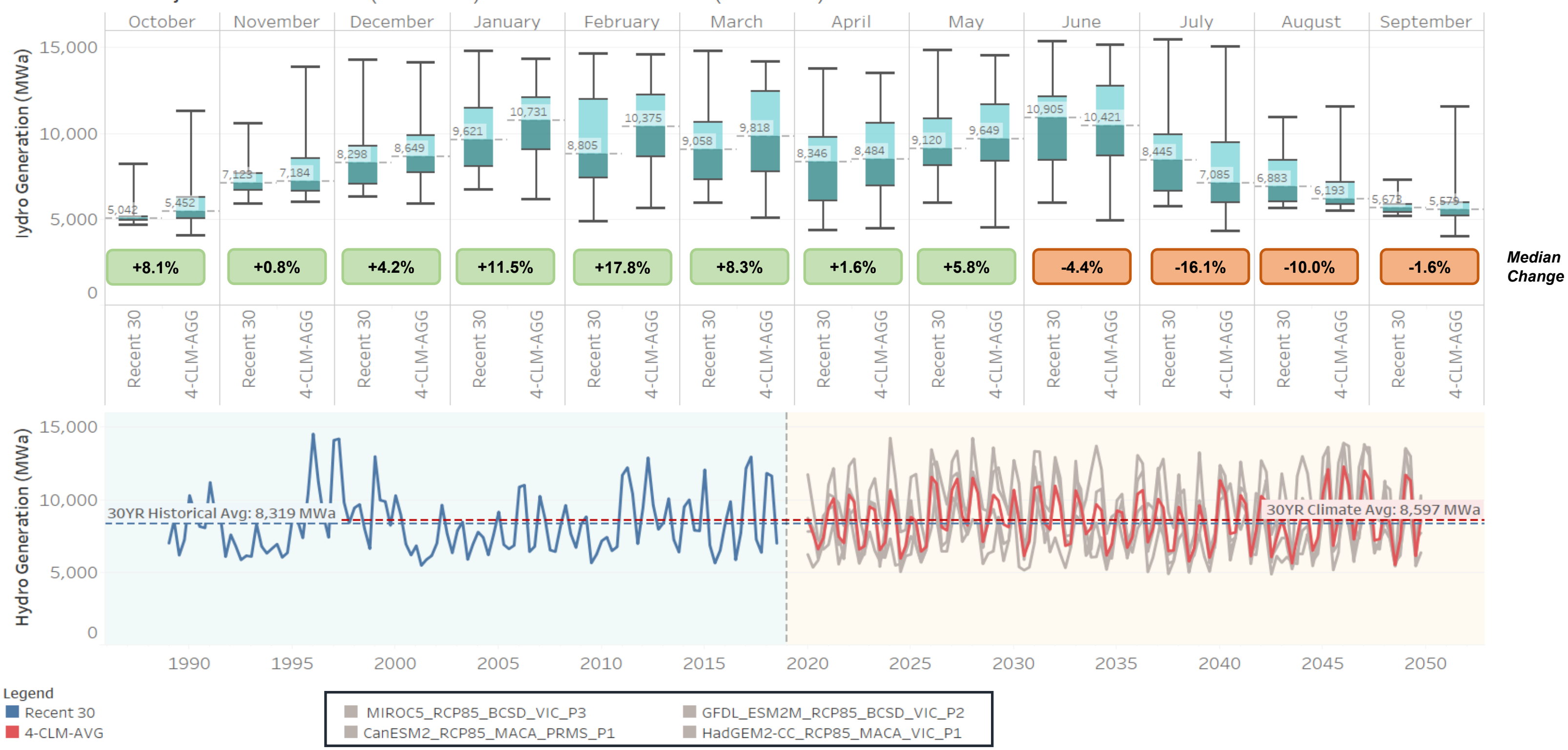
**Average annual hydro generation increases 2.4% in 30-yr climate scenario avg. vs 90-yr historical.**
**Average summer hydro gen decreases 8.5%, while average winter hydro gen increases 6.3%.**



# PNW Utility Review of Climate Change Impacts - V

**Average annual hydro generation increases 3.3% in 30-yr climate scenario avg. vs 30-yr historical.
Average summer hydro gen decreases 5.0%, while average winter hydro gen increases 8.0%.**

**BPA Federal 14 Projects:** 30-Yr Historical (1989-2018) vs 30-Yr Climate Forecast (2020-2050)



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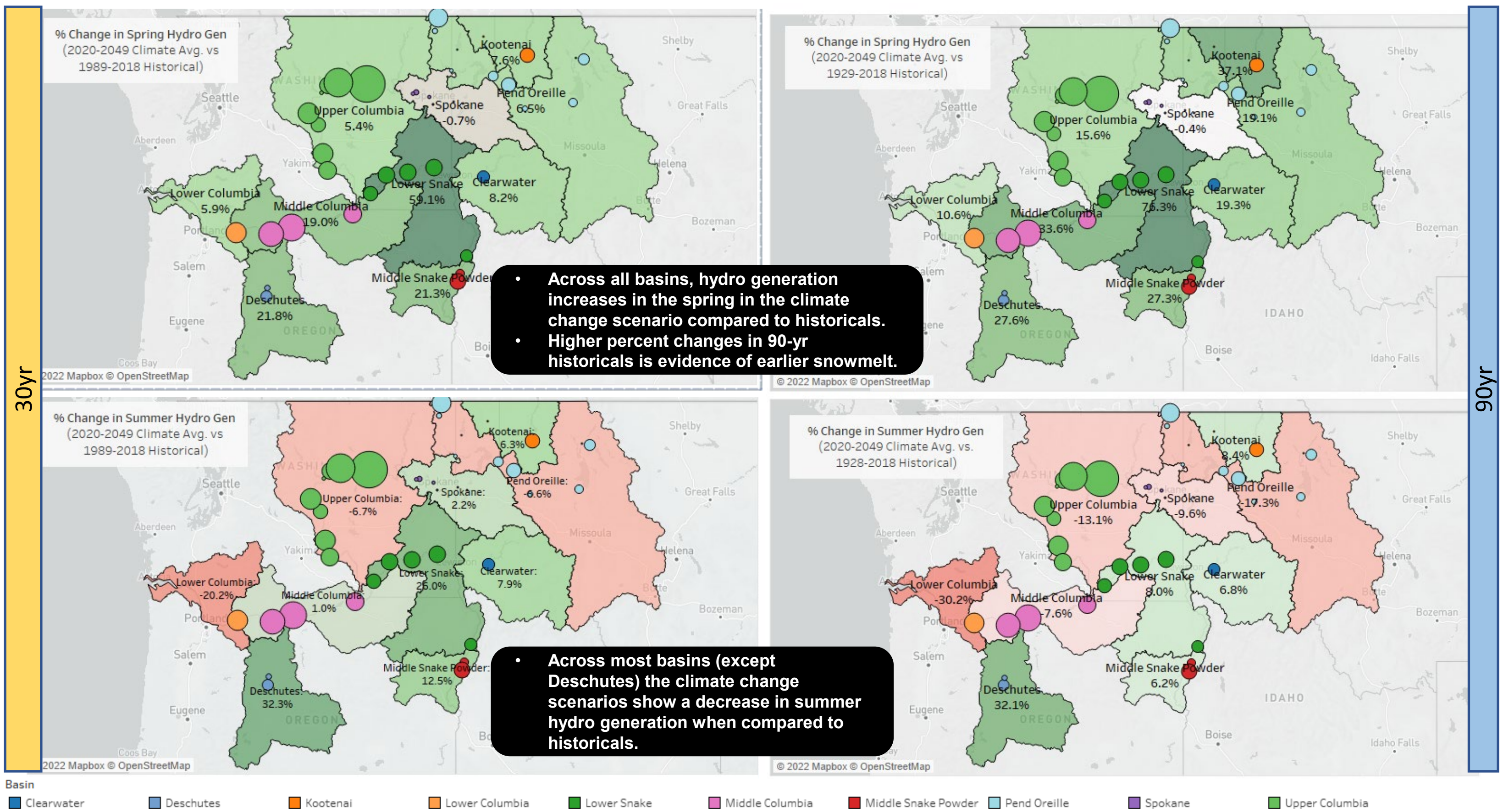
NOTE: Based on BPA's 14 selected federal projects.

# PNW Utility Review of Climate Change Impacts - VI




- **Across all basins, hydro generation increases in the spring in the climate change scenario compared to historicals.**
- **Higher percent changes in 90-yr historicals is evidence of earlier snowmelt.**

- **Across most basins (except Deschutes) the climate change scenarios show a decrease in summer hydro generation when compared to historicals.**



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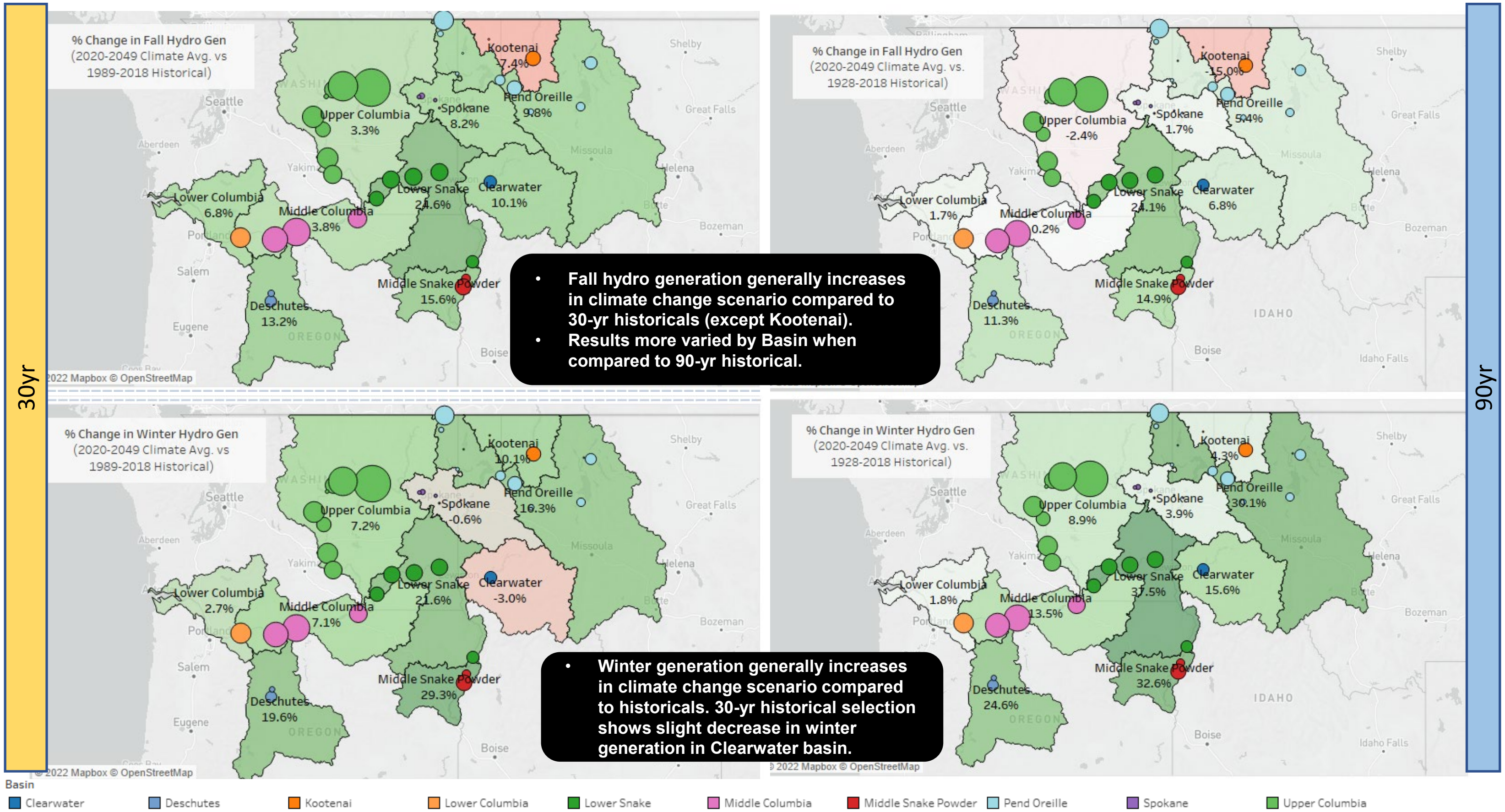
Note: Includes hydro data for projects beyond BPA 14 Federal on slides 8 and 9.
Climate scenario data is average of four climate models.

# PNW Utility Review of Climate Change Impacts - VII




- **Fall hydro generation generally increases in climate change scenario compared to 30-yr historicals (except Kootenai).**
- **Results more varied by Basin when compared to 90-yr historical.**

- **Winter generation generally increases in climate change scenario compared to historicals. 30-yr historical selection shows slight decrease in winter generation in Clearwater basin.**



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Note: Includes hydro data for projects beyond BPA 14 Federal on slides 8 and 9.
Climate scenario data is average of four climate models.

