# Integrated Resource Planning

ROUNDTABLE 22-9

OCTOBER 2022

# MEETING LOGISTICS

**Electronic version of presentation:**

https://www.portlandgeneral.com/our-company/energy-strategy/resource-planning/integrated-resource-planning/irp-public-meetings

**Teams Meeting**

**Join on your computer or mobile app**
Click here to join the meeting

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Meeting ID: 215 719 845 007
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+1 971-277-2317,,233287942#   United States, Portland
Phone Conference ID: 299 540 974#

**Please use Microsoft Edge or Google Chrome with Teams as it will give you the best experience**

# PARTICIPATION

## During the presentation

All attendees will be muted; to unmute yourself via computer, click on the microphone that appears on the screen when you move your mouse

To unmute yourself over the phone, **press *6**

If you call in using your phone in addition to joining via the online link, please make sure to **mute your computer audio**

Use the chat feature to share your comments and questions.

Raise your hand icon to let us know you have a question

## Interaction Agreements

We will ask for comments and questions along the way

Please be polite and respect all participants on the webinar

Please stay on topic; we may interrupt or shorten questions to meet the time commitment of the meeting

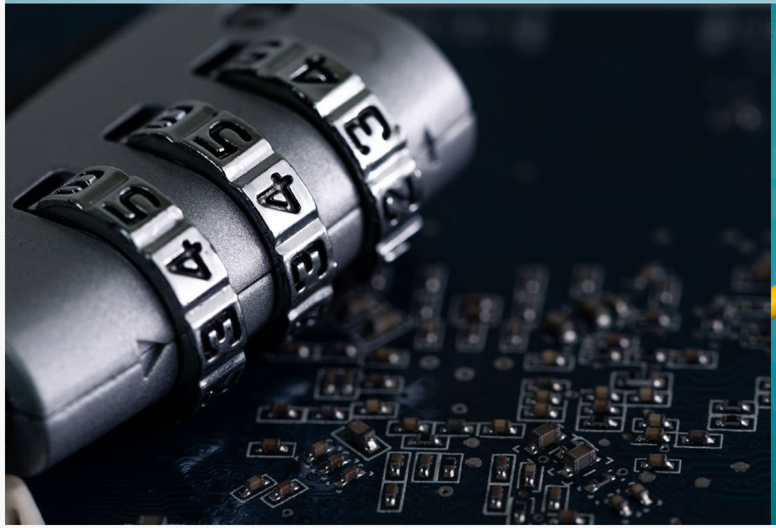
# AGENDA

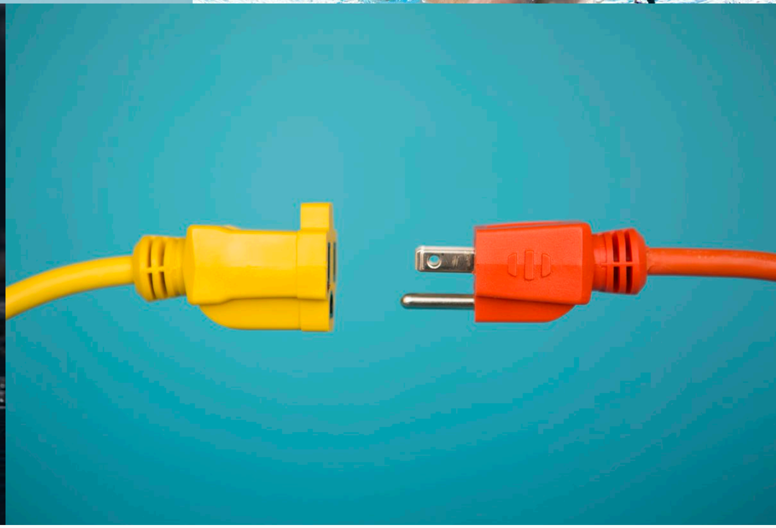
| | |
|---|---|
| 8:30 – 8:40 | Welcome and Introductions |
| 8:40 – 8:45 | Safety Moment |
| 8:45 – 10:00 | Transmission Part II |
| 10:00 – 11:00 | PGE Climate Change Resource Planning Study |
| 11:00 – 11:15 | Resource Adequacy |
| 11:15 – 11:45 | Flexibility Analysis |
| 12:15 – 12:30 | Clean Energy Plan Information |

# SAFETY MOMENT

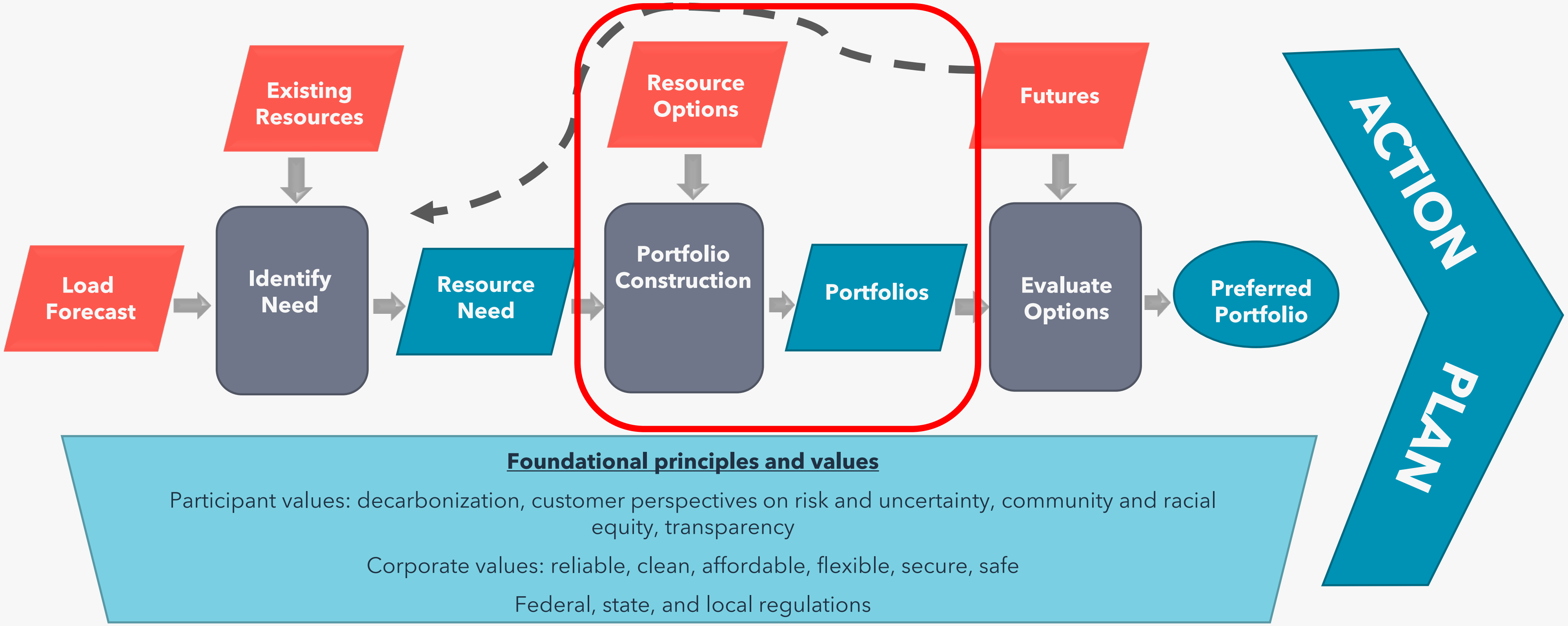
## Emergency Preparedness

- Do one thing a month to have a safety plan in place
- Replace smoke alarm batteries yearly
- Buy a gallon of water at your next grocery trip or boil a gallon of water and seal in a clean container
- Create a communication plan with your community
- For more examples visit: https://do1thing.com/individuals





# IRP ANALYSIS PROCESS



# TRANSMISSION PART II

ROB CAMPBELL, Principal Strategy & Planning Analyst Integrated Resource Planning
JACOB GOODSPEED, Principal Energy Supply Procurement Originator Renewable Initiatives

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# Transmission in the 2023 IRP

Existing | New

2030/2040

## PGE/BPA interface

Assess existing transmission rights on BPA system, find ways to increase interface, open new scheduling points of strategic relevance.

Treatment in IRP to be discussed today.

## Future transmission development

Continue to plan for 2040 system needs collaboratively with Northern Grid, regional RA partners, and remaining engaged with merchant developers.

For discussion in a future roundtable.

## PGE Transmission Planning

Planning to WECC and NERC standards for PGE system upgrades and interface with BPA.

Existing transmission planning process outcomes highlighted in IRP.

## Regional opportunities

Continue to assess and pursue commercial opportunities for existing transmission projects that would expand PGE's transmission footprint and provide a benefit to customers.

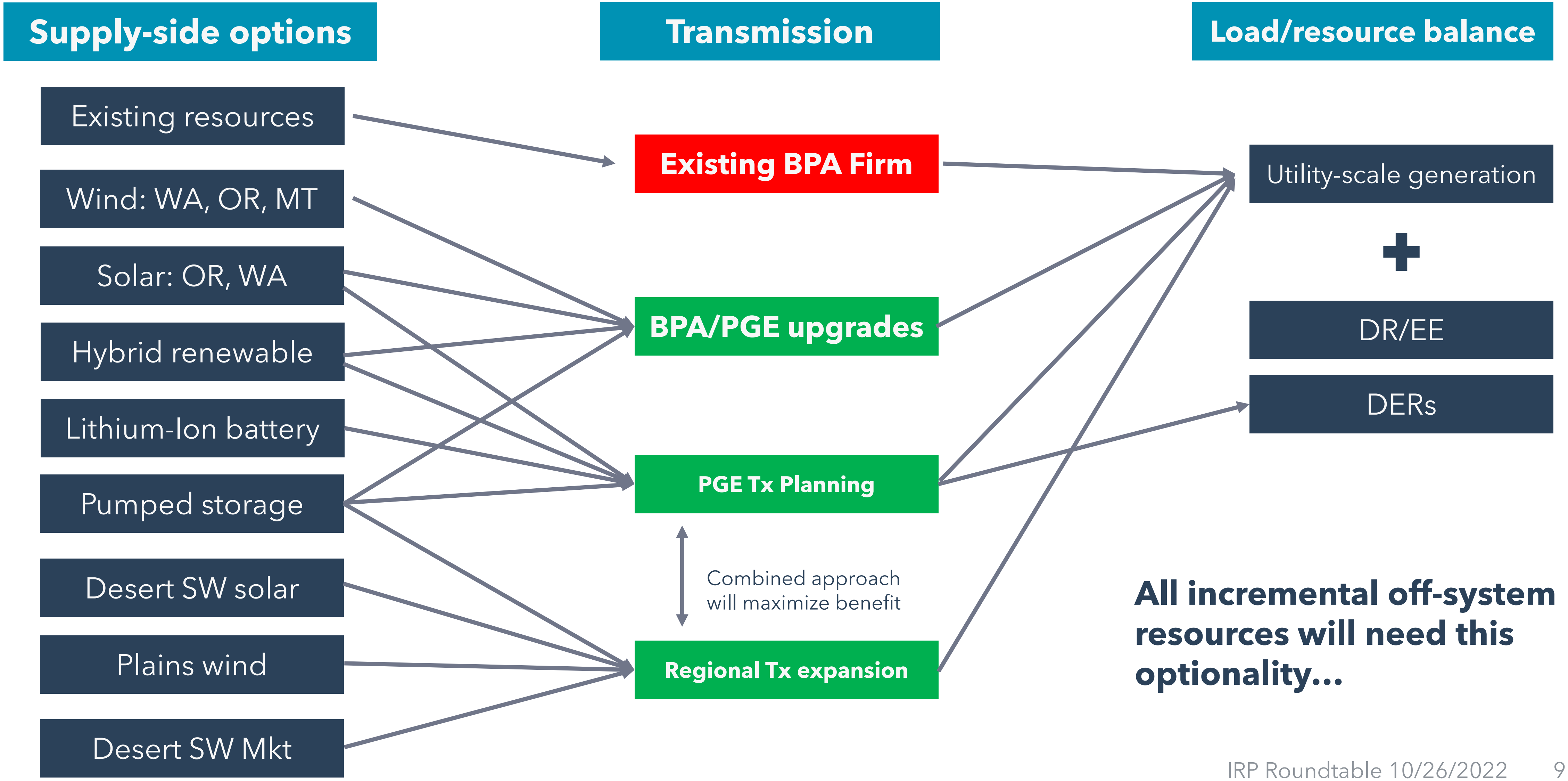
IRP options to be introduced today.

Near-term

Reliability-driven

Affordability-driven

# PGE's "four quadrants" transmission approach adds optionality within the IRP




**All incremental off-system resources will need this optionality...**

# Outline and highlights of today's discussion

## Existing system and rights

- Recognizes constraints on BPA's system and in the BPA/PGE interface
- Assumes TSRs included in cluster studies in 2021 and earlier can be awarded firm service
- Assumes no incremental BPA firm rights after 2021 TSEP
- IRP may select PGE/BPA projects that would increase capacity on South of Allston, West of Cascades South

## Transmission options for IRP consideration

- PGE prioritizing system connectivity that could provide reliability benefit, resource diversity benefit, and that would supplement existing reach.
- Generic transmission option available for portfolio selection.
- Transmission option in modeling generally corresponds to regional transmission buildout that could provide optionality to PGE.

# EXISTING TRANSMISSION SYSTEM

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PGE

# Available transmission: methodology update

## Previous Methodology

- Discussed at the April 2020, March 2021, and August 2022 roundtable meetings
- Utilized posted BPA ATC data to determine transmission capacity
  - ✓ Overstated availability by not accounting for allocations awarded since last updates

## New Method

- Review BPA's 2016-2021 TSEPs
  - ✓ "Study" TSRs get CF
  - ✓ "Confirmed" TSRs get LTF
- TSRs made prior to the 2022 TSEP that point to PGE's system are likely to be granted conditional firm.
- BPA states that TSRs made starting in 2022 would only be granted service once upgrades are complete.

# Available transmission: inventories update

**BPA 2022 TSEP finding:**
less available transmission

These values represent total transmission MW additions available through 2026

ROSE-E's transmission constraint updated to reflect these values

Cross-zone impacts captured in inventories – Each resource addition affect's only its own inventory

| Resource Zones | Conditional Firm (MW) | Long-Term Firm (MW) | Total (MW) |
|---|---|---|---|
| Gorge | 388 | 190 | 578 |
| Montana * | 0 | 0 | 0 |
| SE Washington | 150 | 0 | 150 |
| Offshore | 80 | 0 | 80 |
| Christmas Valley | 510 | 490 | 1000 |
| Willamette Valley | 0 | 10 | 10 |

*** 100 MW of conditional firm to MT pointed at PGE, but contingent on $1.2 billion in upgrades and 2030 energization date.**

**BPA TSEP:** https://www.bpa.gov/energy-and-services/transmission/acquiring-transmission/tsep

# Curtailment potential represents risk

## Point-to-Point (long-term firm)

690 MW available in aggregate, not including the 2022 TSEP, from all resource zones per existing transmission service requests.

Service is for transfer of energy and capacity from Point of Receipt to Point of Delivery.

Can potentially be redirected and/or resold.

Takes priority over conditional firm and other non-firm products.

No additional capacity available.

## Conditional firm

1128 MW available in aggregate, not including the 2022 TSEP, from all resource zones per existing transmission service requests.

Subset of point-to-point transmission that allows BPA to curtail service. This potential curtailment introduces operational and regulatory risks for PGE's customers.

Curtailment can be to relieve system congestion (up to a certain number of hours per year) or to resolve system needs. BPA retains discretion to curtail PGE service per BPA's tariff.

No additional capacity available until upgrades are in service.

# TRANSMISSION PATH OPTIONS

JACOB GOODSPEED

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# Generic versus specific projects in IRPs

**Our IRPs use 'proxy' resources that**

- Have general technological capabilities that are available through public sources (e.g., wind turbine size, hub height)
- Represent behavior within a geographic area (e.g., Columbia Gorge)
- Are subject to locational transmission constraints
- Serve as a placeholder for market availability, which will be determined as part of procurement.

**This balances specificity**

↓ Less information would lead to an *unactionable plan*

↑ More information would create an overly prescriptive and inflexible plan

The IRP estimates the costs and benefits associated with each of these proxy resources when determining actions

# Approach to transmission expansion

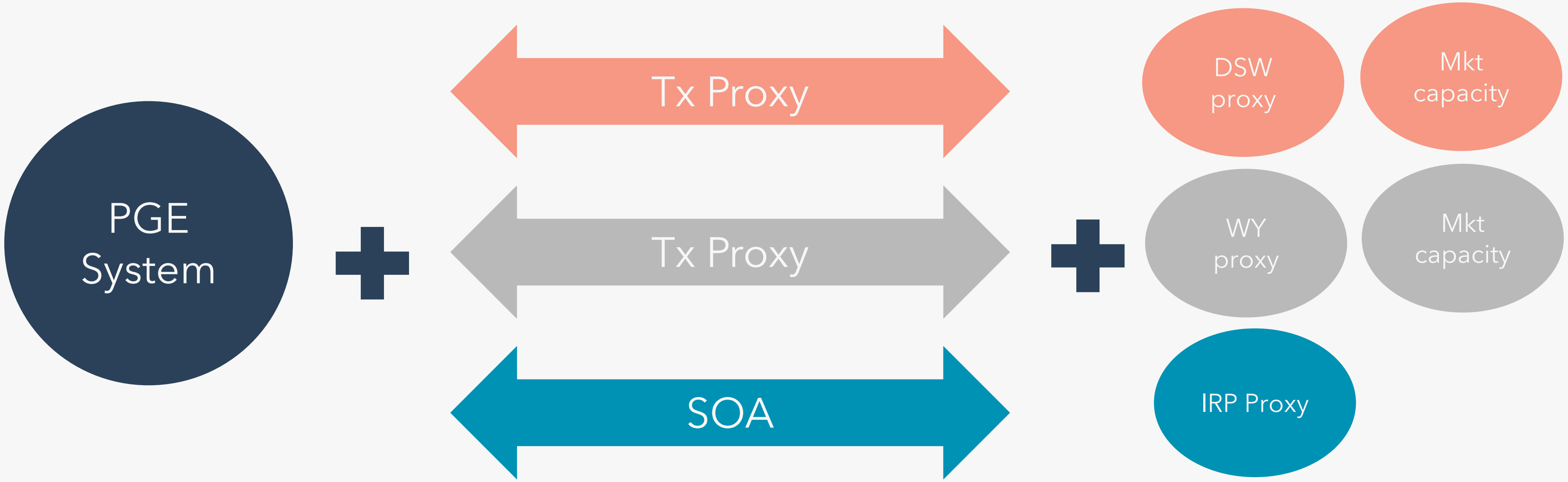
Our capacity expansion model (ROSE-E) will assume the availability of additional transmission capacity expansion options after 2026:

| Path | Resource | Energy and capacity assumption |
|---|---|---|
| Generic proxy transmission (Tx Proxy) | Desert SW Solar (DSW)<br>Wyoming wind (WY)<br>Dispatchable Capacity | Model can select to "build" a transmission path to access resource profiles based on climate zones in the WECC. Transmission resource assumed to be able to access Desert Southwest solar, Wyoming wind, dispatchable capacity, or a combination of resource options.<br><br>Transmission cost, resource and capacity cost, energy and capacity benefits of will each be evaluated by ROSE-E |
| South of Allston Expansion (SOA) | IRP proxy resource | Assumes the ability to increase transfer capacity on PGE's share of South of Allston via upgrade available in 2027. Would unlock additional capacity for resources that leverage BPA rights to get to PGE's system. |

# Transmission option modeling

Currently, ROSE-E can add proxy generation resources (or market transactions) that utilize assumed available BPA transmission to transport PNW proxy resources to load.


Once BPA rights are exhausted per slide 13, ROSE-E will need to pair a generic transmission proxy (GTP) with incremental proxy generation. Transmission availability is otherwise constrained.

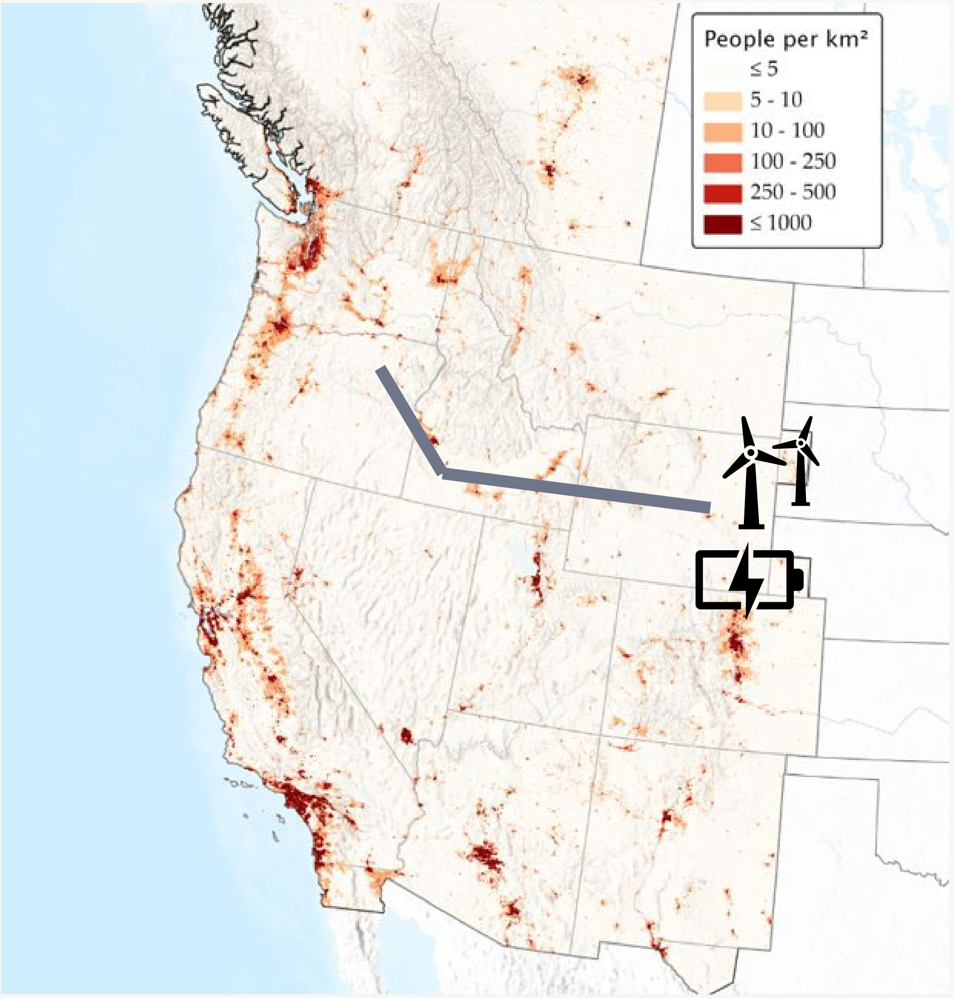


# Access to wind via transmission

East to west transmission could provide access to renewables off-system in in climate zones where wind has high production.

