SPP Future Energy and Resource Needs Study (FERNS): Land Use Analysis Approach

SUMMARY FOR ESWG

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PRESENTED TO

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Brattle

FERNS Capacity Expansion Modeling – Progress Update

Today's presentation primarily focuses on the Land Use Study Brattle is conducting for FERNS. Brattle has also continued the capacity expansion modeling efforts. Updates will be presented at future ESWG meetings, with high level progress consisting of:

- Creating proxy year forecasts consisting of 15 historical weather years of load and renewable data for each future FERNS simulation year (high, medium, and low electrification)
- Coordinating with SPP staff to incorporate thermal scheduled and temperature-driven forced outage data to capture fossil risk conditions
- Benchmarking transmission expansion costs with SPP historic costs and other jurisdiction benchmarks (MISO)
- Forcing in near-term builds and retirements consistent with ITP 2025 siting plans
- Benchmarking new resource capital costs based on ITP 2025 IHS estimates and public sources such as Lazard, NREL ATB, and others
- Capturing net imports and exports with neighboring external regions and benchmarking to historical interchange flows

Brattle has been coordinating with CPPTF, FGSAG, ESWG, SPP Transmission, SPP Policy, and other groups to ensure modeling approach is consistent with SPP planning studies. SPP has the option to utilize the expansion planning results for CPP and other future efforts.

Resource Adequacy Approach - Recap

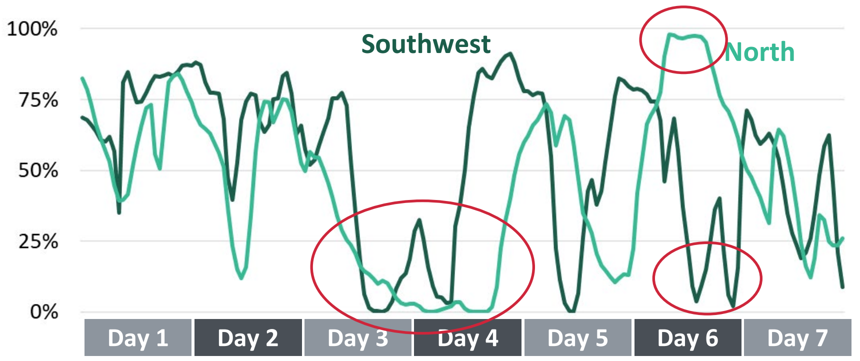
Conventional approach to considering resource adequacy in expansion modeling:

- 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

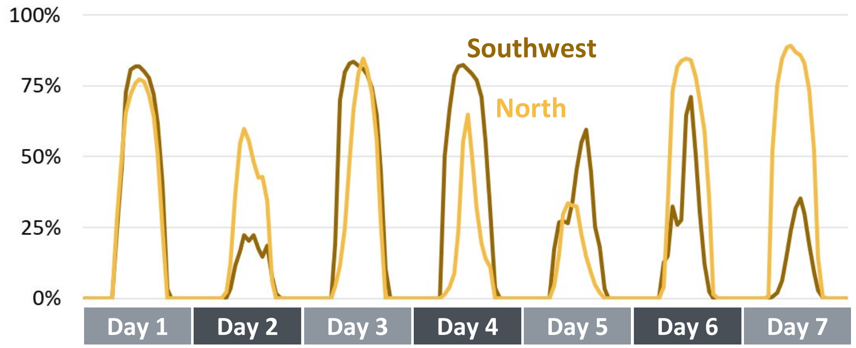
Proposed "dynamic" approach to resource adequacy

- 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)



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

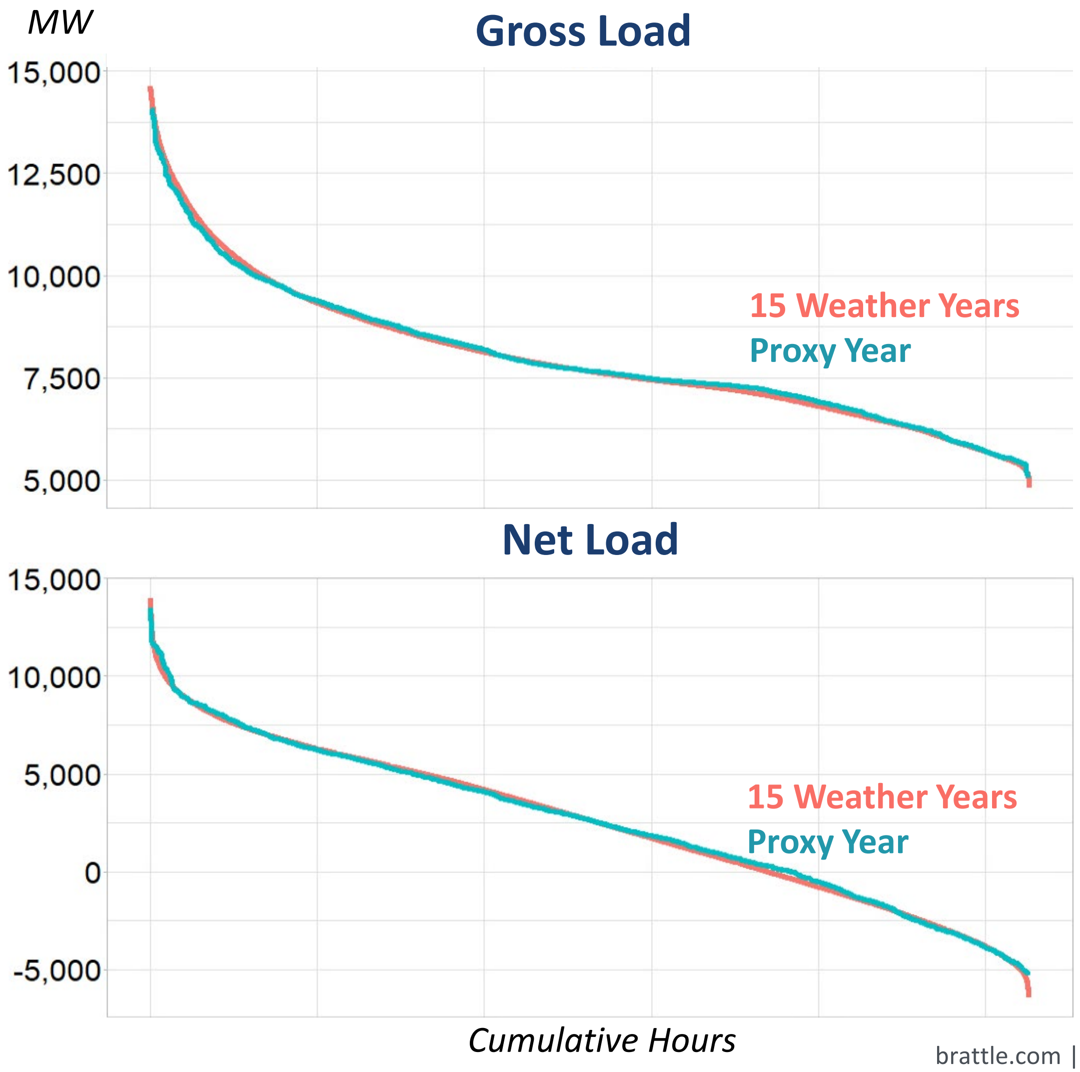


Renewable profile shown for a sample week in March 2020 to highlight hourly and geographic variation in the 15 year dataset.

