FUTURE ENERGY AND RESOURCE NEEDS STUDY (FERNS): PRELIMINARY UPDATE

PRESENTED BY

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PREPARED FOR

SPP Strategic Planning Committee

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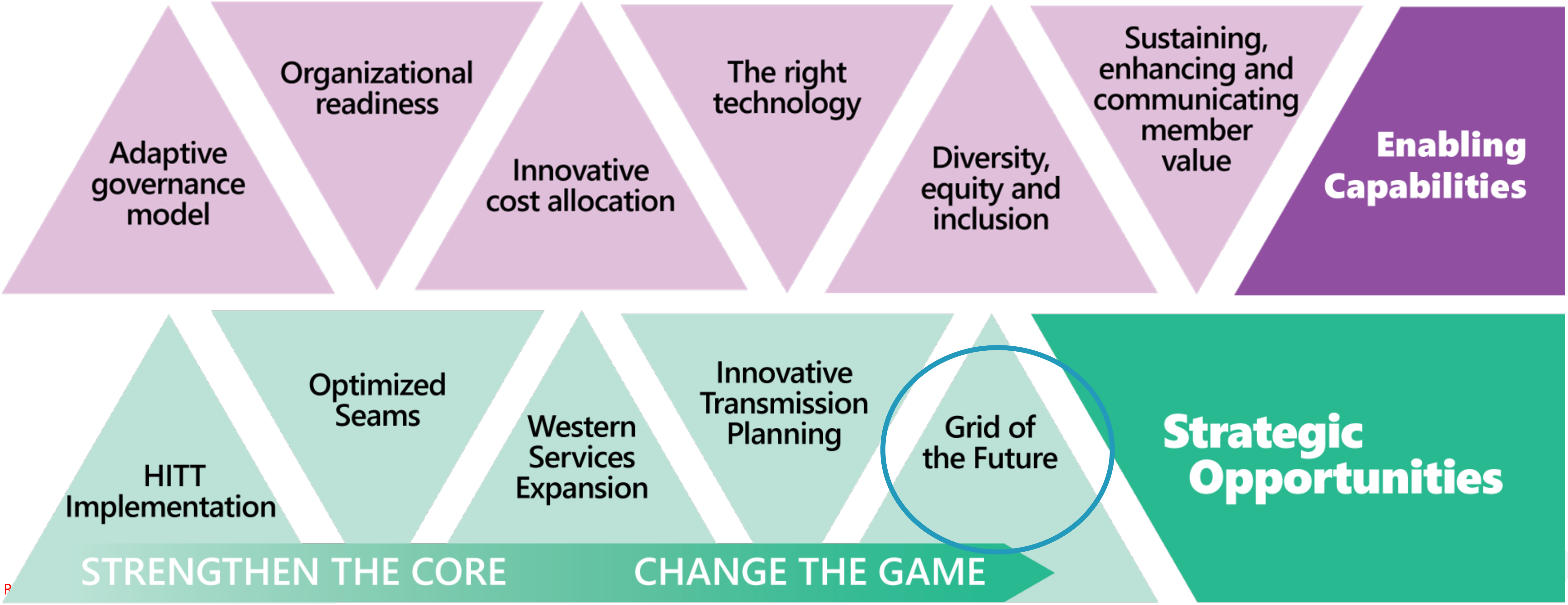
Brattle

spp.org/about-us/strategic-plan/

STRATEGIC PLAN ALIGNMENT

PURPOSE OF THIS PRESENTATION: Review FERNS Study approach and methodology for future use with CPP efforts.



FERNS STUDY OVERVIEW

Purpose

- What is the most cost-effective future resource mix to meet system needs through 2050?
- How do the costs (operational and investment) of these systems vary across future scenarios?
- What are the shortcomings of the current resource adequacy framework in a highly electrified and decarbonized future?

Approach

- Zonal capacity expansion model of SPP for each of the five FERNS scenarios (recognizing interconnection with neighbors)
- Study horizon from 2023 through 2050
- Coordination with SPP Staff and stakeholder groups (e.g. ITP, CPP) on all study inputs

FERNS Study Scenarios

		Carbon Free Resource Shares		
		Low	Moderate	High
Electrification	Low		A1	B1
	Moderate		A2	B2
	High			B3

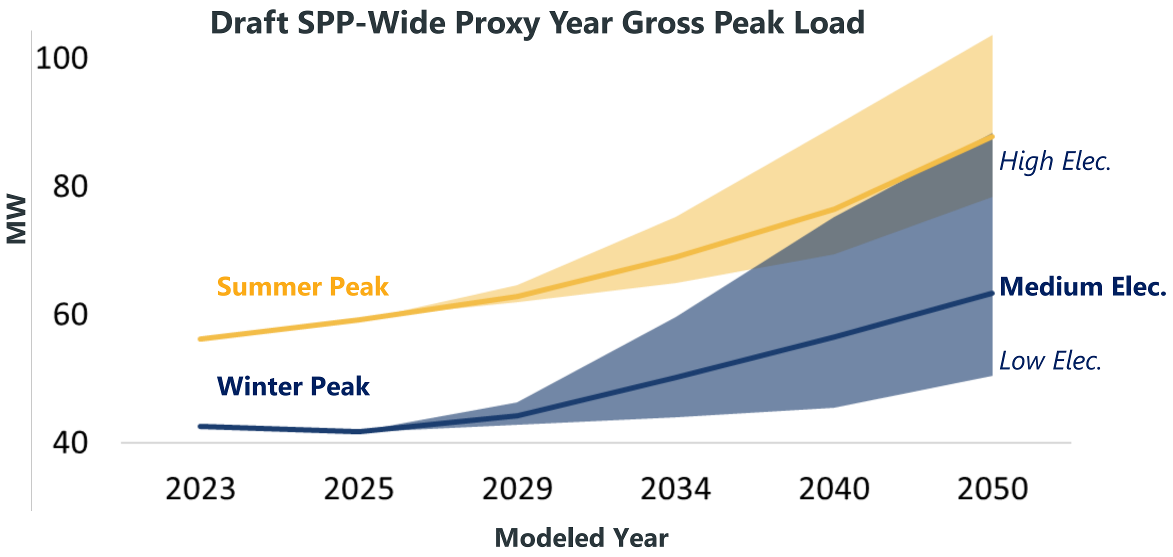
Zones for FERNS Study

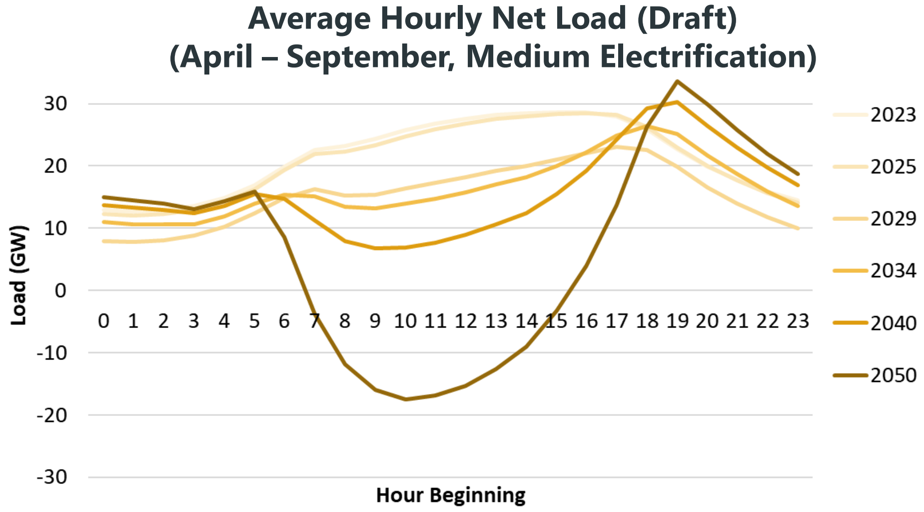
RESULT METRICS (FOR FIVE FERNS SCENARIOS)

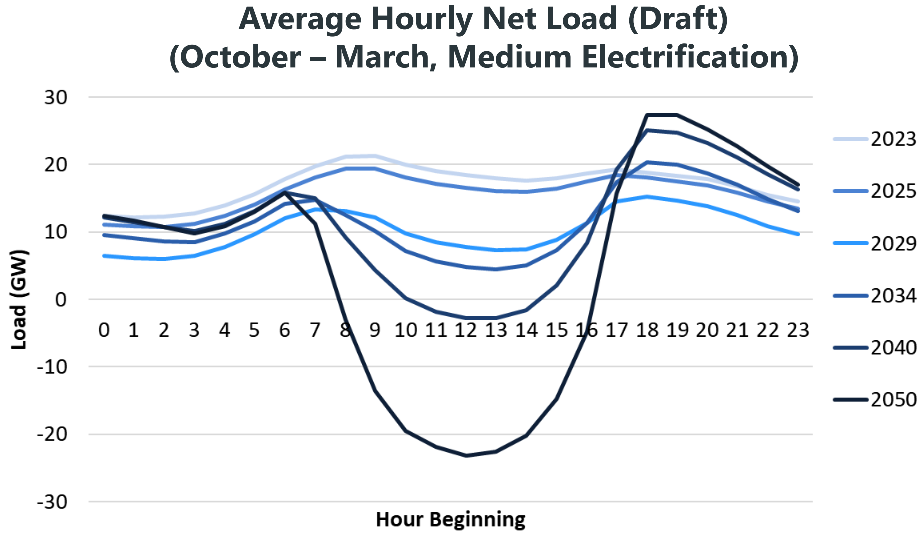
1. Cost effective generation capacity buildout (and retirement) decisions that meets future zonal resource adequacy challenges
2. SPP-wide and zonal resource adequacy challenges over time
3. Zonal market prices (revenues) for energy and resource adequacy
4. Inter zonal congestion and transmission expansion
5. Total system cost (fixed and variable) for each FERNS scenario
6. Indicative energy imports and exports with neighbors
7. Land use information

FUTURE SYSTEM NET LOAD CONDITIONS

- SPP system conditions will evolve with increased electrification and renewable penetration
- Electrification will increase SPP gross peak load by 1.4x – 1.8x by 2050 in the electrification scenarios
- Preliminary capacity expansion results show evolving system needs. At the right are the proxy year SPP-wide net load shapes broken into two seasons:





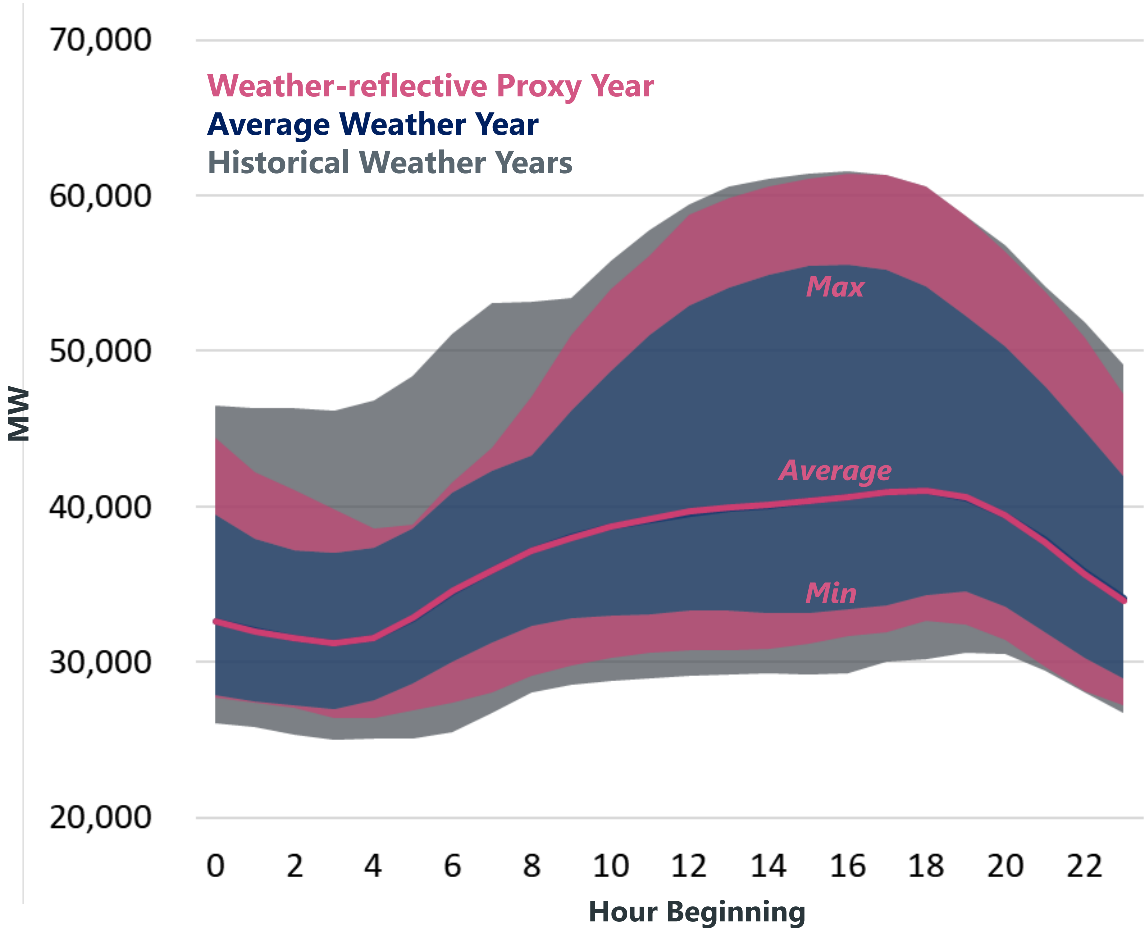


Note results are preliminary and reflect the medium electrification case. Results shown for proxy year.