PGE will allow the model to choose this climate zone and associated transmission as the Wyoming wind and proxy capacity generic transmission option.

Current projects in development would add capacity to the Oregon Gorge and/or to Central Oregon. Regional need to solve for “last mile” across BPA.



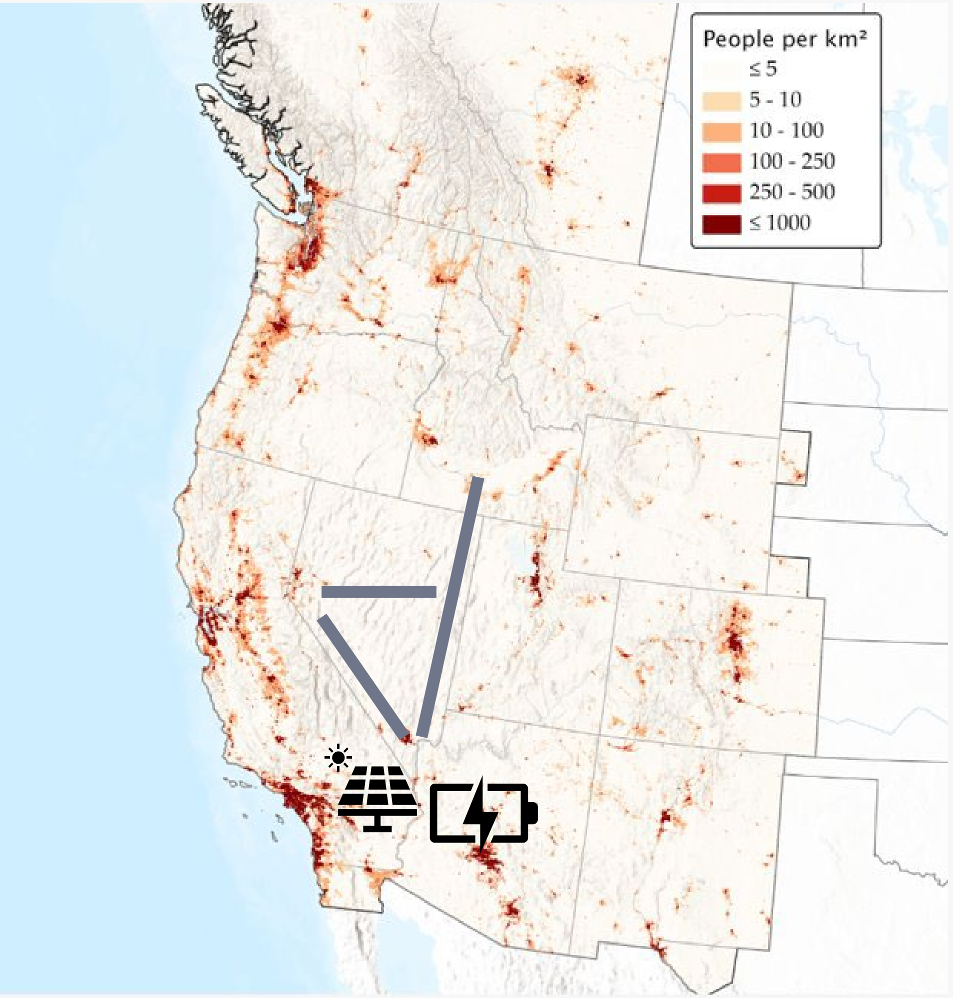

**Projects shown at right are indicative only. Path studied to access resources in the IRP will be generic.**

# Access to solar via transmission

Desert Southwest transmission access could unlock solar resources that are somewhat uncorrelated from PGE production and load.

PGE will allow the model to choose this climate zone and associated proxy transmission as the DSW solar and proxy capacity generic transmission option.

Current projects in development could reach PGE's system through Central Oregon or through COI. Regional need to solve for "last mile" across BPA.




**Projects shown at right are indicative only. Path studied to access resources in the IRP will be generic.**

# CLIMATE ADAPTATION STUDY

ANDRES ALVAREZ, CREATIVE RENEWABLE SOLUTIONS
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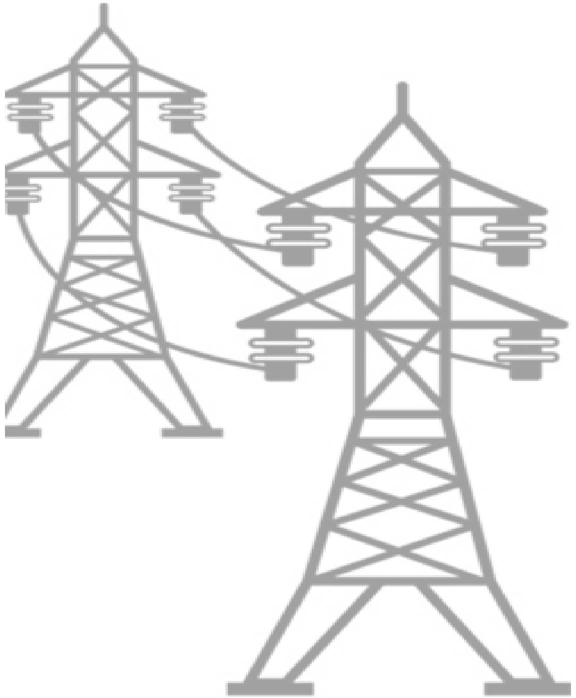

**1. Review of Climate Change in Pacific Northwest IRP Planning**

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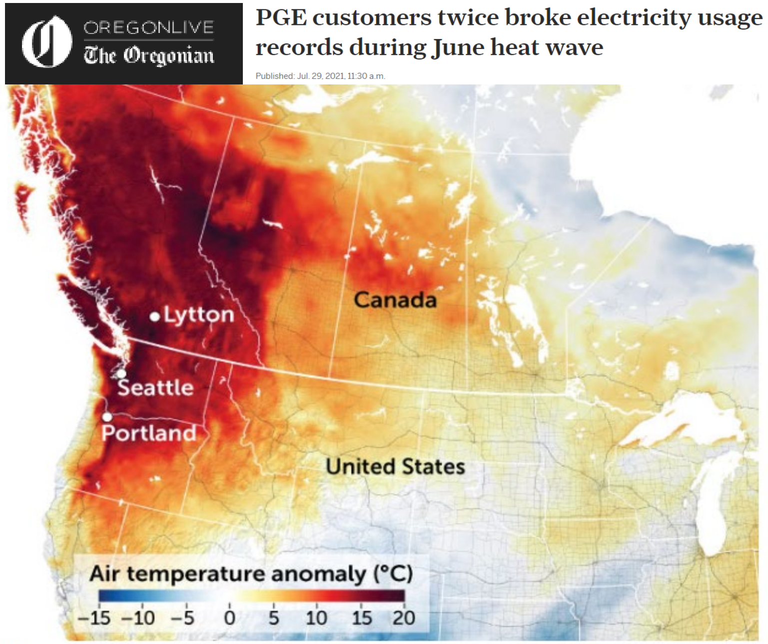
# Observable Climate Change Effects




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.





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

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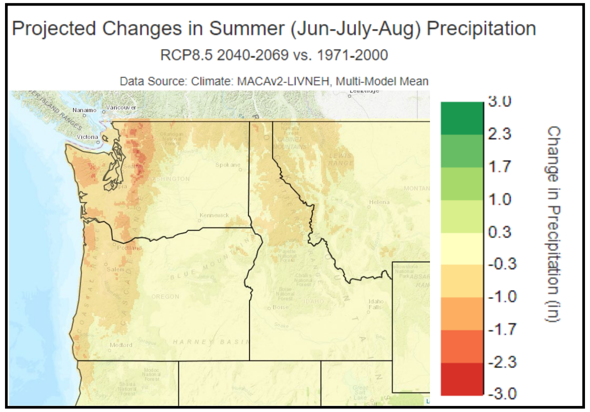
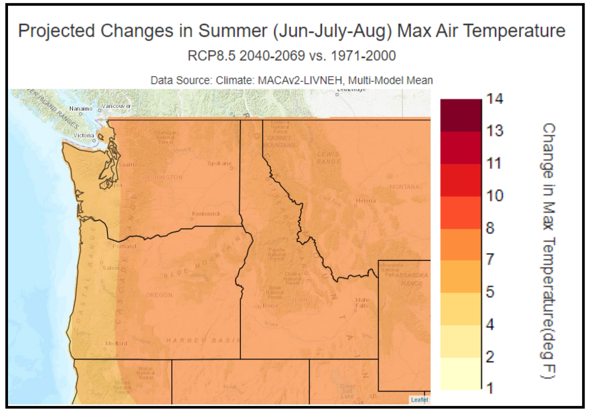
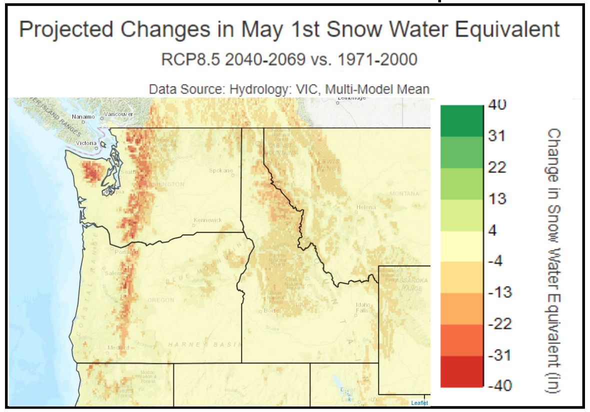
# Climate Change Impacts in the Pacific Northwest



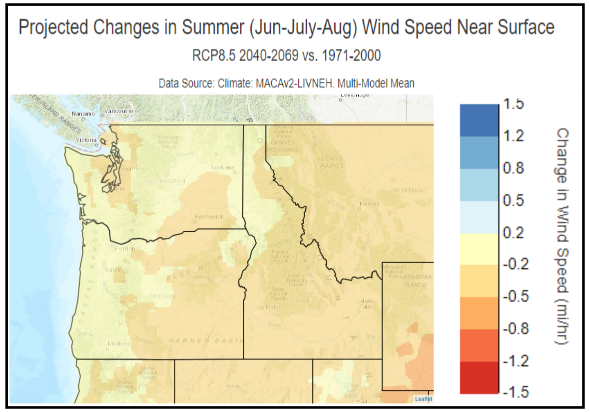

Decrease in Summer Precipitation




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



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

# Climate Impacts on the Power Grid

**Energy Demand**

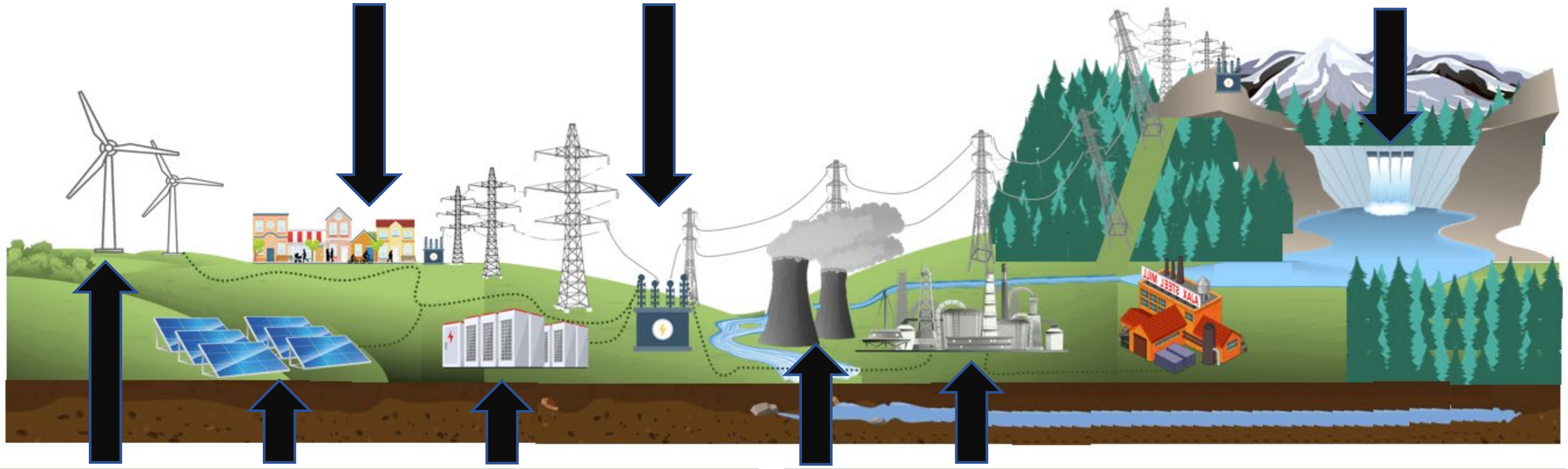
- Higher summer temperatures drive increasing cooling demand (electric)
- Higher winter temperatures reduce demand for heating (electric, gas)

**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**

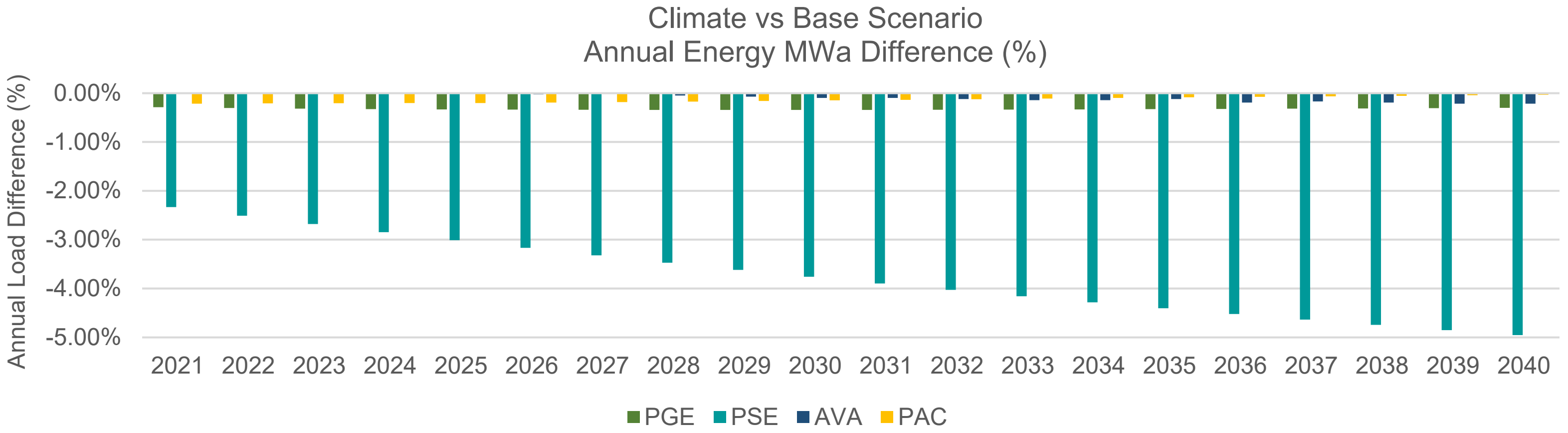
- Higher air and water temperatures reduce fuel conversion efficiency and cause nameplate capacity deratings.
- Reduced water availability for cooling can lead to shutoffs (FOR).

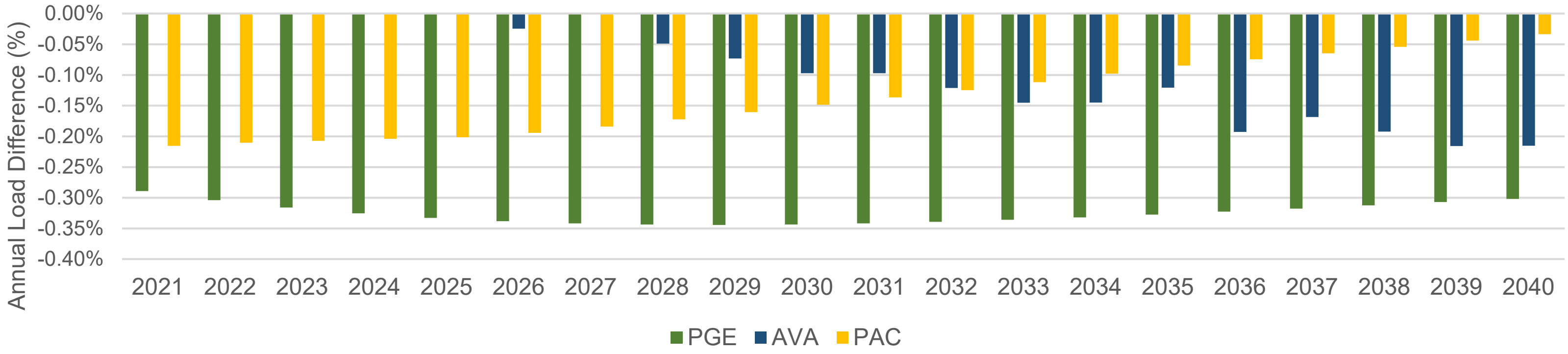
# PNW Utility Review of Climate Change Impacts - I

| 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 | |

# 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.**





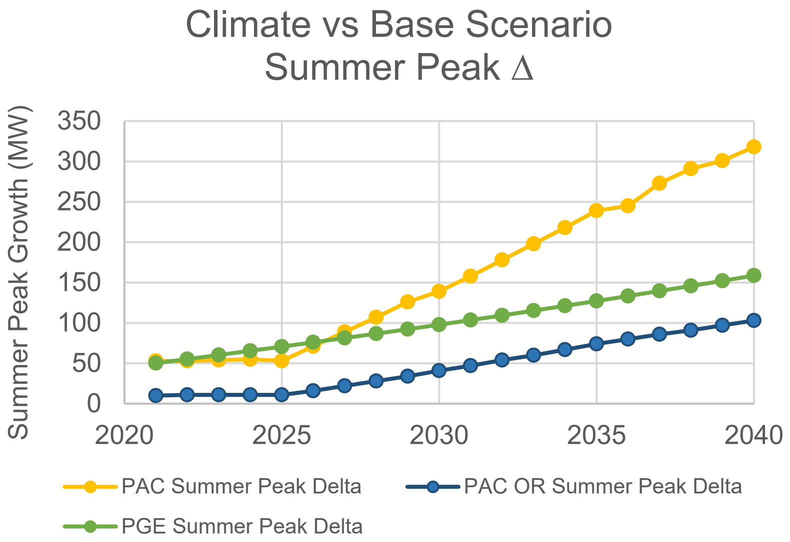


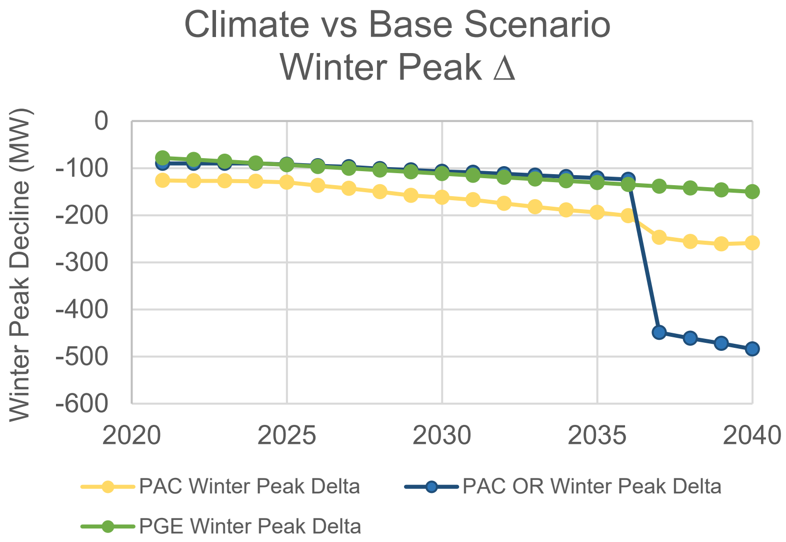

NOTE: **PGE values based on 2016 IRP study.** PSE values based on 2021 IRP (does not include 2023 IRP workshop material).