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

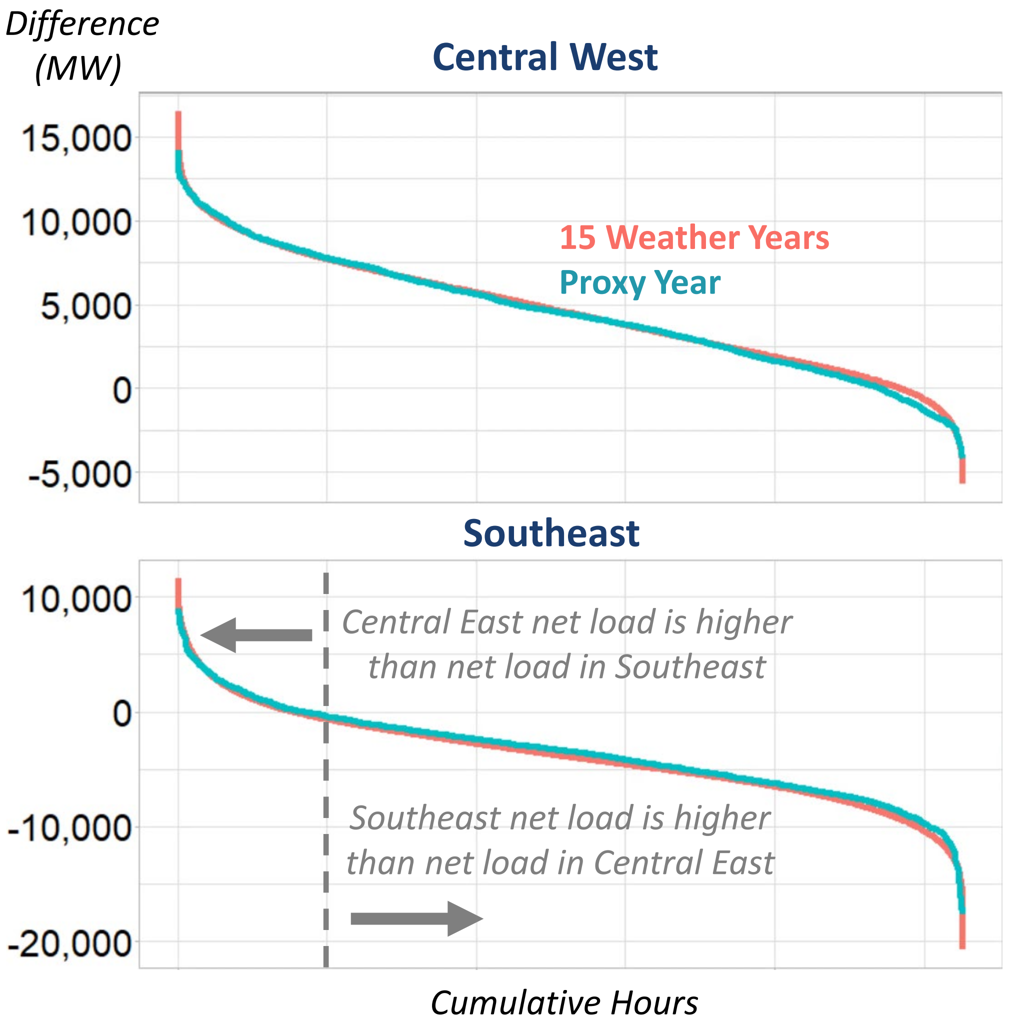


Note: Vertical axis scales differ across figures.

Capturing Geographic Diversity

- 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

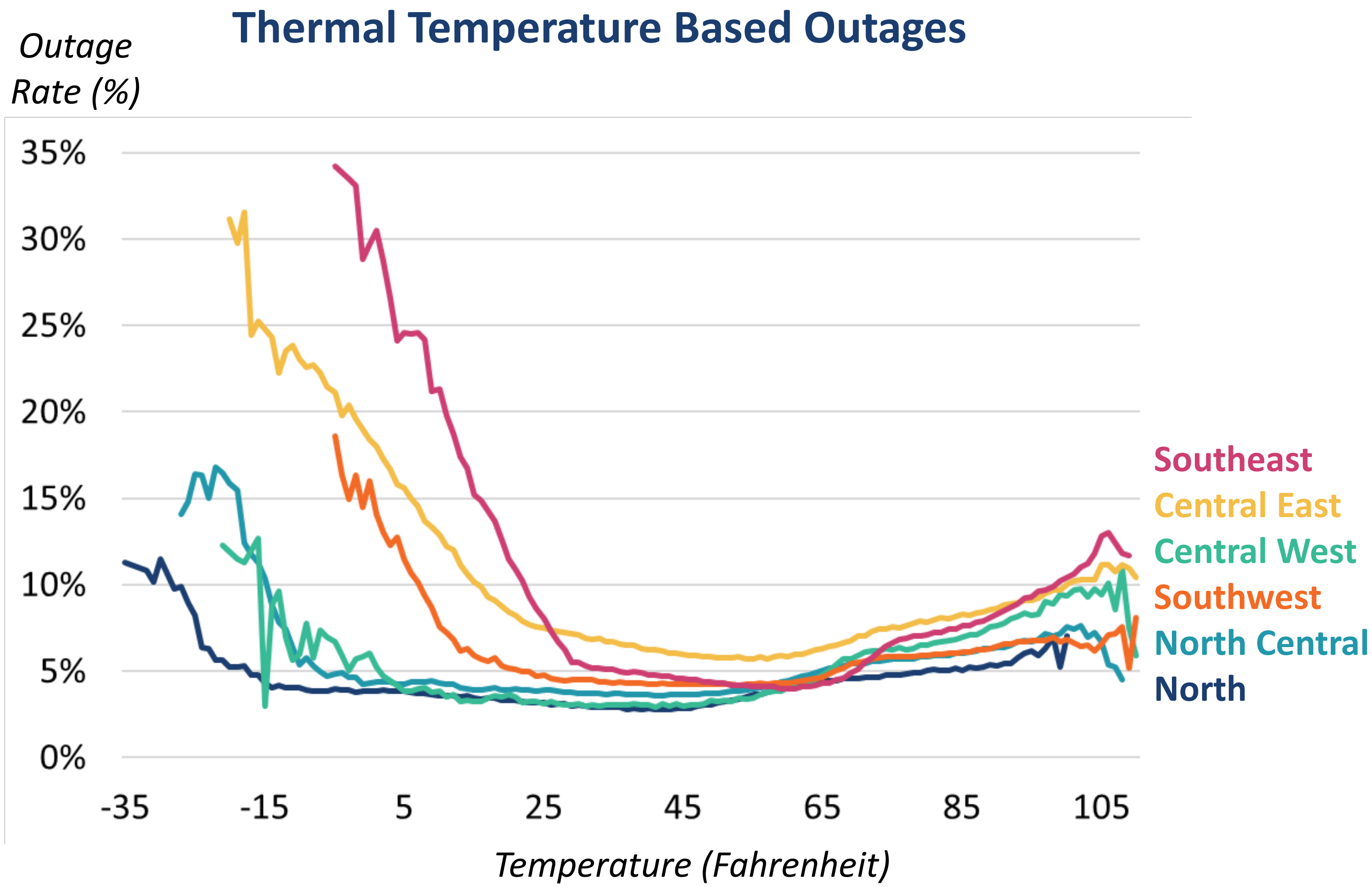
Example
Difference between Central East vs. Central West and Southeast
(2029 Medium Electrification, Net Load)