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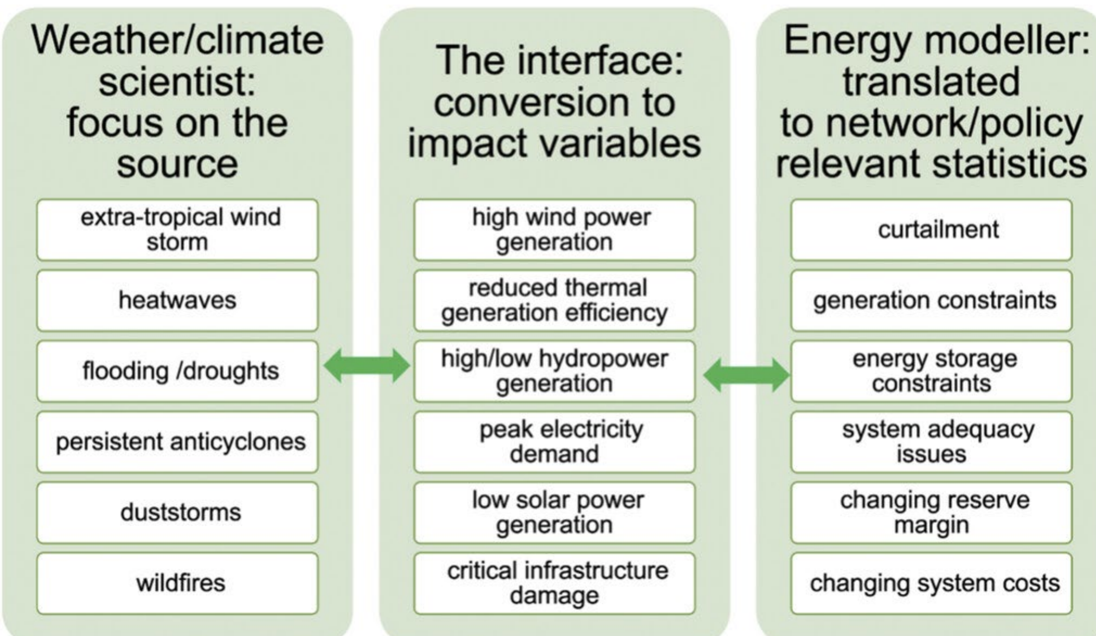
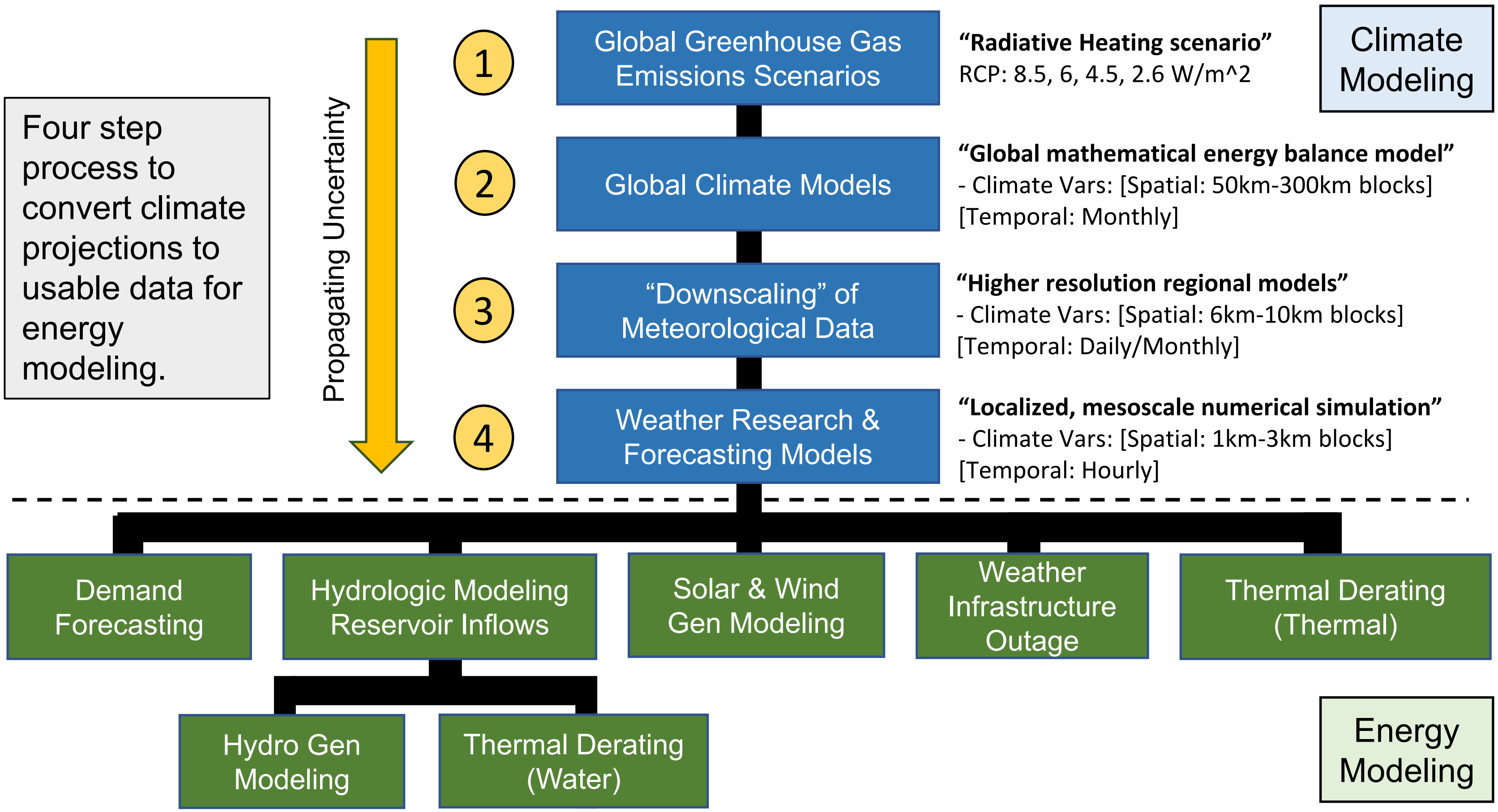
# Climate Change Modeling vs Energy Resource Modeling




**Credit:** https://doi.org/10.1016/j.joule.2022.05.010.

- Disconnect on objectives for generating and using weather data.
- Difference in data temporal and spatial granularity needs.
- Converting climate data into data useful for energy modeling requires multiple steps.

# Climate Modeling Process



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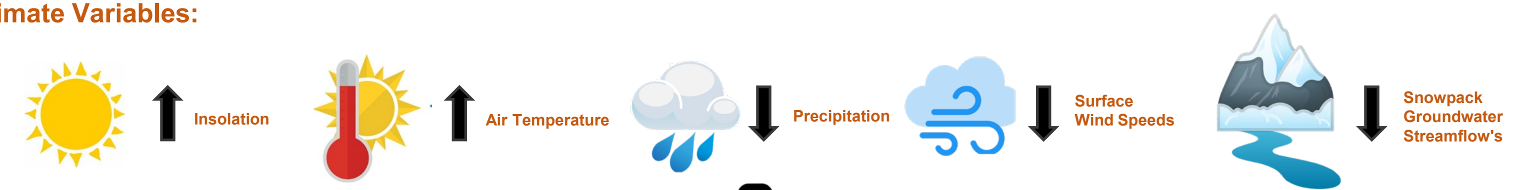
# Climate Change Impacts on Utility Planning

**The Utility RA Climate Challenge: Capturing Granular Concurrency in an Increasingly Weather Driven Power System**

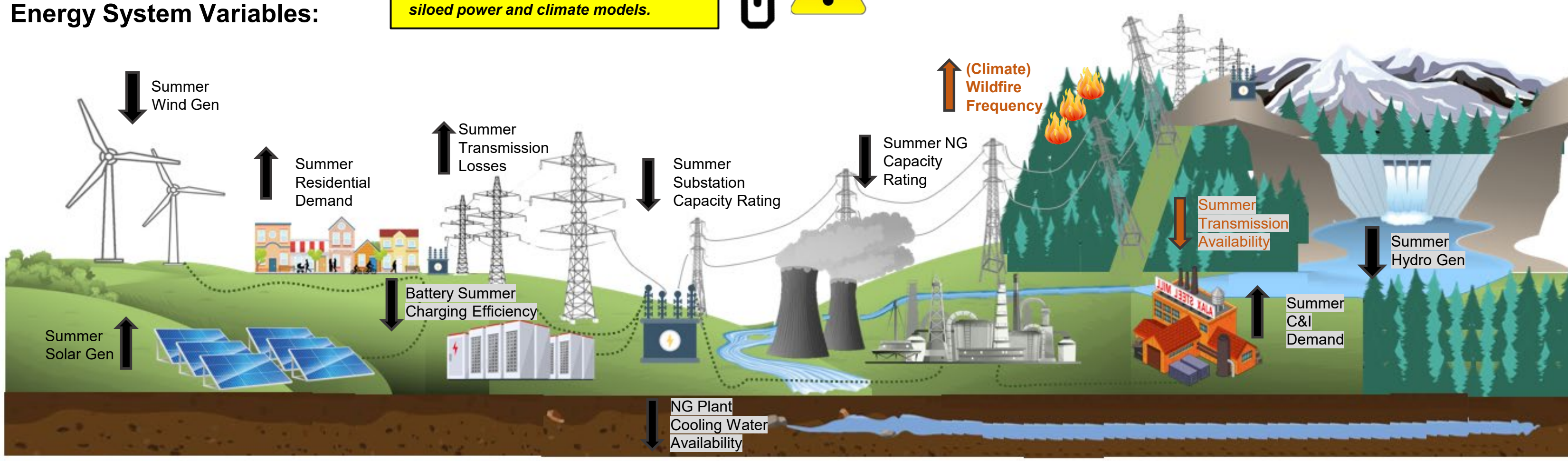
**Summer 2050 in Utility-Ville**

**Climate Variables:**



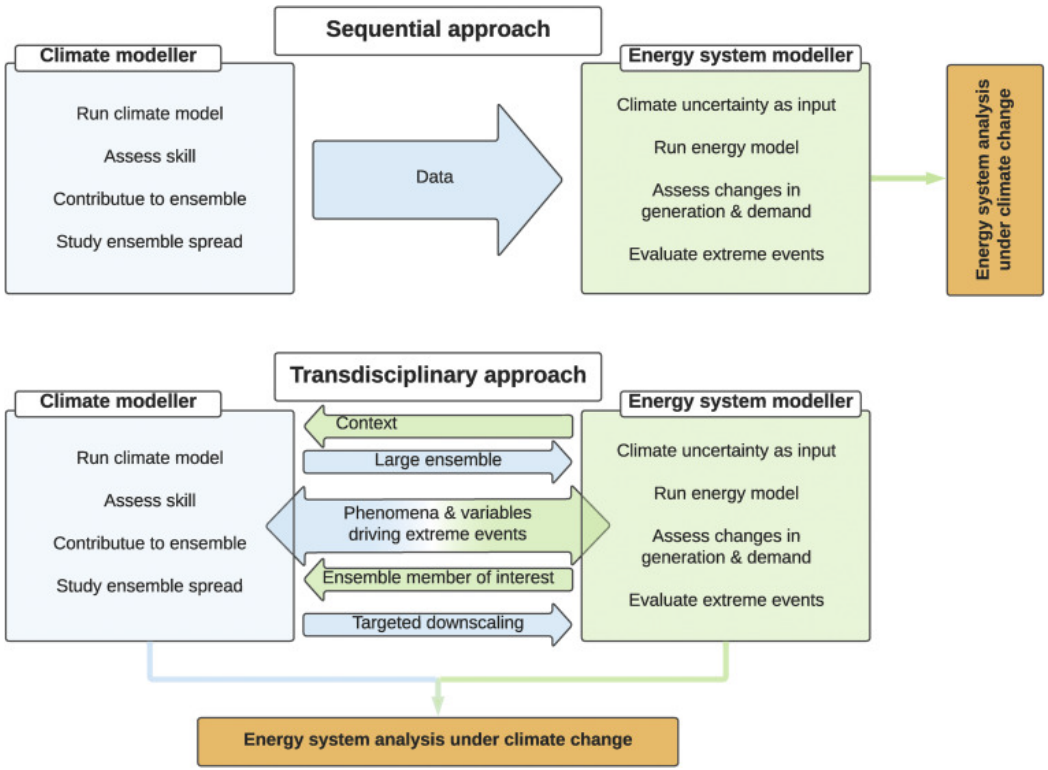

***Variables must be linked appropriately across both time and space in several siloed power and climate models.***

**Energy System Variables:**




 **PUBLIC** Note: All signs are illustrative only

# A new component of future IRP planning




**To ensure data concurrency and granularity requirements there is a need for closer active collaboration between climate scientists and energy system modelers.**

**Credit:** https://doi.org/10.1016/j.joule.2022.05.010.

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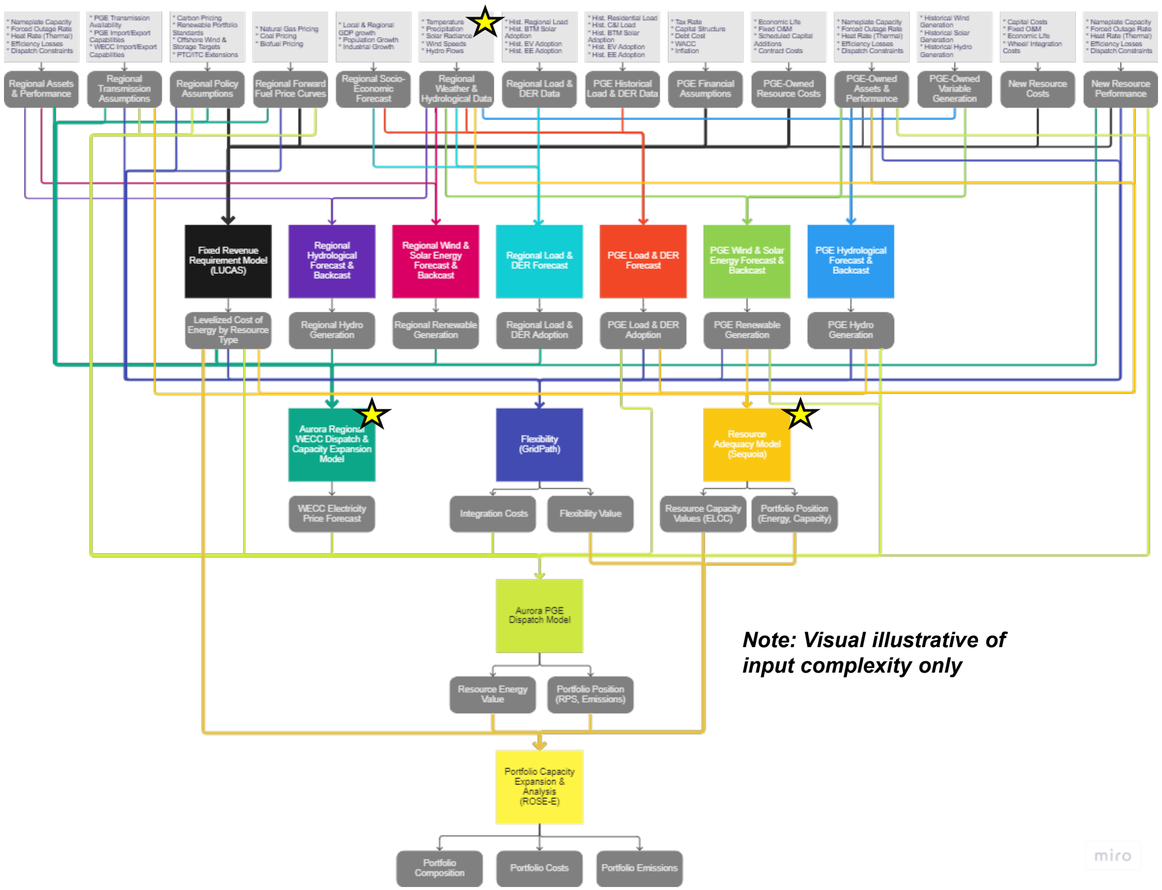
# PGE's Existing IRP Structure




- **PGE uses several key models to identify potential portfolios**
  - Load Forecast Model
  - LUCAS
  - Aurora
  - GridPath
  - Sequoia
  - ROSE-E
- Hundreds of assumptions need to be generated prior to running any of the models above
- Weather and hydrological data are key input across multiple models, making data concurrency a significant challenge.
- **Ex:** Necessary to update WECC Aurora regional hydro profiles if hydro profiles are updated in Sequoia model.