# 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.**



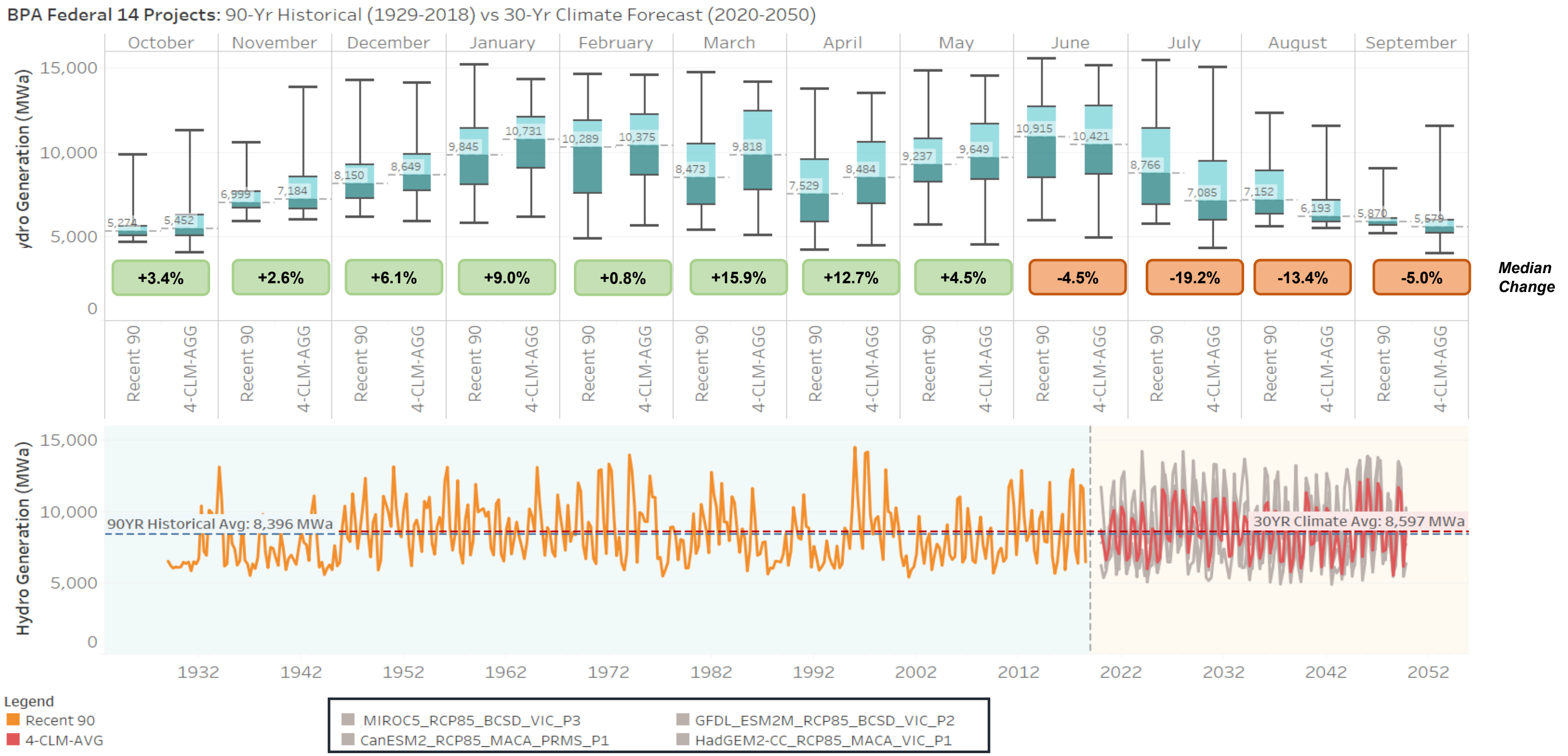





NOTE: **PGE values based on 2016 IRP study.** PAC values based on 2019 IRP study.

# 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%.**








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

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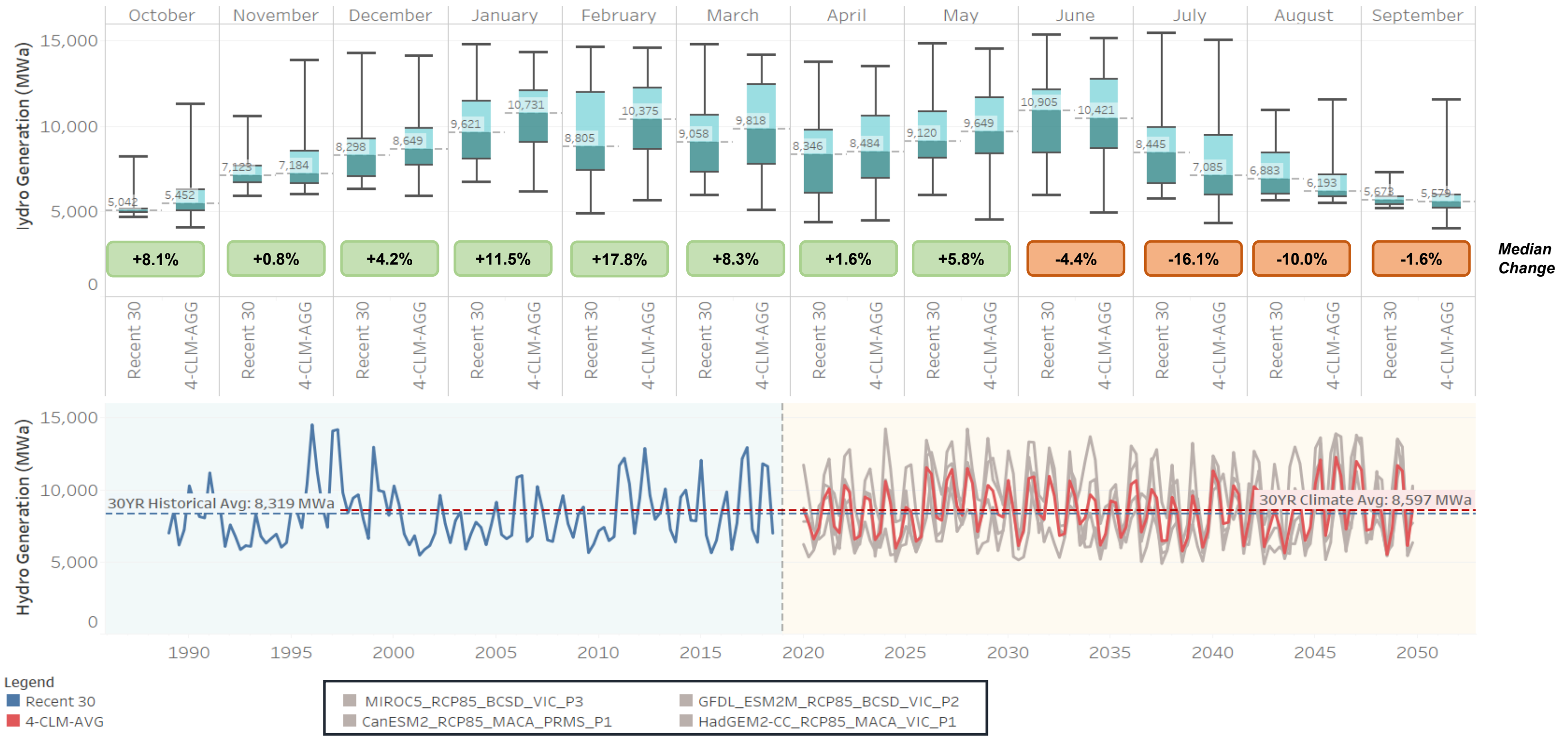
# PNW Utility Review of Climate Change Impacts - V

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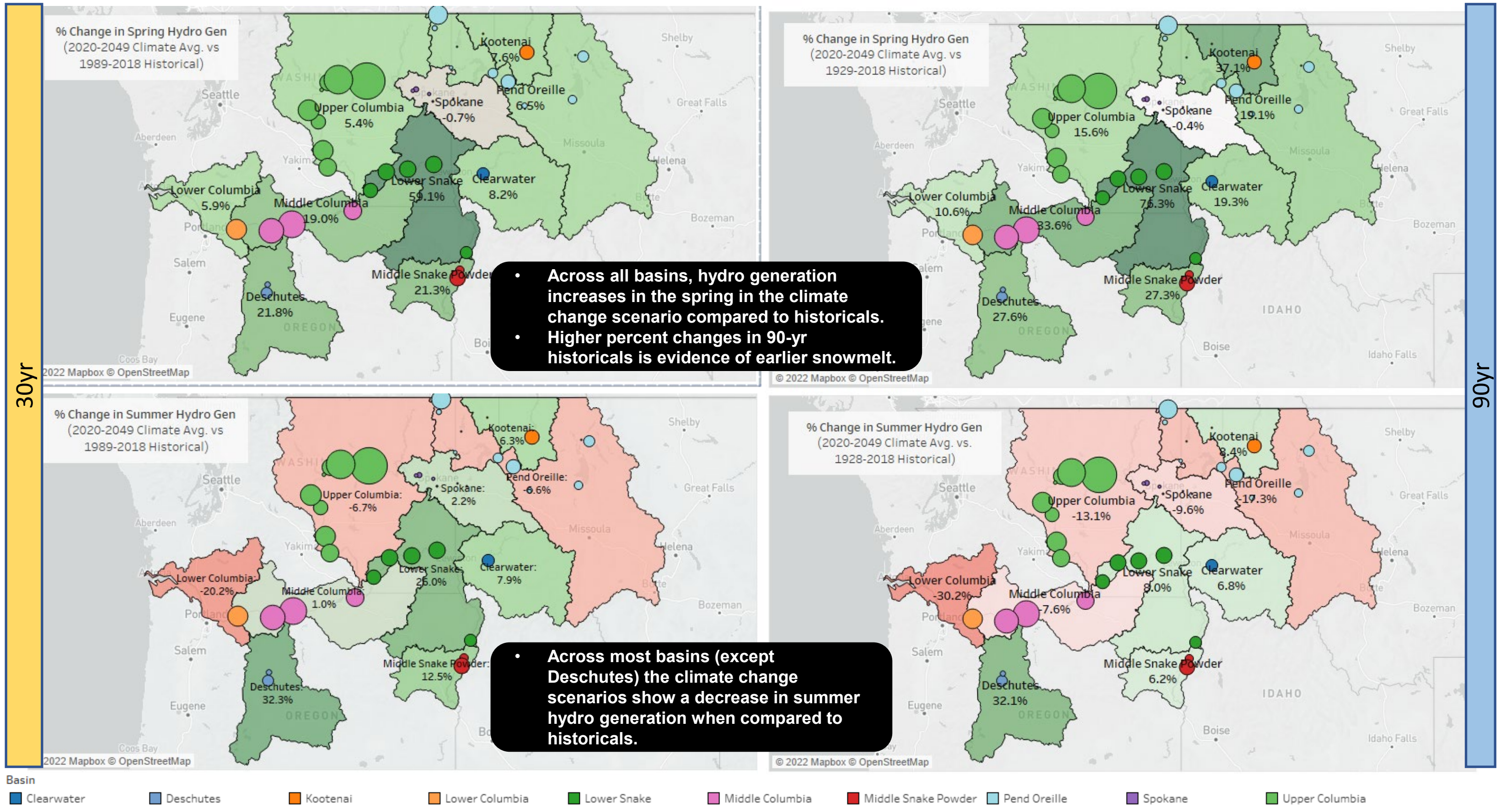
NOTE: Based on BPA's 14 selected federal projects.

# PNW Utility Review of Climate Change Impacts - VI




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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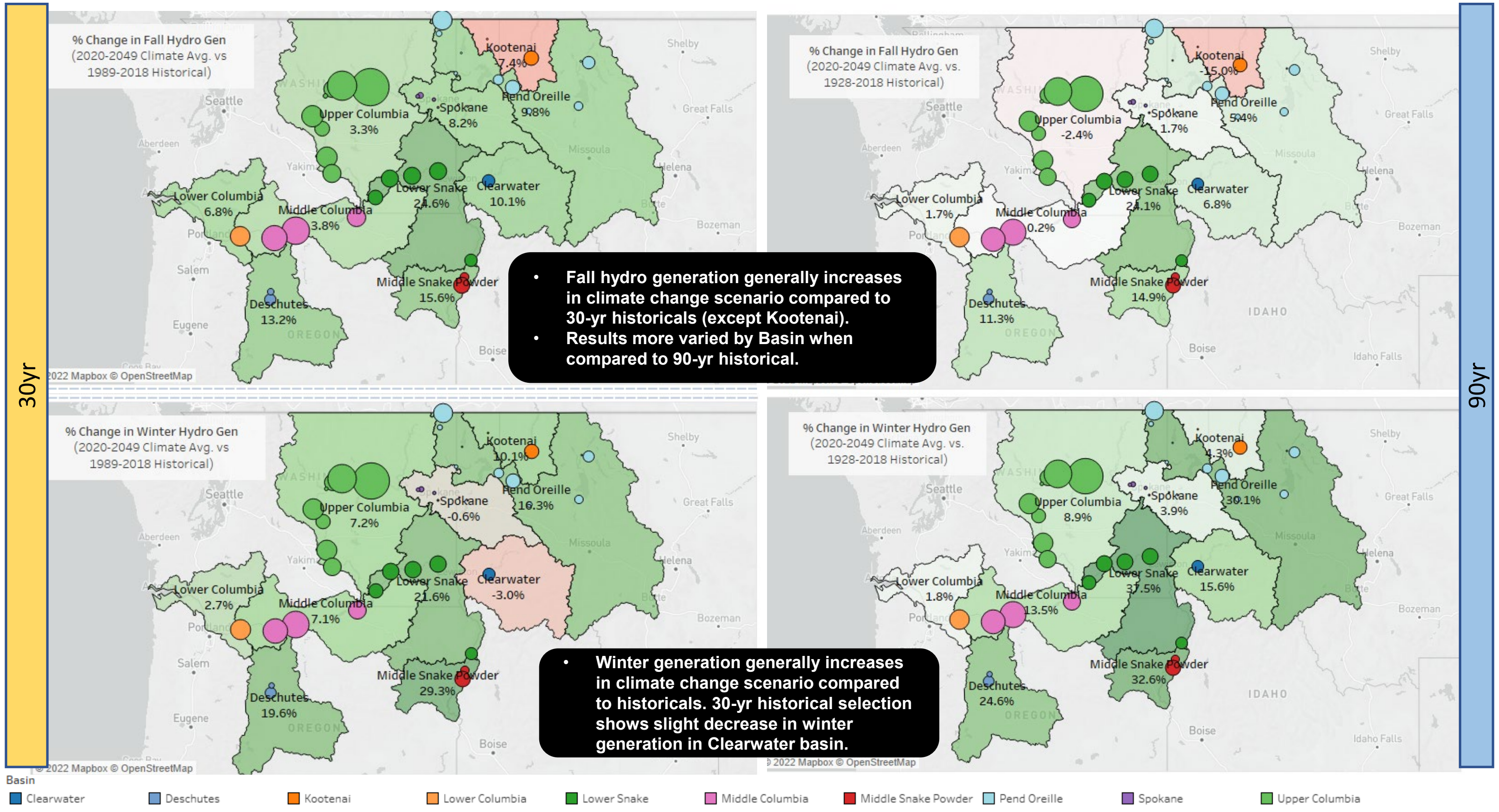
# PNW Utility Review of Climate Change Impacts - VII




- 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.





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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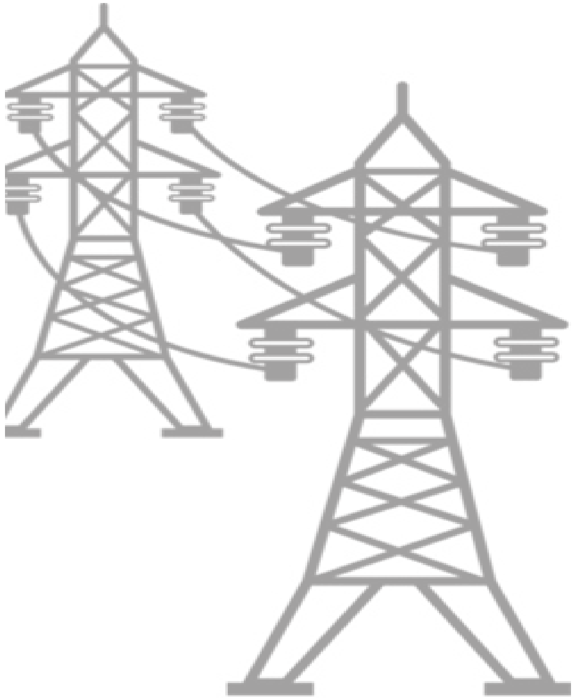

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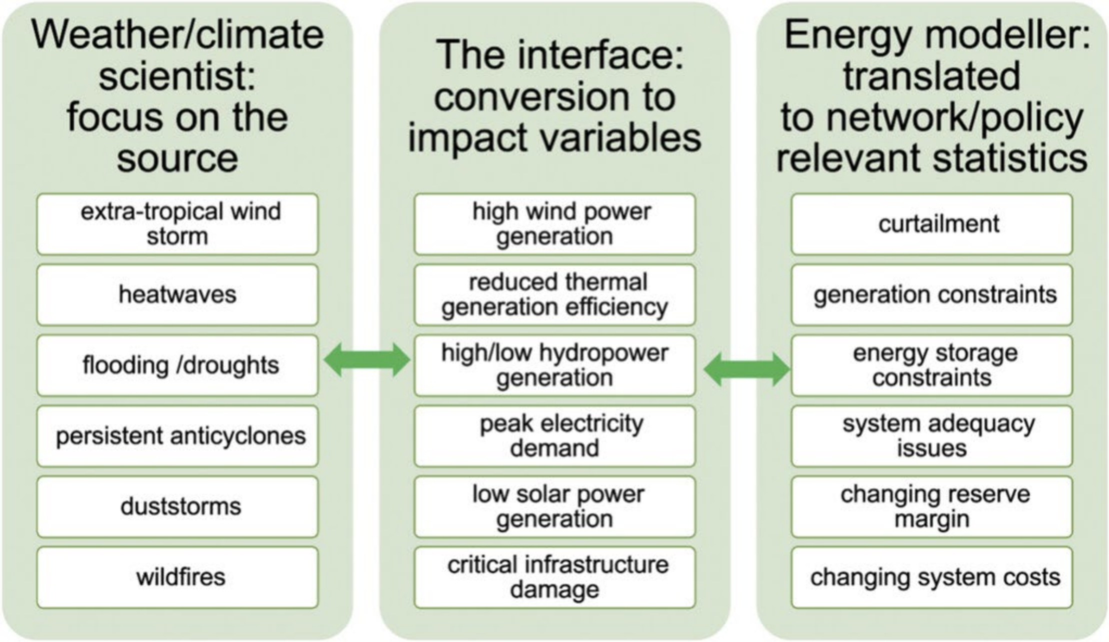
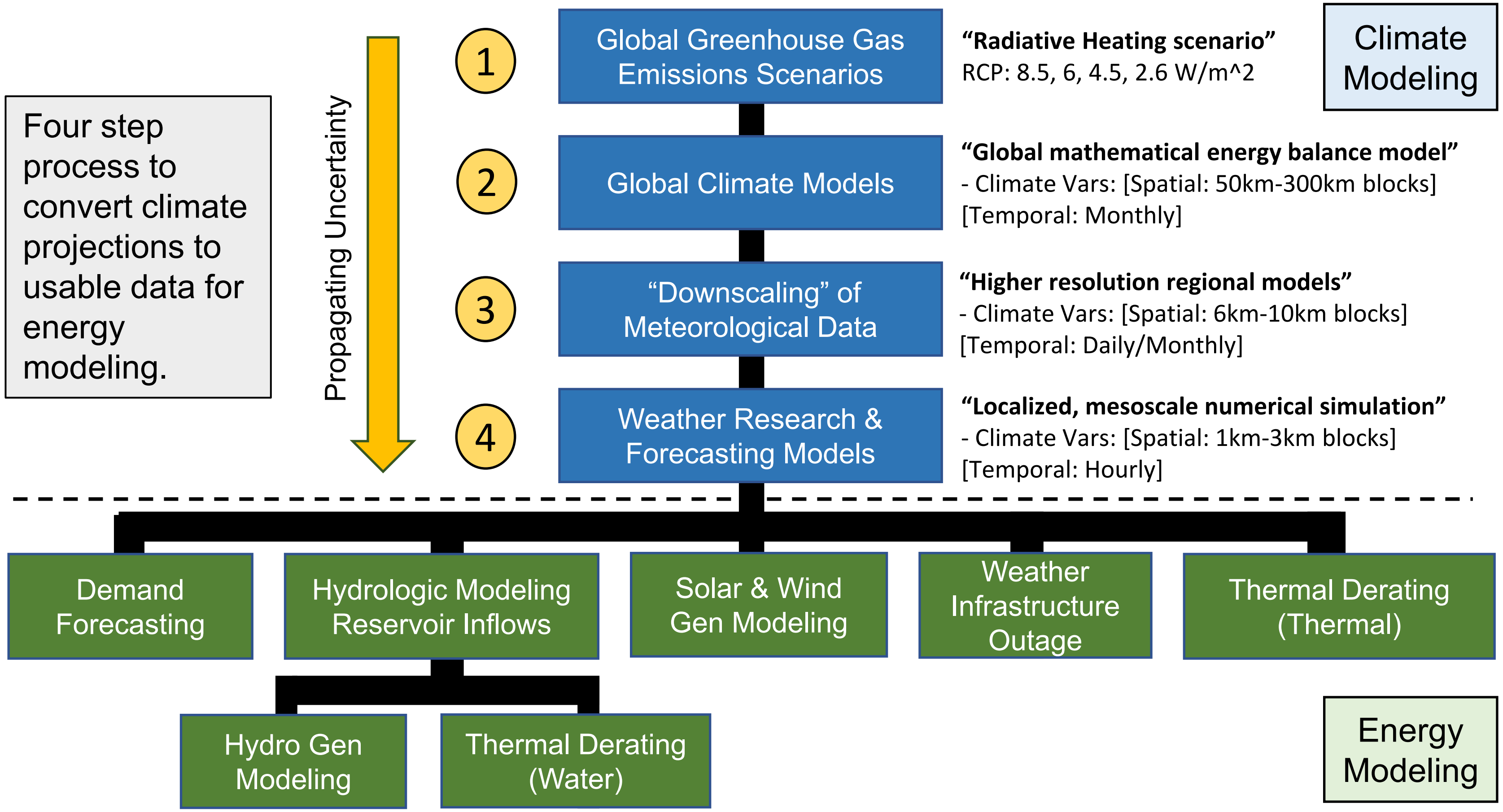
# Climate Change Modeling vs Energy Resource Modeling