MODELING MULTIPLE WEATHER YEARS

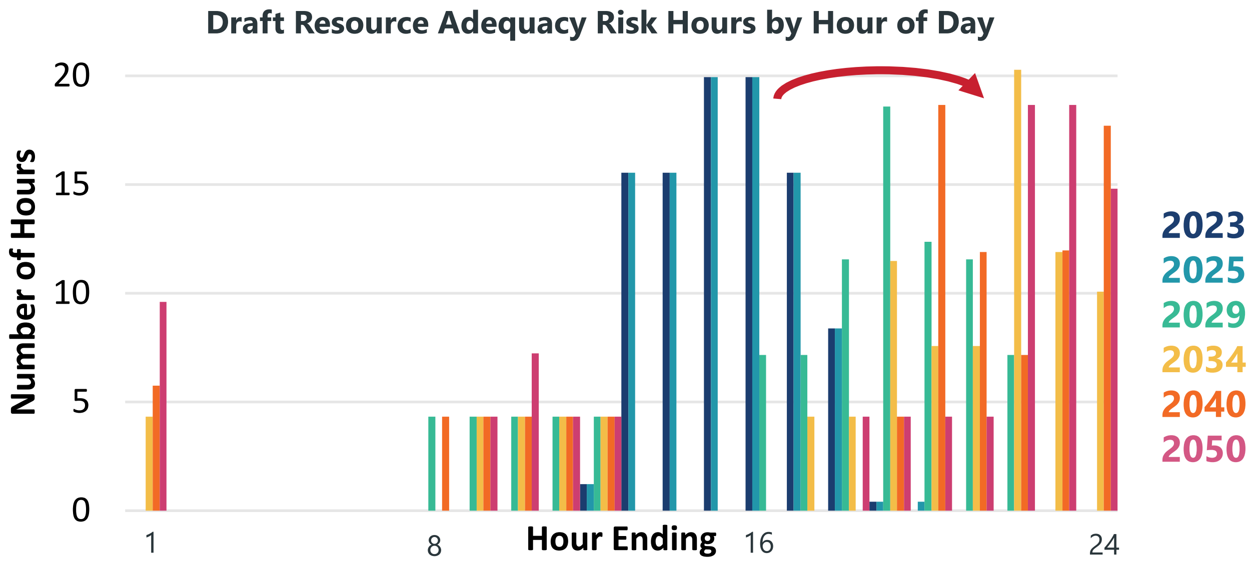
- The FERNS Study uses a **weather-reflective** proxy year, based on load and renewable data for all 15 weather years
  - Includes heat waves, cold snaps, renewable droughts, inter-zonal correlations
  - Realistic seasonal, daily, hourly variations
  - Same average, but full set of weather-related challenges
- The weather-reflective proxy year captures the full range of weather conditions over the past 15 years better than a weather normalized hourly profile
- FERNS resource adequacy results will reflect the expected future challenges SPP may actually experience

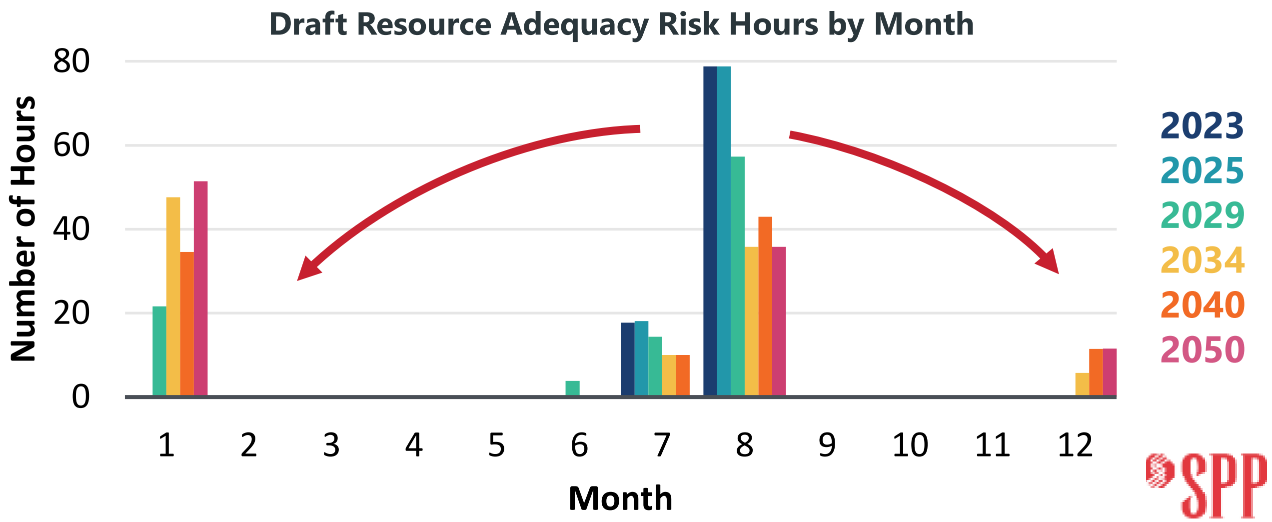
SPP-Wide 24-Hour Load Shape (2029, Medium Scenario)



FUTURE SYSTEM RESOURCE ADEQUACY RISK (DRAFT)

- Evolving net load conditions means resource adequacy risks are changing over time
- Charts show the top 100 hours with highest resource adequacy risk in each year (defined as hours with the lowest "supply cushion").
- By 2030, tight resource adequacy hours shift to evening hours (compared to afternoon hours in earlier years)
- By 2030, tight resource adequacy hours become more frequent in winter months
- These effects are even more pronounced in 2040 and 2050



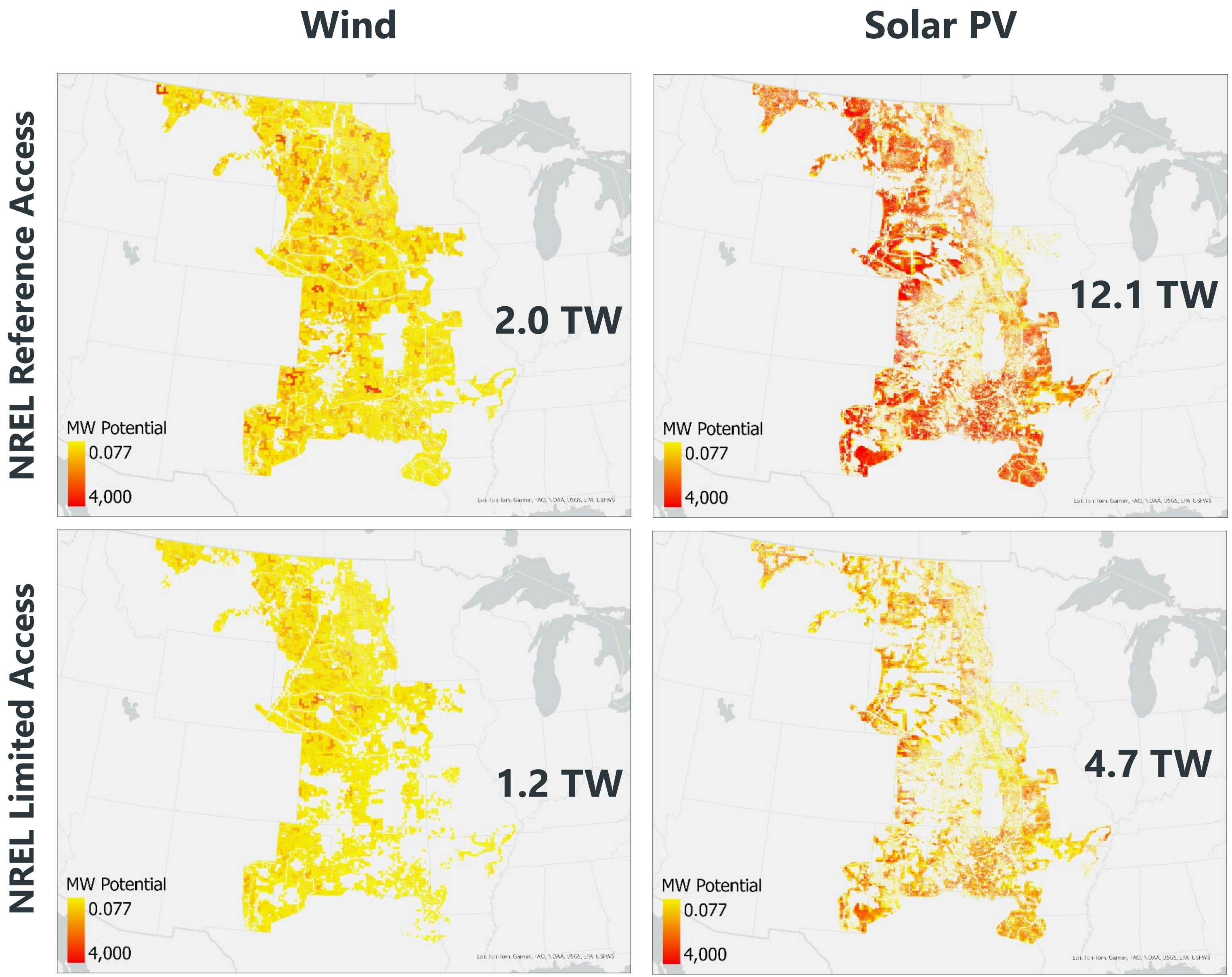


Restricted - Trusted 3rd Party

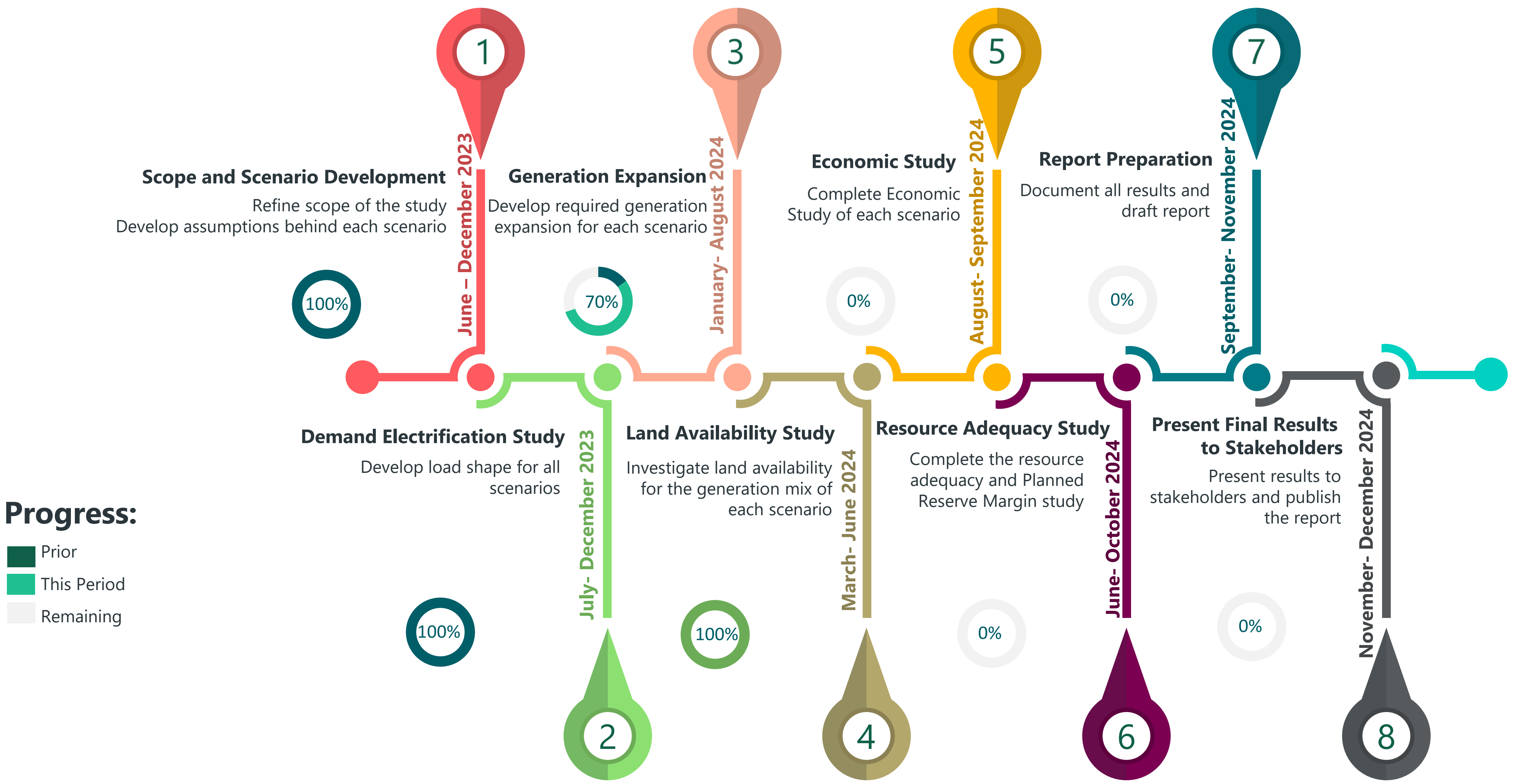
SPP

LAND USE STUDY

- FERNS Study includes a land use analysis to ensure generation expansion results are within physical constraints
- Used detailed land-impact and -availability data from NREL Geospatial Data and The Nature Conservancy's Power of Place data
- All FERNS zonal capacity buildout scenarios will likely be well within these calculated low-impact potential estimates
- More detailed nodal land-use analysis will be conducted for CPP siting efforts