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.

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



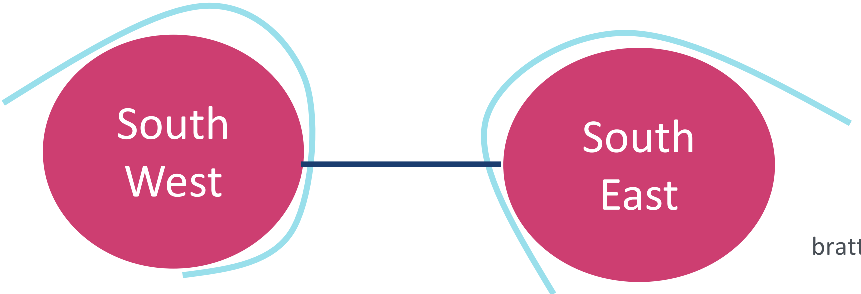
Inter-Zonal Transmission Expansion Costs

- 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:



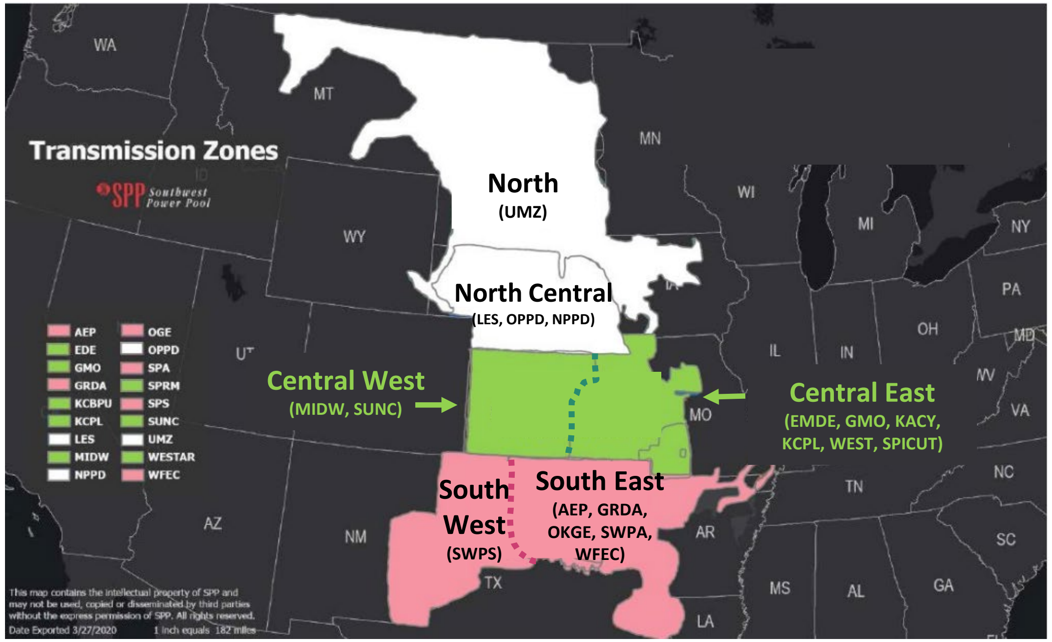
Land Use Analysis

FERNS capacity expansion modeling results will be confirmed with a land-use analysis to ensure that optimally selected resources are within feasibility limits and reflect interconnection cost thresholds:

- NREL and The Nature Conservancy publish data on land-use feasibility of generation capacity for solar and wind across the entire country
  - Both consider physical attributes, federal and state land designations, environmental impacts, social impacts, and local regulatory policies
- Brattle will consider the implications of this data on generation feasibility within the SPP footprint and within the specific FERNS zones
- Estimated generation potential in each zone will be compared to modeled generation build-out and used to inform the low-interconnection cost tiers for renewable generation

Detailed results from Land Use Analysis can then be utilized to select node-specific generation scenarios for the CPP effort