**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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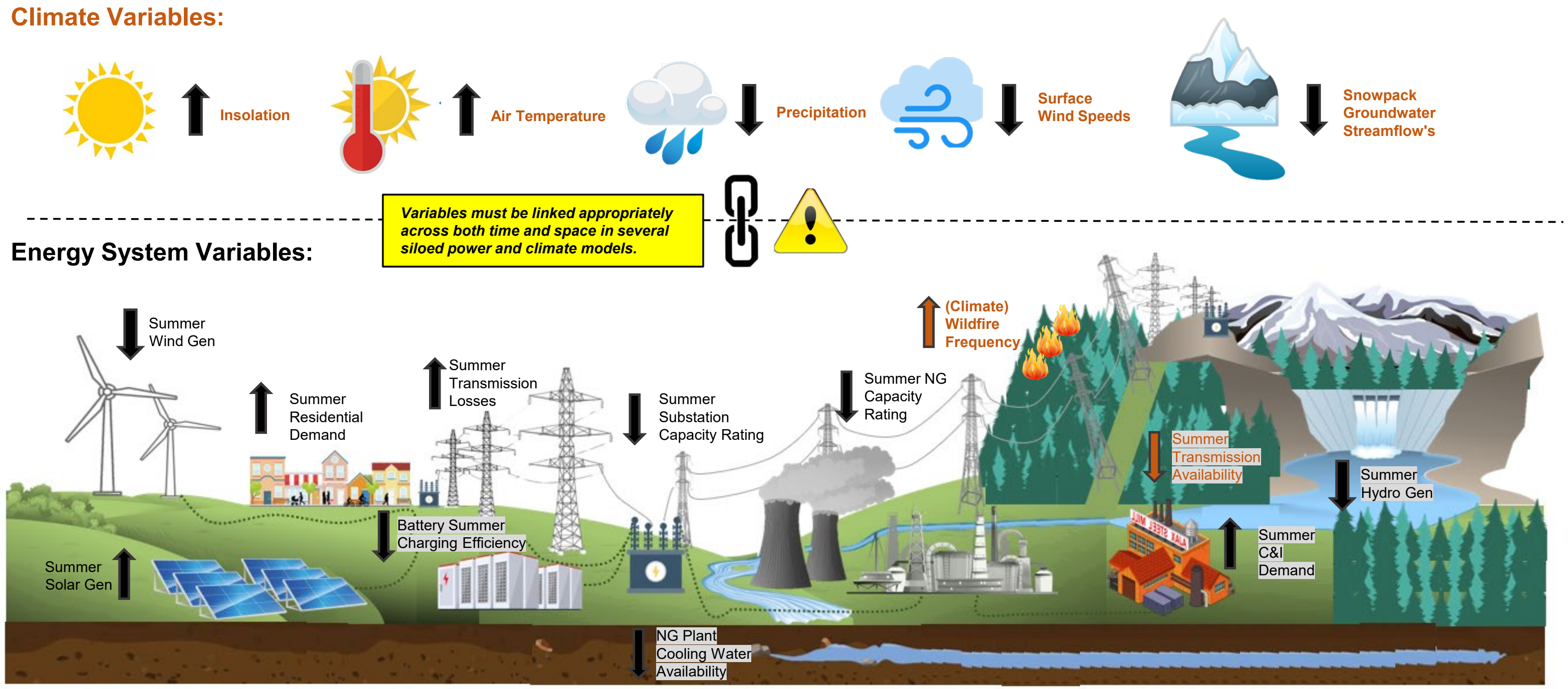
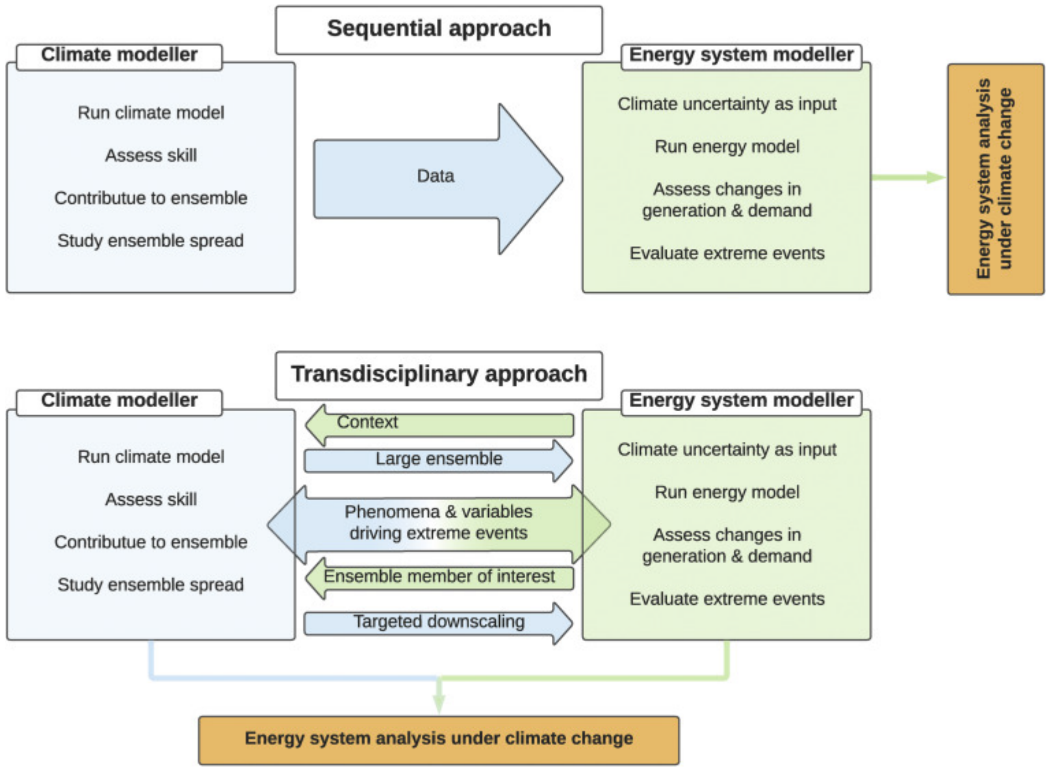
# Climate Change Impacts on Utility Planning

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

**Summer 2050 in Utility-Ville**



# 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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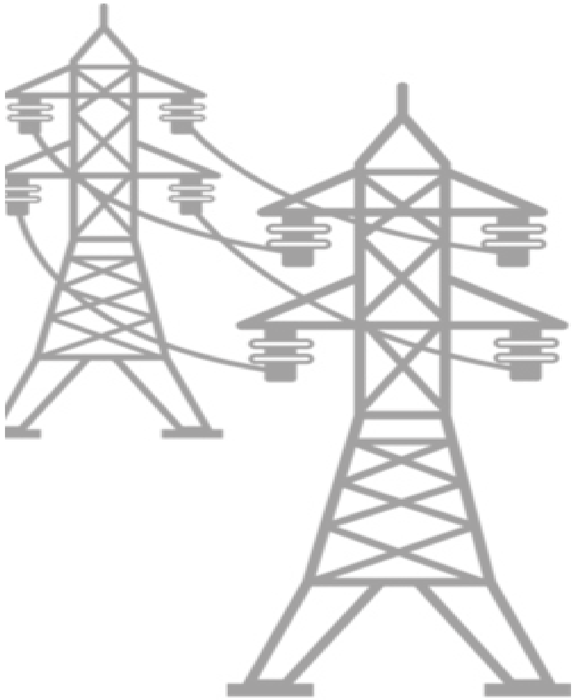

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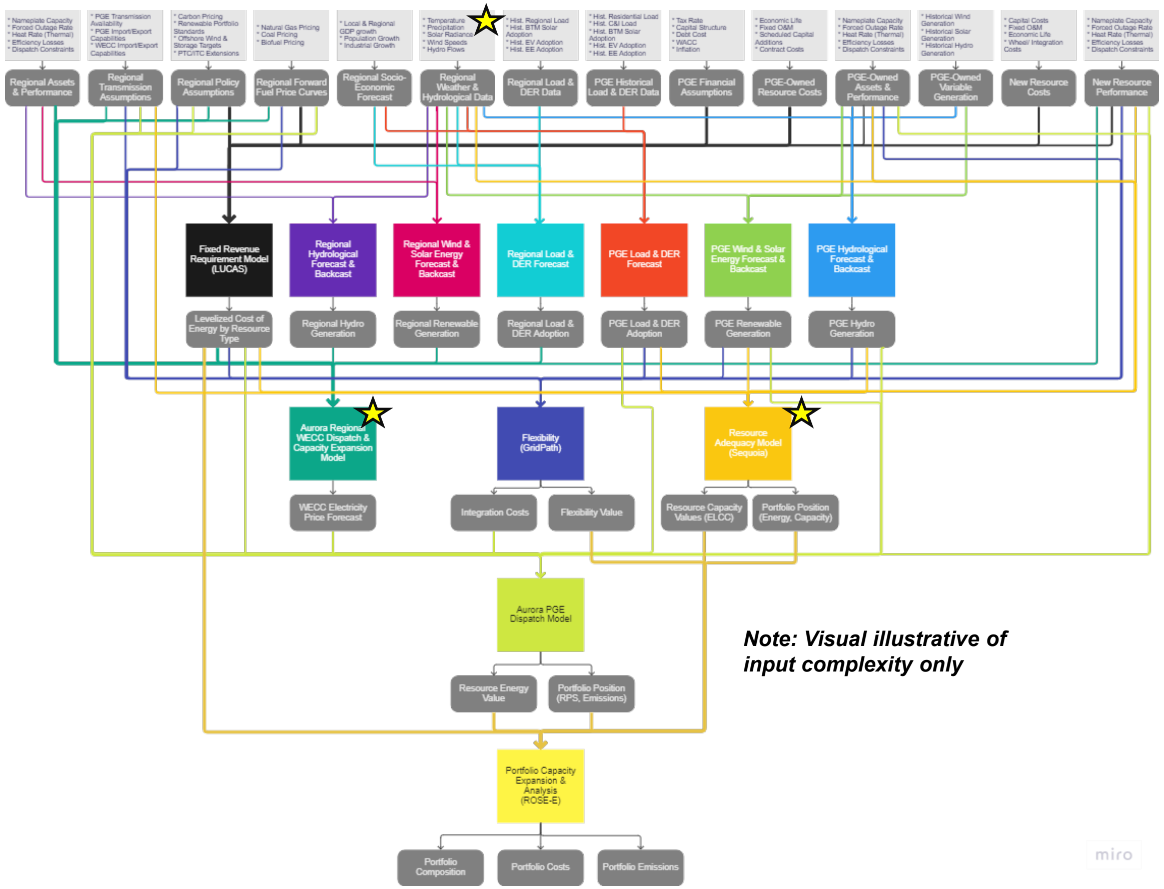
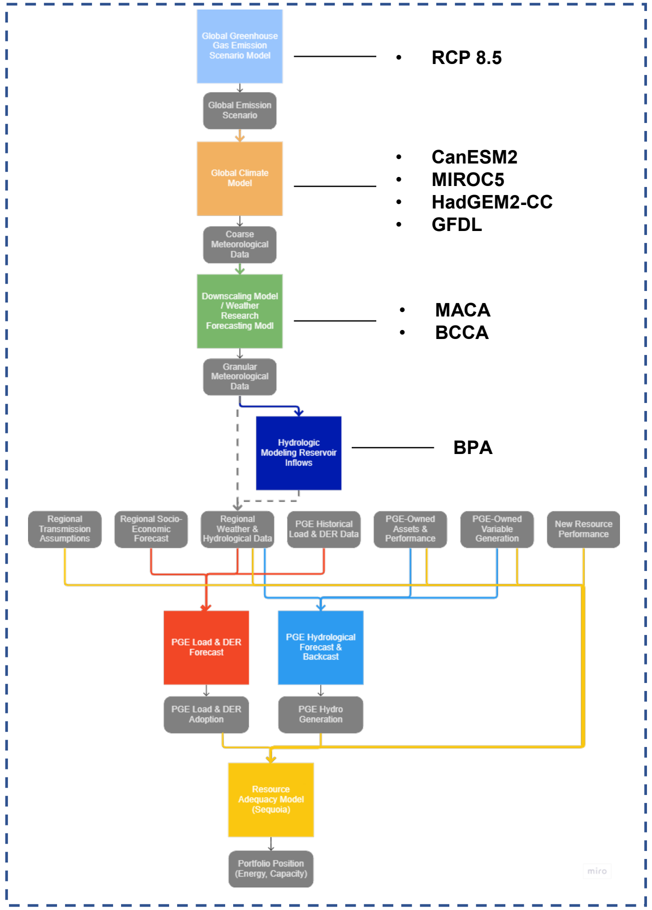
# PGE's Existing IRP Structure




***Note: Visual illustrative of input complexity only***

- **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.

# 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.

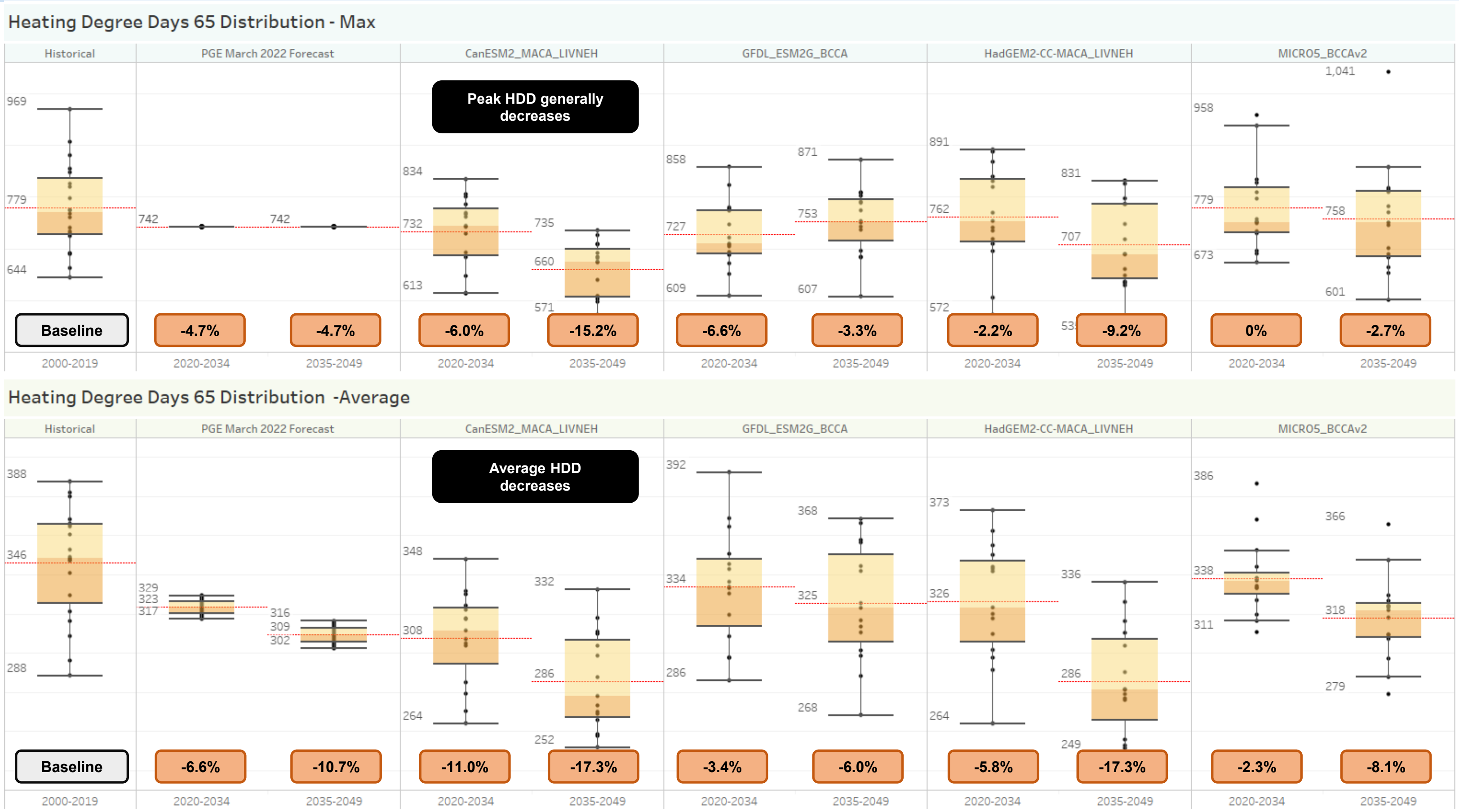
3. **HadGEM2-CC-MACA-VIC-P1:** Warmer scenario; median precipitation above Grand Coulee, but above the median precipitation in the Snake River basin.

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

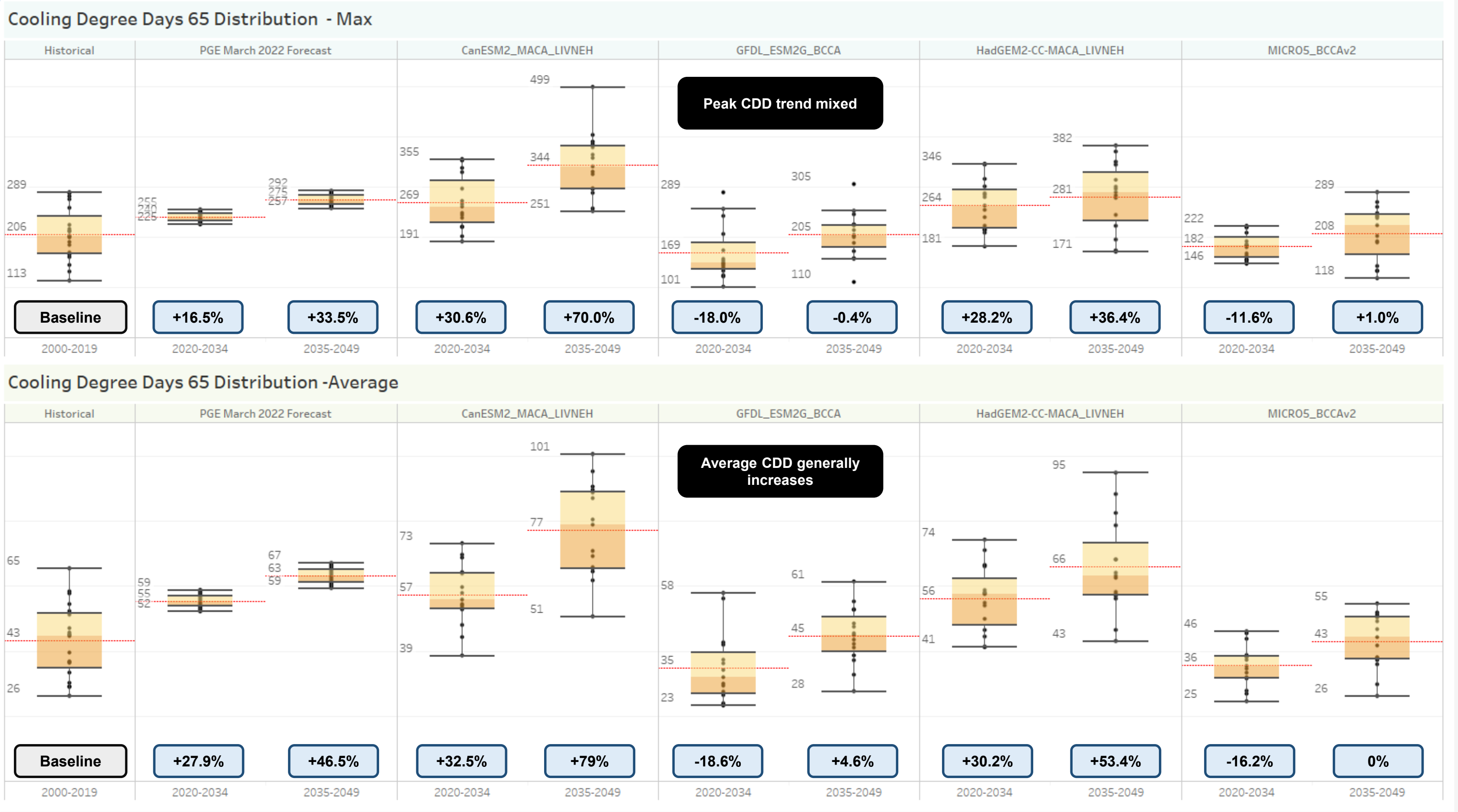
*Note: Hydro generation & flow data acquired from BPA. Climate temperature data acquired separately.*

Creative Renewable Solutions

# PGE Heating Degree Days



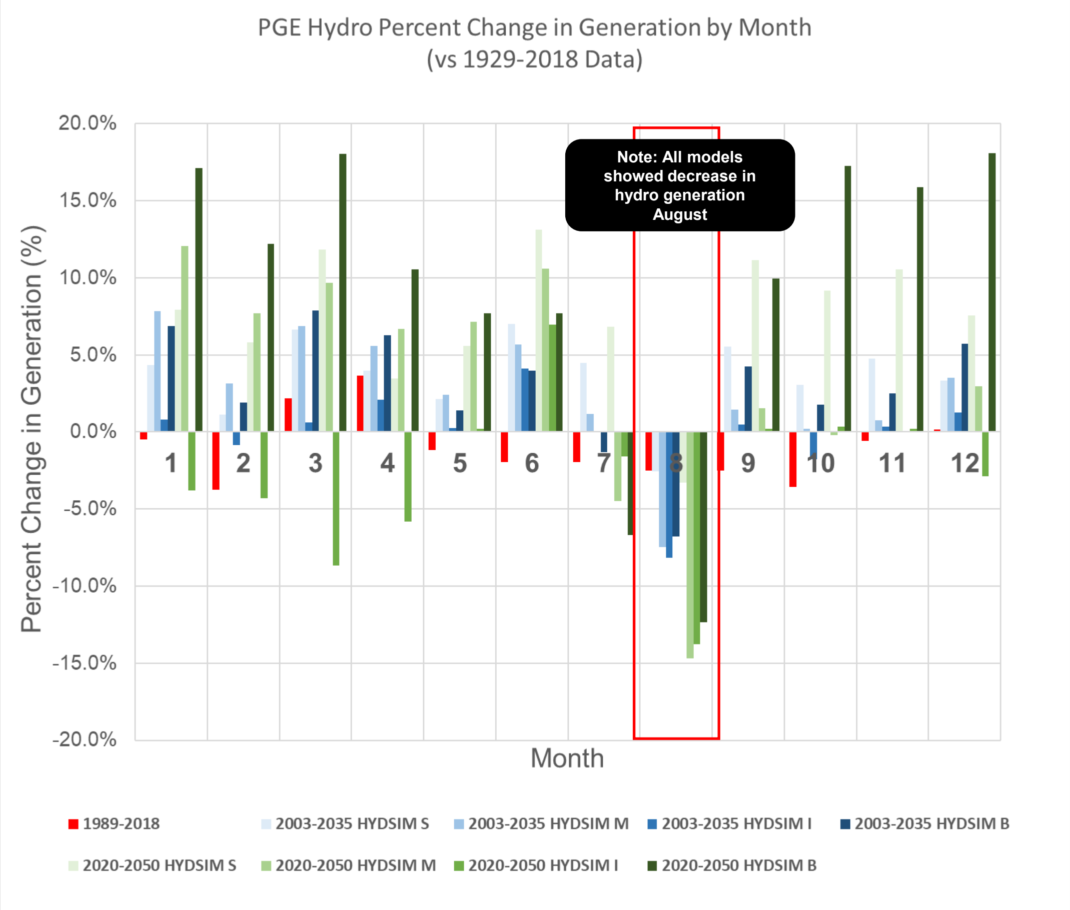
# PGE Cooling Degree Days






PUBLIC

# 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).

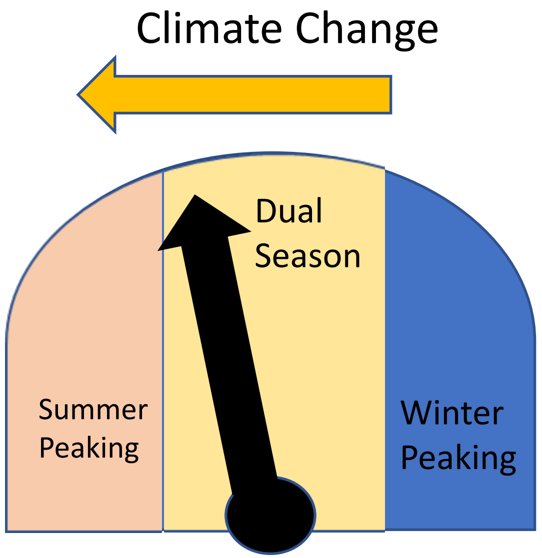
# Preliminary Findings

**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.

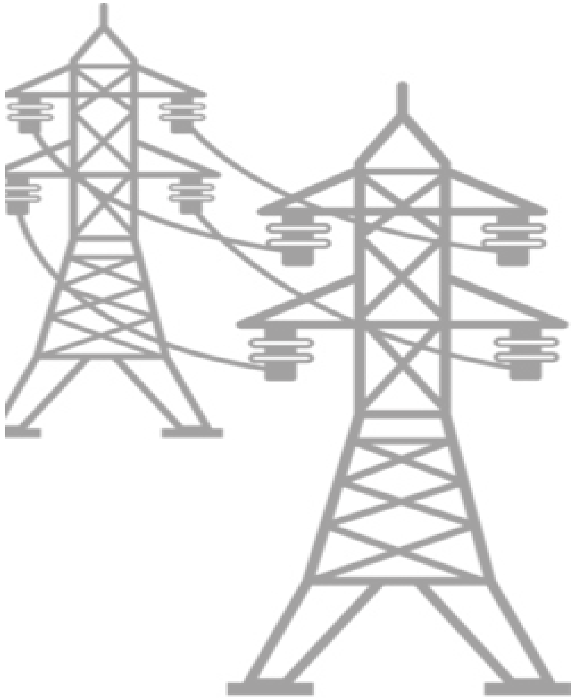







Note: Average of four climate models (2020-2035) compared to the baseline historical data (2000-2019).