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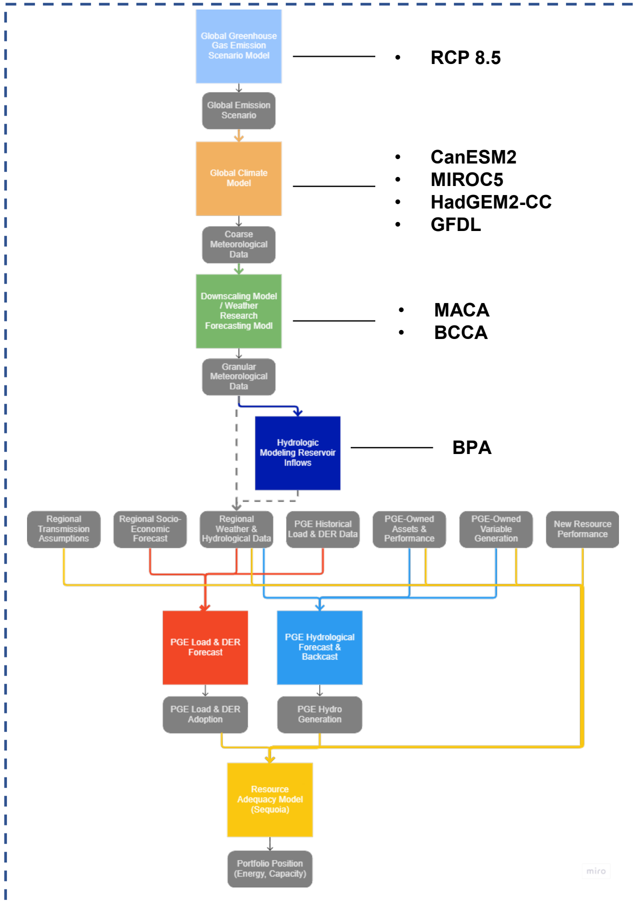
# PGE Climate Sensitivity Approach




- **Initial focus of the 2023 PGE IRP climate sensitivity scenario is on the Sequoia model.**
  - Focus initially on utilizing climate adjusted hydro and load profiles.
  - Test the two climate adjustments separately first (isolate impact) and then jointly (determine if impact is additive, compounding, etc.)

**Leverage same four climate change scenarios as used in the most recent climate change studies issued by BPA and the NWPCC.**

1. **CanESM2-MACA-PRMS-P1**: Warm and wettest scenario.

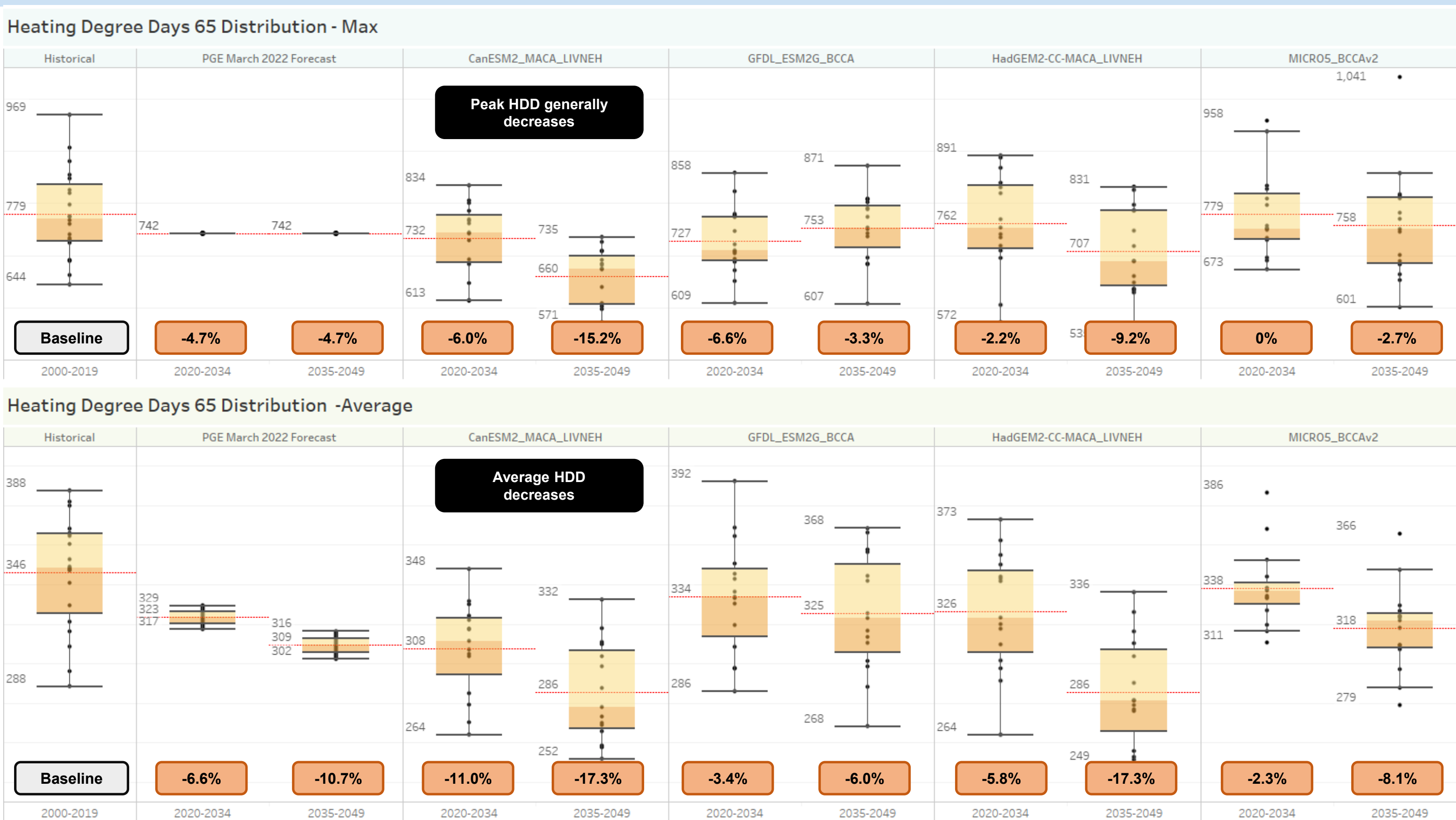
2. **MIROC5-BCSD-VIC-P3**: Near the median temperature projection; just above median precipitation above Grand Coulee, but below median precipitation in the Snake River basin.

3. **HadGEM2-CC-MACA-VIC-P1:** Warmer scenario; median precipitation above Grand Coulee, but above the median precipitation in the Snake River basin.

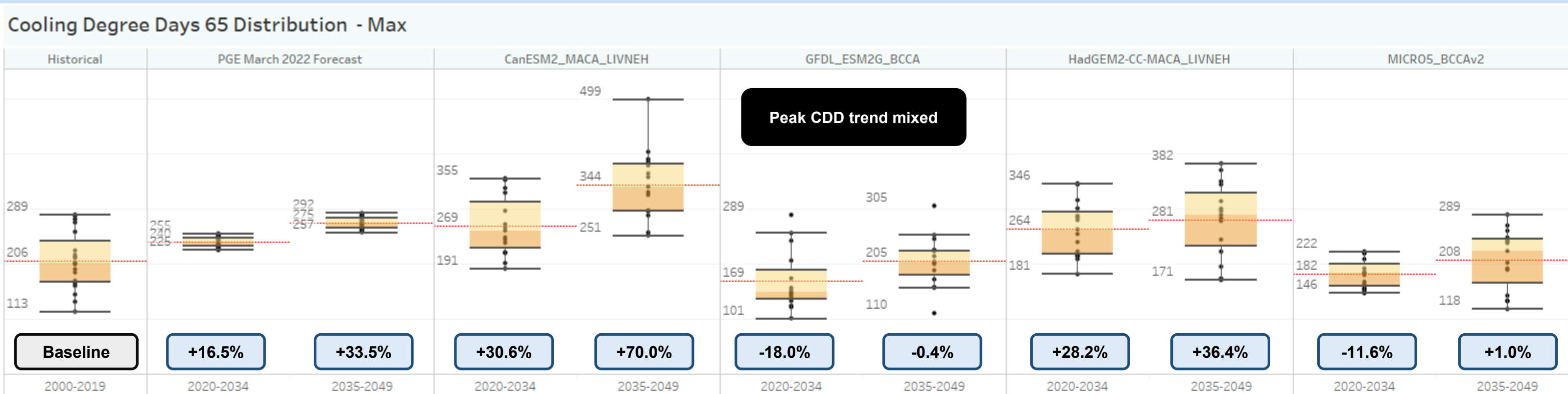
4. **GFDL-BCSD-VIC-P2**: One of the coolest and driest scenarios.

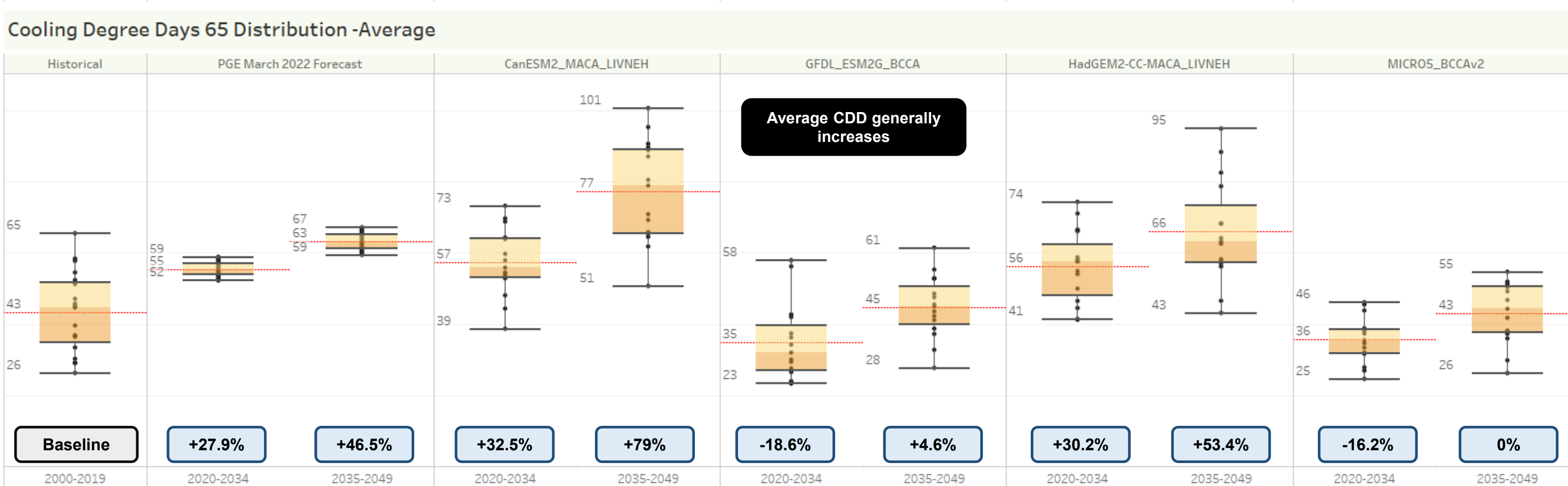
*Note: Hydro generation & flow data acquired from BPA. Climate temperature data acquired separately.*

# PGE Heating Degree Days

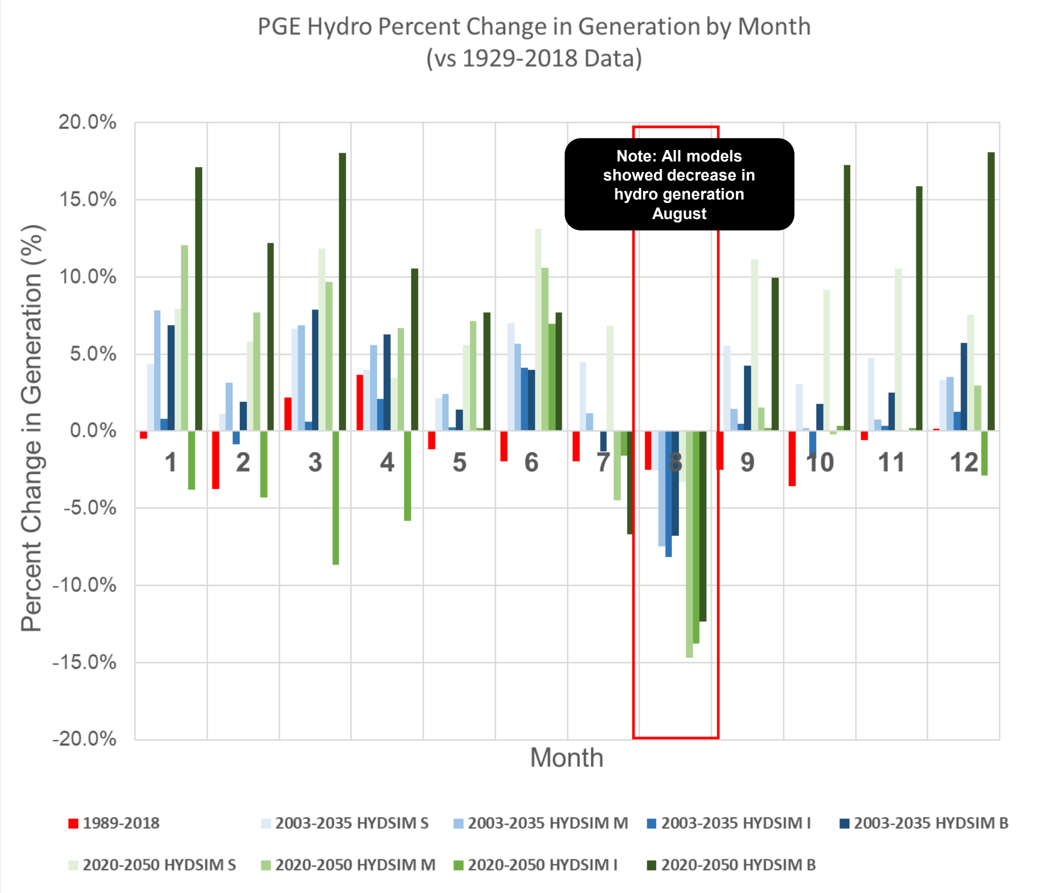


# PGE Cooling Degree Days



# Seasonal Change PGE Hydro Generation




- **On June 6, 2022, BPA released a letter recommending the use of a smaller subset of hydro data (1989-2018) for their future resource planning studies.**
- **BPA expects that the recent 30-year subset will better capture observed and emerging climate change trends.**
- **For PGE's sequoia model, a subset of hydro years will need to be selected. Impact on PGE's hydro generation will vary depending on whether:**
  - A 30-year "historical" data set is used exclusively (1989-2018)
  - A hybrid historical-climate data set is used (2003-2035)
  - A climate data set is used exclusively (2020-2050).