TIMELINE OF THE STUDY MILESTONES



APPENDIX

AS PRESENTED TO ESWG

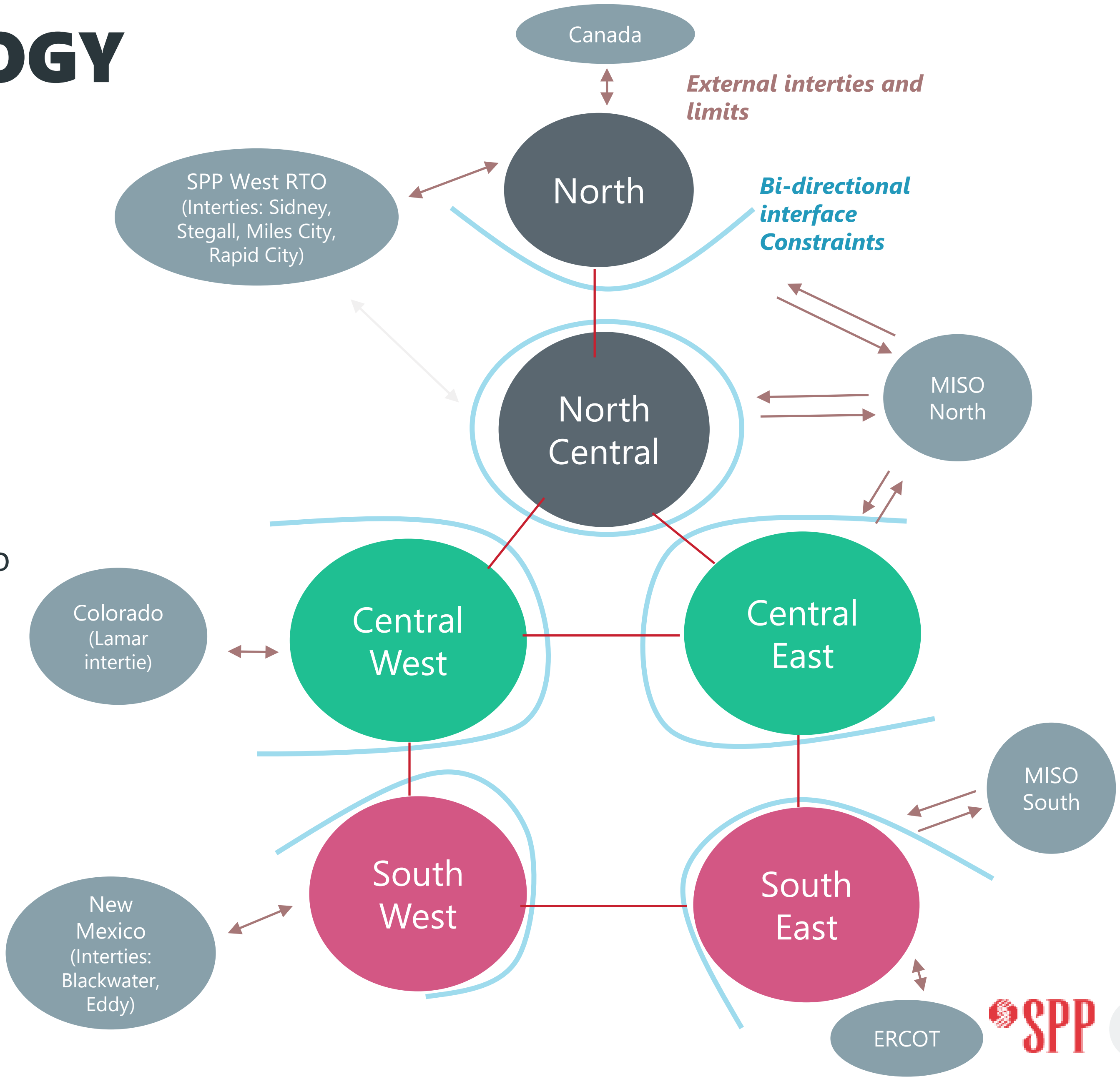
SUMMARY OF ALL MODELING INPUTS

Data Element	Description and Source Notes (may differ by year modeled)
Energy Zones	Six internal energy zones consistent with 2023 LOLE Study zones
Transmission Topology And Limits	Interface limits between each internal zone and the rest of SPP consistent with 2023 LOLE study limits; economic expansion of transmission limits is a model option with cost assumptions developed based on SPP current estimates and MISO forward looking costs.
Imports and Exports	Import and export limits based on SPP documentation. Hourly transfer capability based on simplified modeling of external zones to capture regional variations in load, renewables for potential SPP diversity benefits.
Load Growth	Baseline, IRA, and Central scenarios developed by EER for SPP FERNS Demand Electrification that represents a range of electrification scenarios
Hourly Load Shapes	Hourly shapes developed by EER for SPP FERNS Demand Electrification that vary by (weather) year, region, end-use, and scenario for 2023, 2025, 2029, 2034, 2040, 2050
Existing Generator Data	SPP data (2025 ITP) for existing unit capacities, heat rates, and additional operational characteristics by region
Scheduled Additions/Retirements (near term)	SPP data (2025 ITP) and Interconnection Queue studies to force into the model by capacity, location, date
Cost Trajectory for New Gen by Zone	Capital, fixed, and variable cost projections for new generators by resource type and zone from SPP IHS forecasts; zonal costs and intra-zonal transmission adders as function of resource availability and transmission headroom/cost by zone informed by SPP interconnection studies
Hourly Renewable Output by Zone	Hourly renewable profiles for all SPP and external zones, for all weather years available in the load dataset, available through Imperial College London (renewables.ninja)
Fuel Prices by Zone	Natural gas, coal, and oil prices from SPP IHS forecasts and sensitivities used in 2024 and 2025 ITP parameters additional fuel types supplemented from other public sources like the NREL.
Reserve Margin/RA framework	The conventional approach would be to model normalized peak loads plus planning reserve margin and capacity accreditations based on ELCC values (specified as a function of resource shares). Given that we expect the current RA framework won't be adequate in the future, we propose modeling an alternative approach to procure capacity based on hourly energy needs given load and renewable weather variability. This approach will be able to identify dynamically the specific times of the year and hours of the day that give rise to RA challenges in the future modeling proxy weather years with heat waves, cold snap, renewable droughts etc.
Clean Energy Policies	Carbon-free resource scenarios will be based on federal, state, and SPP member policies with moderate only including existing mandates with high including new and aspirational policies
Tax Credits	IRA-based PTC for solar and onshore wind and ITC for OSW and battery storage, assumed extended through study horizon

ZONAL MODEL TOPOLOGY

- Simultaneous transmission export/import limits constrain hourly energy flows between zone
  - Based on zonal export/import limits used in 2023 LOLE study
- Inter-zonal transmission constraints can create congestion and price differences in the model, limiting generation expansion, showing needs for additional zonal resources, or inter-zonal transmission capacity
- In addition to the internal SPP zones, we propose to model the interties for up to 8 external zones with variable hourly transmission flows to/from SPP to capture the economic and resilience benefit interregional diversity

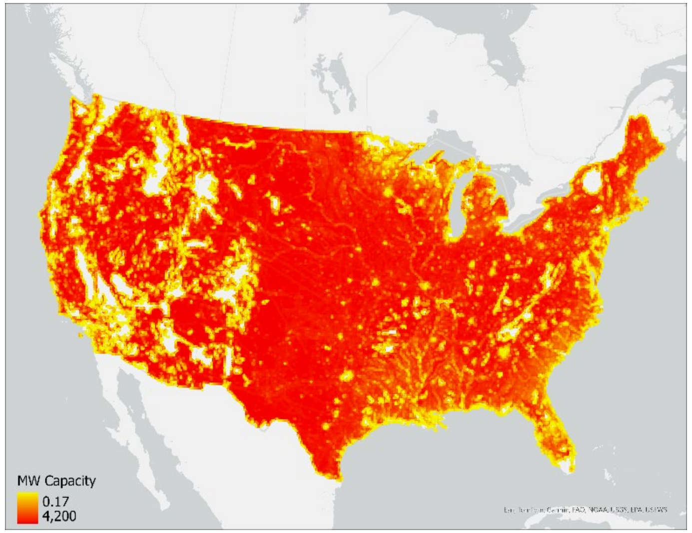
SPP Zones and Interties to Neighboring Systems



LAND USE ANALYSIS – DATA

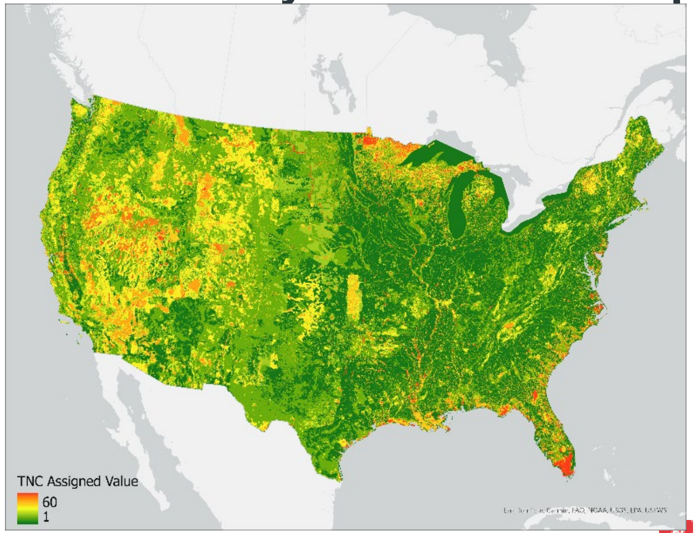
- NREL Geospatial Data:
  - NREL data provides estimates of generation potential across the continental U.S. NREL incorporates data sets from local, state and federal sources that account for protected lands, zoning requirements, setback requirements, etc. NREL provides 3 scenarios of generation potential (open, reference, limited) dependent on impact of land use restrictions on building capabilities.
- Nature Conservancy Power of Place Data:
  - The Nature Conservancy data incorporates land use restrictions from both an environmental and social perspective. Data is reported as a land impact score (1 to 60 for environmental; -10 to 40 for social) for each 250x250 meter square of the U.S. They consider their data to be synergistic with the NREL data, providing additional context to land importance beyond NREL's technical potential.
- At a high level: NREL provides generation potential across the country adjusted for certain land use considerations, while TNC provides buildable area estimates based on complementing environmental and social restrictions.

NREL Solar Generation Capacity (Open Access)



Source: NREL Solar Supply Curves

Nature Conservancy Environmental Impact Estimat

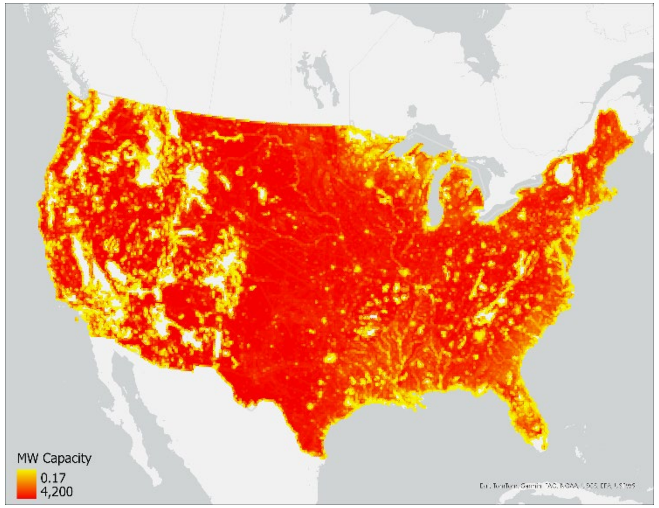


Source: The Nature Conservancy, Power of Place

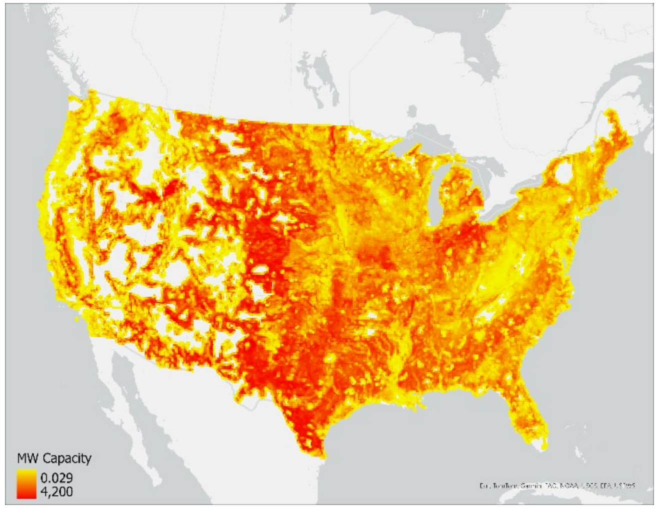
LAND USE ANALYSIS – NREL DATA AND ASSUMPTIONS

- The 3 NREL scenarios estimate MW generation potential for each 33.2km^2 area of the U.S. after considering varying level of land availability.
  - The "open" scenario removes only physical restrictions such as building footprints, protected federal land, etc.
  - The "reference" scenario is the base assumption used for subsequent NREL analysis and incorporates further restrictions based on county and local building restrictions and their impacts estimated by NREL.
  - The "limited" scenario considers very limited development potential, incl. larger setbacks and building limitations.
- We use the NREL "reference" scenario for our analysis in combination with TNC land use restrictions and use the "limited" scenario as a sensitivity for very restrictive exclusions.
- We assume that generation potential is evenly distributed throughout each represented 33.2km^2 area.