Creative Renewable Solutions



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**

# 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 within 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.

# RESOURCE ADEQUACY MODEL CHANGES & CLIMATE SENSITIVITIES

TOMÀS MORRISSEY, Principal Integrated Resource Planning Analyst

ROUNDTABLE 22-9

PGE

# Sequoia 101 (the Adequacy Model)

Sequoia is stochastic adequacy model. It simulates load and resource combinations to answer two primary questions:

1. How much capacity do we need to keep the system adequate?
2. How much capacity do resources provide to the system?

The model was developed following the 2019 IRP and was used in the 2019 IRP Update and in the ongoing 2021 RFP. Sequoia is PGE's long term planning model rather than an operations model.

# What inputs are changing and why

**Reducing the number of temperature and hydro years in the model to better capture recent weather events.**

- For temperatures, the Corporate Load Forecast uses trended temperature data that are mostly in the range of the four climate models reviewed for the IRP. We will continue to use that forecast but shorten the number of weather years in Sequoia.
- For hydro, the IRP will include sensitivities using climate change model hydro data. For the reference case, we will update from the 1929-2007 record to the 1989-2018 record.
- PGE will continue to evaluate using climate change model data for future planning work.

**Increasing light-load-hour (10 PM to 6 AM, Sunday's, and holidays) market availability to provide more energy for storage to charge.**

# Draft results from July 2022 roundtable

Values here, and throughout this presentation, are for year 2026 reference case (does not include contract renewals)

| | **Year 2026 capacity need (MW)** | |
|---|---|---|
| | Summer | Winter |
| July 2022 draft need results | 761 | 863 |

# Temperature years vs. model inputs

Corporate load forecast creates monthly values using trended temperature data

IRP team has a 42-year hourly load record based on neural net and actual loads (on an annual energy basis the loads are similar across the 42-years)

Sequoia loads start with the 42-year hourly record. The record is scaled up/down to match the corporate forecast for monthly peak and energy.

For the 2023 IRP, we start with the scaled 42-year load record but only allow the model to select from the most recent 30-years.

# Using fewer temperature years

Switching from 42 to 30 temperature years (1992 – 2021) in the model **increases summer need and decreases winter need.**

| | Year 2026 capacity impact (MW) | |
|---|---|---|
| | Summer | Winter |
| July 2022 draft need results | 761 | 863 |
| Switch to 30 temp years | 62 ↑ | (34) ↓ |

***Impacts shown are individual and marginal, not cumulative***

# Sequoia hydro years

Sequoia historically has pulled from a 79-year (1929 – 2007) hydro record, new data from BPA are now available that run through 2018. Switching to 30 year (1989-2018) hydro record for 2023 IRP.

We are planning to run hydro sensitivities using data from the four climate change models reviewed by Creative Renewable Solutions.

# Using fewer hydro years

Switching from 79 to 30 hydro years in the model **increases summer need and decreases winter need.**

| | **Year 2026 capacity impact (MW)** | |
|---|---|---|
| | Summer | Winter |
| July 2022 draft need results | 761 | 863 |
| Switch to 30 temp years | 62 ↑ | (34) ↓ |
| Switch to 30 hydro years | 13 ↑ | (3) ↓ |

***Impacts shown are individual and marginal, not cumulative***

# Increasing LLH market minimum

Light-load-hour market previously ranged from 999 MW to 200 MW depending on load (higher load correlated with lower market). New market ranges from 999 MW to 400 MW. This **reduces need in both seasons.**

| | **Year 2026 capacity impact (MW)** | |
|---|---|---|
| | Summer | Winter |
| July 2022 draft need results | 761 | 863 |
| Switch to 30 temp years | 62 ↑ | (34) ↓ |
| Switch to 30 hydro years | 13 ↑ | (3) ↓ |
| Increase to 400 LLH market | (7) ↓ | (23) ↓ |

***Impacts shown are individual and marginal, not cumulative***

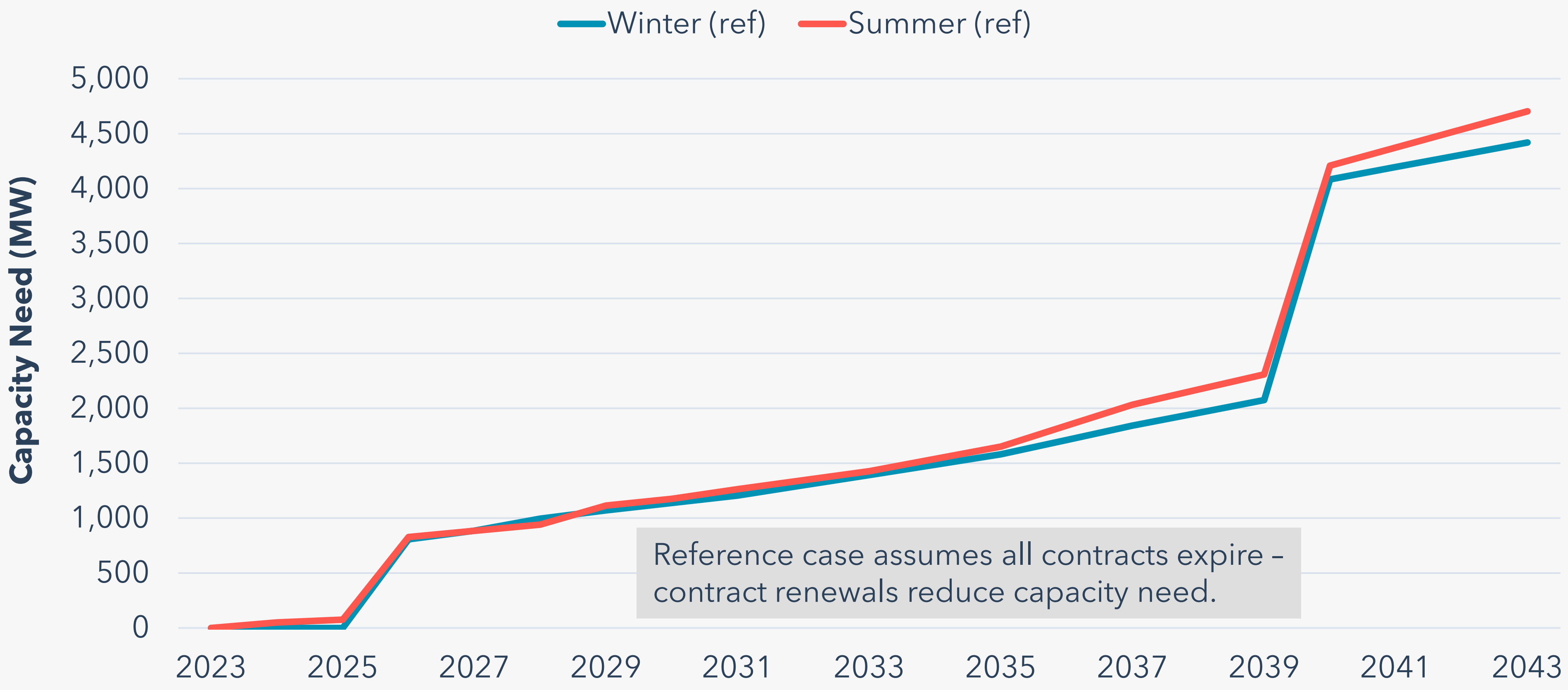
# Cumulative results

**Summer need increases by 67 MW, winter need falls by 56 MW.**

| | Year 2026 capacity impact (MW) | |
|---|---|---|
| | Summer | Winter |
| July 2022 draft need results | 761 | 863 |
| Switch to 30 temp years | 62 ↑ | (34) ↓ |
| Switch to 30 hydro years | 13 ↑ | (3) ↓ |
| Increase to 400 LLH market | (7) ↓ | (23) ↓ |
| Oct. 2022 draft need results | 828 ↑ | 807 ↓ |

***Individual marginal changes will not necessarily sum to the total change***

# Updated reference case capacity need



# FLEXIBILITY ANALYSIS

ANA MILEVA, BLUE MARBLE ANALYTICS
ROUNDTABLE 22-9

**Blue Marble Analytics** creates innovative, high-quality grid analytics software to guide clean energy planning and policy.

We provide consulting and software-development services for power-system planning and portfolio optimization and management.

Blue Marble
Analytics

**Ana Mileva** is the founder of Blue Marble Analytics and the primary architect of the GridPath platform. She was previously a consultant at E3. And has wide-ranging experience consulting and developing planning models for utilities, government agencies, NGOs, and developers.

Experience in the last two PGE IRPs

- 2016 IRP: led capacity-adequacy and reliability study (E3)
- 2019 IRP: led flexibility adequacy analysis

Expertise across a range of topics including:

- Software development
- Data analytics
- Resource planning and portfolio optimization
- Asset optimization and valuation
- Renewables integration
- Storage, demand response, hybrid resources
- Clean energy policy

*All data is draft until filed.*

# Flexibility Analysis Scope Overview

- A set of studies that aim to assess **flexibility needs, costs, and value**.
- Studies will be conducted using multi-stage optimal commitment and dispatch in **GridPath**, an open-source grid planning platform.

### Flexibility Adequacy

This component assesses flexibility adequacy and the contribution of different resources.

### Variable Energy Resource (VER) Integration Costs

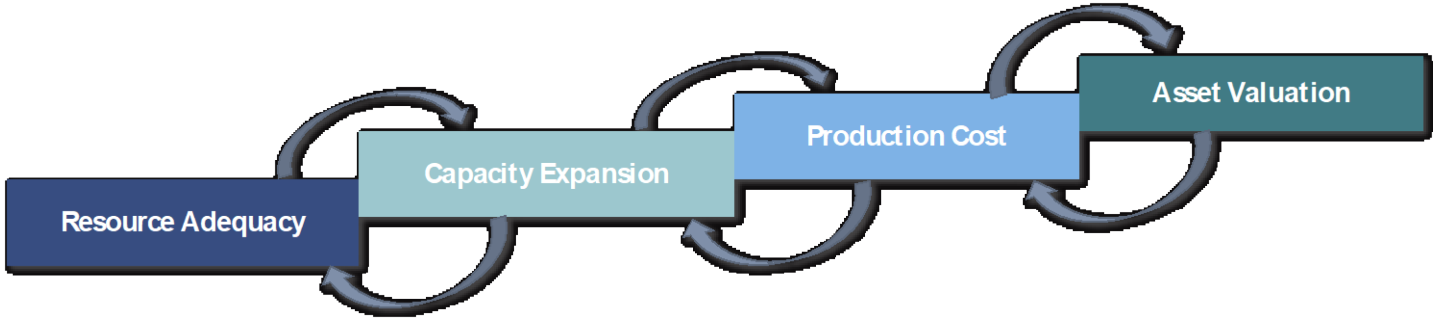
This component estimates the costs of integrating additional VREs into the PGE system.

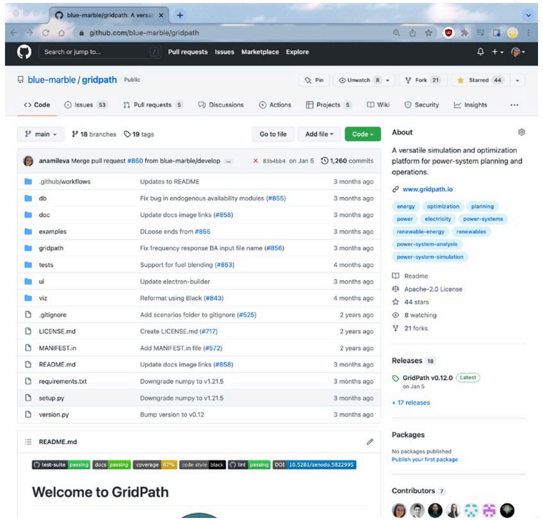
### Flexibility Value

This component evaluates the value of flexibility provided by resources such as energy storage.

*All data is draft until filed.*

# **GridPath** is an open-source modeling ecosystem that enables faster and more technically sophisticated planning for the clean energy transition.




**GridPath's modular architecture enables:**

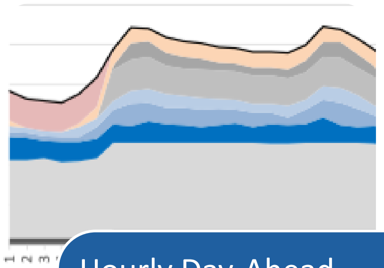
| **A seamless interface between different modeling approaches** | **Varying levels of complexity** | **Extensibility and adaptability** |
|---|---|---|
| Reduces the labor-intensive data-translation requirements across applications | User has flexibility to include or exclude features easily<br><br>User-defined granularity levels for modeling | Novel functionality can be added quickly and seamlessly to tackle new questions about an evolving, decarbonizing grid |

- Open-source codebase available at https://github.com/blue-marble/gridpath
- GridPath has been benchmarked against PLEXOS and RESOLVE

*All data is draft until filed.*

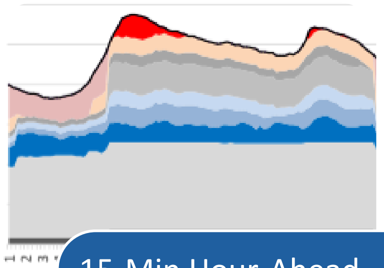
# Flexibility Modeling of PGE's System with GridPath

Multi-stage unit-commitment and dispatch



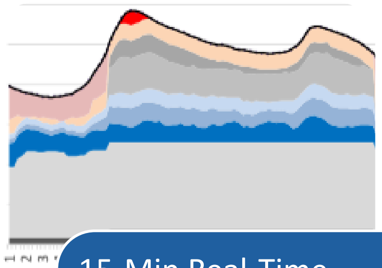
**Hourly Day-Ahead Commitment**

- Generator commitment schedules based on day-ahead load and renewable forecasts (hourly)
- Contingency, load-following, and regulation reserves



**15-Min Hour-Ahead Commitment**

- Residual generator commitment schedules based on hour-ahead load and renewable forecasts
- Contingency, load-following, and regulation reserves



**15-Min Real-Time Dispatch**

- Actual load and renewable output
- Contingency and regulation reserves
- Load-following reserves allowed to dispatch to compensate for net load forecast error

Generators modeled with a high level of operational fidelity

- Heat rate curves
- Minimum up and down times
- Ramp rates

Includes market availability, regulation, contingency, and load-following reserve requirements

*All data is draft until filed.*

# GridPath Base Case Set-up

# GridPath Base Case Set-up

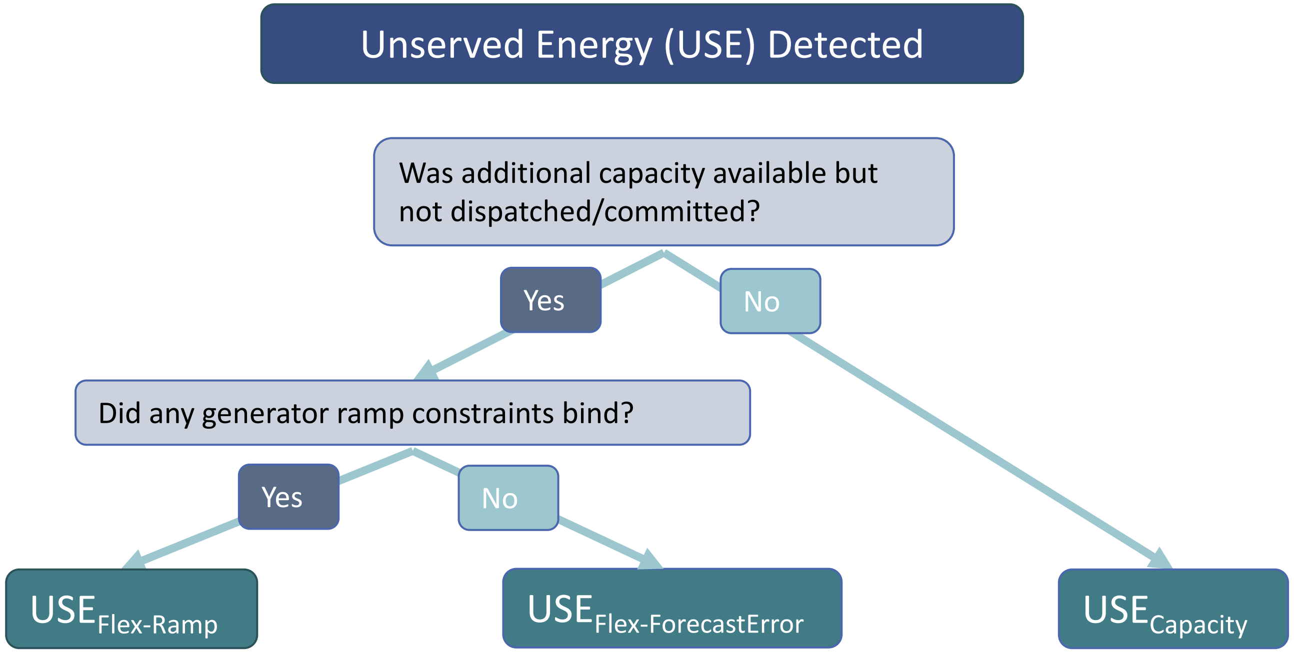
| Input | Flexibility Adequacy Study | Flexibility Value and Integration Cost Studies |
|---|---|---|
| Time frame | 2026 | 2026 |
| Gas prices | Reference | Reference |
| Carbon prices | Reference | Reference |
| Electricity prices | Reference | Reference |
| Load | Updated to 2026, average year | Updated to 2026, average year |
| VER generation | Updated to 2026, average year | Updated to 2026, average year |
| Existing contracts | Updated | Updated |
| Market availability | Limited in on-peak summer and winter<br>Unconstrained in off-peak and non-winter and summer peak | Limited in on-peak summer and winter<br>Unconstrained in off-peak and non-winter and summer peak |
| Reserves | Regulation, contingency, and load-following reserves | Regulation, contingency, and load-following reserves |
| Capacity Availability | DA, HLH block capacity that is more expensive than existing system generation & markets | RFP proxy resources including new wind, solar, and batteries & expensive, unconstrained purchases |

*All data is draft until filed.*

# Flexibility Adequacy

# Measuring Unserved Energy Due to Flexibility ($USE_{Flex}$)

- Important to distinguish between loss-of-load events attributable to flexibility shortages and those due to capacity shortages
- The approach also distinguishes between uncertainty- and variability-related events




*All data is draft until filed.*

# Unserved Energy Due to Flexibility

| Real Time Unserved Energy (USE) | |
|---|---|
| # Timepoints | 36 |
| % Timepoints | 0.1% |
| Total MWh | 158 |
| Max MW | 80 |

- All realized USE occurs during times when the DA capacity is not fully committed
  - USE is caused by insufficient flexibility, not capacity shortages
- Ramping constraints don't bind during the times with USE
  - Flexibility events are caused by forecast error, not insufficient ramping capability

*All data is draft until filed.*

# Seasonal Distribution of $USE_{Flex}$

HOUR ENDING

MWa USE

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Jan | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.6 | 0.0 | 0.0 | 0.0 | [illegible] | 0.0 |
| Feb | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.4 | 0.0 | 0.8 | [illegible] | 0.0 | 0.0 | 0.0 | 0.0 |
| Mar | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Apr | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| May | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Jun | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Jul | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.4 | 0.0 | 0.0 | 0.0 |
| Aug | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.5 | 0.0 | 0.0 |
| Sep | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.8 | 0.0 | 0.0 | 0.0 | 0.0 |
| Oct | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Nov | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Dec | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.6 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | [illegible] | 0.0 | 0.0 | 0.0 | 0.2 |