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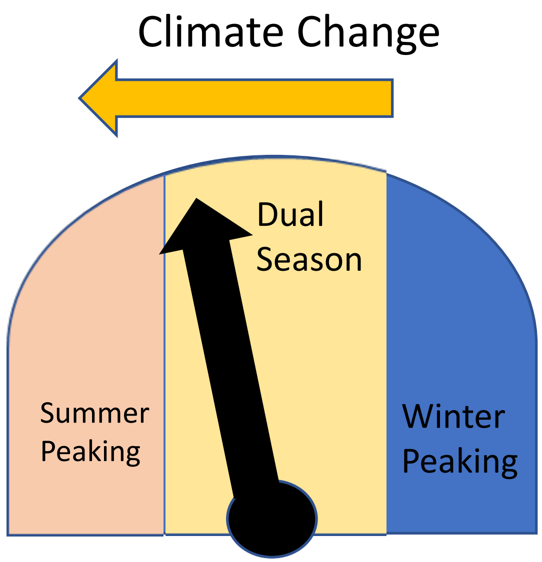
# Preliminary Findings

**Load Forecast**

- Under the climate scenarios, PGE annual HDD peak decreases 3.7% and the average HDD decreases 5.6%.*
- PGE annual CDD peak increases 7.2% and the average CDD increases 7.0%.*

**Hydro Generation Forecast**

- Under the climate scenarios, PGE's annual hydro generation increases 5.6%.*
- Impact on PGE hydro generation will vary depending on the climate model tested, the hydro facility, and the season.
- Generally, across the climate models, a decrease in hydro generation is seen in August.



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Note: Average of four climate models (2020-2035) compared to the baseline historical data (2000-2019).

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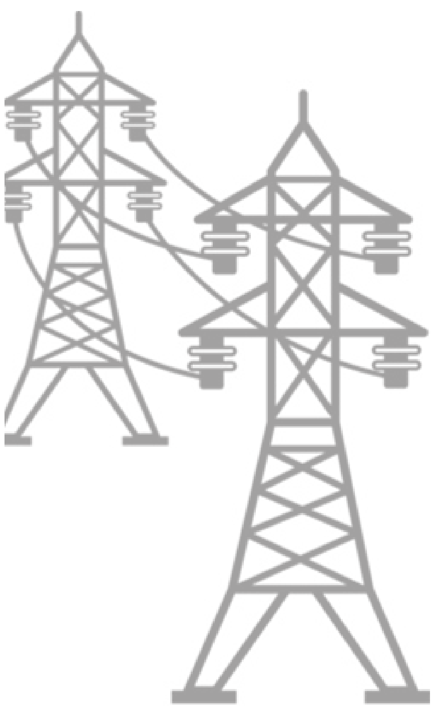

1. Review of Climate Change in Pacific Northwest IRP Planning

2. Climate Change Modeling & Applications to Resource Planning

3. Quantifying Climate Change Impact for Load & Generation

4. Incorporating Climate Change into PGE's IRP Framework

**5. Recommendations**

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# Recommendations

**Recommendations:**

- **For the 2023 Portland General Electric IRP, the company should focus on performing a preliminary Sequoia study to quantify the impact of climate change forecasts on PGE's load, hydro generation, and peak need.**
  - CRS has been actively working with PGE's IRP team to provide the necessary data for this initial analysis.
  - First Sequoia runs underway.
- **Beyond the 2023 Portland General Electric IRP, the company should continue to develop internal modeling capabilities in order to generate climate change adjusted wind, solar, and thermal generation forecasts.**
  - Data concurrency in IRP modeling should remain an important priority. However, additional work will be required to reconcile data concurrency between stochastic and deterministic models.
- **Portland General Electric should also continue to engage in Bonneville Power Authority's climate change modeling workshops and proceedings. Specifically, PGE should ensure that BPA refines the hydro modeling to include PGE specific hydro facilities in the Willamette Basin.**
- **Portland General Electric should establish a benchmarking mechanism for actual resource generation compared to the climate change adjusted forecast to actively track the forecasting error for future IRPs (narrowing of climate ensembles tested).**
- **Portland General Electric consider staffing a climate scientist <u>within</u> the Integrated Resource Planning team in order to perform the following functions:**
  - Provide additional context for the various climate change forecasts and maintain the company informed of climate risks to both transmission and generation assets (flooding, wildfires, storms, etc).
  - Generate ensemble of climate forecasts (temperature, radiation, wind, precipitation) for PGE's service territory load zones and generation assets.
  - Collaborate with IRP team to generate "energy modeling ready" data for load and resource generation forecasts.
  - Manage benchmarking of actual resource generation versus climate forecasted generation.

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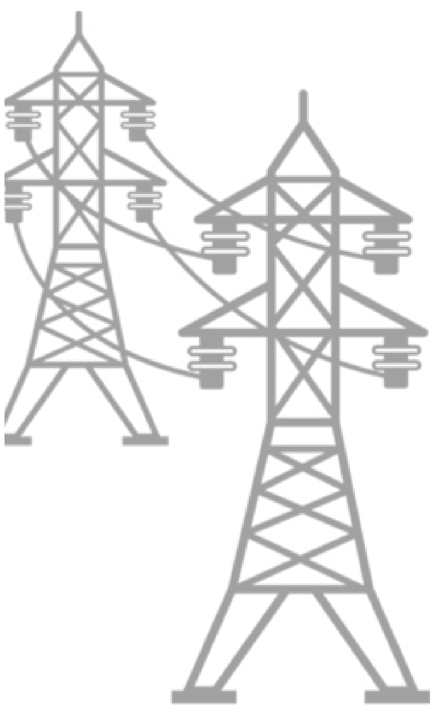
# APPENDIX



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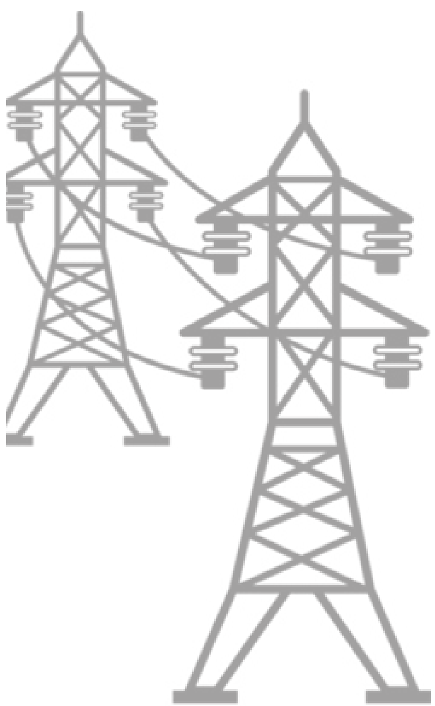
# Academia Review



# Academia Review of Climate Change Impacts

| Entity | Title | Region | Load & Gen Climate Risks in IRP | | | Notes: |
|---|---|---|---|---|---|---|
| Pacific Northwest NATIONAL LABORATORY | Compound climate events transform electrical power shortfall risk in the Pacific Northwest | PNW | Electric Demand<br>Hydro Gen | Solar Gen<br>Wind Gen | Thermal Gen<br>Storage | Electric demand and hydro generation adjusted for two climate. GENSYS used to estimate resource adequacy of PNW. Regional LOLP doubled, but peak capacity need reduced by 60%. |
| Argonne NATIONAL LABORATORY | Analysis of Drought Impacts on Electricity Production in the Western and Texas Interconnections of the United States. | Western US and TX | Electric Demand<br>Hydro Gen | Solar Gen<br>Wind Gen | Thermal Gen<br>Storage | Historically, 10-year drought reduces hydroelectric generation by 26% in the PNW. |
| Centro UC Cambio Global<br>Berkeley UNIVERSITY OF CALIFORNIA | Climate change impacts on two high-elevation hydropower systems in California. | CA | Electric Demand<br>Hydro Gen | Solar Gen<br>Wind Gen | Thermal Gen<br>Storage | Rising temperature will reduce annual hydropower generation by up to 8.2% in 2050 in CA. |
| Portland State UNIVERSITY | Climate change implications for wind power resources in the Northwest United States | PNW | Electric Demand<br>Hydro Gen | Solar Gen<br>Wind Gen | Thermal Gen<br>Storage | Wind generation potential may reduce by 40% in spring and summer months due to a 4-6% decrease in wind speed in Northwest U.S. |
| ETH zürich | Projections of long-term changes in solar radiation based on CMIP5 climate models and their influence on energy yields of photovoltaic systems | PNW, CA, Southeast U.S. | Electric Demand<br>Hydro Gen | Solar Gen<br>Wind Gen | Thermal Gen<br>Storage | Rising solar radiation (GHI) is likely to increase solar output by 0-3% in southeast U.S. and increasing temperatures to decline solar output by 0-3% in CA. |
| ARIZONA BOARD OF REGENTS ASU • NAU • UA<br>ASU Arizona State University | Impacts of climate change on electric power supply in the Western United States | Western US | Electric Demand<br>Hydro Gen | Solar Gen<br>Wind Gen | Thermal Gen<br>Storage | Climate change driven temperature changes in the Western US is likely to reduce the average summertime capacity of thermal facilities by 1.4-3.5%. |
| Pacific Northwest NATIONAL LABORATORY | Climate Change Impacts on Residential and Commercial Loads in the Western U.S. Grid | Western US | Electric Demand<br>Hydro Gen | Solar Gen<br>Wind Gen | Thermal Gen<br>Storage | Commercial buildings will see 5-10% increase in their peak load (MW), while residential buildings will see more than 10% increase in peak load by 2045 in Western U.S. Both sectors will see a 2-8% increase in monthly summer load (MWh), due to increased AC usage. Autumn and Spring monthly load experience similar increase too. |

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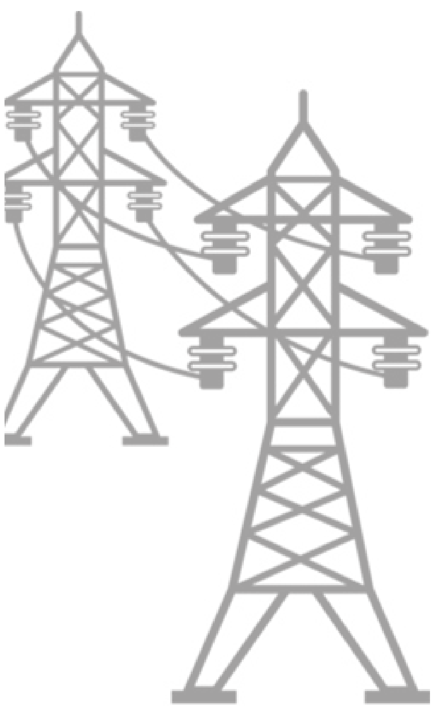
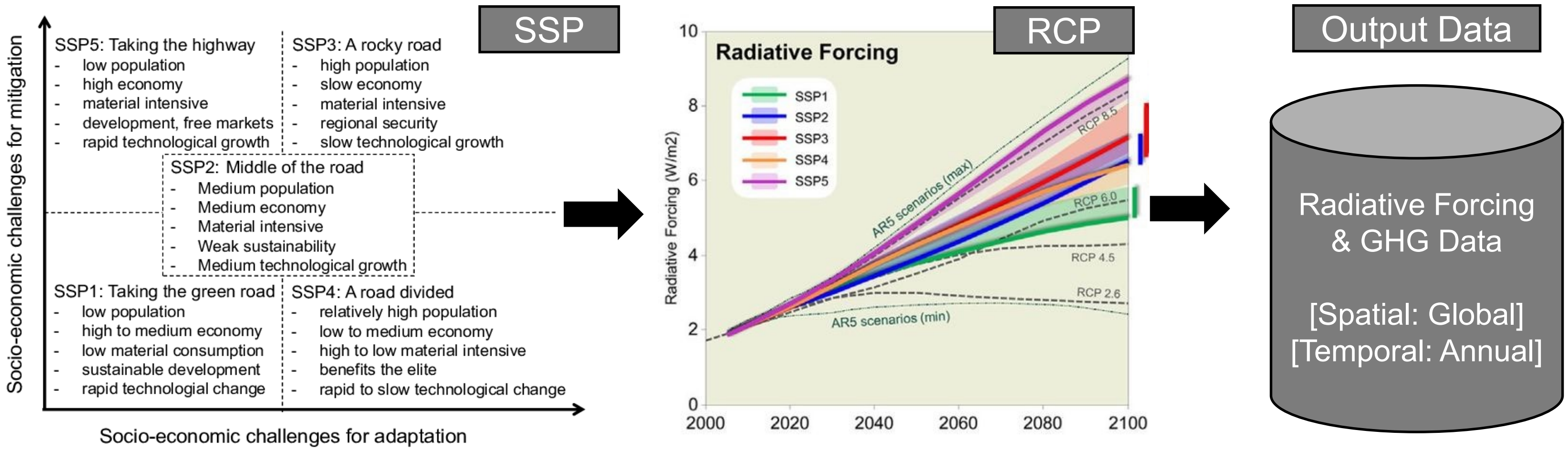
# Climate Modeling Data Conversion Process



# Climate Modeling – Emission Scenarios




- Produced by the Intergovernmental Panel of Climate Change (IPCC) in 2014, **Representative Concertation Pathways (RCP)** are standardized **future scenarios** of **atmospheric greenhouse gas concentrations** and corresponding **radiative forcing**.
  - Four pathways were developed describing potential global warming temperature rise by 2100, spanning a broad range of radiative forcing (2.6, 4.5, 6.0, and 8.5 watts per meter squared)
  - Only RCP1.9 limits global warming to below 1.5 °C, the goal of the 2015 Paris Agreement.
- Introduced in 2020 by the IPCC, **Shared Social Economic Pathways (SSPs)** are five pathways describing **broad socioeconomic trends** that could shape future society and ultimately lead to certain RCP pathways.
  - “Narrative” behind the RCP pathways.
  - Only SSP5 produces a reference scenario that is consistent with RCP8.5.