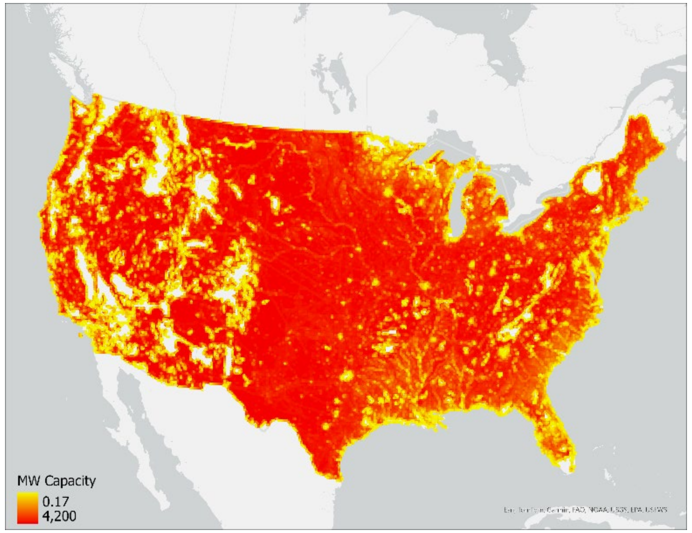
Zones for FERNS Study



Land Use Analysis – Data Explanation

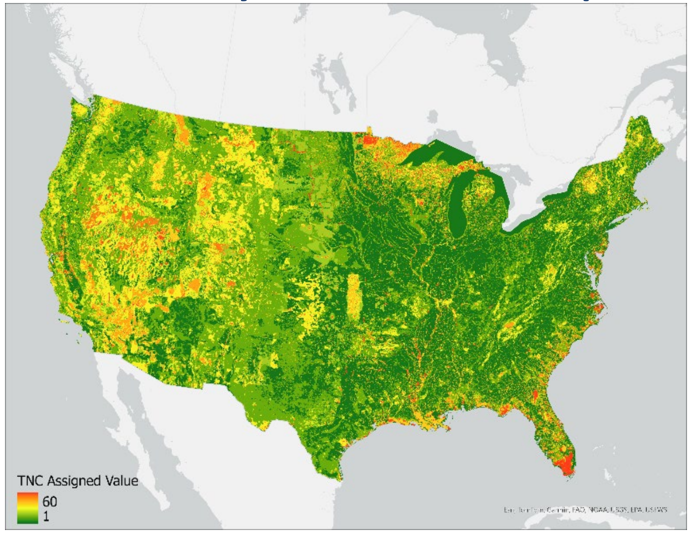
- NREL Geospatial Data:
  - NREL data provides estimates of generation potential across the continental U.S. NREL incorporates data sets from local, state and federal sources that account for protected lands, zoning requirements, setback requirements, etc. NREL provides 3 scenarios of generation potential (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 Estimate

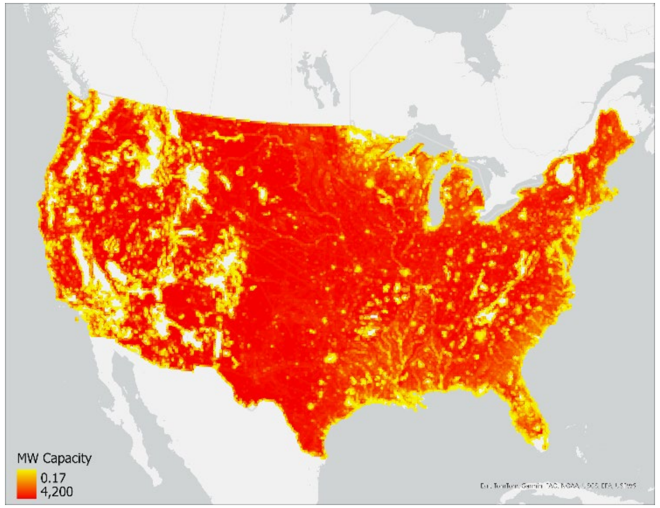


Source: The Nature Conservancy, Power of Place

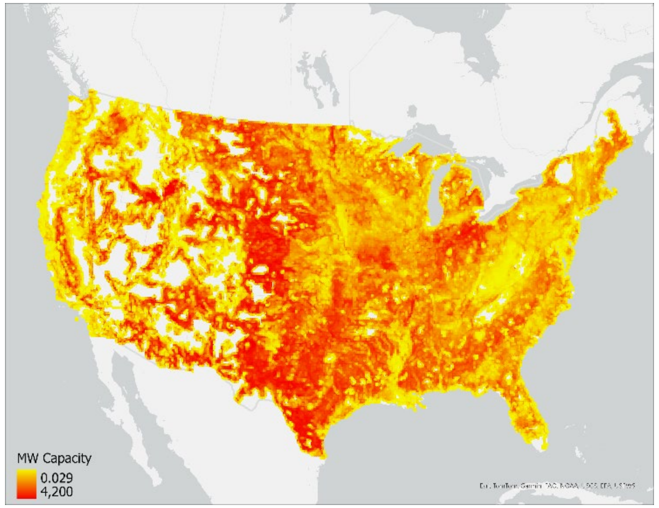
Land Use Analysis – NREL Data and Assumptions

- 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.

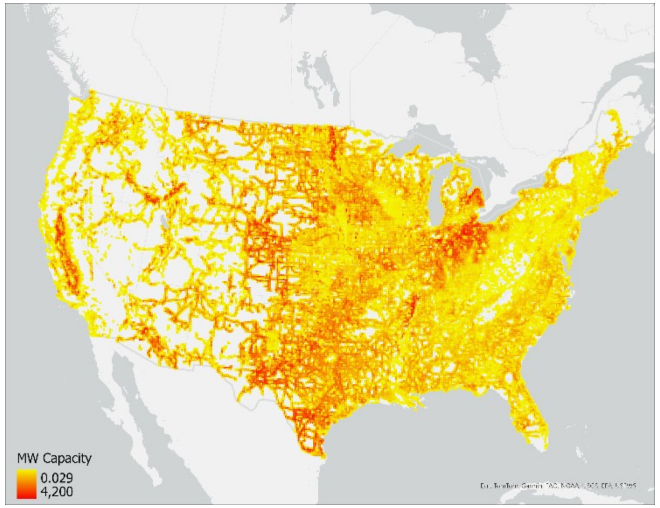
Solar Example



Open



Reference



Limited

Land Use Analysis – TNC Data and Assumptions

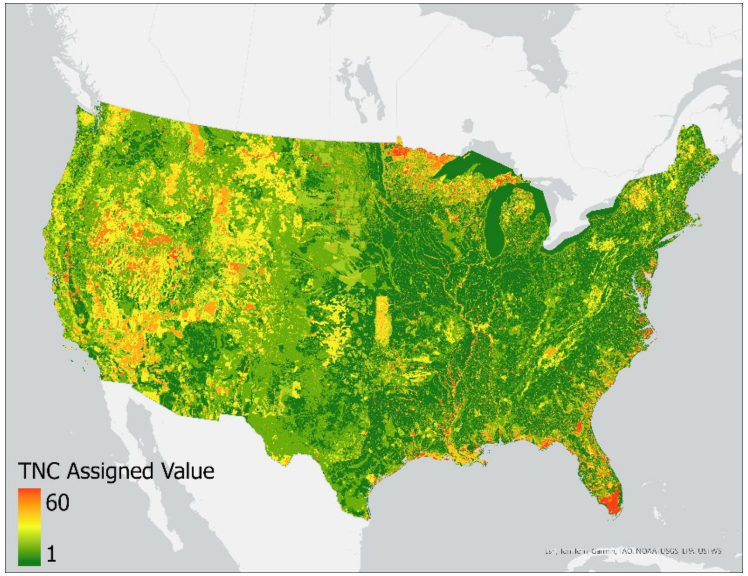
- The Social and Environmental data sets classify each 250x250 m^2 section of the country into a set of land classifications. These include the following (among other categories):