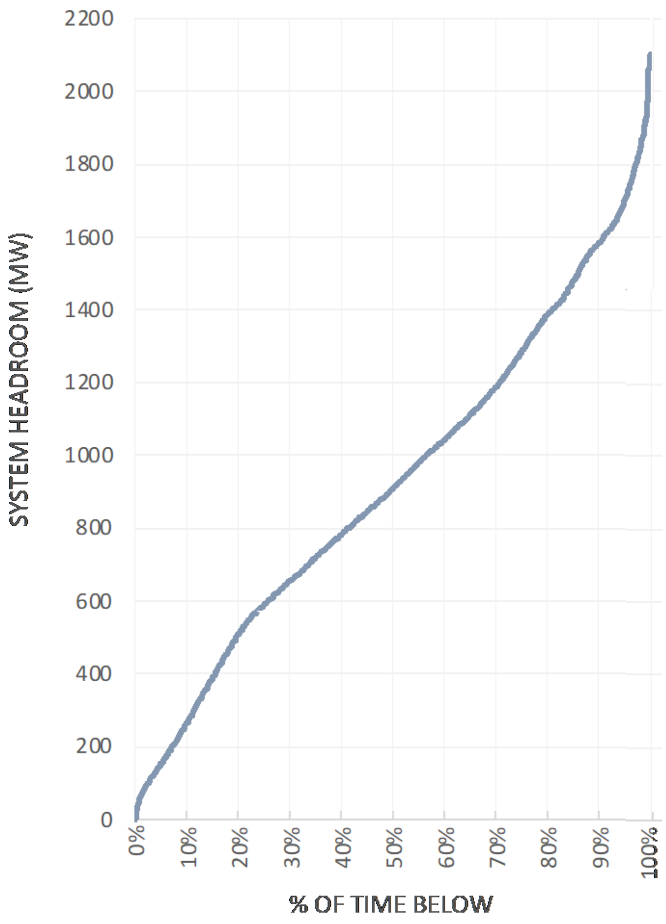
% TIME WITH USE

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Jan | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 3.2% | 1.6% | 0.0% | 0.0% | 1.6% | 0.0% |
| Feb | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 2.7% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.9% | 0.9% | 3.6% | 0.9% | 0.0% | 0.0% | 0.9% | 0.0% |
| Mar | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% |
| Apr | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.8% | 0.0% | 0.0% | 0.0% | 0.0% |
| May | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% |
| Jun | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% |
| Jul | 0.0% | 0.0% | 0.0% | 0.0% | 0.8% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.8% | 0.8% | 1.6% | 0.0% | 0.8% | 0.0% |
| Aug | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 3.2% | 0.0% | 0.0% |
| Sep | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 1.7% | 0.8% | 0.0% | 0.0% | 0.0% |
| Oct | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% |
| Nov | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% |
| Dec | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.8% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.8% | 0.0% | 0.0% | 0.0% | 0.8% |

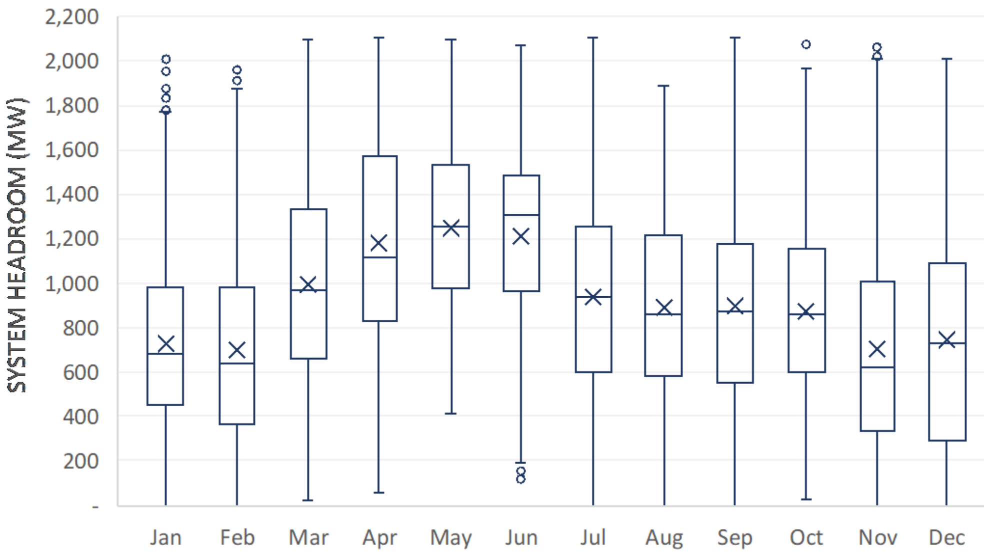
- In planning scenarios, flexibility-related unserved energy is concentrated during the winter and summer evening net load peak hours

*All data is draft until filed.*

# Estimated Flexibility Headroom




- From a long-term planning perspective, PGE's system is most headroom-constrained in the winter months
- Headroom during the summer months is higher on average but also drops to ~250 MW or below around 10% of the time
- Headroom is more plentiful in the spring




*All data is draft until filed.*

# Flexibility Adequacy Key Takeaways

- If no flexible resources are added and the resource adequacy need is filled with an inflexible block DA product, flexibility challenges are encountered by the model
- In this planning scenario, the key driver of flexibility challenges for the system is forecast error, not operational constraints such as ramping or minimum up/down time
- The times of flexibility need are aligned with times of resource adequacy stress
- The flexibility adequacy issues encountered could be addressed by planning for a diverse portfolio containing wind and solar, and operationally flexible hybrid resources and batteries instead of highly inflexible DA capacity blocks

*All data is draft until filed.*

# Flexibility Value

# Flexibility Value

- Objective: estimate operational flexibility value of different new resources when added to the PGE system in 2026
- A case is run with and without each potential new resource, and system operational costs are compared

| | Round-trip Efficiency |
|---|---|
| 2-hour Battery | 85% |
| 4-hour Battery | |
| 6-hour Battery | |
| 8-hour Battery | |
| 10-hour PHS | 80% |

*All data is draft until filed.*

# Flexibility Value

| | Flexibility Value (2023$/kW-year) |
|---|---|
| 2-hour Battery | 8.35 |
| 4-hour Battery | 9.77 |
| 6-hour Battery | 10.68 |
| 8-hour Battery | 11.78 |
| 10-hour PHS | 11.47 |

- Values are dependent on the system the resources are added to, e.g., VER penetration, other flexibility resources, market assumptions, etc.
- Marginal flexibility benefits decrease as more flexible resource capacity is added to the system
- These numbers represent “mid” estimates

*All data is draft until filed.*

# Integration Costs

# VER Integration Costs

- Objective: estimate integration costs of different new resources when added to the PGE system in 2026

| | Solar | MT wind | WA wind |
|---|---|---|---|
| **Integration Cost (2023$/MWh)** | 2.83 | 0.95 | 2.57 |

- Test resources: MT wind, WA wind, solar
- 100 aMW of each new resource is added to the system in separate runs
- Incremental cost of the test resource estimated as the difference in system cost relative to a separate case adding 100 aMW resource block matching weekly capacity factor to isolate operational costs over short timeframes

*All data is draft until filed.*

# Thank You

**Contact**

ana@bluemarble.run

# PORTFOLIO ANALYSIS

NIHIT SHAH, Principal Integrated Resource Planning Analyst
ROUNDTABLE 22-9

# Portfolio analysis in the 2023 IRP

## June Roundtable review

**In the coming IRP, portfolio analysis will be conducted like earlier iterations:**

- Model will choose optimal combination of proxy supply-side resources
- Cost, risk metrics, and portfolio-CBIs be used to determine a Preferred Portfolio and Action Plan

**Given the uncertainty of the resources required to meet 2040's emission reduction targets, portfolio analysis post 2030 will focus on:**

- System requirements (more granularity on energy and capacity needs)
- A qualitative assessment of the possible pathways to 2040

This will provide to us (both PGE and our public participants) the opportunity to evaluate viable emission-free options that traditional analysis with current supply-side options would not provide

# Portfolio analysis – Definitions

**Portfolio:** A fixed set of resource decisions set in all scenarios. The model (ROSE-E) creates resource buildouts around those choices in each scenario.

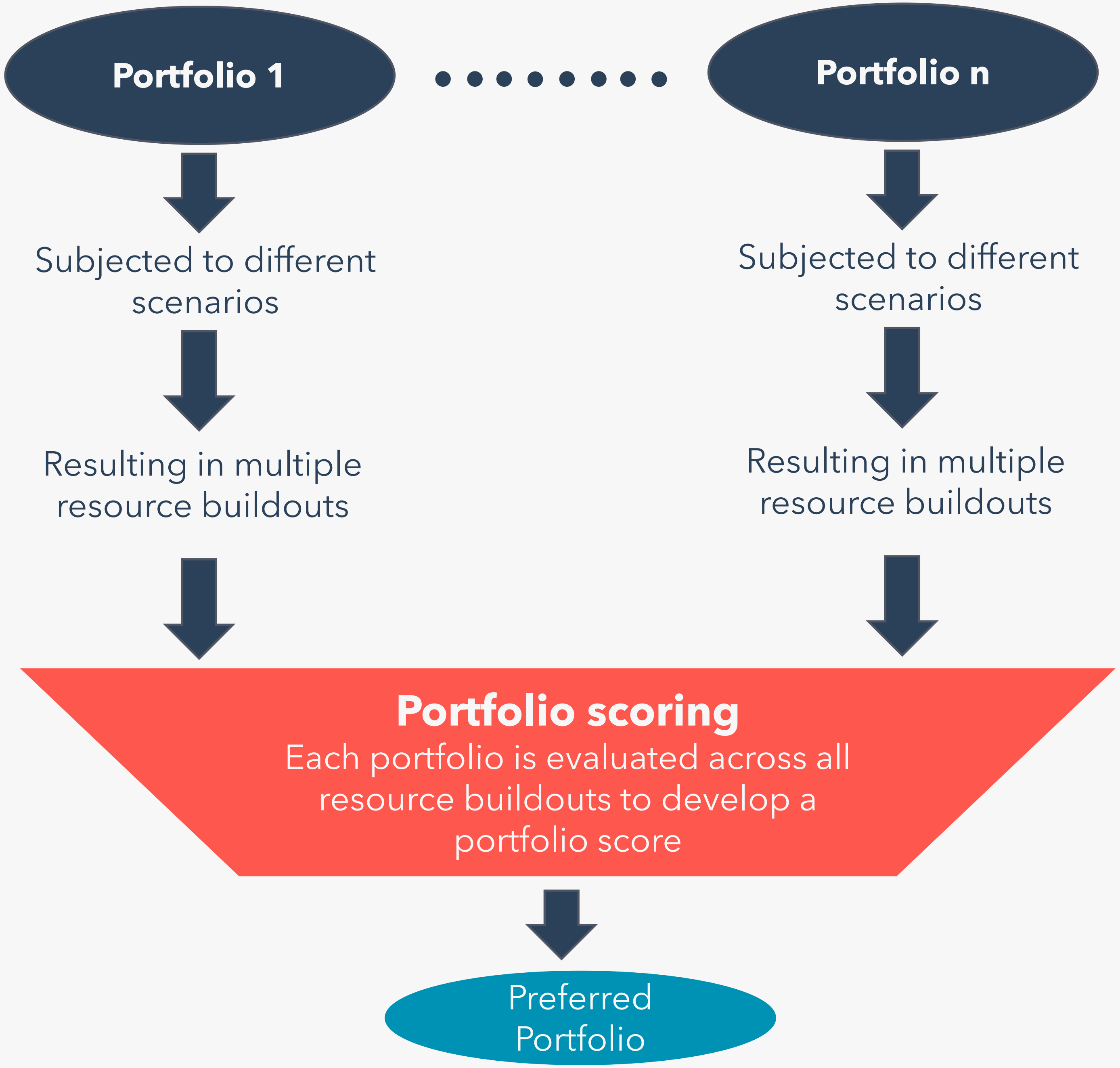
**Scenarios:** Refer to elements that are varied within portfolio analysis resulting in multiple resource buildouts. Some of the predefined scenarios are - need, technology cost, price, hydro.

**Resource buildout:** Least cost set of incremental resource additions given a set of specific input conditions such as a portfolio and scenario.

**Sensitivities:** Sensitivities test the robustness or provide additional information on the preferred portfolio by forcing changes resource constraints or other inputs.

# From a portfolio to the Preferred Portfolio

Portfolio scoring currently under development



# Portfolios ideas

| Portfolio ideas | Description |
| --- | --- |
| **Hydrogen, offshore wind, long duration storage** | A portfolio that includes each of these technologies per UM2225 |
| **Pumped hydro storage (PSH)** | Limiting the build of PSH to one project |
| **Oregon-only resources** | Limiting selection to only Oregon-sited resources |

| Additional portfolio options |
| --- |
| **Community based renewable energy resources** |
| **Transmission expansion** |
| **Non-cost-effective energy efficiency (EE) and demand response (DR)** |

**Stakeholder's portfolio ideas → IRP@PGN.com by 11/4/2022**

# CLEAN ENERGY PLAN UPDATE

ANGELA LONG, Senior Manager Strategy & Planning

Distributed Resource Planning

ROUNDTABLE 22-9

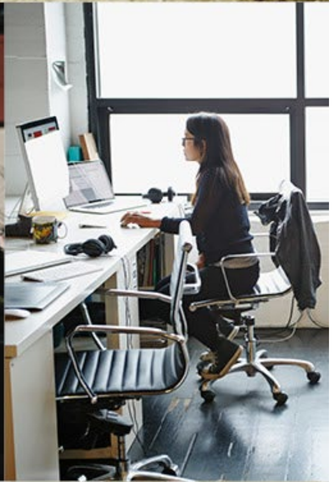
# NEXT STEPS

A recording from today's webinar will be available in one week

**Upcoming Roundtables:**

- November 16
- December 15
- January 26
- February 23
- March TBD





# THANK YOU

CONTACT US AT:
IRP@PGN.COM

# APPENDIX A: CLIMATE STUDY

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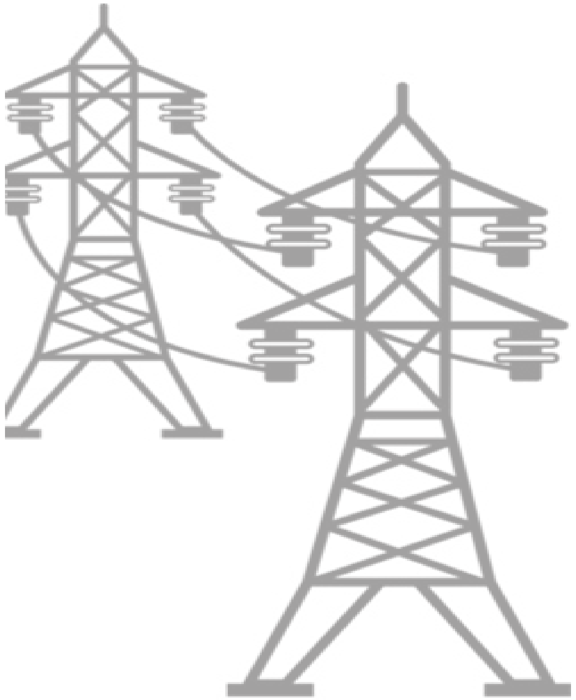
# APPENDIX



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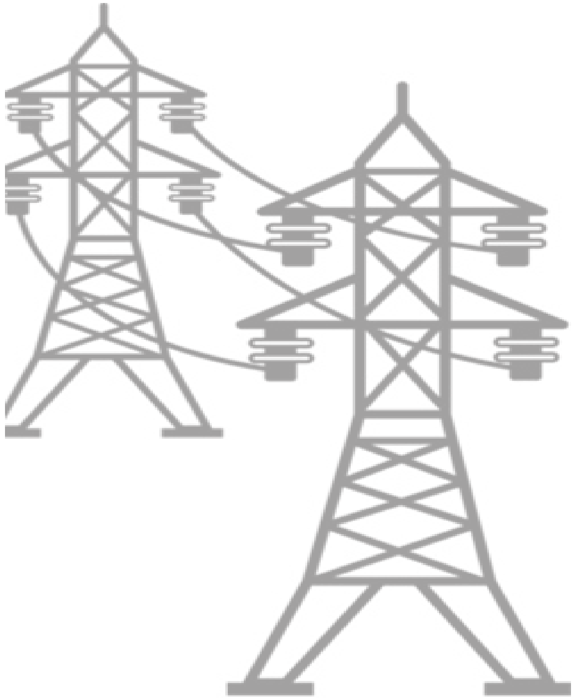
# Academia Review



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# 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 | Solar Gen | Thermal Gen | 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%. |
| | | | Hydro Gen | Wind Gen | Storage | |
| 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 | Solar Gen | Thermal Gen | Historically, 10-year drought reduces hydroelectric generation by 26% in the PNW. |
| | | | Hydro Gen | Wind Gen | Storage | |
| Centro UC Cambio Global; Berkeley University of California | Climate change impacts on two high-elevation hydropower systems in California. | CA | Electric Demand | Solar Gen | Thermal Gen | Rising temperature will reduce annual hydropower generation by up to 8.2% in 2050 in CA. |
| | | | Hydro Gen | Wind Gen | Storage | |
| Portland State University | Climate change implications for wind power resources in the Northwest United States | PNW | Electric Demand | Solar Gen | Thermal Gen | 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. |
| | | | Hydro Gen | Wind Gen | Storage | |
| 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 | Solar Gen | Thermal Gen | 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. |
| | | | Hydro Gen | Wind Gen | Storage | |
| Arizona Board of Regents ASU • NAU • UA; ASU Arizona State University | Impacts of climate change on electric power supply in the Western United States | Western US | Electric Demand | Solar Gen | Thermal Gen | 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%. |
| | | | Hydro Gen | Wind Gen | Storage | |
| Pacific Northwest National Laboratory | Climate Change Impacts on Residential and Commercial Loads in the Western U.S. Grid | Western US | Electric Demand | Solar Gen | Thermal Gen | 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. |
| | | | Hydro Gen | Wind Gen | Storage | |

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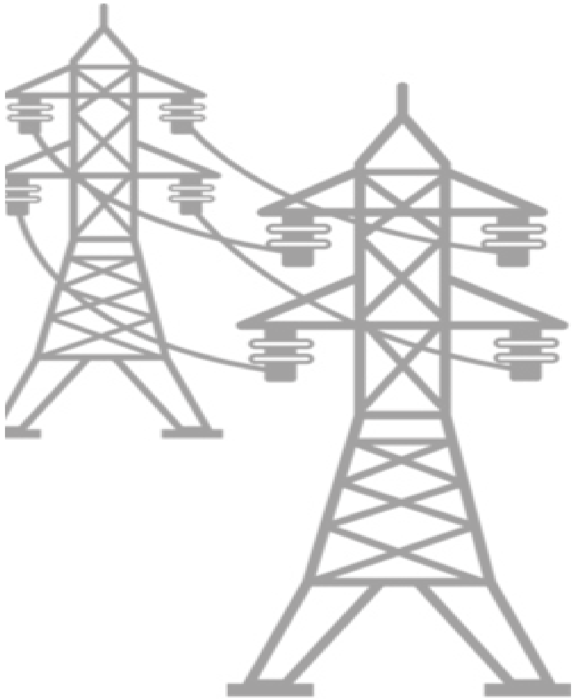
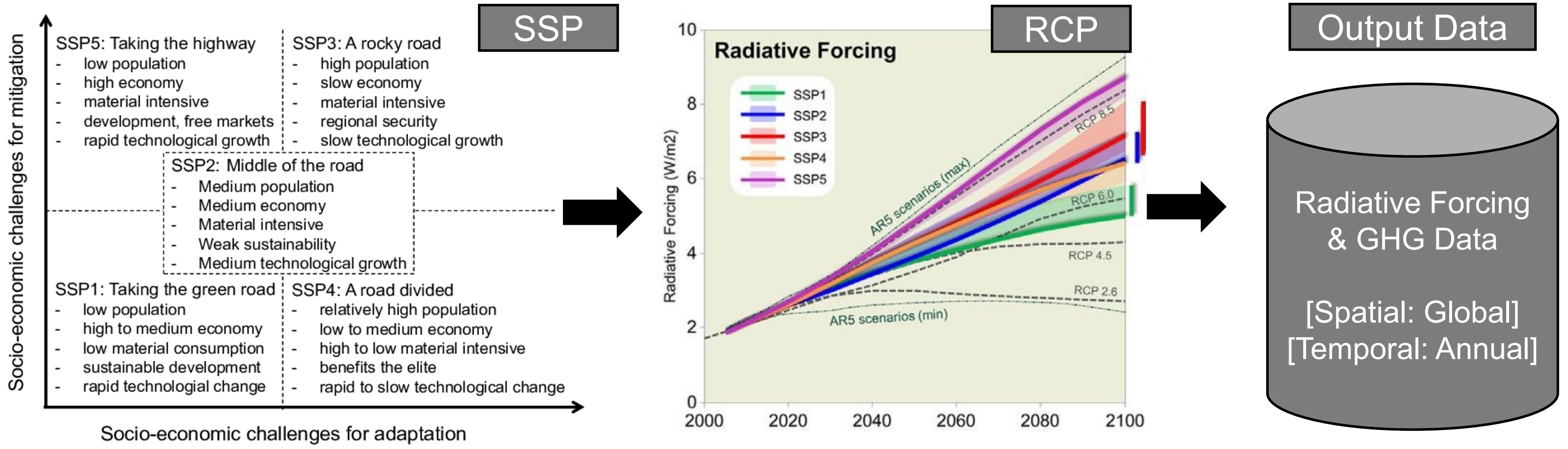
# Climate Modeling Data Conversion Process