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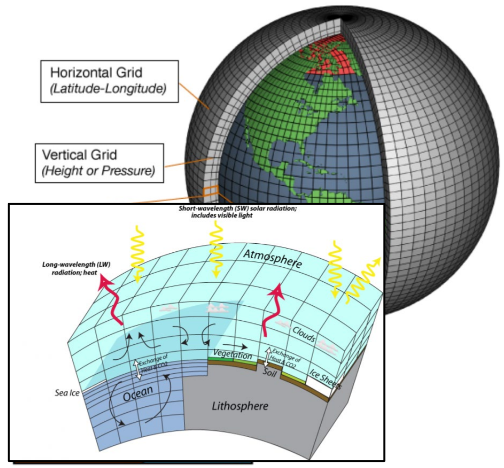
# Climate Modeling – GCMs Models

| Input Data | Global Climate Model (s) | Output Data |
|---|---|---|
| Radiative Forcing & GHG Data<br><br>[Spatial: Global]<br>[Temporal: Annual] |  | Surface air temperature, relative humidity, precipitation, surface wind speeds, solar radiation<br><br>**[Spatial: 50km-300km blocks]**<br>**[Temporal: Monthly]** |



- A **global climate model (GCM)** is a complex **mathematical representation** of the **major climate system** components (atmosphere, land surface, ocean, and sea ice), and their interactions. Earth's energy balance between the four components is the key to long-term climate prediction.
- Climate models are constantly being updated, as different modelling groups around the world incorporate higher spatial resolution, new physical processes and biogeochemical cycles.
- The 2021 IPCC sixth assessment report (AR6) features new state-of-the-art CMIP6 models. CMIP6 will consist of the "runs" from around 100 distinct climate models being produced across 49 different modelling groups

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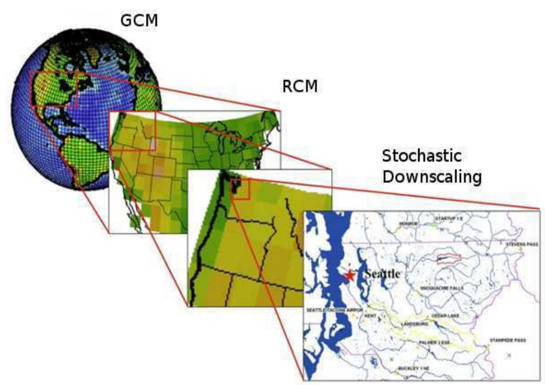
# Climate Modeling – Downscaling

**Input Data**

Surface air temperature, relative humidity, precipitation, surface wind speeds, solar radiation

**[Spatial: 50km-300km blocks]**
**[Temporal: Daily]**

**Downscaling Method(s)**




**Output Data**

Surface air temperature, relative humidity, precipitation, surface wind speeds, solar radiation

**[Spatial: 6km-10km blocks]**
**[Temporal: Daily/Monthly]**

- **Downscaling** methods are used to **refine the temporal and spatial resolution** of **GCM weather predictions**, capturing the more granular effect of geography and other factors that are missed by coarse GCM models.
- There are two general approaches of downscaling:
  - **Dynamical** – Outputs from a GCM are used to drive higher resolution **regional climate models (RCM)** with a better representation of local terrain and other conditions.
  - **Statistical** – where statistical links are established between large-scale climate phenomena and observed local-scale climate. (Bias correction required).

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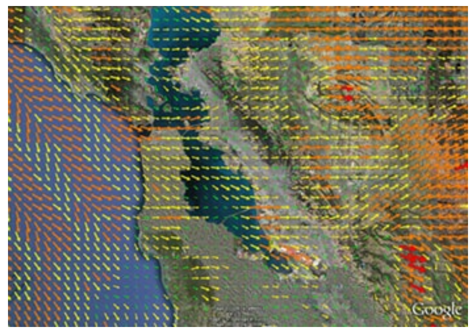
# Climate Modeling – Weather Research & Forecasting

**Input Data**

Surface air temperature, relative humidity, precipitation, surface wind speeds, solar radiation

**[Spatial: 6km-10km blocks]**
**[Temporal: Daily]**

**Weather Research & Forecasting**



**Output Data**

Surface air temperature, relative humidity, precipitation, surface wind speeds, solar radiation

**[Spatial: 1-3km blocks]**
**[Temporal: Hourly]**

- **Weather Research & Forecasting Models** are mesoscale numerical weather prediction model used to further dynamically downscale climate data to a higher resolution over regions of interest.
- WRF models can be adapted and utilized as RCM models for the purpose of downscaling data. However, several technical differences exist, and WRF models are better for localized weather event predictions.
- **WRFs are useful at predicting weather at temporal and spatial resolutions for energy modeling.**

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# Quantifying Climate Change Impact for Load & Generation

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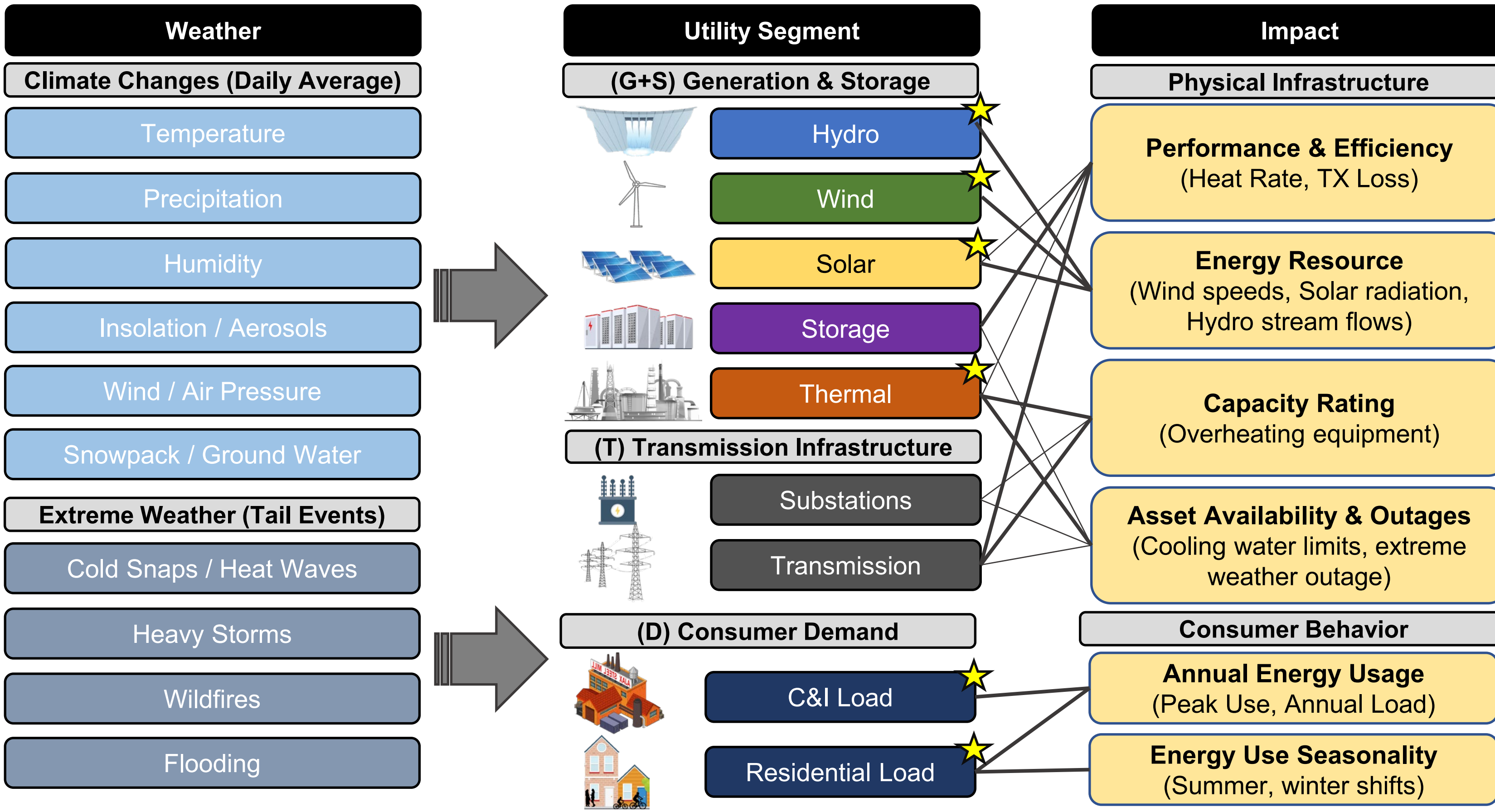
# Climate Change Impacts on Utility Planning - I



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Note: Resiliency not a part of resource adequacy discussion above, which pertains to speed of recovery.

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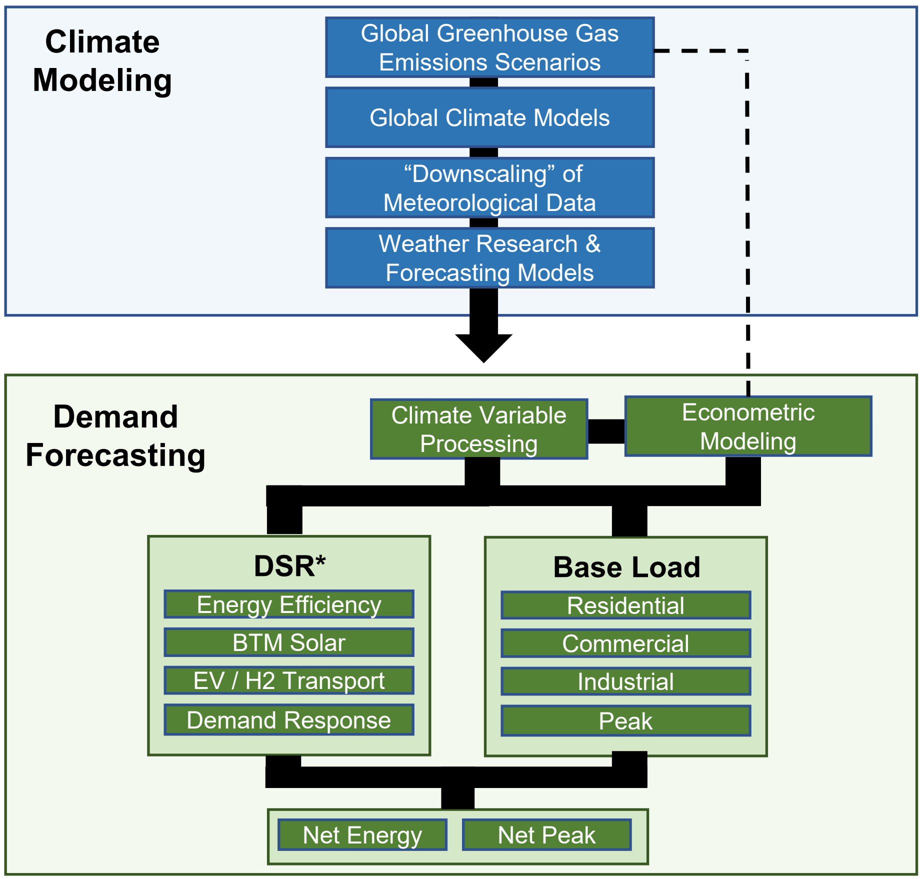
# Load Forecasting - I




- While weather is a highly influential factor in load forecasting process, the impact will vary on different segments of demand side modeling.
    - **Residential Load:** Residential customers see greater energy usage as AC uptake increases with warming temperatures.
    - **Commercial/Industrial Load:** Industrial customers are less temperature dependent and may be influenced more by economic metrics.
    - **Peak Load:** Higher daily max temperatures in the summer and higher minimum temperatures in the winter will shift load peaking seasons.
    - **BTM Solar:** BTM solar generation panels efficiency degrades in warmer temperatures, offset by greater solar radiance.
    - **Transport/DR/EE:** Likely less influenced by climate factors in adoption and cost-benefit models.