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

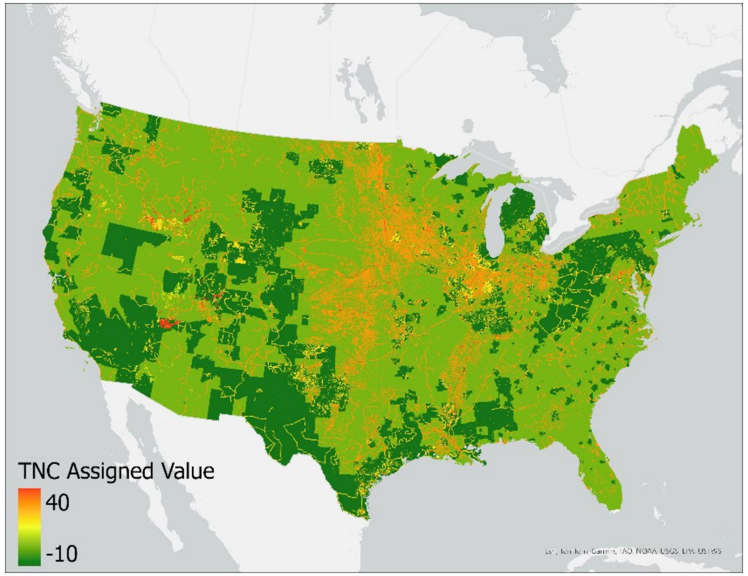
- Each category is assigned a certain value (so that the score for area that is both a wetland and an intact habitat equals the sum for both values). The aggregate values create the scale of impact shown. Low scores signify the best development sites, high scores reflect high impacts (least desirable).
- 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)

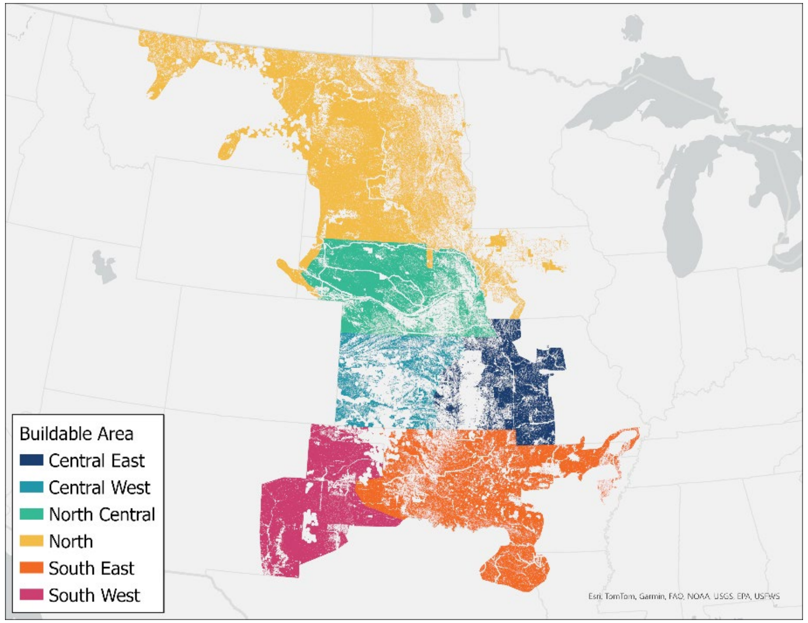
Environmental



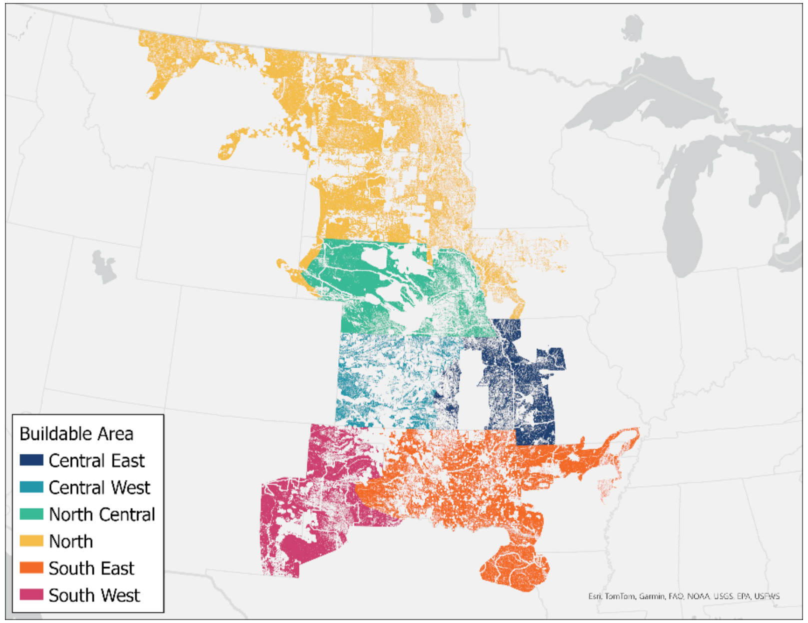
Social



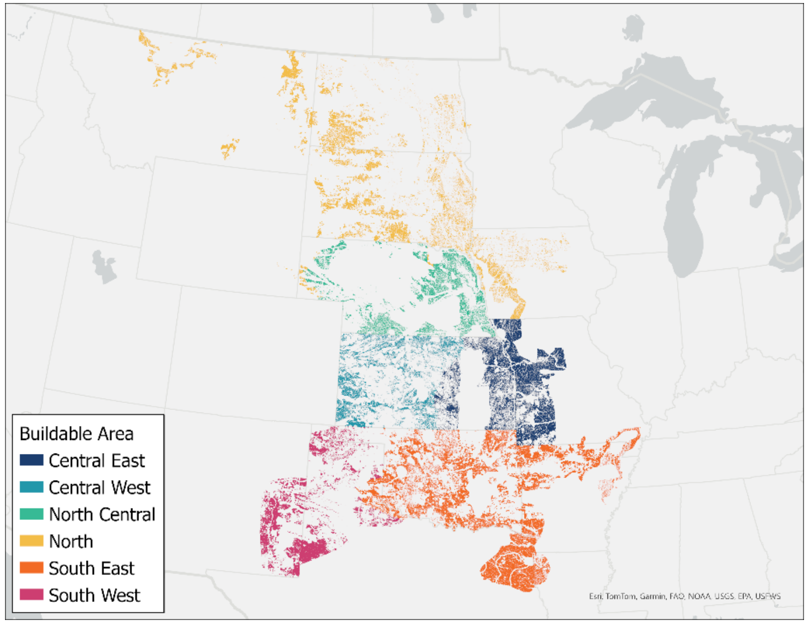
Land Use Analysis – TNC data for Solar PV