# 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.

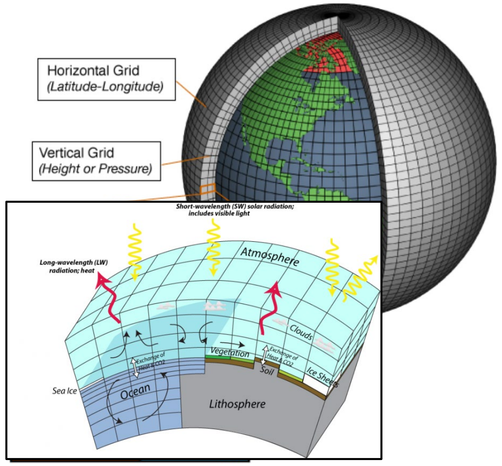
# Climate Modeling – GCMs Models

**Input Data**

Radiative Forcing
& GHG Data

[Spatial: Global]
[Temporal: Annual]

**Global Climate Model (s)**



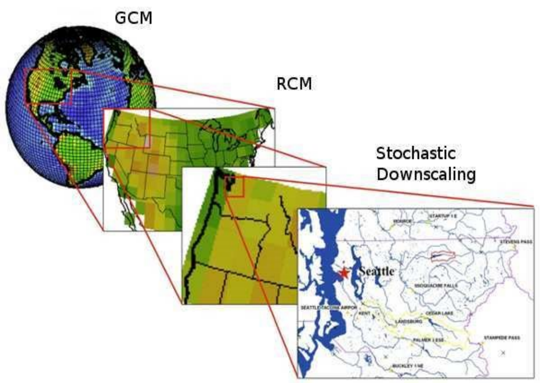

**Output Data**

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

[Spatial: 50km-300km blocks]
[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

# Climate Modeling – Downscaling

| Input Data | Downscaling Method(s) | Output Data |
|---|---|---|
| Surface air temperature, relative humidity, precipitation, surface wind speeds, solar radiation<br>**[Spatial: 50km-300km blocks]**<br>**[Temporal: Daily]** |  | Surface air temperature, relative humidity, precipitation, surface wind speeds, solar radiation<br>**[Spatial: 6km-10km blocks]**<br>**[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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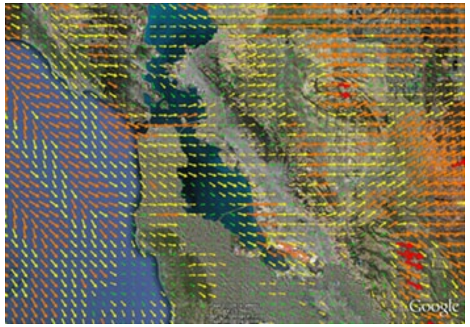
# Climate Modeling – Weather Research & Forecasting

**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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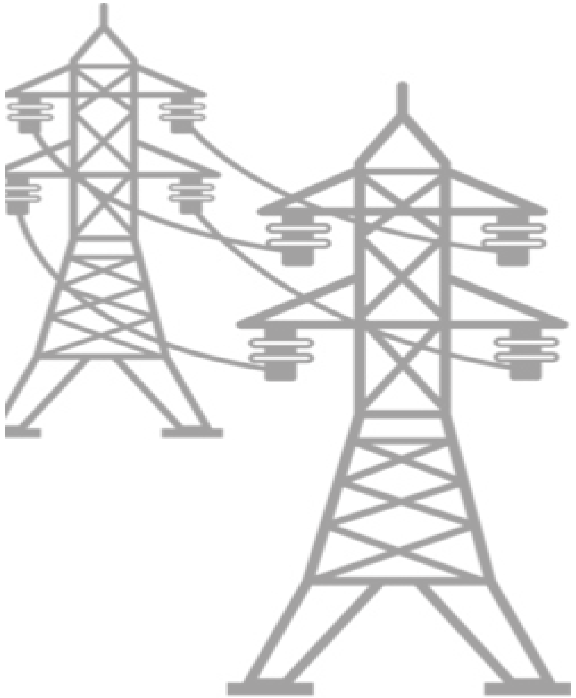
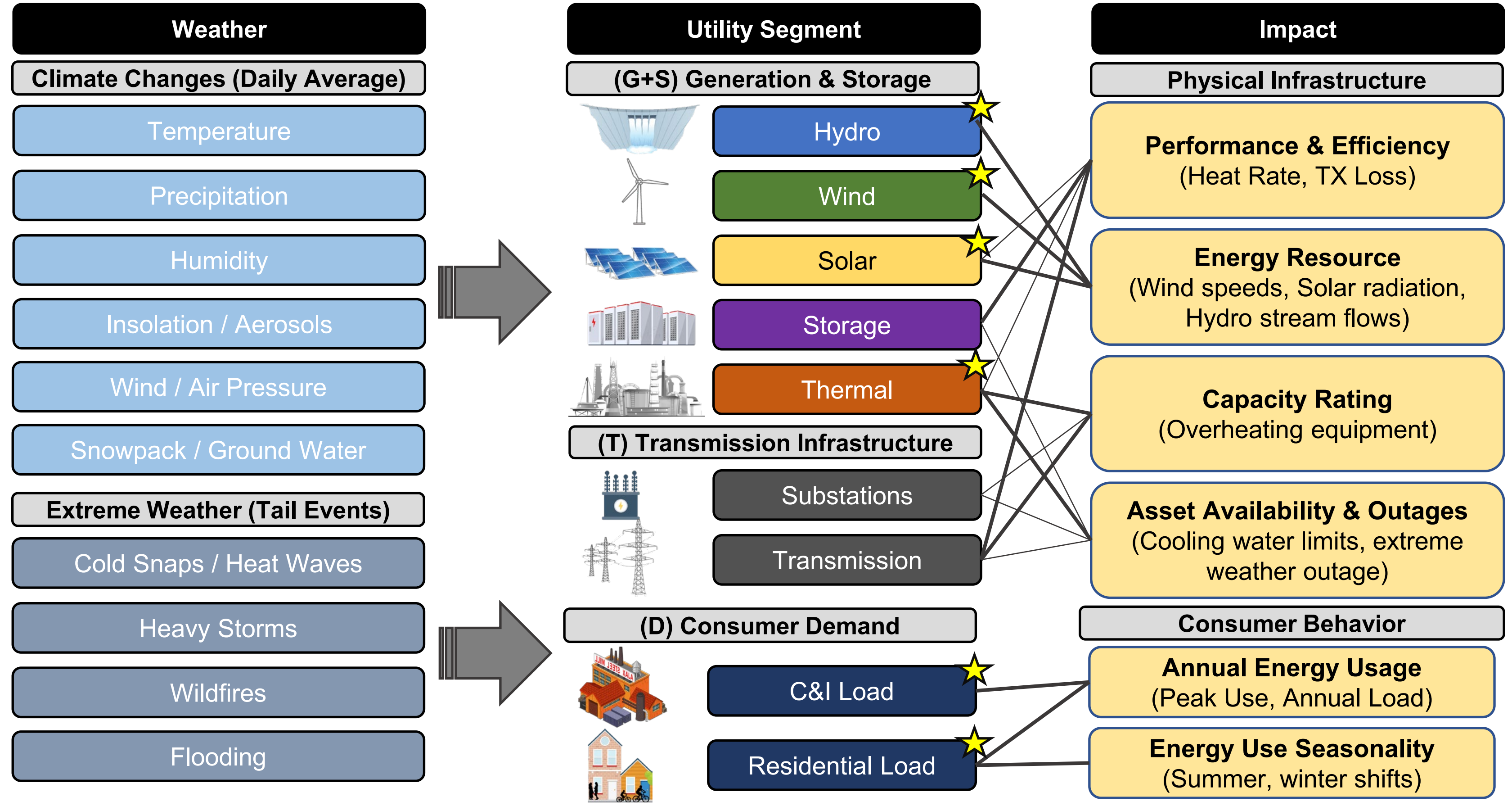
# Quantifying Climate Change Impact for Load & Generation



# Climate Change Impacts on Utility Planning - I



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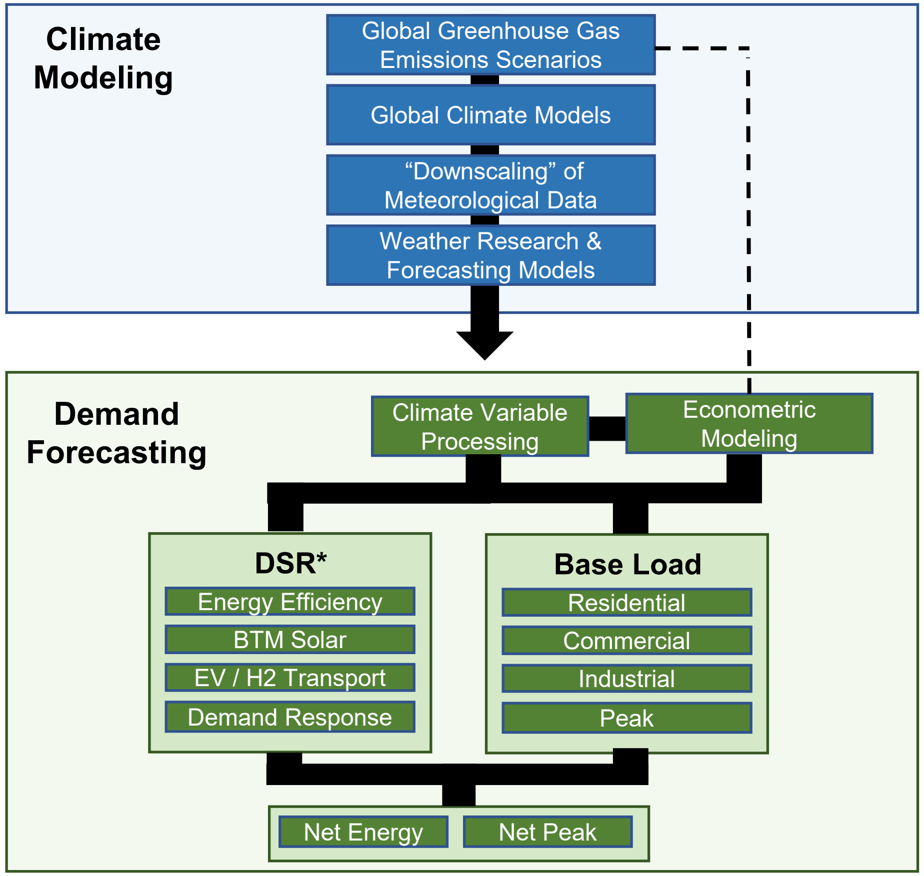
Note: Resiliency not a part of resource adequacy discussion above, which pertains to speed of recovery.

# 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.

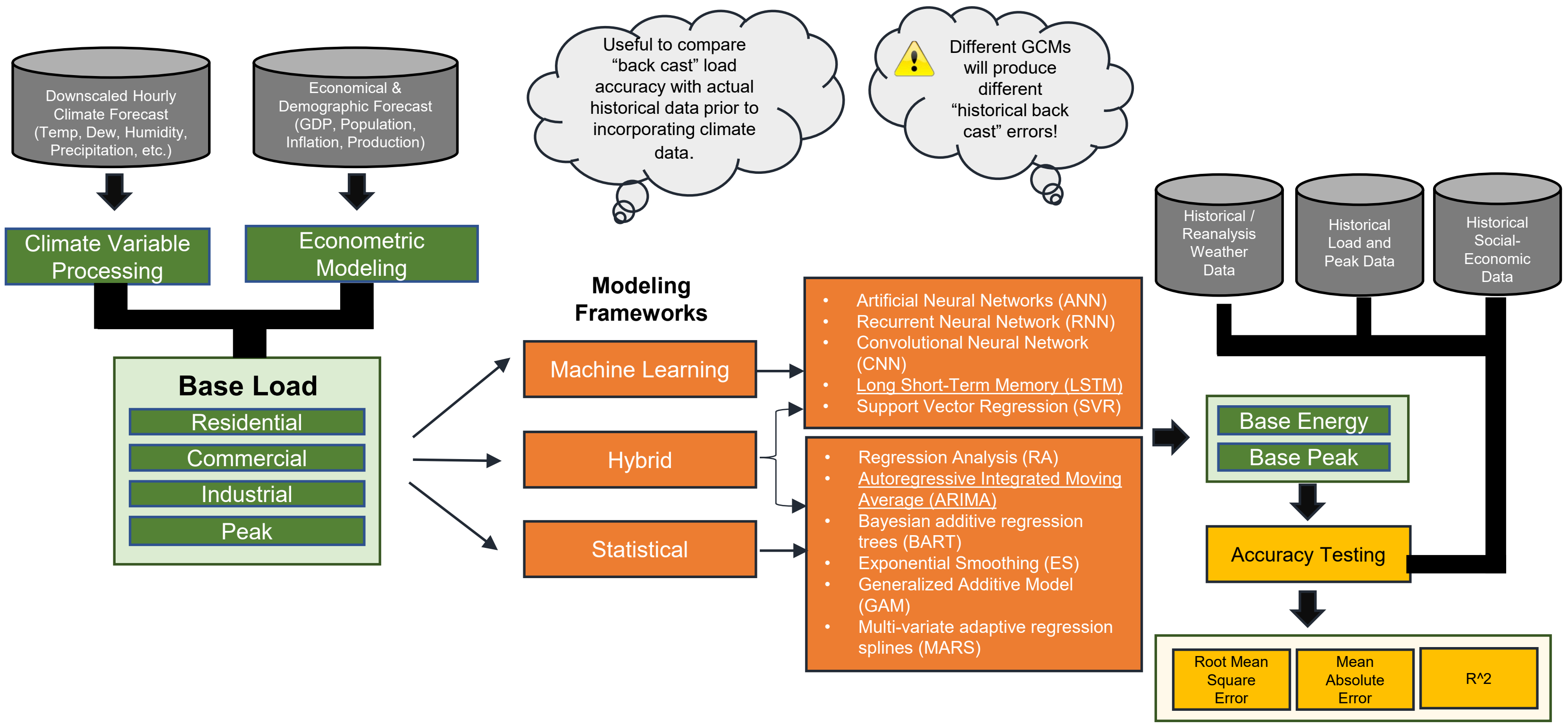




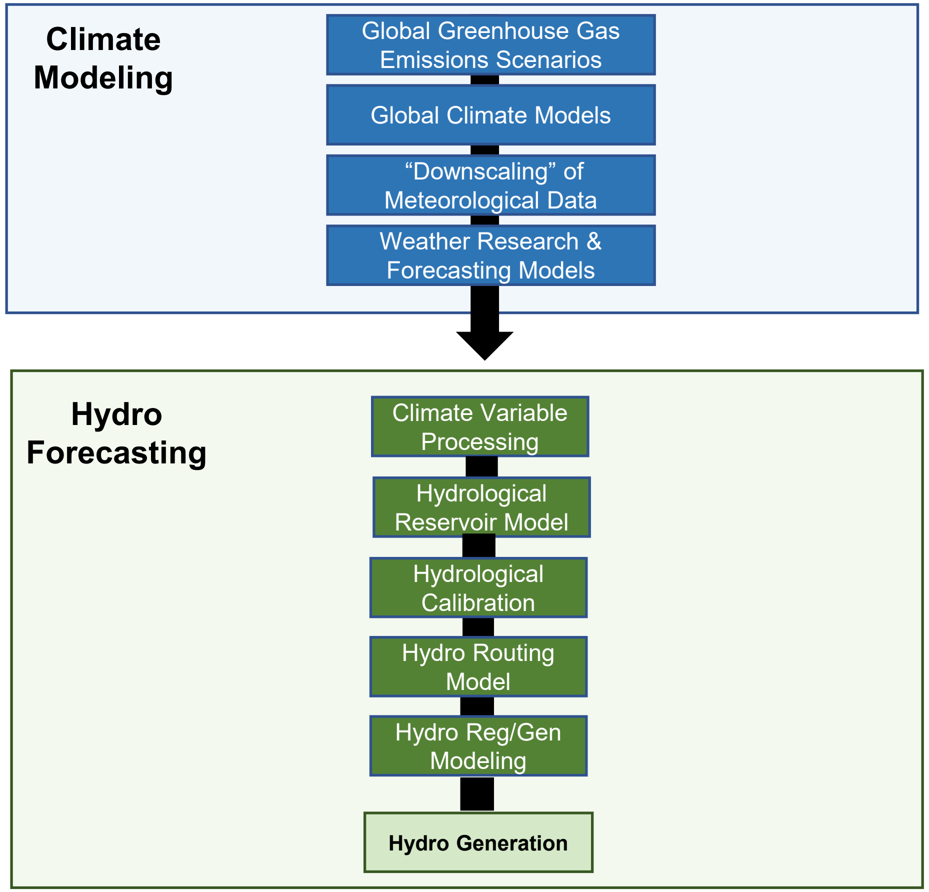
Note: Incorporating climate forecasts into DSR modeling was not reviewed in more detail in this research report.

# 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.

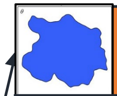
# Hydro Forecasting - II

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

Climate Variable Processing

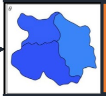
Hydrological Reservoir Model

**Spatial Resolution**



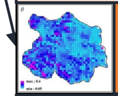
Lumped

- EPIC
- ARM
- SVAT
- VM
- XAJ



Semi-Distributed

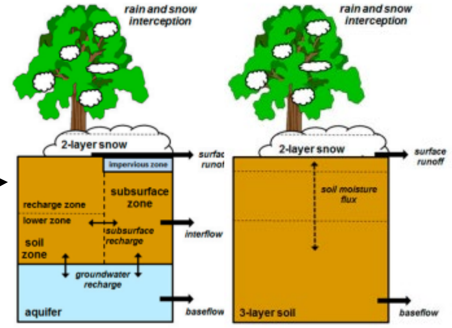
- GLERL
- ARNO
- LASCAM
- TOPMODEL



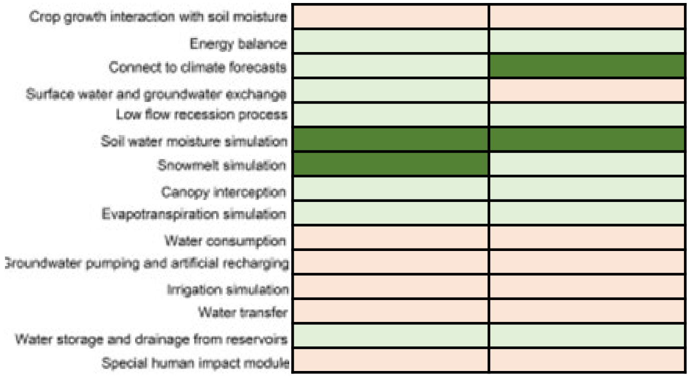
Distributed

- 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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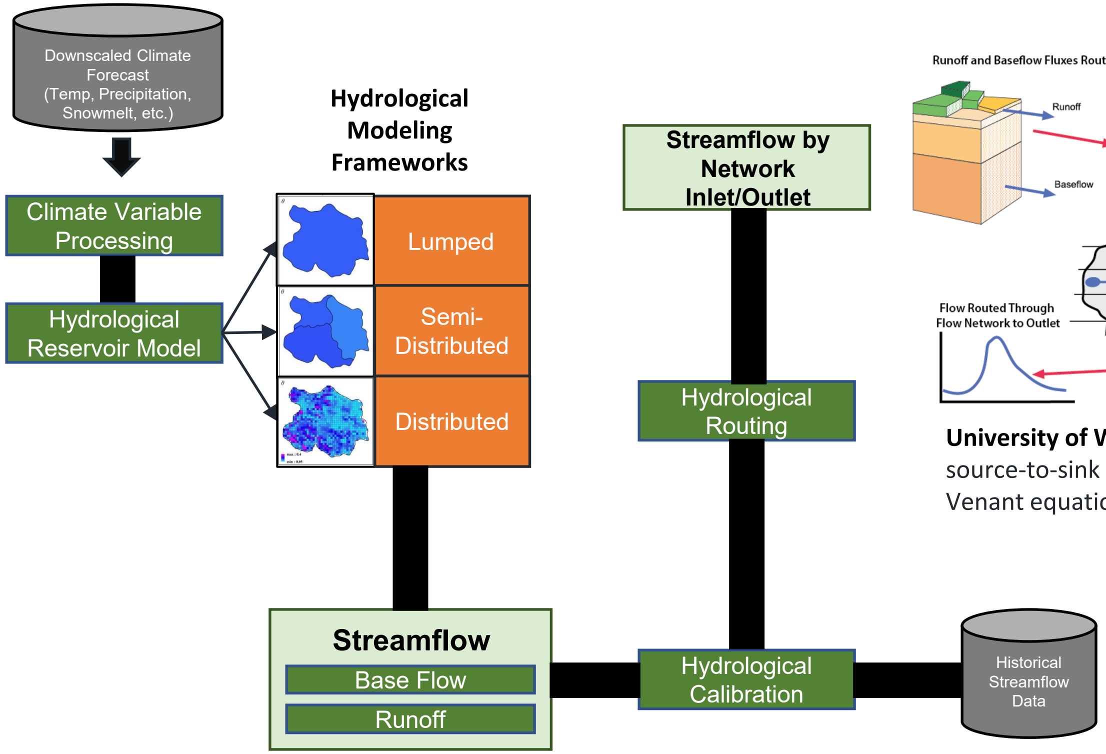
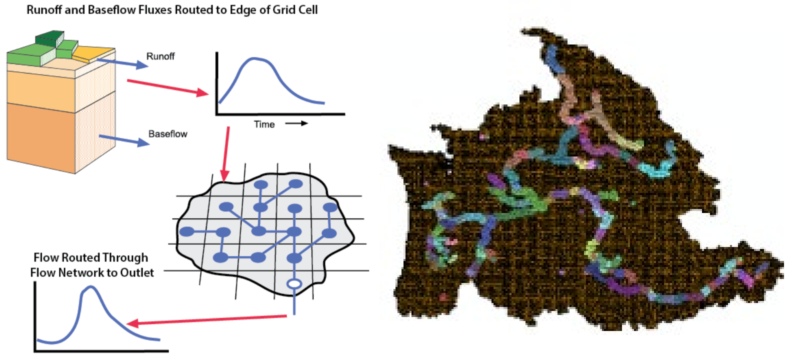
[1] Figures from Koch, Julian. (2016). Evaluating spatial patterns in hydrological modelling. 10.13140/RG.2.2.34737.79204.
[2] Figure from Mizukami, Naoki & Clark, Martyn & Gutmann, Ethan & Mendoza, Pablo & Newman, A. & Nijssen, Bart & Livneh, Ben & Hay, Lauren & Arnold, Jeffrey. (2016). Implications 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