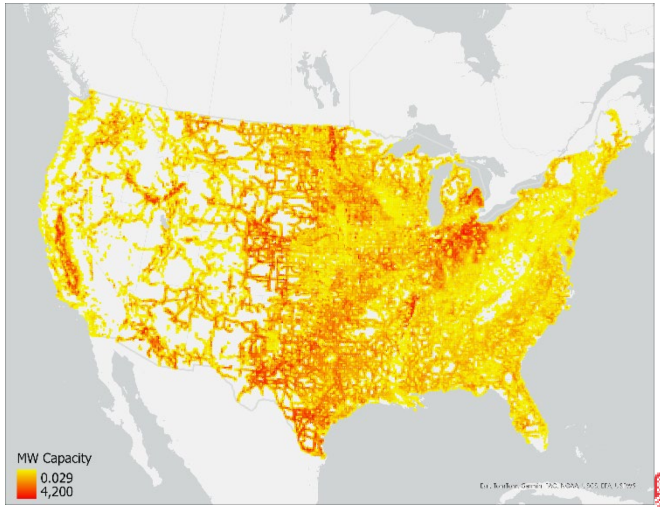
Solar Example



Open



Reference



Limited

LAND USE ANALYSIS – TNC DATA AND ASSUMPTIONS

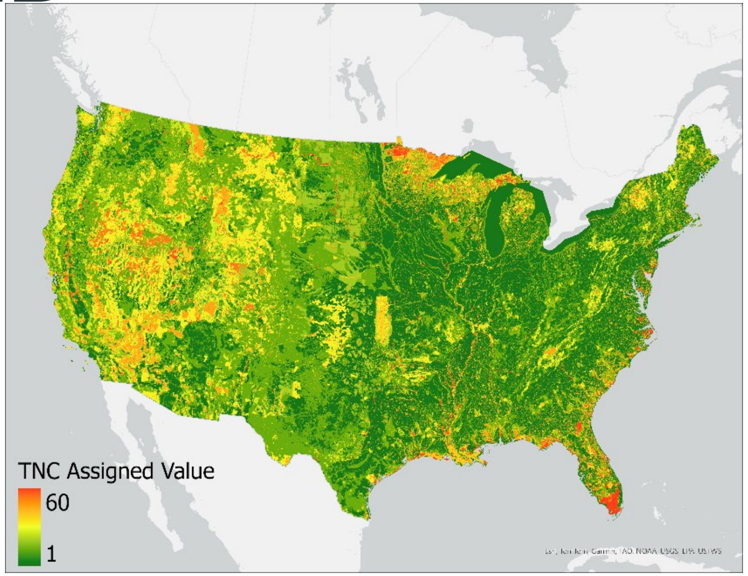
- The Social and Environmental data sets classify each 250x250 m^2 section of the country into a set of land classifications. These include the following (among other categories):

Environmental	Social
Wetlands	Productive and Valuable Farmland
Managed Areas	Recreational Areas
Threatened & Endangered Habitat	Scenic Areas
Intact Habitat	Energy Communities (per IRA)

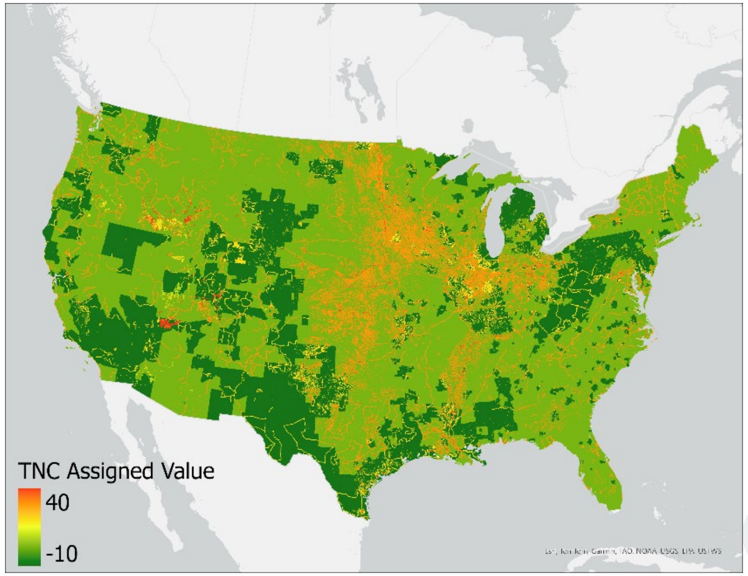
- Each category is assigned a certain value (so that the score for area that is both a wetland and an intact habitat equals the sum for both values). The aggregate values create the scale of impact shown. Low scores signify the best development sites, high scores reflect high impacts (least desirable).
- Based on conversations with TNC and our own interpretation of the data, we remove areas that receive a score higher than 5 on the environmental scale, and 1 on the social scale. See exploration on next slide.

Note: the social impact score can be negative (representing socially beneficial development)

Environmental



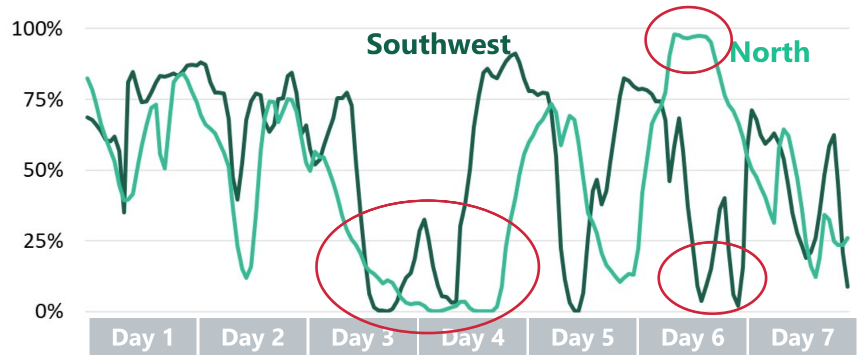
Social



RESOURCE ADEQUACY APPROACH - RECAP

- **Conventional approach to considering resource adequacy in expansion modeling:**
  - Based on forecasted normalized summer peaks plus planning reserve margins
  - Capacity accreditations based on ELCC values (specified as a function of resource shares)
  - Challenge: requires a lot of assumptions (about the nature of future resource adequacy challenges, ELCCs, and planning reserve margin) that will change significantly in an increasingly decarbonized and electrified future
- **Proposed "dynamic" approach to resource adequacy**
  - Create a proxy weather year based on load and renewable data for 15 weather years to approximate the expected future challenges SPP may experience
    - Heat waves, cold snaps, renewable droughts
    - Realistic seasonal, daily, hourly variations
  - Each year will be represented by 20+ three-day periods that capture representative conditions across all available weather years.
    - Each 3-day period has a different probabilistic weight consistent with 8760 hours in 15 weather years
  - The simulation will balance supply and demand in every hour, including operating reserve requirements. This will identify when resource adequacy challenges will occur in the future
    - Future risk likely concentrated in certain months/hours outside of summer peaks
    - The model will choose generation investments and technologies capable of meeting needs
  - The results will inform when the existing RA frameworks may need to be modified in the future (but will need to be confirmed through probabilistic LOLE analyses with SERVM)

Example: Hourly Wind Profiles
(March 2020 Week in North and Southwest Regions)



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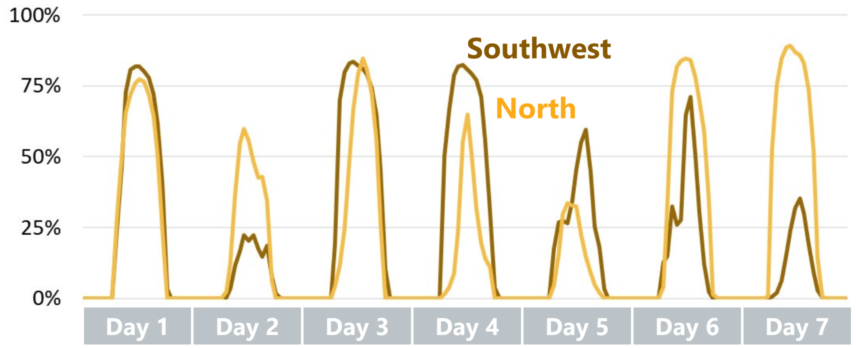
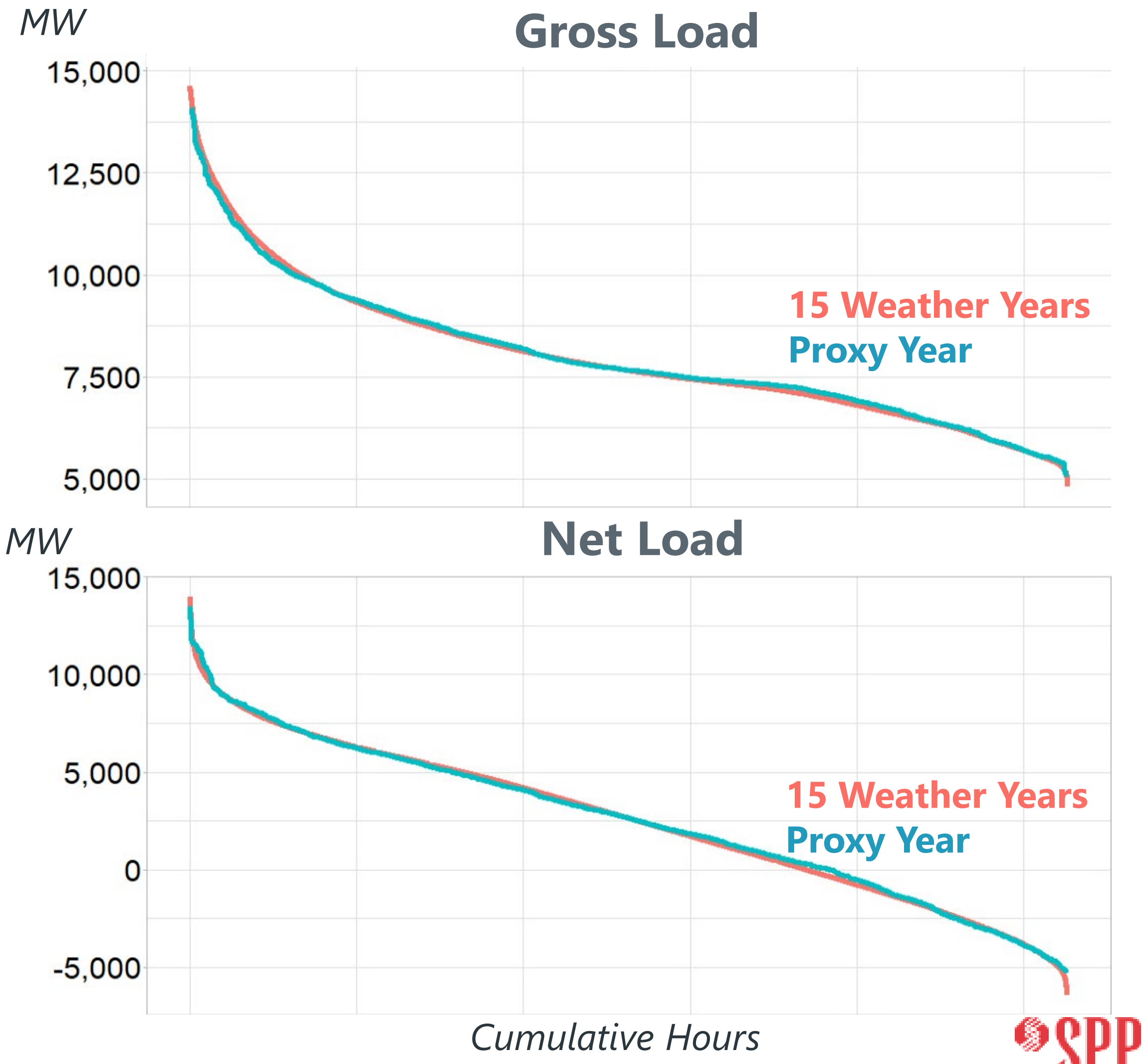


Renewable profile shown for a sample week in March 2020 to highlight hourly and geographic variation in the 15 year dataset.

PROXY YEAR APPROACH

- Example: Gross load and net load shown for Central East region for 2029 in medium electrification scenario for all 15 weather years
- Net load calculated with renewable generation profile for same 15 weather years, assumes SPP renewable capacity mix based on NREL study
- 15 weather years of load and renewable data are represented by a single proxy year comprised of 25 three-day periods
  - Each period has a weight based on the frequency of periods with similar conditions occur for the entire 15-year sample
  - Periods are selected based on "k-means clustering algorithm" and selected based on gross load, net load, solar hourly capacity factor, and wind hour capacity factors for 2029 SPP wide data
- Applied to all zones and all modeled years

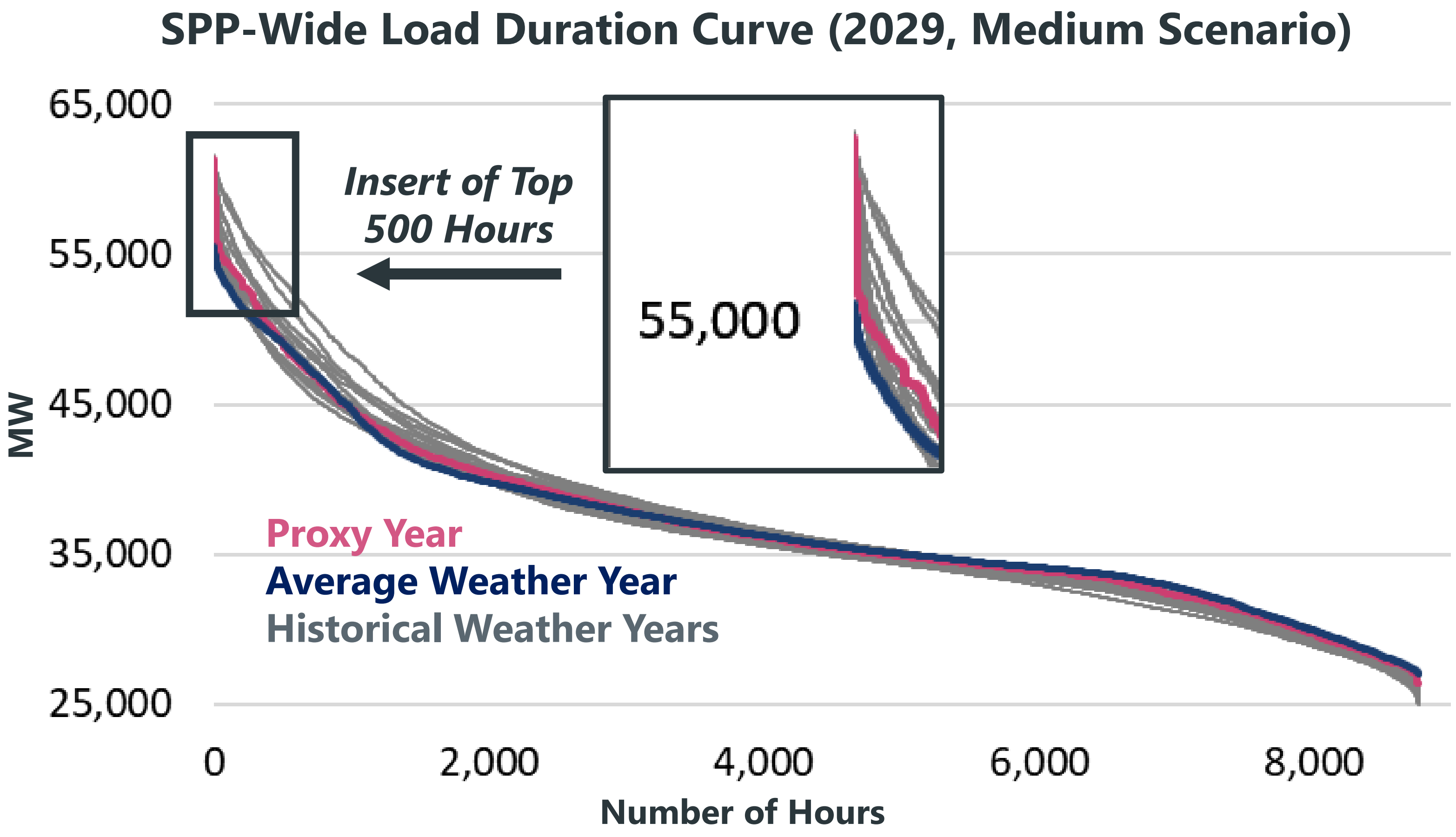
**Example:
Central East 2029, Medium Electrification**



Note: Vertical axis scales differ across figures.