Environmental Score Threshold: 20
Social Score Threshold: 10



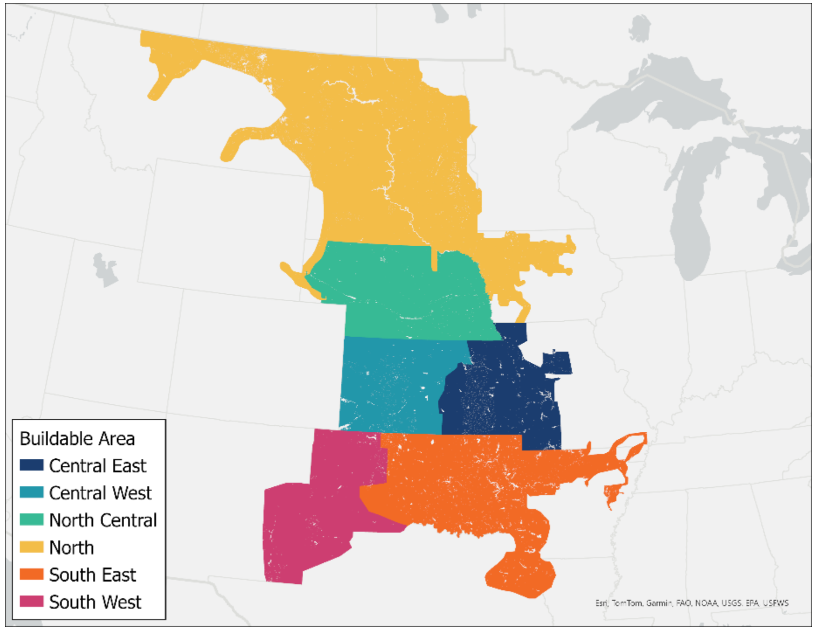
Environmental Score Threshold: 10
Social Score Threshold: 5



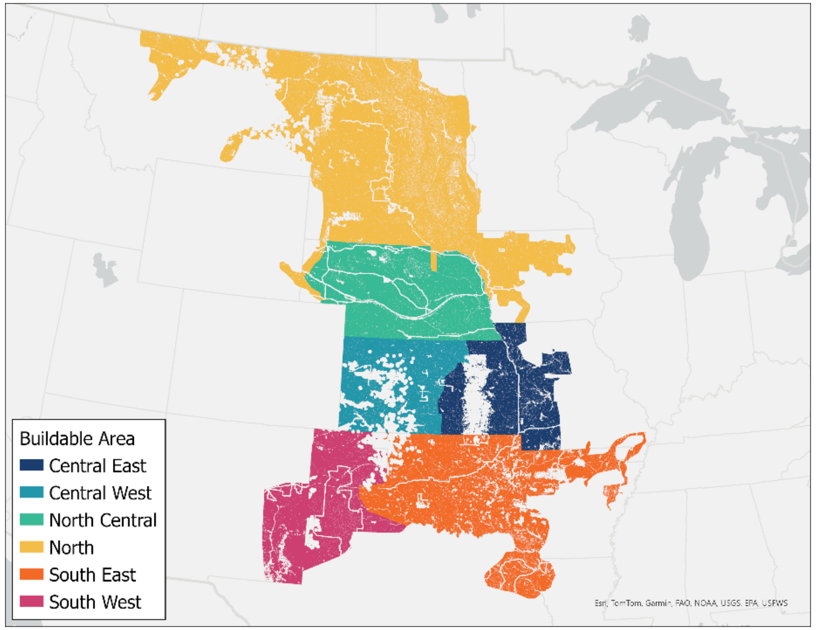
Environmental Score Threshold: 5
Social Score Threshold: 1

- We considered varying thresholds applied to the TNC land use scales to determine the amount of buildable land within SPP's footprint and within each FERNS zone.
- To be conservative in our analysis we continue with the most restrictive (lowest) thresholds to use as potential building areas.