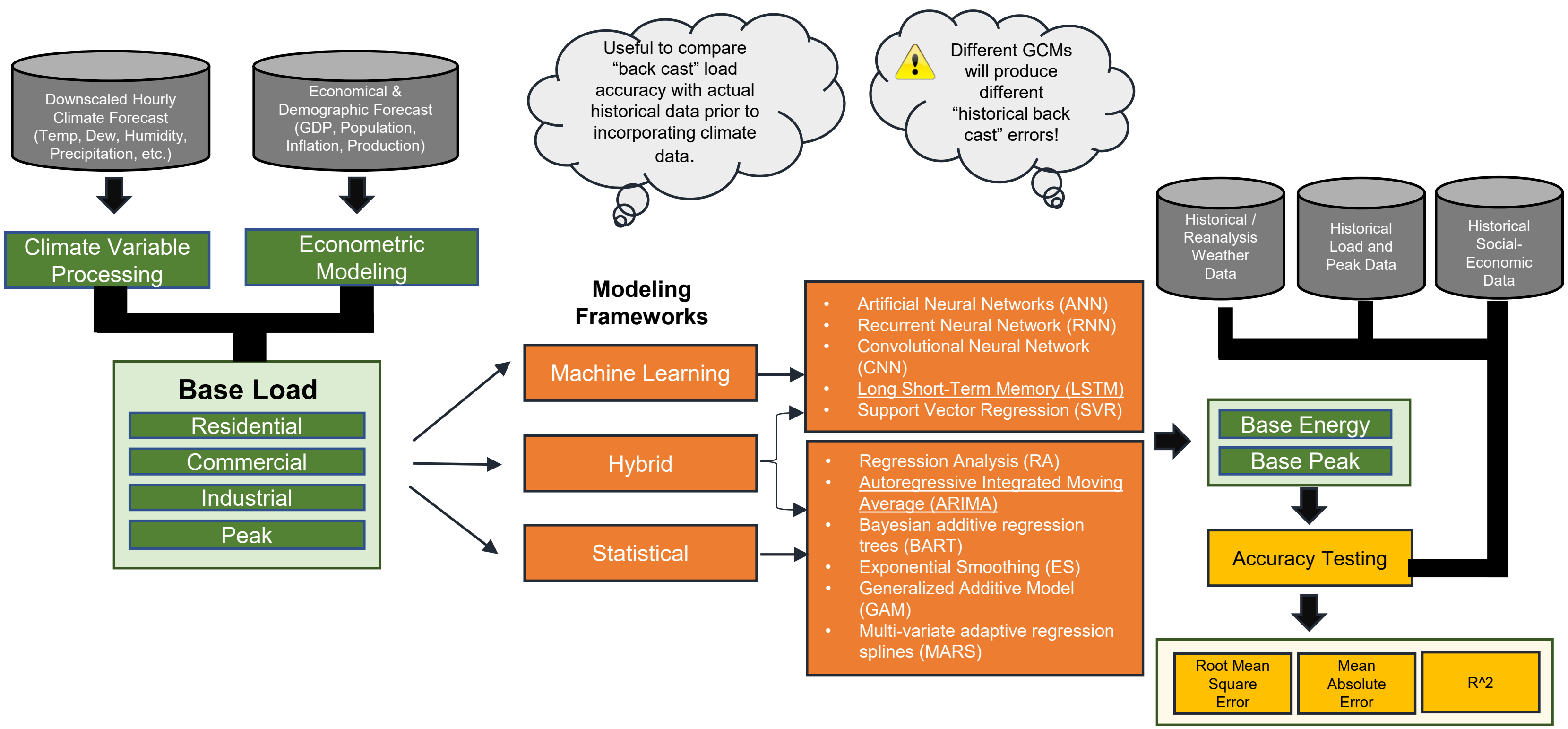




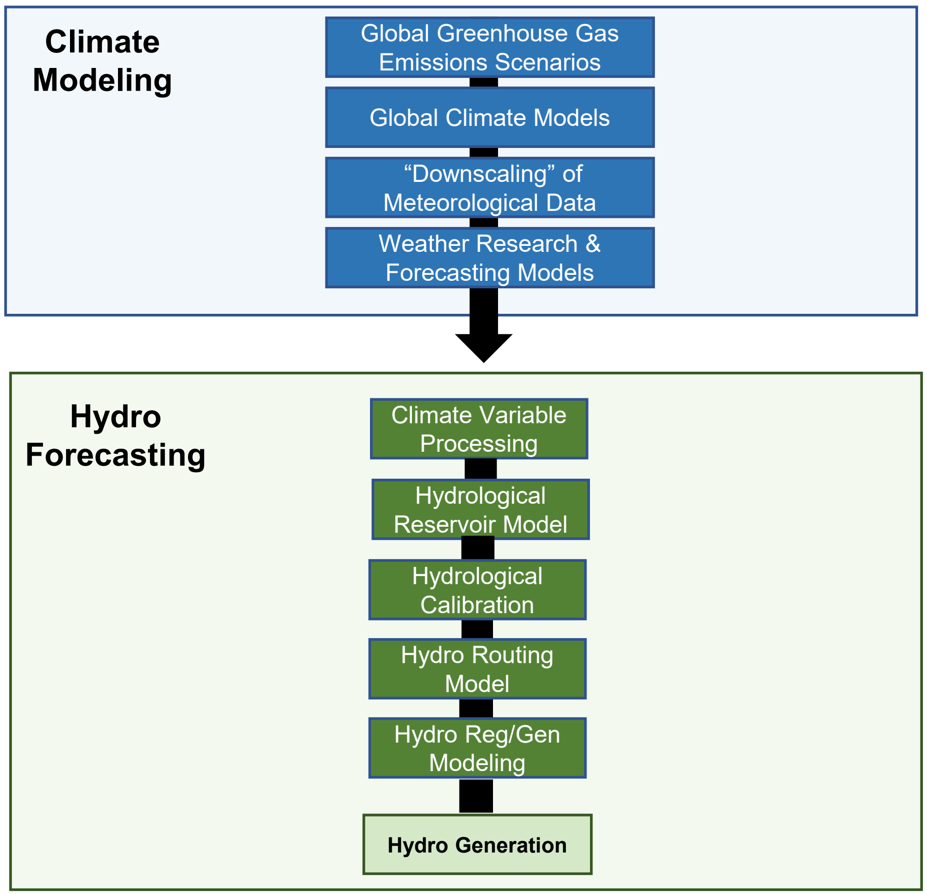
Note: Incorporating climate forecasts into DSR modeling was not reviewed in more detail in this research report.

# Long-Term Load Forecasting - II

**Several load modeling frameworks (Statistical, ML, hybrid) exist, but further investigation is required to identify the most "accurate" methodologies. ML techniques such as LSTM have shown promising results in prior research.**



# Hydro Forecasting - I




- In the PNW, hydro generation represents 48% of the energy mix. Climate modeling of future hydro flows is critical for PNW utilities, as preliminary climate modeling shows seasonal shift of hydro generation.
- **Hydrological reservoir models** estimate the surface and ground water resource in a gridded region considering environmental factors such as precipitation, snow melt, and temperature. For energy, particular focus is on stream flows.
- **Hydrological calibration** is the process of correcting bias in projected stream flows using historical stream flow data.
- **Hydrological routing models** stream inflow through a series of hydro reservoirs and river networks subject to flow regulation limits.
- **Hydro regulation and generation modeling** converts stream inflows to power generation based on hydro turbine equipment ratings, performance, and environment assumptions.

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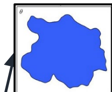
# Hydro Forecasting - II

Downscaled Climate Forecast (Temp, Precipitation, Snowmelt, etc.)

Climate Variable Processing

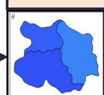
Hydrological Reservoir Model

**Spatial Resolution**



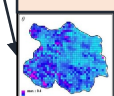
Lumped

- EPIC
- ARM
- SVAT
- VM
- XAJ



Semi-Distributed

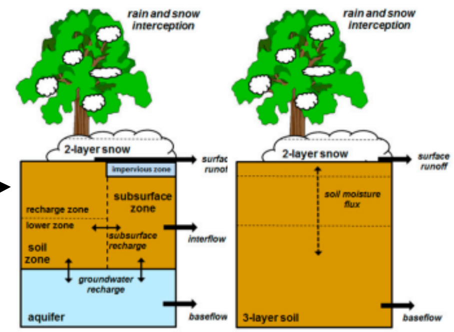
- GLERL
- ARNO
- LASCAM
- TOPMODEL



Distributed

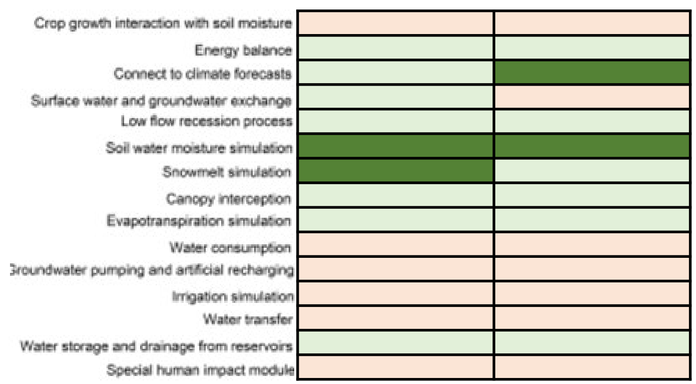
- VIC
- PRMS
- SWAT
- GWAVA

**Hydrological Modeling Frameworks**




**Precipitation Run-Off Modeling System (PRMS)**

**Variable Infiltration Capacity (VIC)**




BPA Climate Study used variation of VIC & PRMS Models:

**VIC-P1:** Parameters calibrated by UW to the NRNI flow dataset provided by the RMJOC.

**VIC-P2:** Parameters calibrated by Oak Ridge National Laboratory (Naz et al., 2016).

**VIC-P3:** Parameters calibrated by the National Center for Atmospheric Research.

**PRMS-P1:** Parameters calibrated by UW to the NRNI flow dataset provided by the RMJOC.



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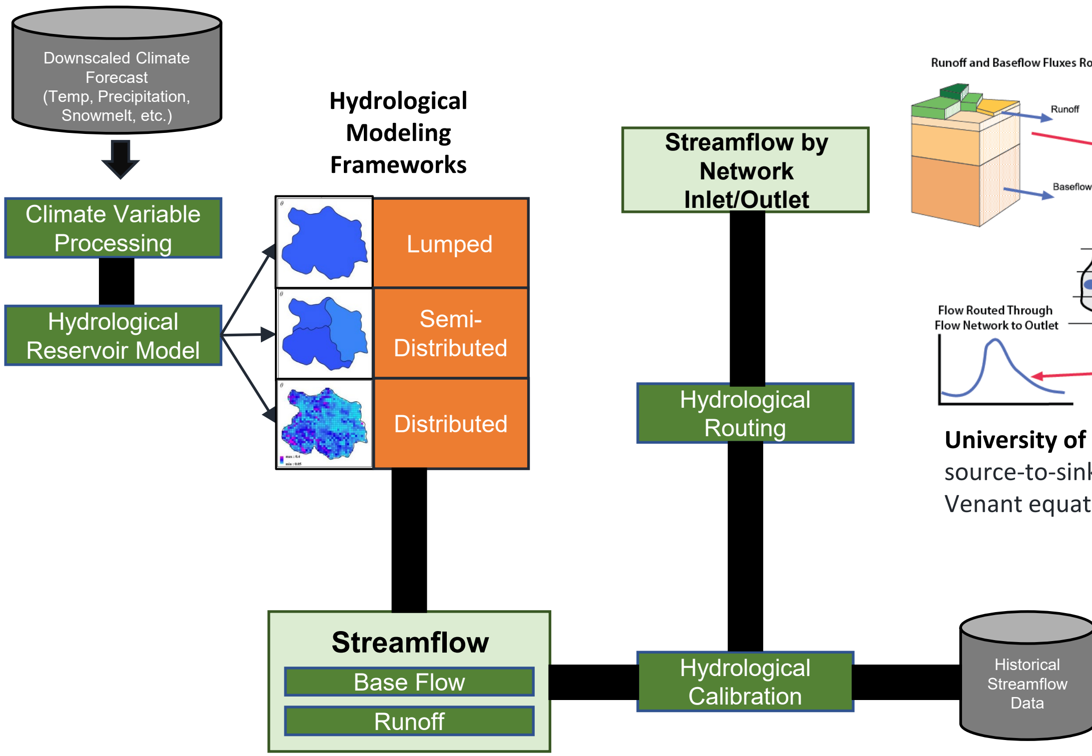
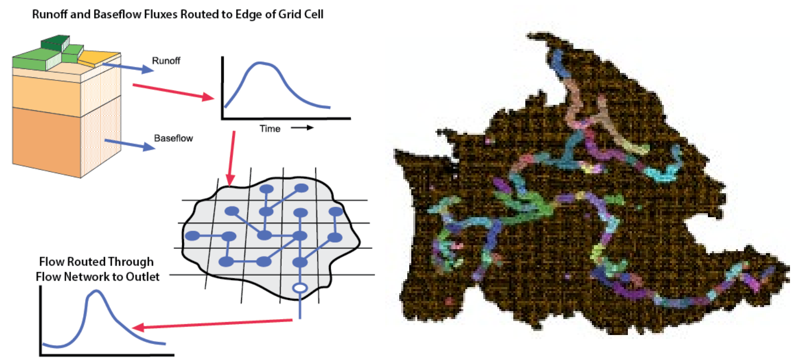
[1] Figures from Koch, Julian. (2016). Evaluating spatial patterns in hydrological modelling. 10.13140/RG.2.2.34737.79204.
[2] Figure from Mizukami, Naoki & Clark, Martyn & Gutmann, Ethan & Mendoza, Pablo & Newman, A. & Nijssen, Bart & Livneh, Ben & Hay, Lauren & Arnold, Jeffrey. (2016). Implications of the methodological choices for hydrologic portrayals of climate change over the Contiguous United. Journal of Hydrometeorology. 17. 10.1175/JHM-D-14-0187.1.
[3] Table from https://doi.org/10.5194/piahs-383-261-2020