PROXY YEAR APPROACH – WEATHER REFLECTIVE

- Proxy year weather approach captures the impact of 15 years of weather conditions across SPP

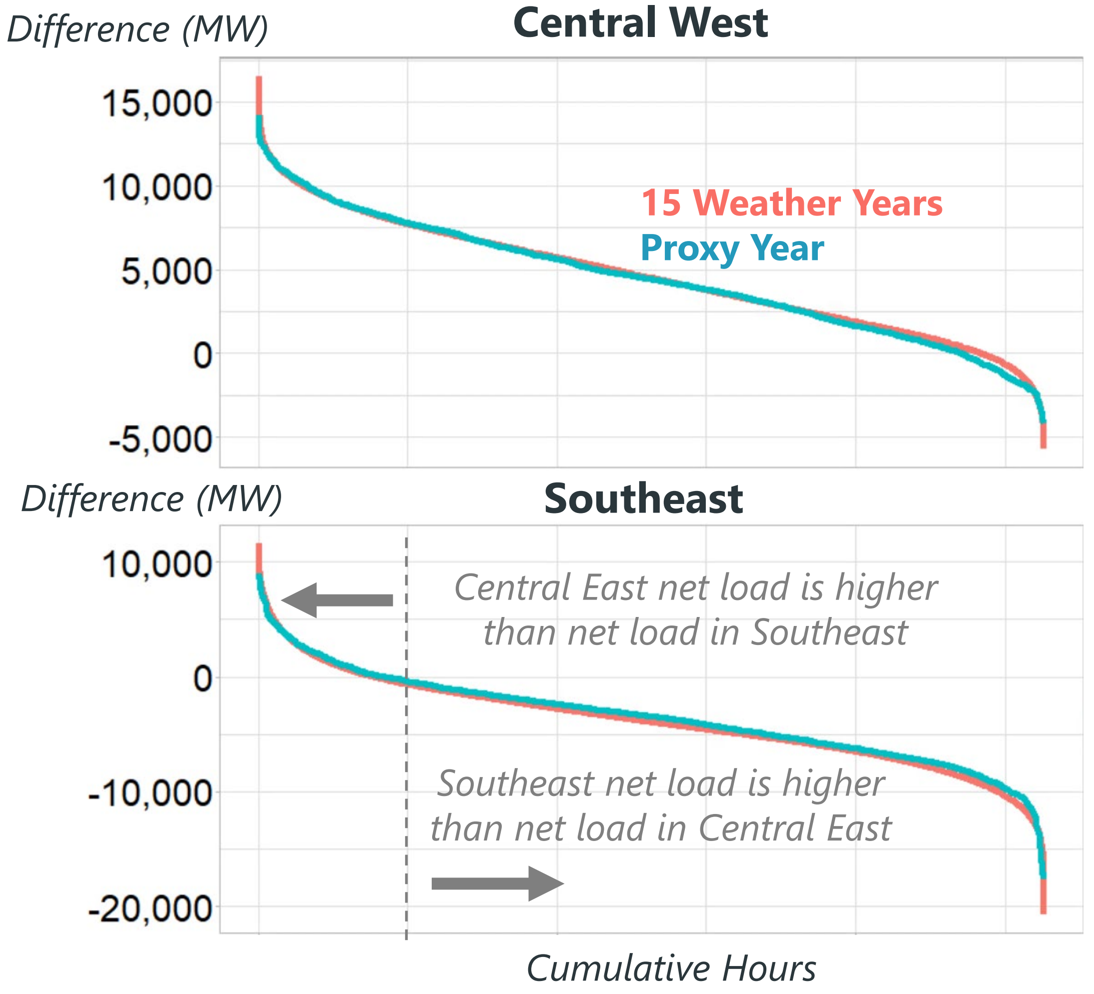


Note: Axis starts at 25,000 MW.

GEOGRAPHIC DIVERSITY

Example
Difference between Central East vs. Central West and Southeast
(2029 Medium Electrification, Net Load)

- Geographic diversity between hourly renewable generation and loads of SPP zones helps reduce costs and improve resource adequacy
  - Variation in net load across regions suggests opportunities for transmission flows and will drive generation and transmission capacity build decisions in our modeling
- We test how well our proxy year data captures the diversity between SPP regions by comparing net load difference duration curves between all pairs of simulated zones (for all 15 weather years)
- Example: Comparison of Southeast and Central West regions in the charts at the right
  - Shows that we capture differences in net loads well in our proxy year

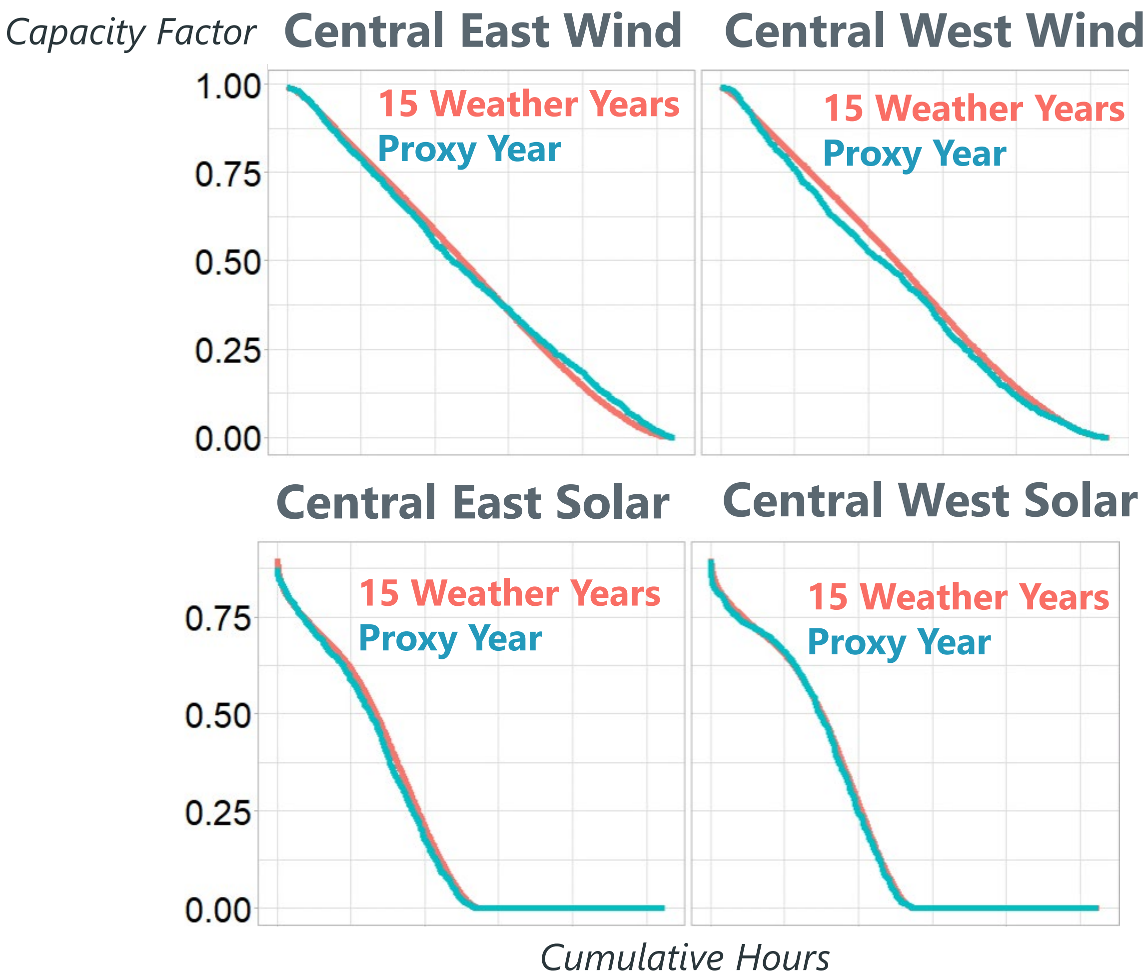


Note: Charts show difference between Central East minus each region. When the charted net load is positive, Central East has higher net load than the other region. The charted net load is negative in hours when Central East net load is less than the compared regions. Vertical axis scales differ across figures.

RENEWABLE RESOURCES

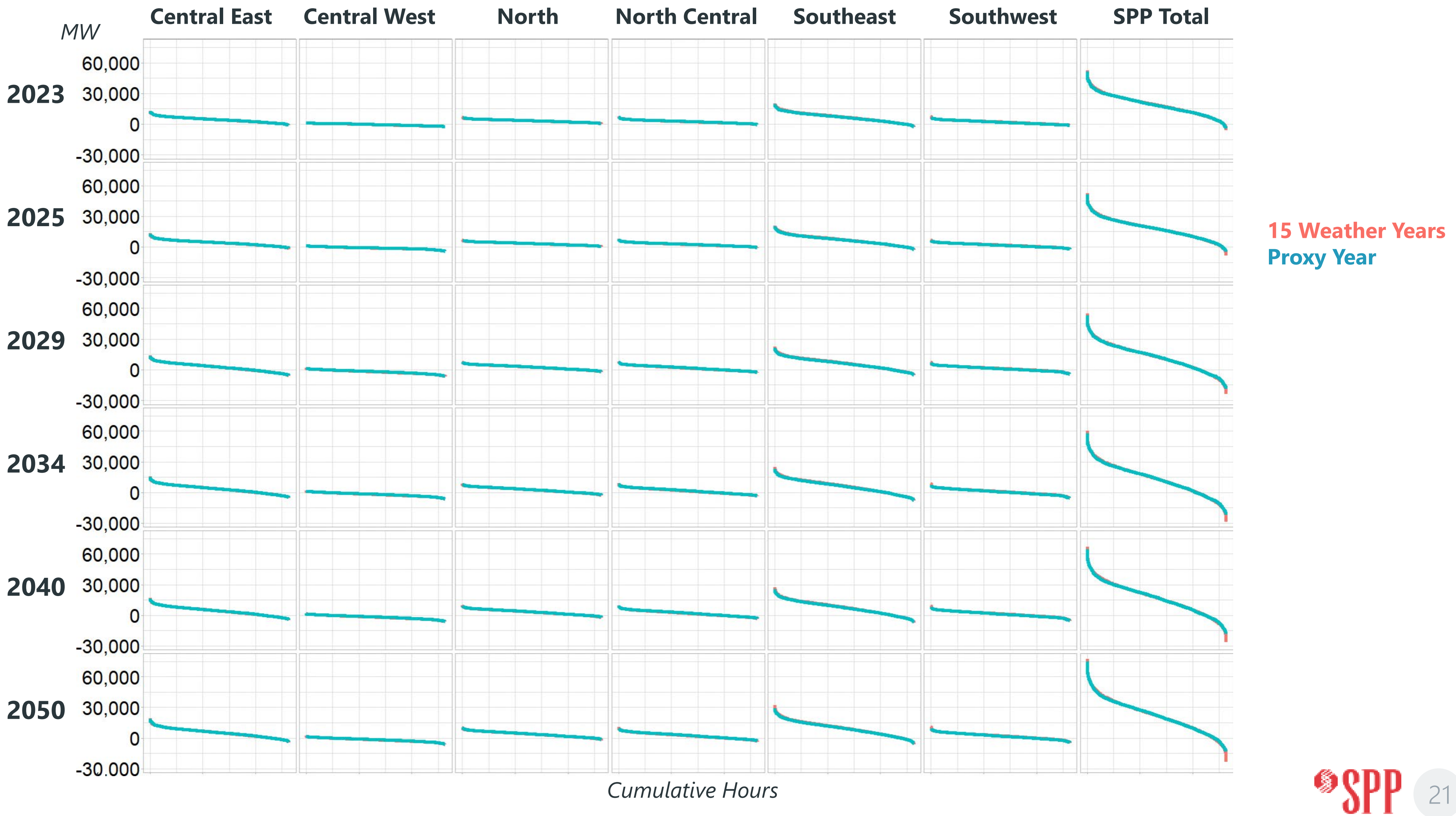
- Renewable generation profiles vary by region within SPP to capture differences in resource conditions across the ISO
- The proxy year and associated weights represent the renewable conditions based on the past 15 years of weather data
  - Renewable generation profiles are shown as hourly capacity factors from 0-1, expressed as a fraction of installed capacity
  - Solar generates at 0% capacity factor for around half of the hours (overnight), while wind has closer to a 50% average capacity factor (true diagonal line)