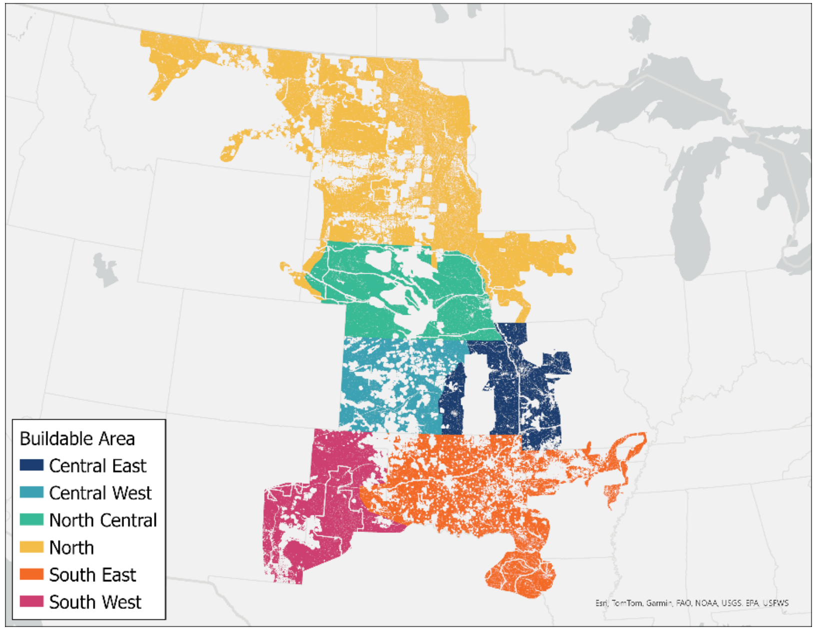
Land Use Analysis – TNC data for Wind



Environmental Score Threshold: 20
Social Score Threshold: 10



Environmental Score Threshold: 10
Social Score Threshold: 5

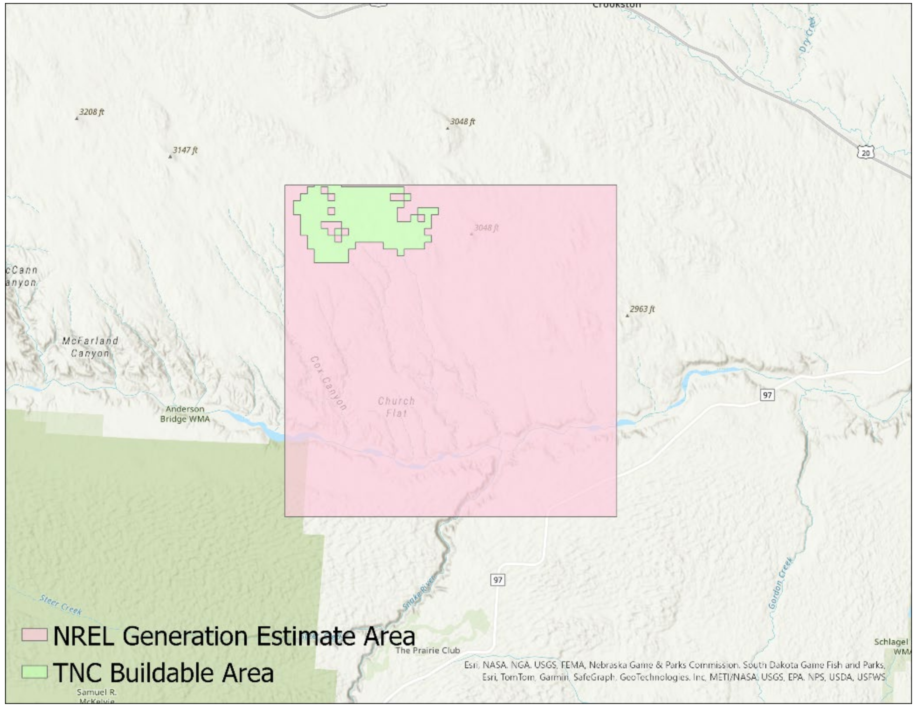


Environmental Score Threshold: 5
Social Score Threshold: 1

- Wind has a much more expansive footprint then solar PV, as shown by potential building areas above.

Land Use Analysis – MW Potential based on NREL and TNC data

1. Our land use analysis begins with considering TNC's data. We filter to areas of the country below the defined threshold for the environmental (10) and social (5) impact. This is the "buildable" (low impact) area
2. For each square of NREL's data, we consider the estimated MW of capacity as evenly distributed across the 33.2 km^2 and calculate the portion of that area that is determined to be "buildable" based on the TNC data
3. The portion of each NREL area that is considered "buildable" provides a percentage to multiply by the original MW estimate for the area
4. The resulting value is our TNC-adjusted NREL generation potential for a given area of the country
5. These estimated values are summed across the FERNS-modeled SPP zones in tables of the next slides

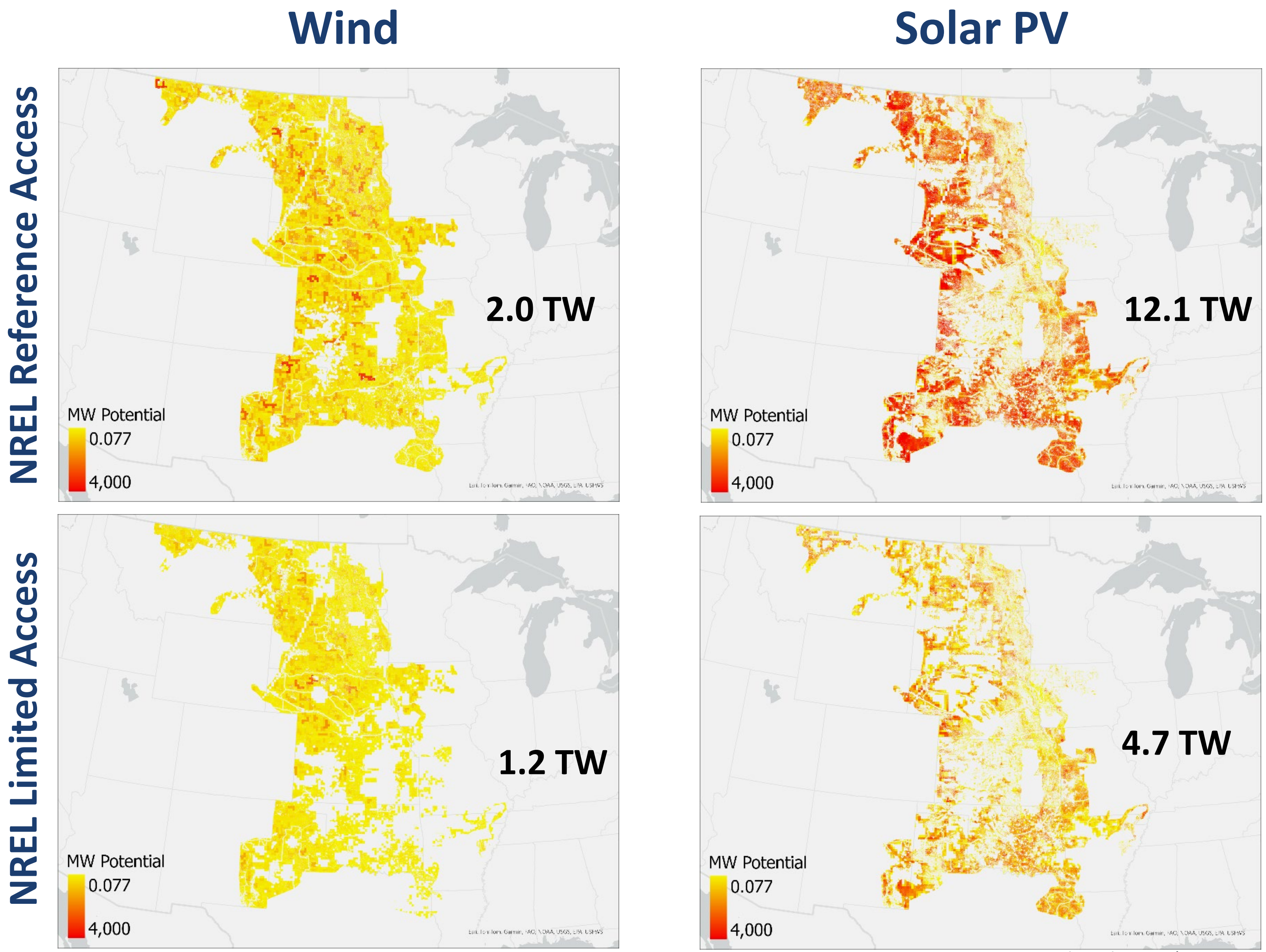


The area of the green shape divided by the area of the whole square is multiplied by the MW estimate for that area from NREL. The resulting MW estimate is considered the available generation potential for that area. TNC buildable area shown represents an environmental threshold of 10 and social threshold of 5.