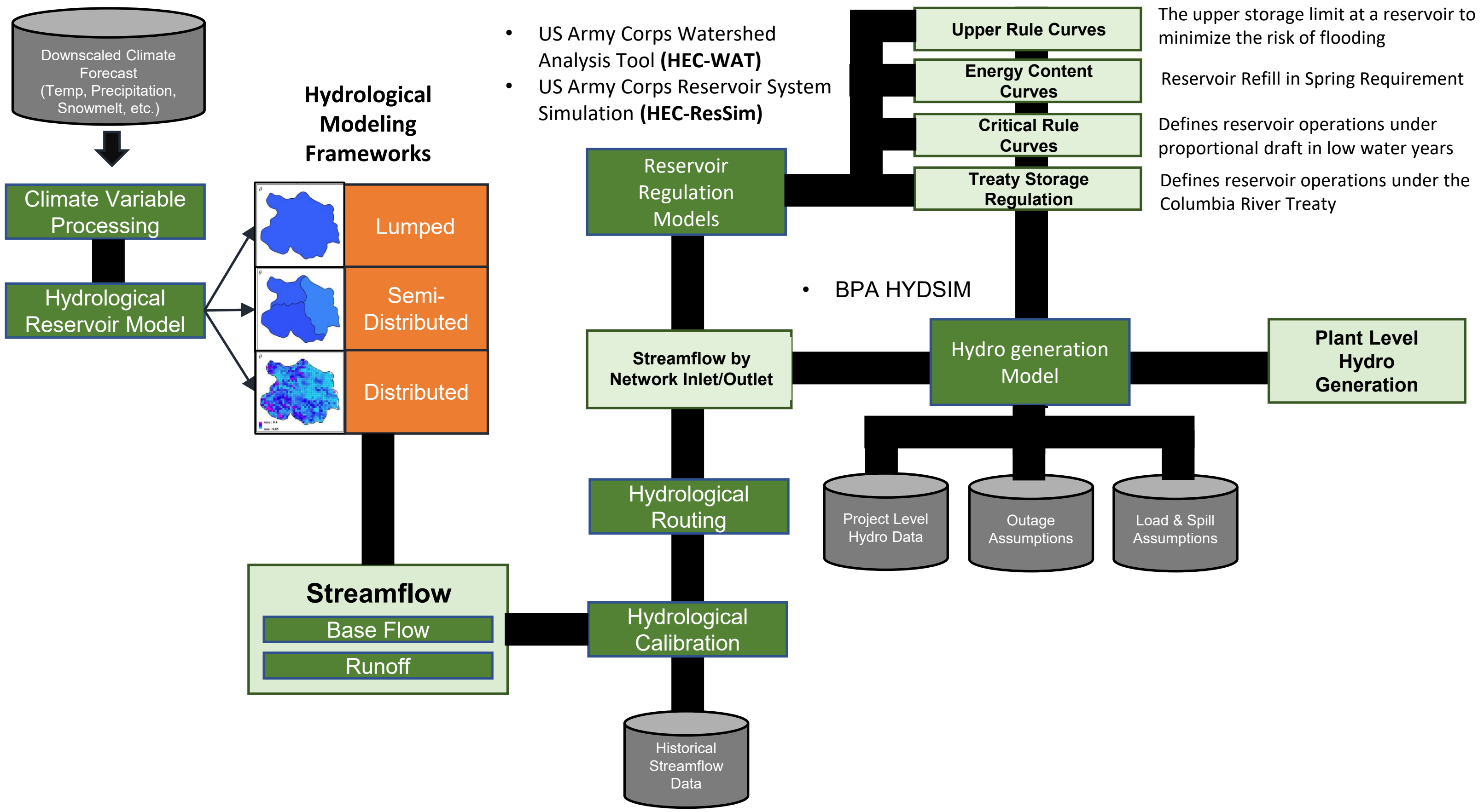
# Hydro Forecasting - III



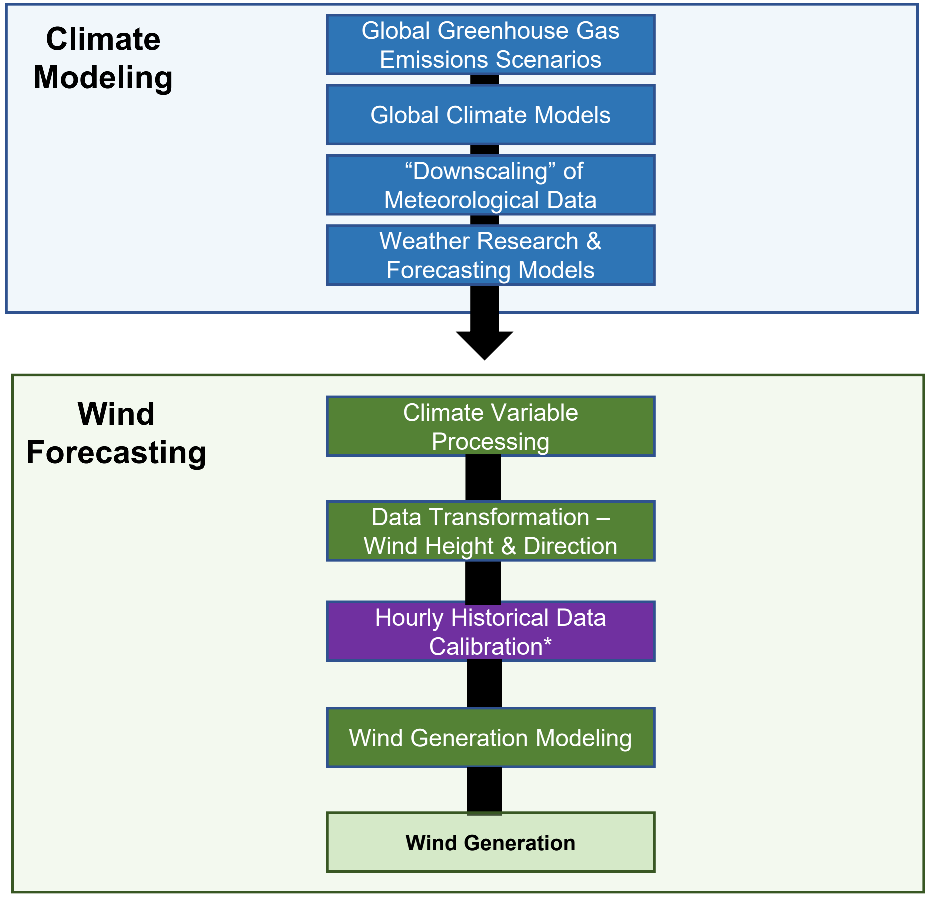




**University of Washington RVIC Model:** The routing model is a source-to-sink model that solves a linearized version of the Saint-Venant equations.

# Hydro Forecasting - IV



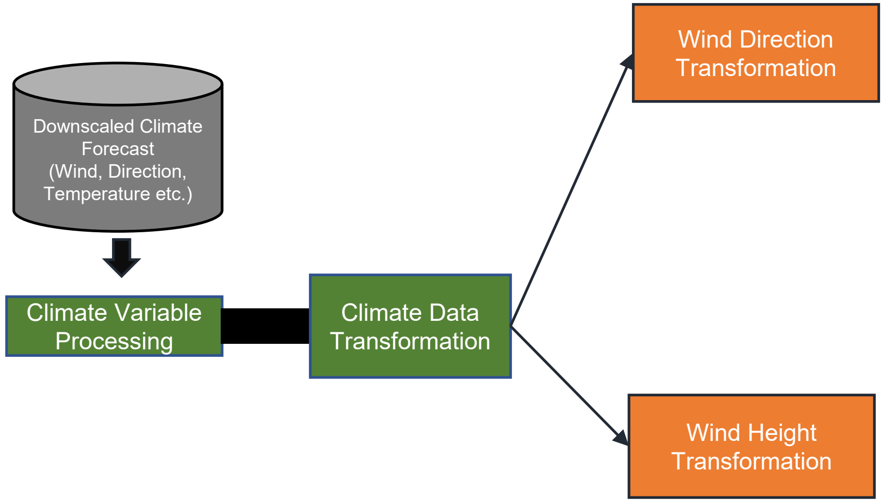
# Wind Forecasting - I




- 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.

Note: Step may not be necessary

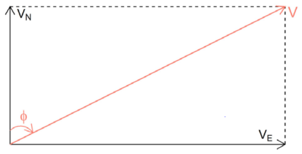
# Wind Forecasting - II




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

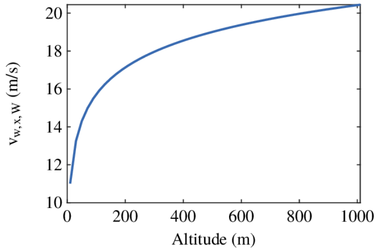
$$(1) \quad V = \sqrt{V_N^2 + V_E^2}$$

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




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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Source: https://www.nwcouncil.org/2021powerplan_method-to-estimate-climate-change-wind-generation/

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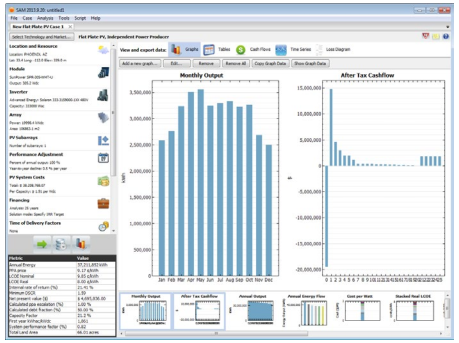
# Wind Forecasting - III

For the wind generation model, a modified NREL SAM wind dataset 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 combined with Climate Change Wind Speed and Direction Data. WRF modeling provides temperature and pressure data.



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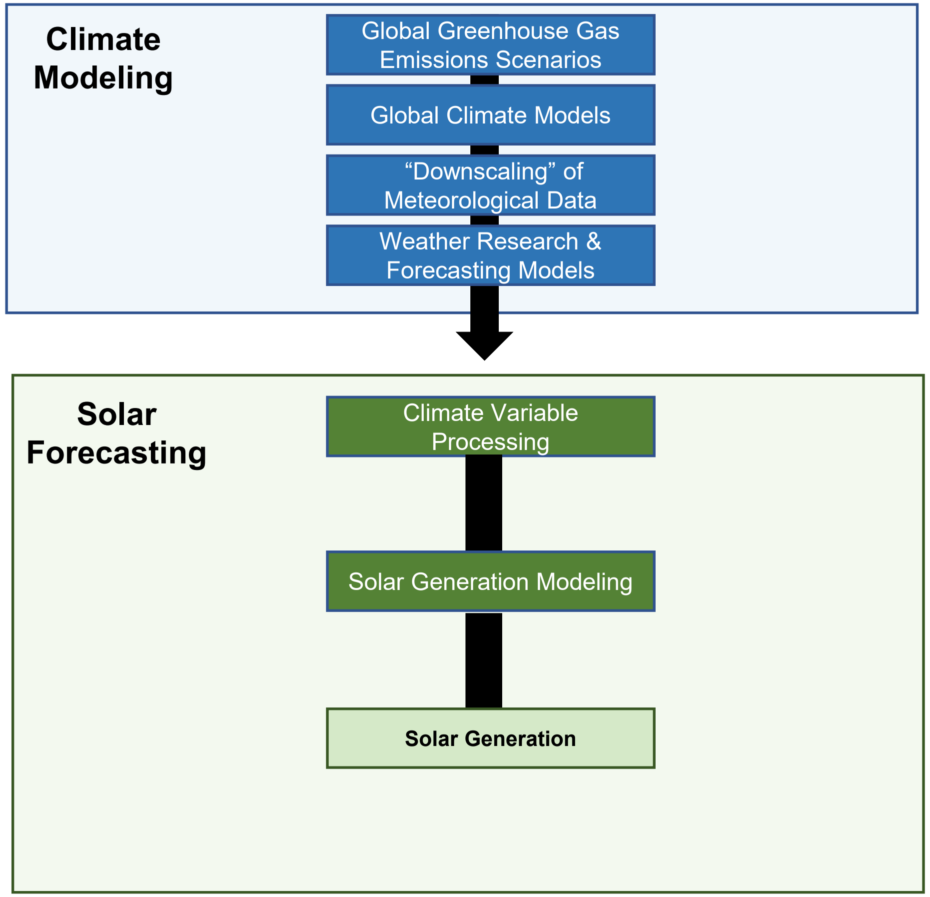
Note: Required if Climate Data does not go through WRFM model to generate hourly outputs. Daily average climate values would need to be adjusted.

# 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.

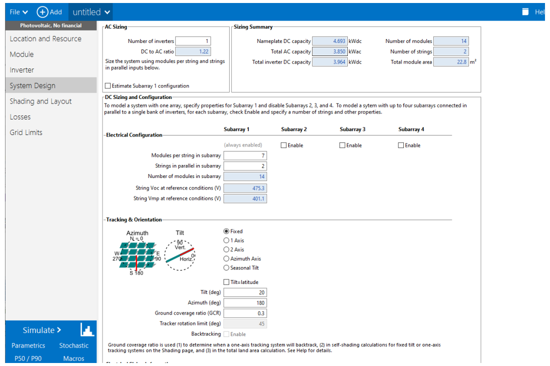
Note: Step may not be necessary

# Solar Forecasting - II

For the solar generation model, a modified NREL SAM solar dataset was input into the NREL SAM Solar tool.

**NREL SAM Tool Inputs:**

- Irradiance
- Temperature
- Wind Speed
- Solar Farm Performance Assumptions



Downscaled Climate Forecast (Irradiance, Temperature etc.)

Climate Variable Processing

Solar Generation Model

Plant Level Solar Generation

Solar Array Assumptions (Tech, Array, Losses, etc)

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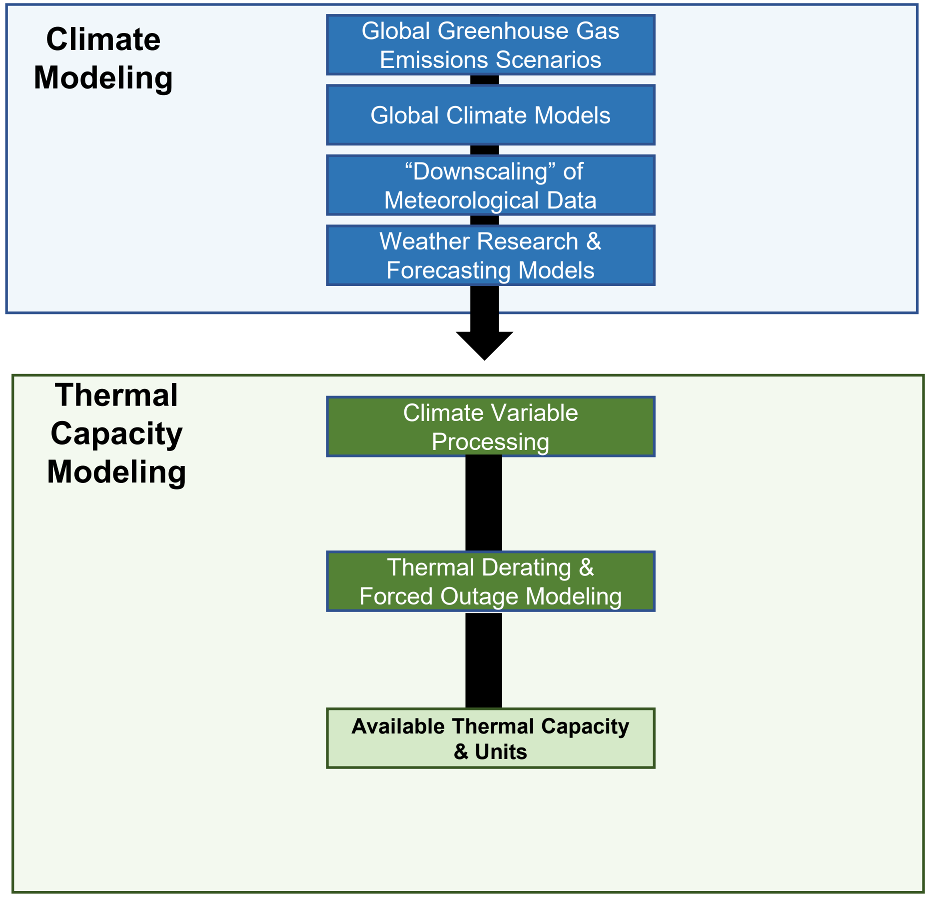
# Thermal Generation Forecasting




- 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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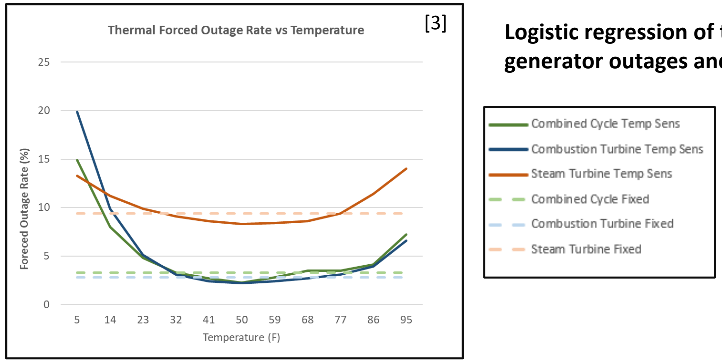
# Thermal Generation Forecasting

Downscaled Climate Forecast (Temperature)

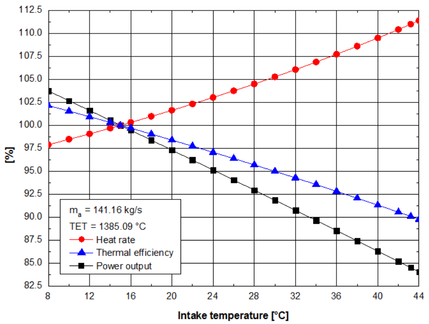
Climate Variable Processing → Thermal Derating & Forced Outage Modeling → Number of Thermal Units Available / Degraded Capacity of Each Thermal Unit → **Available Thermal Capacity & Units**

[3]




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

[1][2]




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



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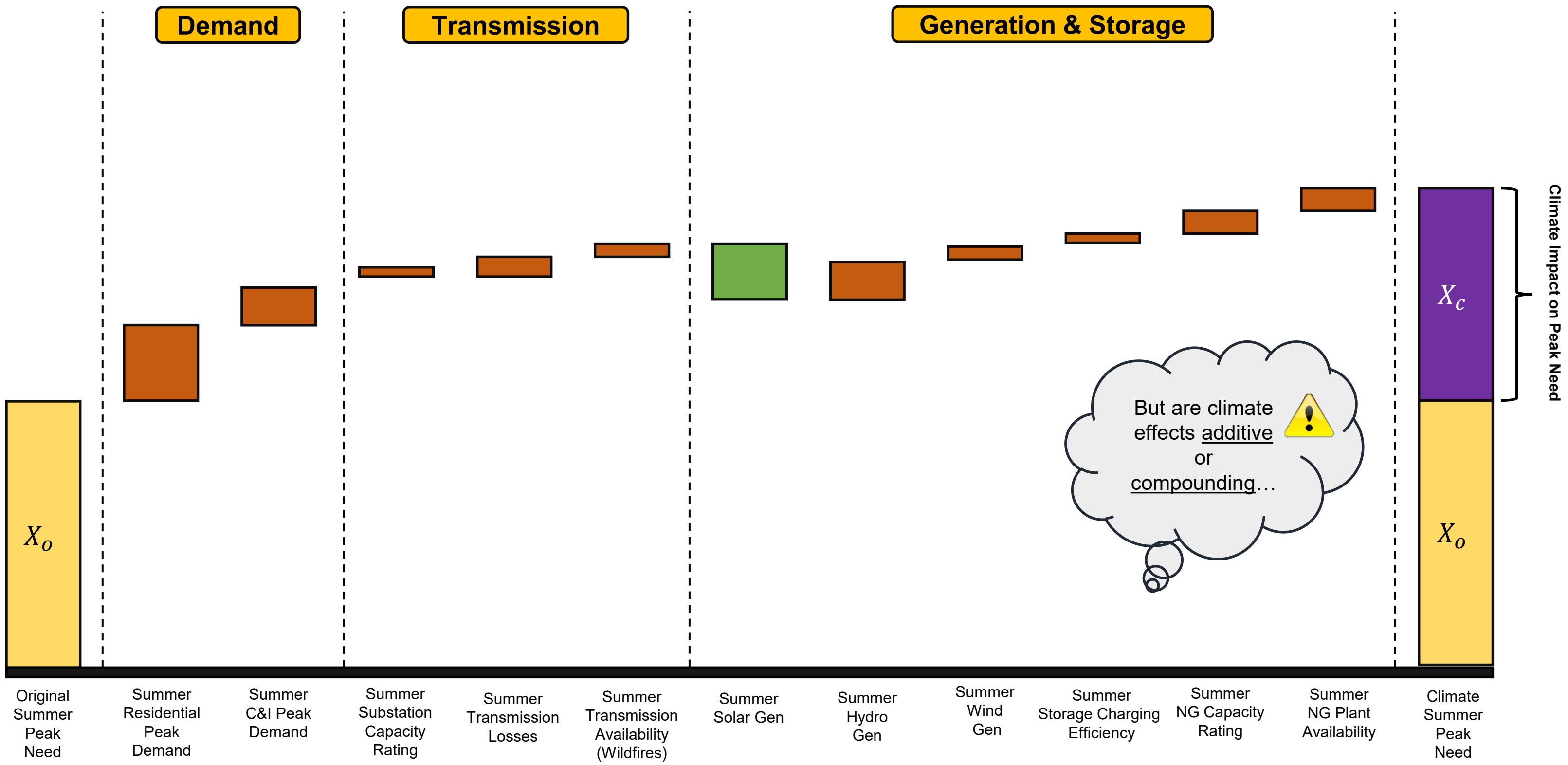
[1] https://doi.org/10.1016/j.applthermaleng.2011.04.045.
[2] https://doi.org/10.1016/j.joei.2014.07.006
[3] https://doi.org/10.1016/j.apenergy.2019.114424

# 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.