Example:
Wind & Solar in Central East and Central West

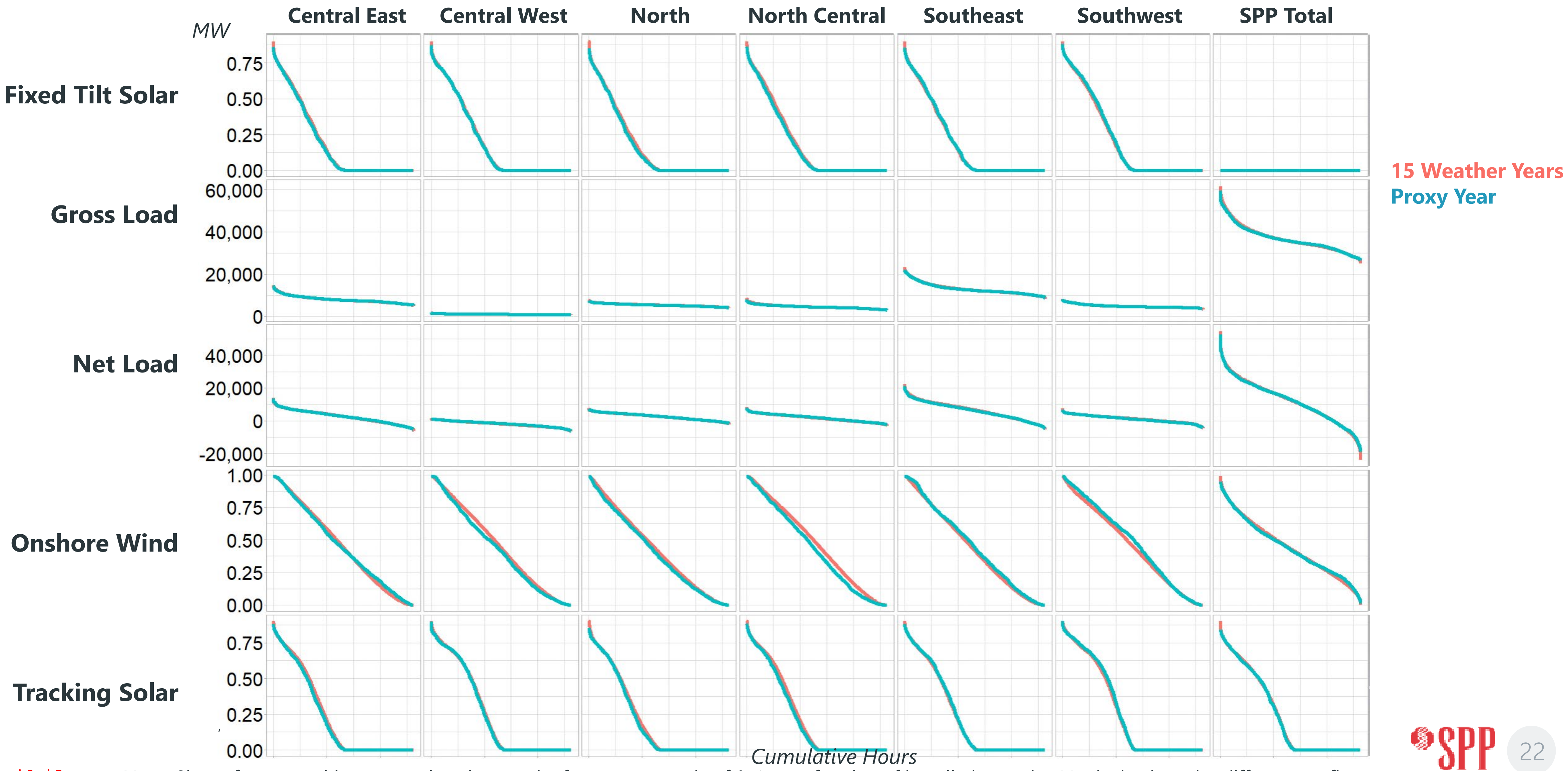


Note: Charts hourly capacity factors on a scale of 0-1, expressed as a fraction of installed capacity. Vertical axis scales differ across figures.

2029 MEDIUM ELECTRIFICATION NET LOAD: ALL MODEL YEARS



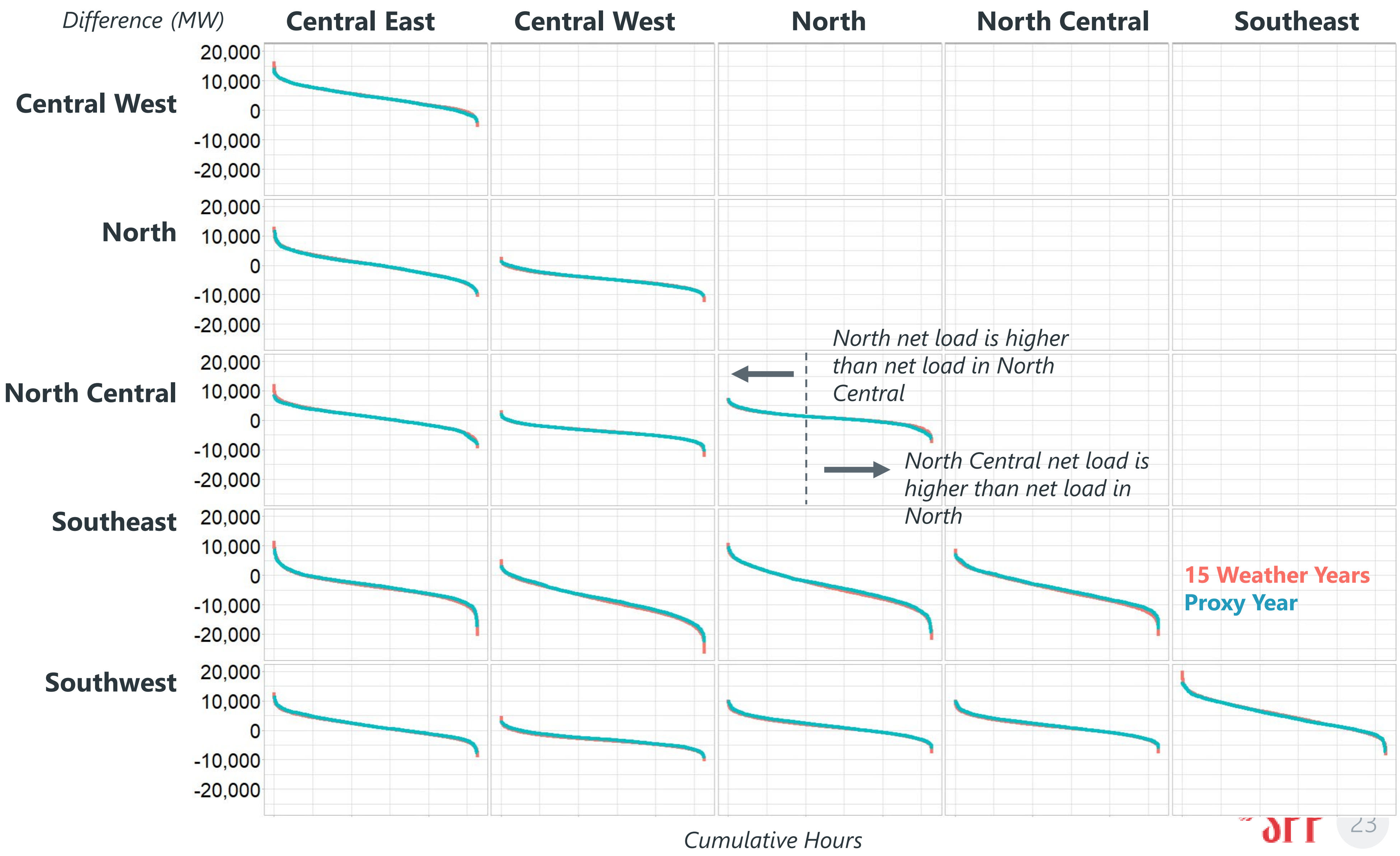
2029 MEDIUM ELECTRIFICATION: ALL PROFILES



Note: Charts for renewables express hourly capacity factors on a scale of 0-1, as a fraction of installed capacity. Vertical axis scales differ across figures.

Difference between Column Region vs. Row Region
(2029 Medium Electrification, Net Load)

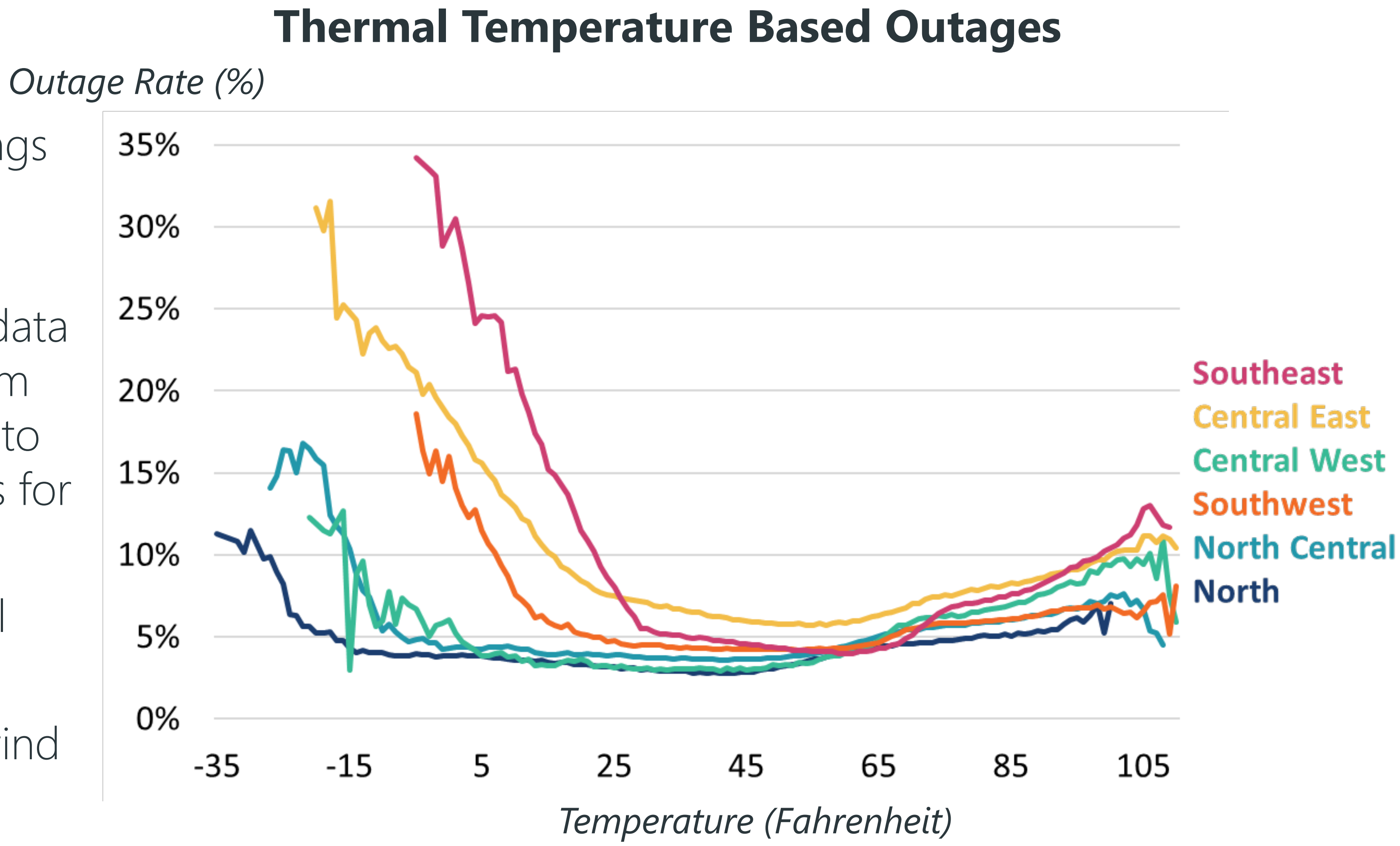
- Figure shows net load of region in column minus net load of region in row
- When the charted net load is positive, the column region has a higher net load than the row region
- The charted net load is negative in hours when the row region's net load is less than the column region