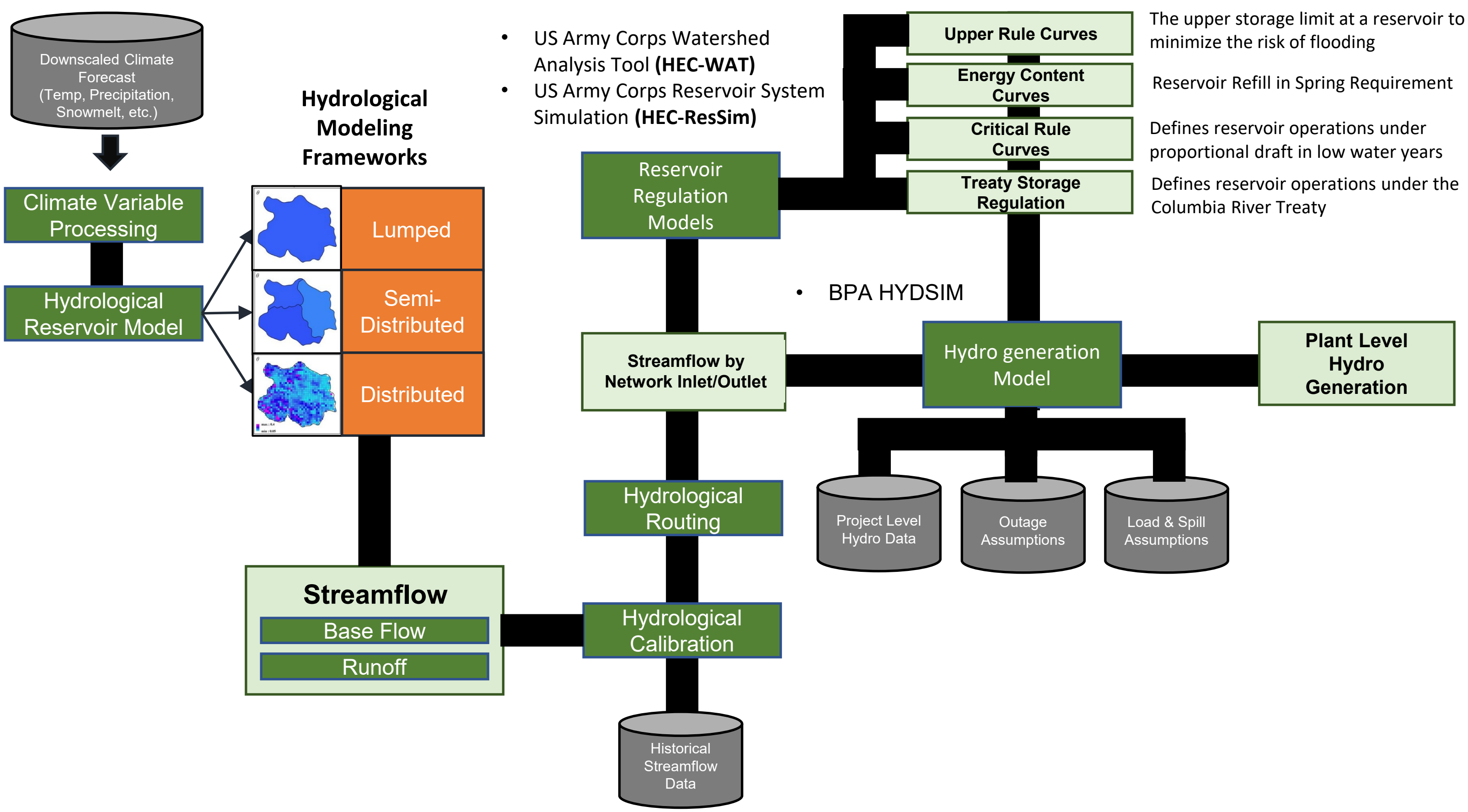
# Hydro Forecasting - III




**University of Washington RVIC Model:** The routing model is a source-to-sink model that solves a linearized version of the Saint-Venant equations.

# Hydro Forecasting - IV



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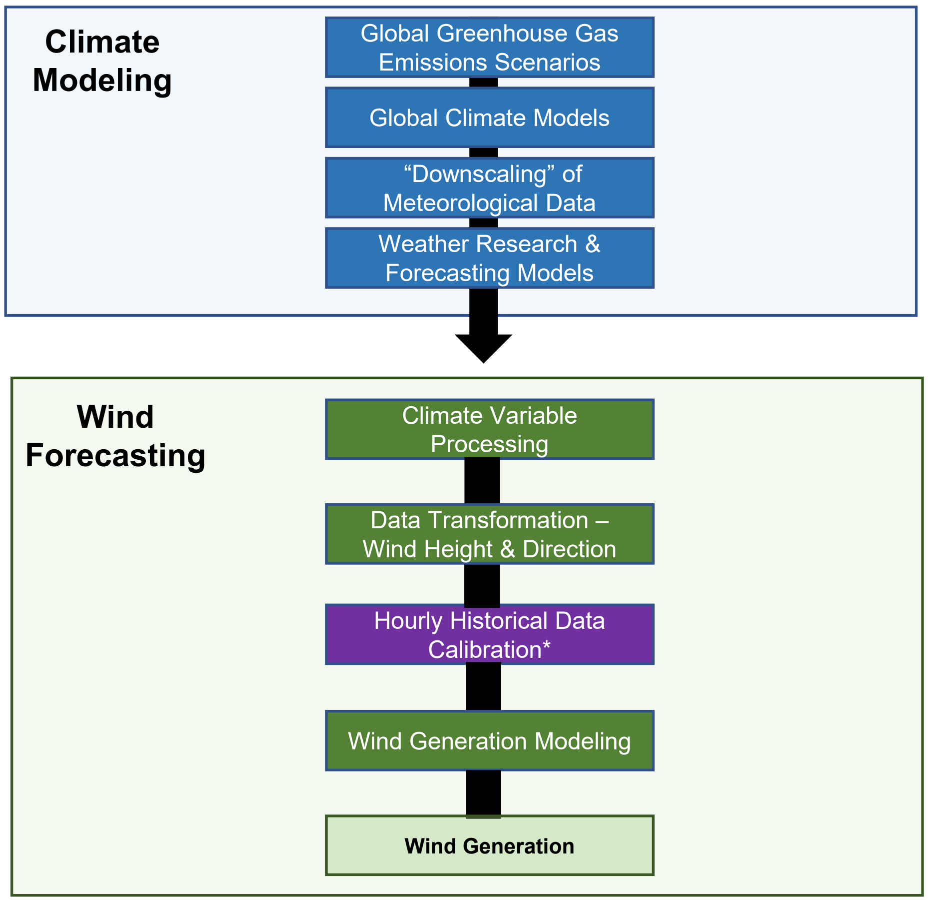
# Wind Forecasting - I




- As of 2020, wind generation represents greater than 7% of energy production in the PNW.
- Impact of climate change on wind will vary by geography (different wind ensembles). Key climate drivers will be changing wind speeds and air density (temperature and pressure).
- **Data Transformation**: Climate data (wind speed and direction) must be transformed into polar coordinates. Surface wind speeds (10m) must be extrapolated to hub heights.
- **Data Calibration**: This step is required if the climate data has not undergone the WRFM model step or if key data inputs (i.e., pressure) are not available from climate model. Daily average wind speeds and directions are converted to hourly averages using historical data.
- **Wind Power Modeling:** Tools such as NREL SAM generate hourly power generation data using the newly modified climate wind data.



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Note: Step may not be necessary

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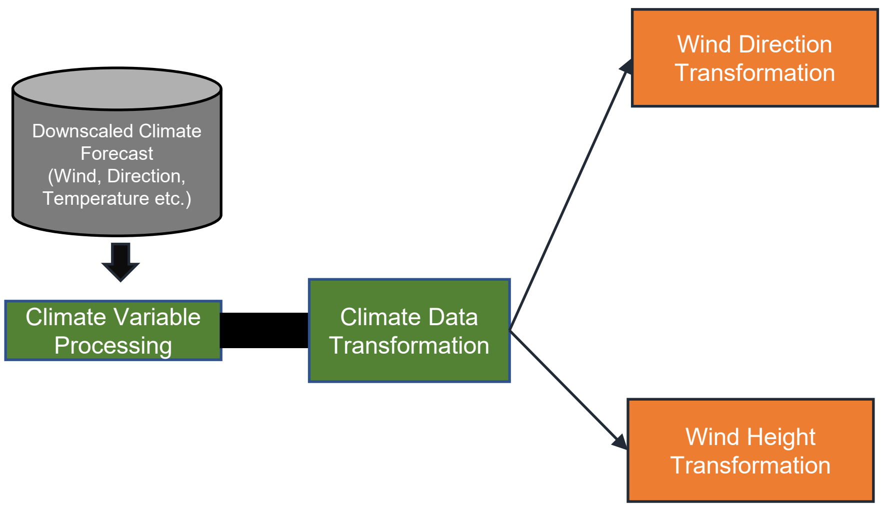
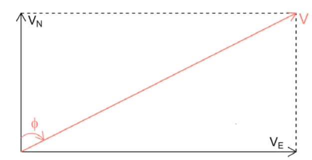
# Wind Forecasting - II




The polar coordinates $V$ and $\phi$ are calculated from the cartesian $V_N$ and $V_E$ by Equations (1) and (2) below.

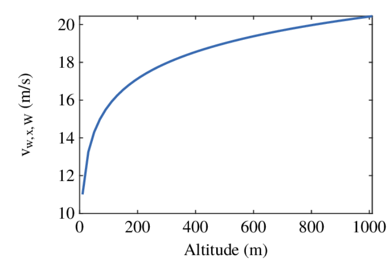
$$(1) \quad V = \sqrt{V_N^2 + V_E^2}$$

$$(2) \quad \phi = tan^{-1}\left[\frac{V_E}{V_N}\right]$$




where $V1$ and $V2$ are the wind speeds at heights $H_1$ and $H_2$, and where $H_0$ is the roughness coefficient length, in meters.

$$(3) \quad \frac{V_2}{V_1} = \frac{ln\left[\frac{H_2}{H_0}\right]}{ln\left[\frac{H_1}{H_0}\right]}$$



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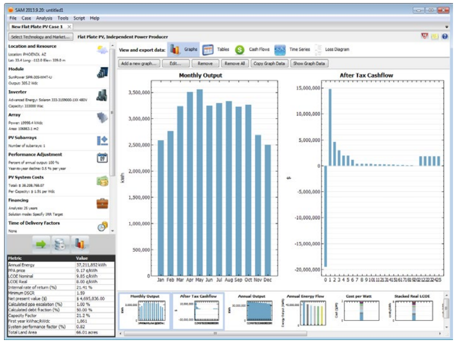
# Wind Forecasting - III

For the wind generation model, a <u>modified NREL SAM wind dataset</u> was input into the NREL SAM Wind tool.

**NREL SAM Tool Inputs:**

- Hourly Wind Speeds and Direction at hub height
- Hourly Temperature
- Hourly Pressure
- Turbine & Performance Assumptions



Downscaled Climate Forecast (Wind, Direction, Temperature etc.)

Climate Variable Processing → Climate Data Transformation → Historical Data Calibration* → Wind Generation Model → **Plant Level Wind Generation**

Wind Turbine Assumptions (Tech, Array, Losses, etc)

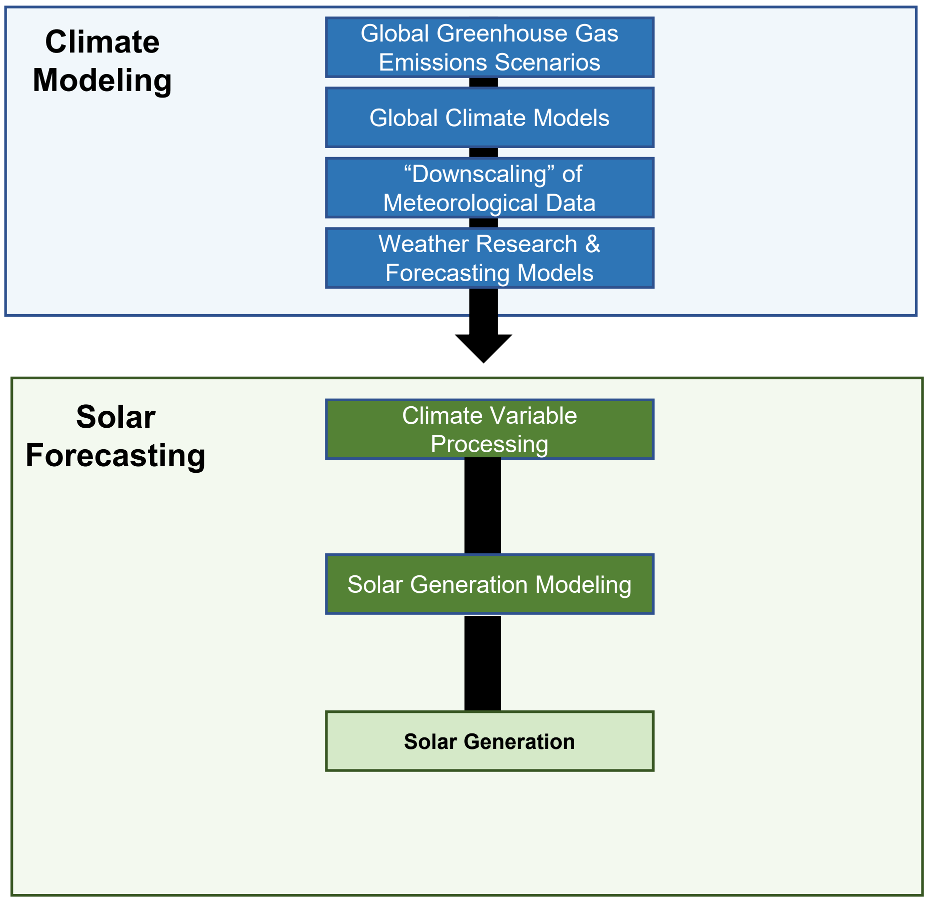
Prior NW Council study used Historical NREL temperature and pressure data <u>combined</u> with Climate Change Wind Speed and Direction Data. WRF modeling provides temperature and pressure data.





Note: Required if Climate Data does not go through WRFM model to generate hourly outputs. Daily average climate values would need to be adjusted.