Restricted - Trusted 3rd Party

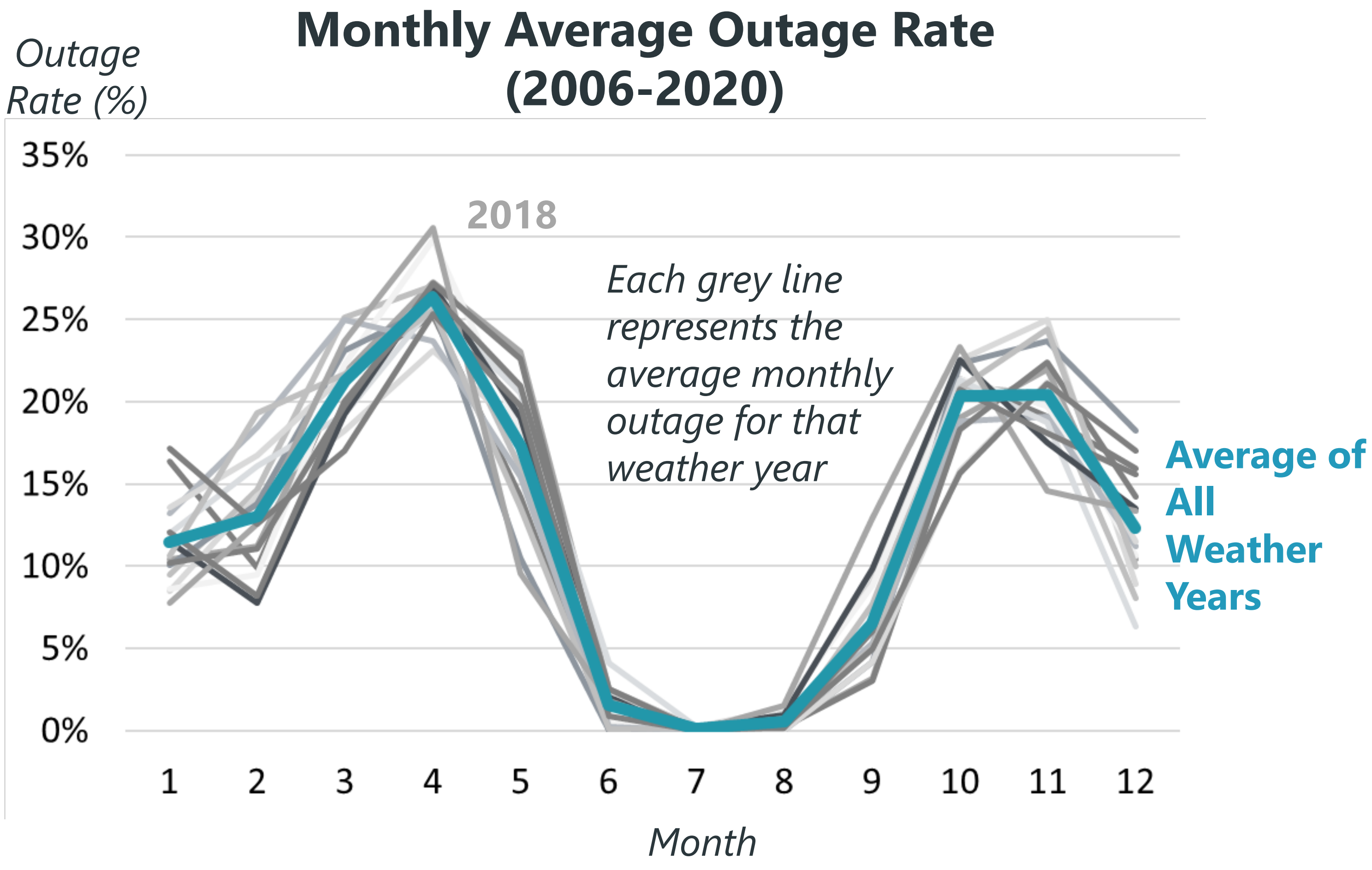
WEATHER-RELATED OUTAGES

- SPP provides LOLE zonal temperature and outage mappings in *Combined Zonal Outages.xlsx*
- We mapped the outage rates to LOLE zonal hourly temperature data for weather years 2006-2020 from *Cold Weather SERVM Inputs.xlsx* to get historical hourly outage rates for all weather years and zones
- Outage rates are the same for all thermal units within a zone
- No forced outages for solar or wind assets are modeled



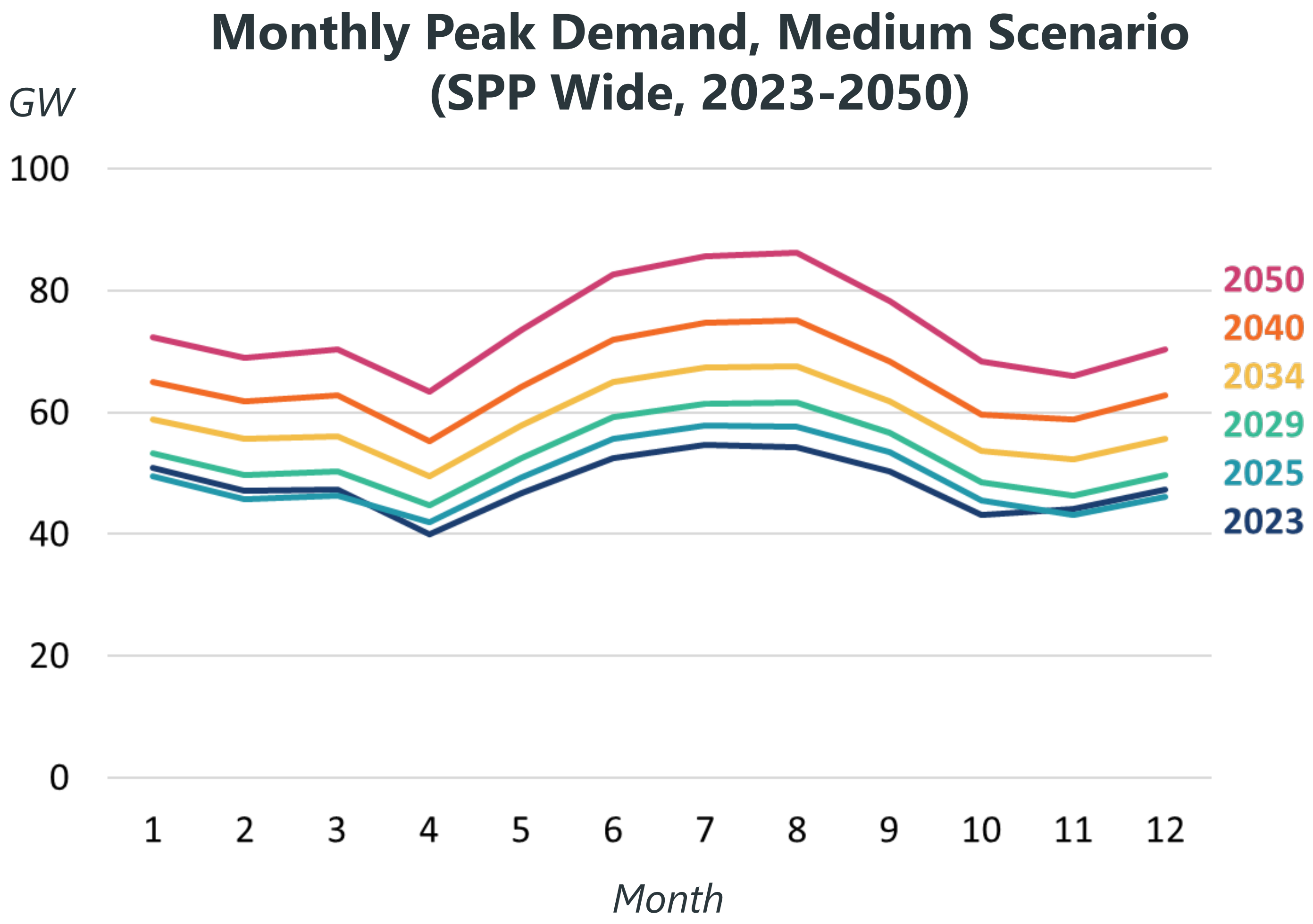
PLANNED & MAINTENANCE OUTAGES

- Planned and maintenance outages are added to weather-related outages
- SPP provides RTO-wide hourly historical planned and maintenance outages for 1980-2022 in *Combined Zonal Outages.xlsx*
- We used the monthly averages of all weather years to capture the planned and maintenance outages in the model



PLANNED & MAINTENANCE OUTAGES CONT.

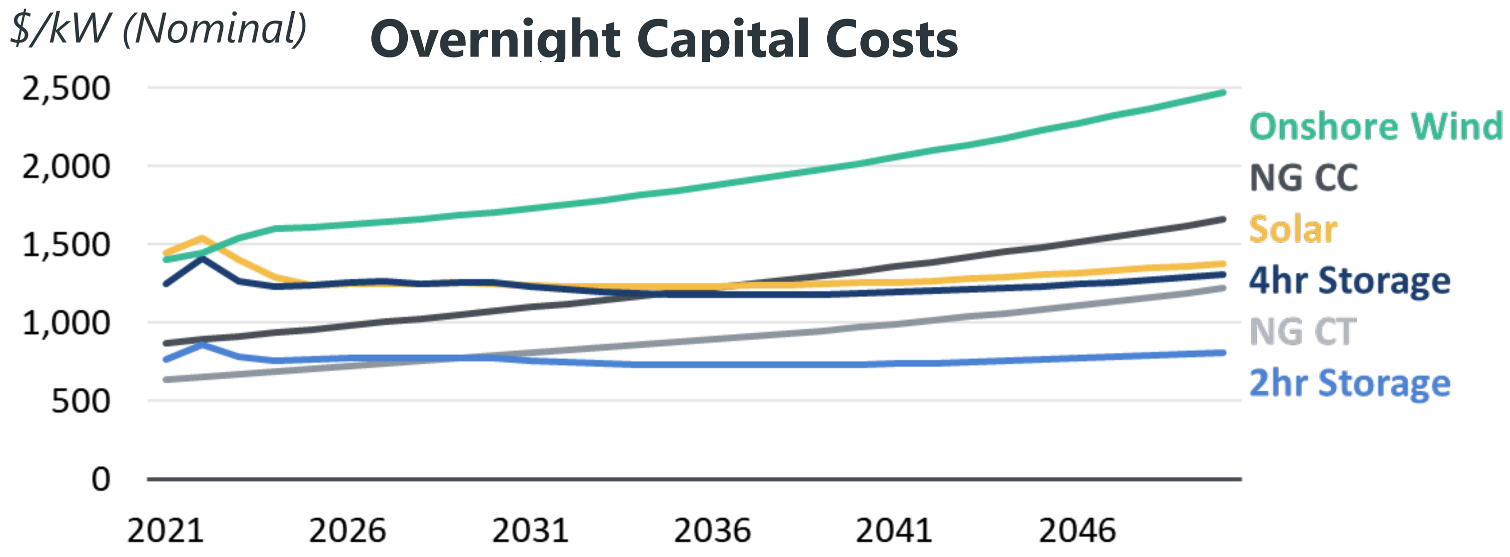
- Most planned outages occur during shoulder seasons leaving most capacity available during summer and winter months
- Based on forecasted load growth from Evolved Energy Research (EER), peak demand conditions will follow a similar monthly trend as today
- Planned outages could be scheduled in other months, if load conditions change in the future

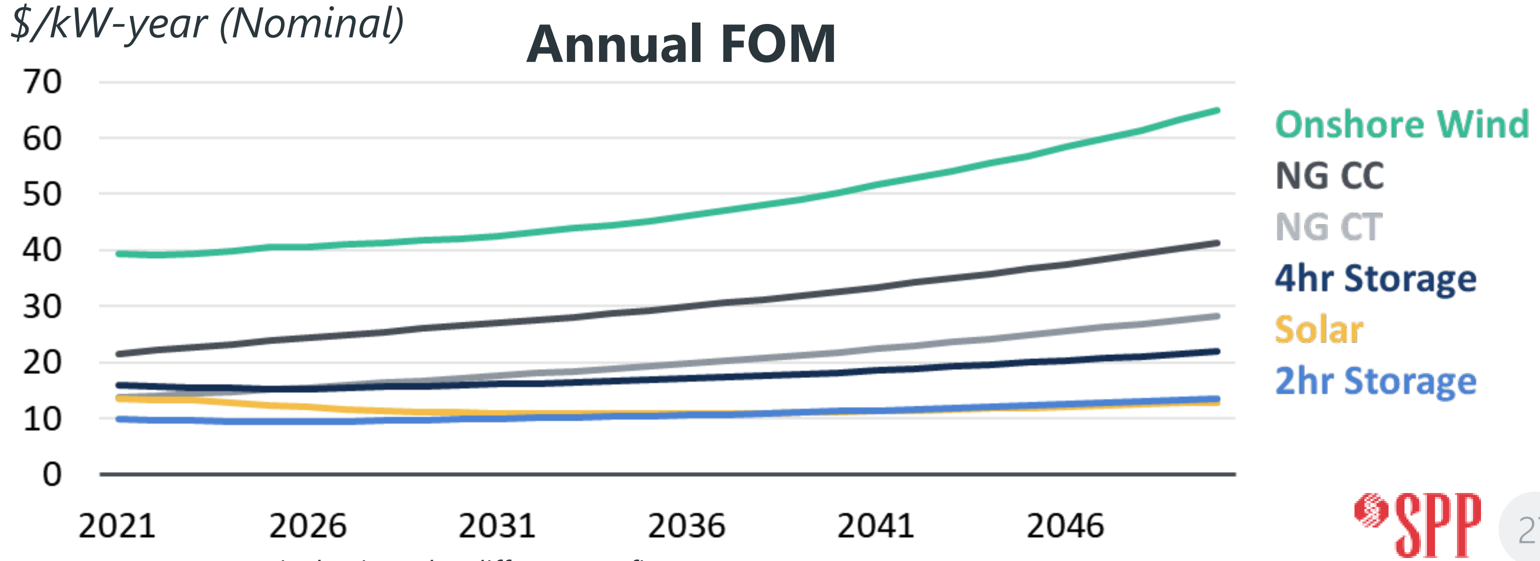


Note: Data shows the maximum monthly peak value based on all 15 weather years of data.