# Solar Forecasting - I




- Impact of climate change on solar generation driven by increased solar radiation (GHI) and decreased solar efficiency due to higher temperatures.
- Unlike hydro or wind, most climate models are equipped to output the variables most critical for solar production modeling (temperature, irradiance). Therefore, pre-processing is minimal assuming the climate modeling has already been performed.
- **Solar Power Modeling:** Tools such as NREL SAM generate hourly power generation data using the newly modified climate wind data.

Note: Step may not be necessary



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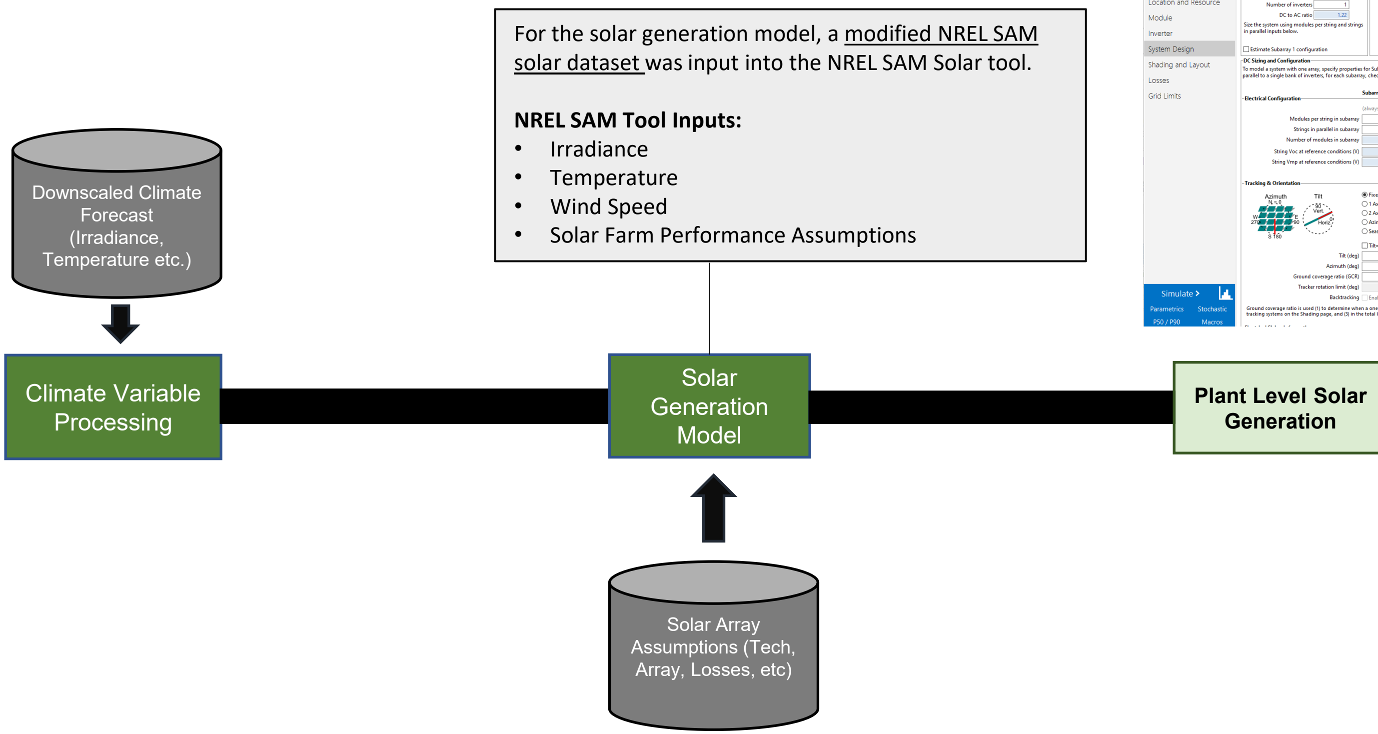
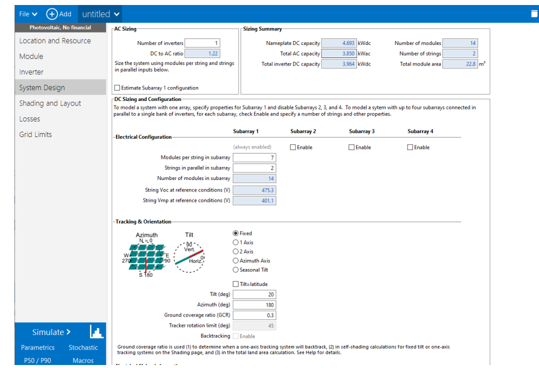
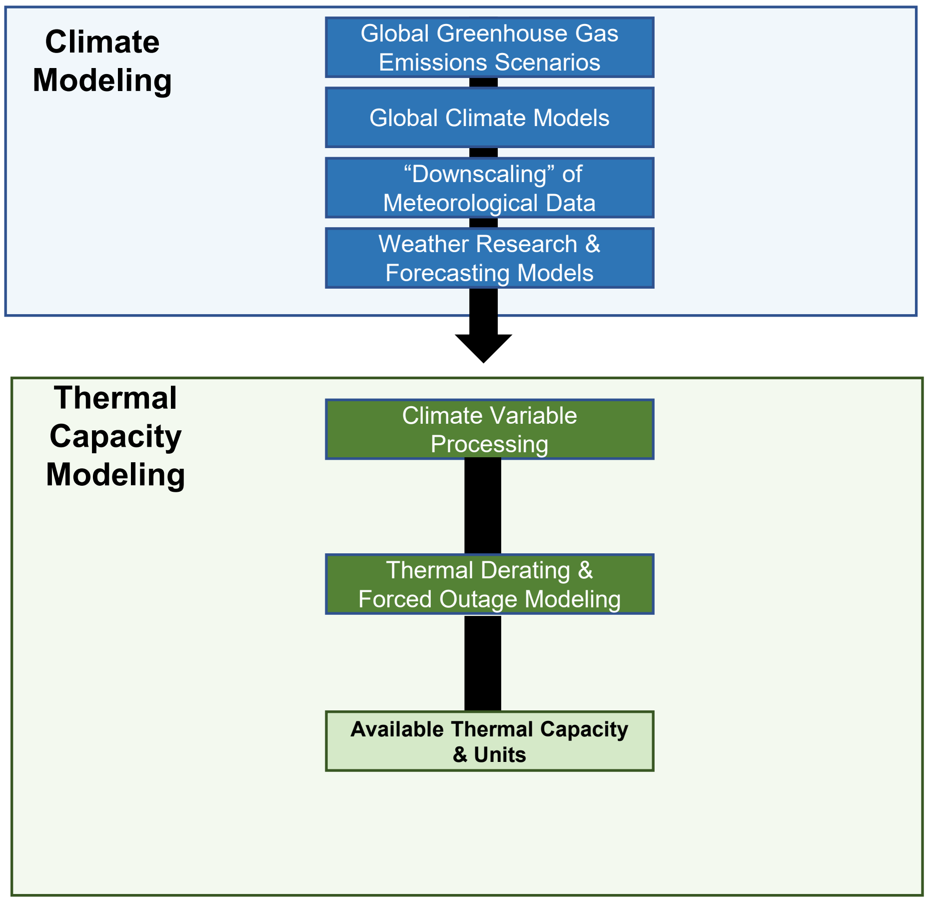
# Solar Forecasting - II



# Thermal Generation Forecasting




- Climate change impacts thermal powered generators by reducing the availability of thermal units (i.e., higher forced outages) and decreasing the capacity of available thermal units.
- Historically, thermal units have been derated based on seasonal capacity ratings (summer/winter) and the availability described by an annual forced outage rate (uncorrelated availability).
- However, multiple studies using NERC GAD data has shown a correlation between temperature and the availability of capacity from thermal units.
- **Thermal Derating & Forced Outage Modeling:** Modeling used to represent the number of available thermal units and their respective capacities incorporating the dynamic impact of temperature.

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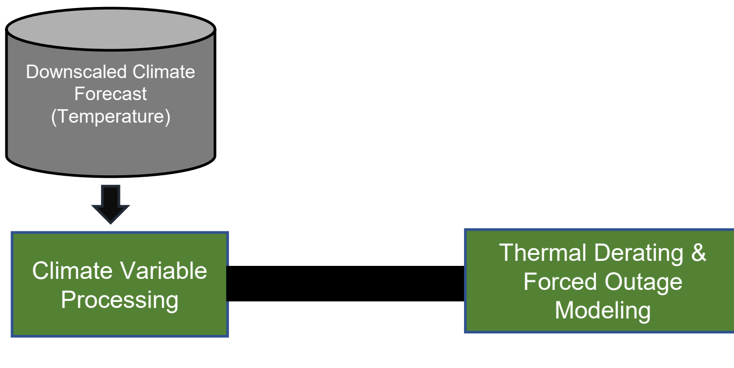
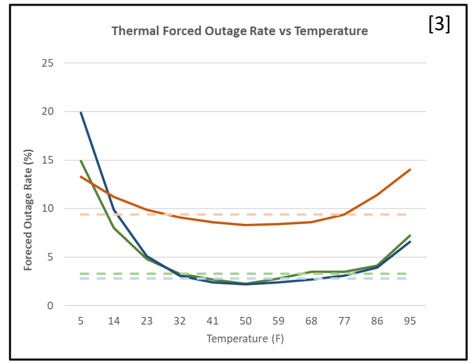
# Thermal Generation Forecasting

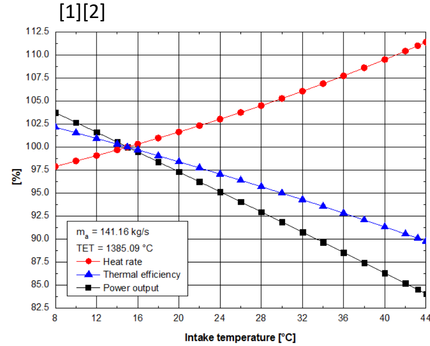



[3]




**Logistic regression of thermal generator outages and temperatures**

[1][2]




**Thermal generator performance degradation with increasing ambient temperatures**



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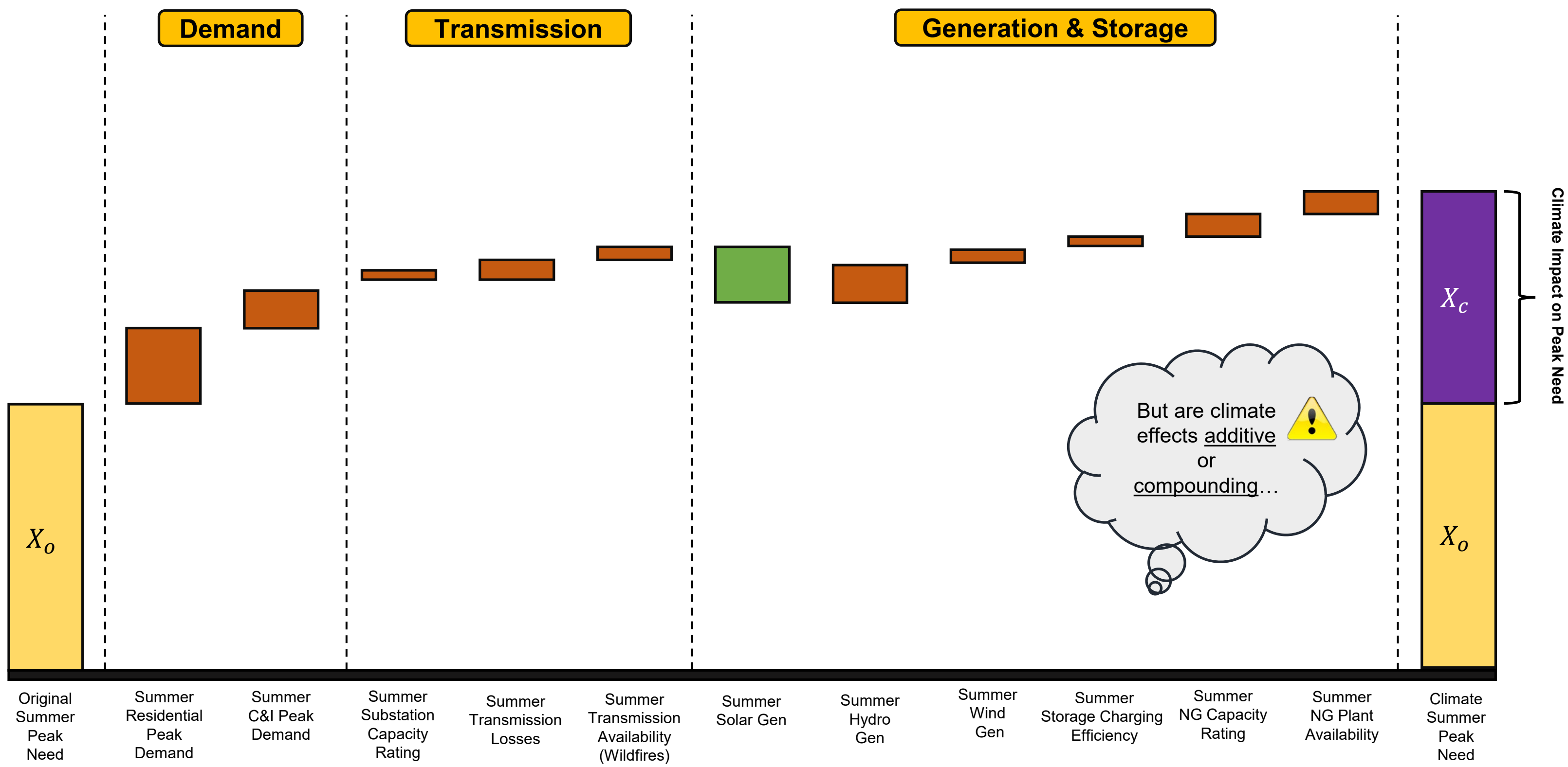
[1] https://doi.org/10.1016/j.applthermaleng.2011.04.045.
[2] https://doi.org/10.1016/j.joei.2014.07.006
[3] https://doi.org/10.1016/j.apenergy.2019.114424

# Climate Change Impacts on Utility Planning Recap

**Largest climate impacts on system resource adequacy and reliability must be addressed with climate adaptation investment**



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Note: All impacts are illustrative only. Does not include other potential risks (flooding, storms, etc.) Climate change impact could also reduce peak need in certain scenarios and seasons.