GENERATION CAPITAL AND FIXED O&M COST ASSUMPTIONS

- New resources can be built in the model based on resource costs consistent with 2025 ITP planning and supplemented with NREL ATB 2023
- ATB 2023 NG CC and NG CT FOM costs are scaled by SPP to ATB CAPEX ratios
- Regional cost variation implemented based on increasing supply cost curves informed by SPP interconnection data. See methodology description on following slides
- We've benchmarked these costs against NREL ATB, see appendix

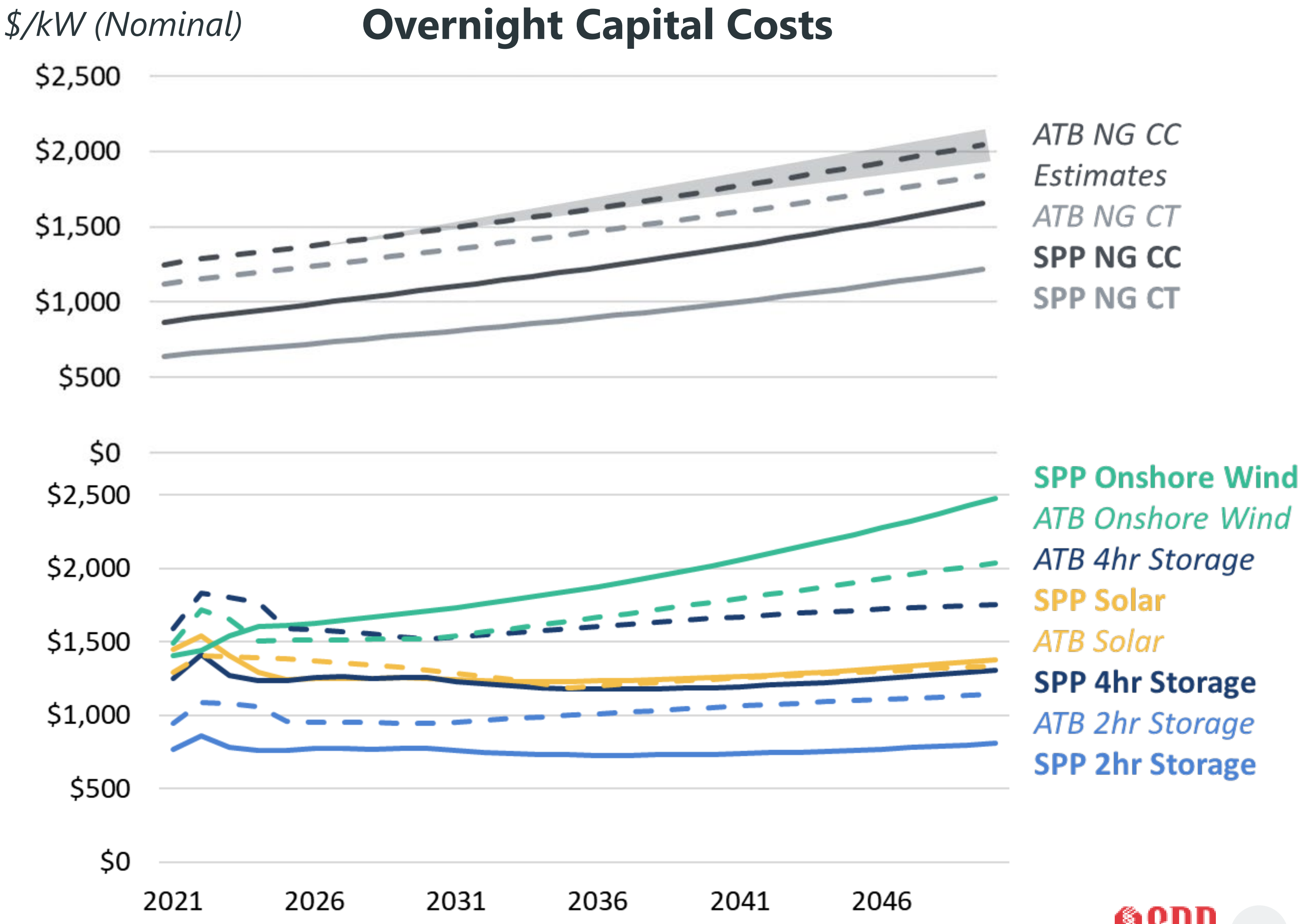




Note: Vertical axis scales differ across figures.

COST ASSUMPTION BENCHMARKING

- We compared the SPP specific 2025 ITP planning resource costs with the NREL ATB national averages to confirm the modeling inputs
- SPP costs are a bit lower for CCs and CTs than national ATB costs, but overall, in the same ballpark
- Solar, wind, and storage resource costs are within the range of ATB estimates, only the ATB Moderate scenario is shown



Note: Vertical axis scales differ across figures. Grey shading for NG CCs is the range between the ATB conservative and aggressive scenarios. Dashed lines reference moderate ATB costs. ATB CT costs are the same for all scenarios.

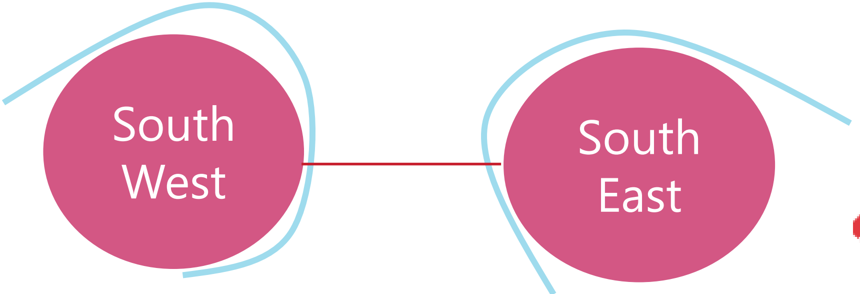
INTER-ZONAL TRANSMISSION EXPANSION COSTS

- SPP provided costs are compared to MISO's Transmission Cost Estimate Guide (2023). We propose using MISO expansion costs in FERNS modeling to recognize recent cost increases.
- Transmission cost calculations assume that expanding transmission by 1000 MW between neighboring SPP zones may require:
  - 350 miles of single-circuit 345 kV transmission lines
  - Three substations with 345/115 kV, 1,500 MVA rated transformers
  - Assumes 1,000 MW contingency limit
  - Annualized based on discount rate and annual revenue requirement
  - Divided by 2 to represent the cost of upgrading each zone's import/export constraint

Transmission Expansion Costs between neighboring SPP zones

	SPP	MISO
Substations ($)	$11.4 million	$15.1 million
Voltage Transformers ($)	$7.2 million	$9.8 million
New Single Circuit 345 kV ($/mile)	$1.6 million	$3.3 million
Total ($)	$615 million	$1,243 million
Annual Expansion Costs ($/MW-yr)	$25,318	$51,149

Example:

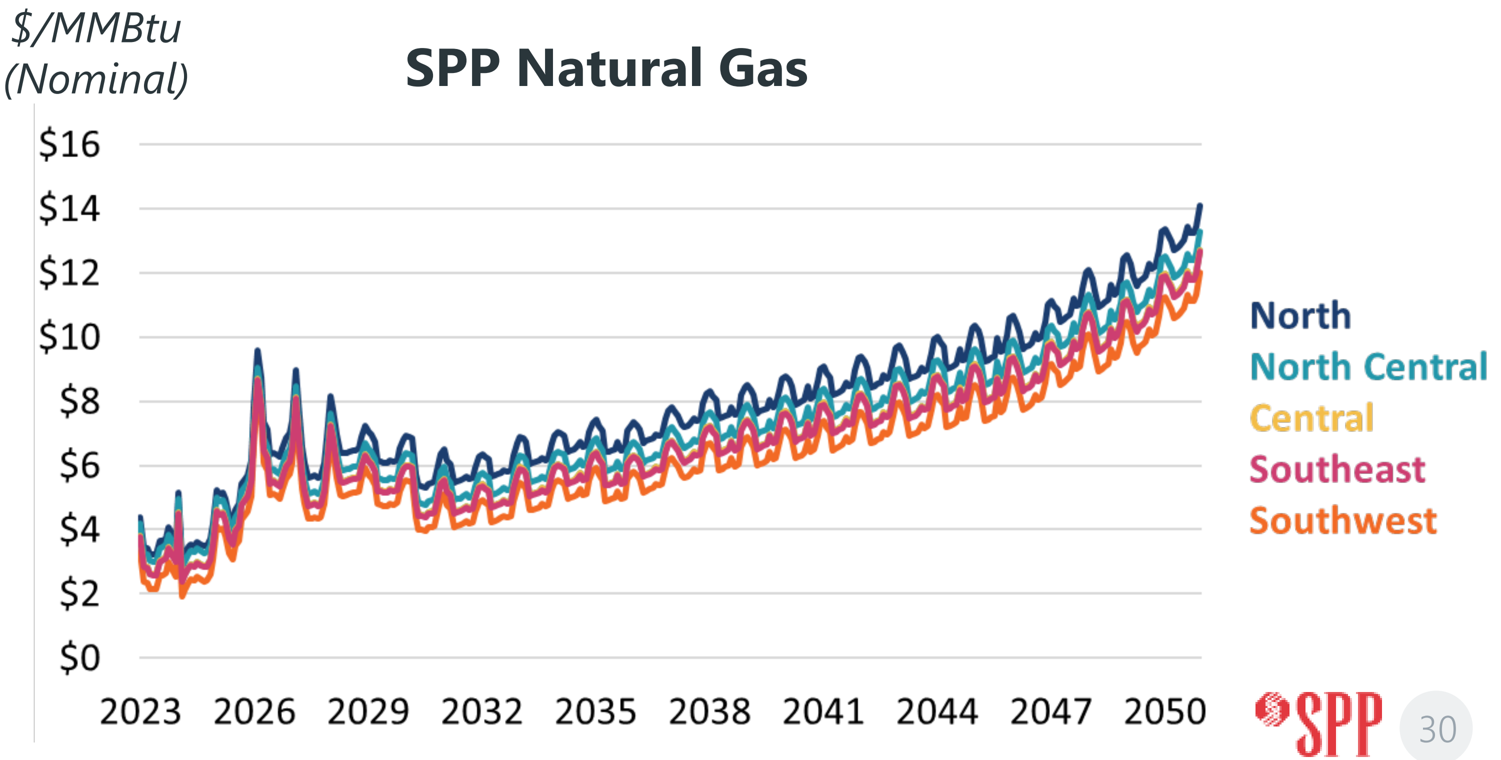


NATURAL GAS PRICES

- Natural gas prices for internal and external zones vary by region
- Modeled zones are mapped to gas hubs in SPP provided *ITP 2025 Fuel Costs.xlsx* based on gas units' Powerflow Area Numbers
- Annual basis differentials from SPP provided *ITP 2025 Fuel Costs.xlsx* are applied to monthly Henry Hub prices from SPP provided *North American Natural Gas LongTerm Outlook Market outlook data tables February 2024.xlsx*
- Prices are adjusted using an annual inflation rate of 2.6%

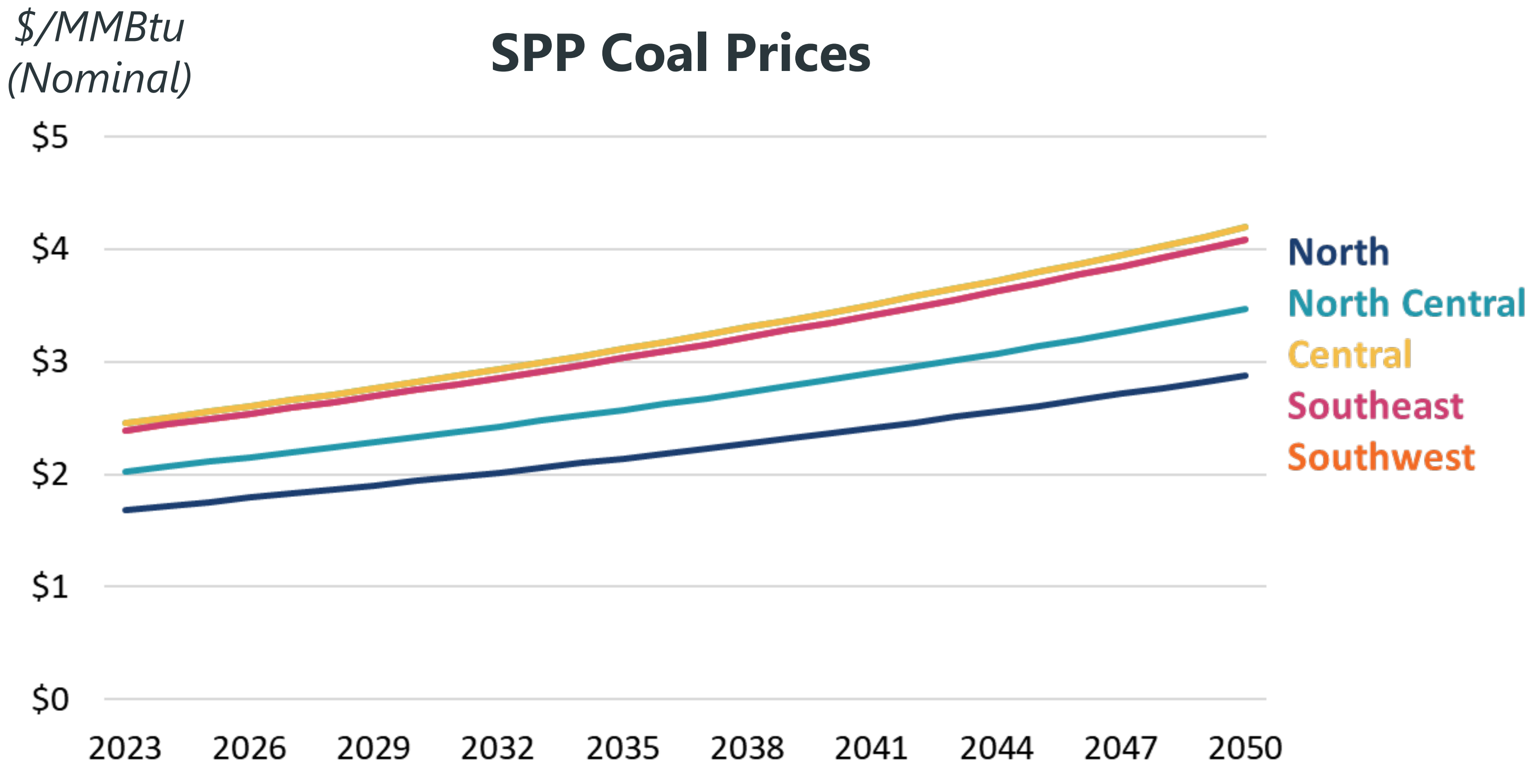
Gas Price Hub Mapping

Zones	Gas Price Hubs
North	NG Dakotas
North Central	NG Nebraska
Central West	NG KSMO
Central East	NG KSMO
Southwest	NG West SPP
Southeast	NG Oklahoma



COAL PRICES

- Coal prices for internal and external zones vary by region
- Modeled zones are mapped to coal price basins in SPP provided *Fuel Prices - 03.06.2024.xlsx* based on location
- Prices in workbook are adjusted using an annual inflation rate of 2.6%



OTHER FUEL PRICES

- Oil, nuclear, and biogen prices are nationwide, the same prices are used for all zones
- Oil: Prices are from SPP provided *Fuel Prices - 03.06.2024.xlsx*
- Nuclear: Forecasted prices from ATB (2023)
- Biogen: Forecasted prices from ATB (2023) which assumes:
  - Fuel costs are representative costs of woody biomass taken from the 2016 Billion Ton Report (DOE, 2016)
  - Regional variations will likely ultimately impact biomass feedstock costs, but these are not included in the 2023 ATB.
  - Assumes a plant size of 50 MW
- All prices are adjusted using an annual inflation rate of 2.6%