Generation Potential within NREL+TNC Limited Areas

- The maps to the right show generation potential across the SPP footprint by using the “reference” and “limited” NREL datasets and removing TNC determined high-impact (>10/5*) areas.
- Across SPP, generation potential is estimated to range between 1.2 TW and 2.0 TW for wind and between 4.7 TW and 12.1 TW for solar.
- Estimates are conservative as they may duplicate removal of certain land exclusions.
  - E.g., Areas of Critical Environmental Concern (US Department of Interior) are excluded from both NREL and TNC data

* Maps show generation potential based on a TNC environmental threshold better than 10 and social threshold better than 5.



Generation Potential Results by FERNS Zone

- Total low-impact generation potential for each zone exceeds 264 GW (3.3 TW SPP wide) of solar and wind power, even in the most restrictive case shown
- These estimates consider all land within each zone and do not consider proximity to existing transmission or subs, which would impact the price and ease to install additional capacity.

Total GW of Generation Capacity by Zone

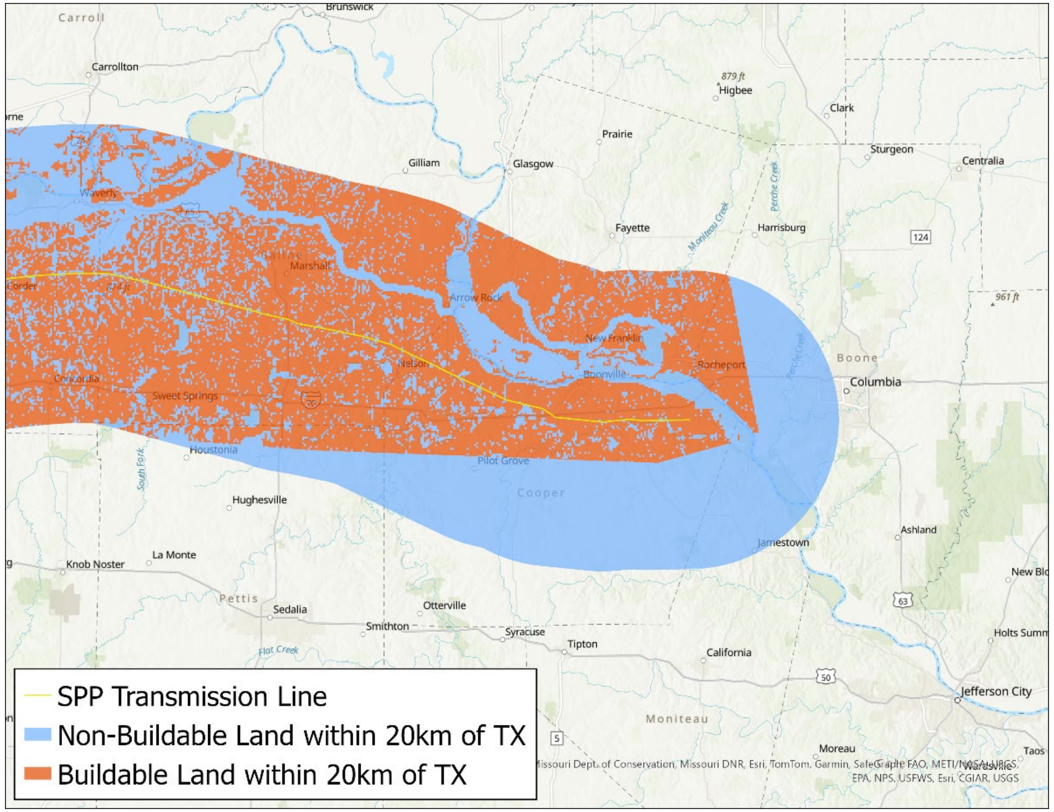
				TNC Scenario					
	Env: 20, Social: 10			Env: 10, Social: 5			Env: 5, Social: 1		
NREL Scenario	Wind	Solar	Total	Wind	Solar	Total	Wind	Solar	Total
Reference Case									
Central East	156	1,064	1,220	140	863	1,003	120	729	849
Central West	231	883	1,114	174	708	882	143	480	624
North	935	5,495	6,430	802	4,186	4,988	661	1,094	1,755
North Central	335	2,085	2,419	301	1,612	1,913	238	434	672
South East	385	3,466	3,851	321	2,945	3,266	261	1,892	2,153
South West	305	2,310	2,615	251	1,775	2,026	226	736	961
Total Reference Case	**2,347**	**15,303**	**17,650**	**1,989**	**12,089**	**14,078**	**1,649**	**5,365**	**7,014**
Limited Case									
Central East	36	528	565	32	430	462	27	374	401
Central West	107	320	426	94	268	362	75	188	264
North	676	1,999	2,675	576	1,562	2,138	468	457	925
North Central	234	710	945	211	553	764	167	194	361
South East	109	1,504	1,613	93	1,256	1,349	75	873	947
South West	197	850	1,047	172	652	824	160	285	445
Total Limited Case	**1,359**	**5,912**	**7,271**	**1,178**	**4,721**	**5,898**	**972**	**2,372**	**3,343**

We use the NREL Reference Case and TNC thresholds of 10 and 5 as our base case.

Land Use Analysis – Transmission Consideration for CPP

1. We take the output of our preceding steps as the input to this transmission network proximity analysis for possible use in the CPP
2. We use transmission of 230kV or above as a rough proxy for more attractive interconnection points
3. This initial (illustrative) analysis assumes that land within 20 kilometers of existing 230+kV transmission infrastructure provides the most attractive interconnection options
4. With the estimated generation potential from the previous step, we remove generation potential that is not within 20 kilometers of the identified transmission lines

We are looking for feedback from SPP staff and stakeholders how to best specify transmission proximity in this analysis



All Shaded areas are within 20 kilometers of transmission lines 230 kV or higher, with red denoting areas considered buildable by TNC and blue denoting other areas. Building area depicted above is representative of an environmental threshold of 10 and social threshold of 5.

Generation Potential within 20km of 230+kV Transmission

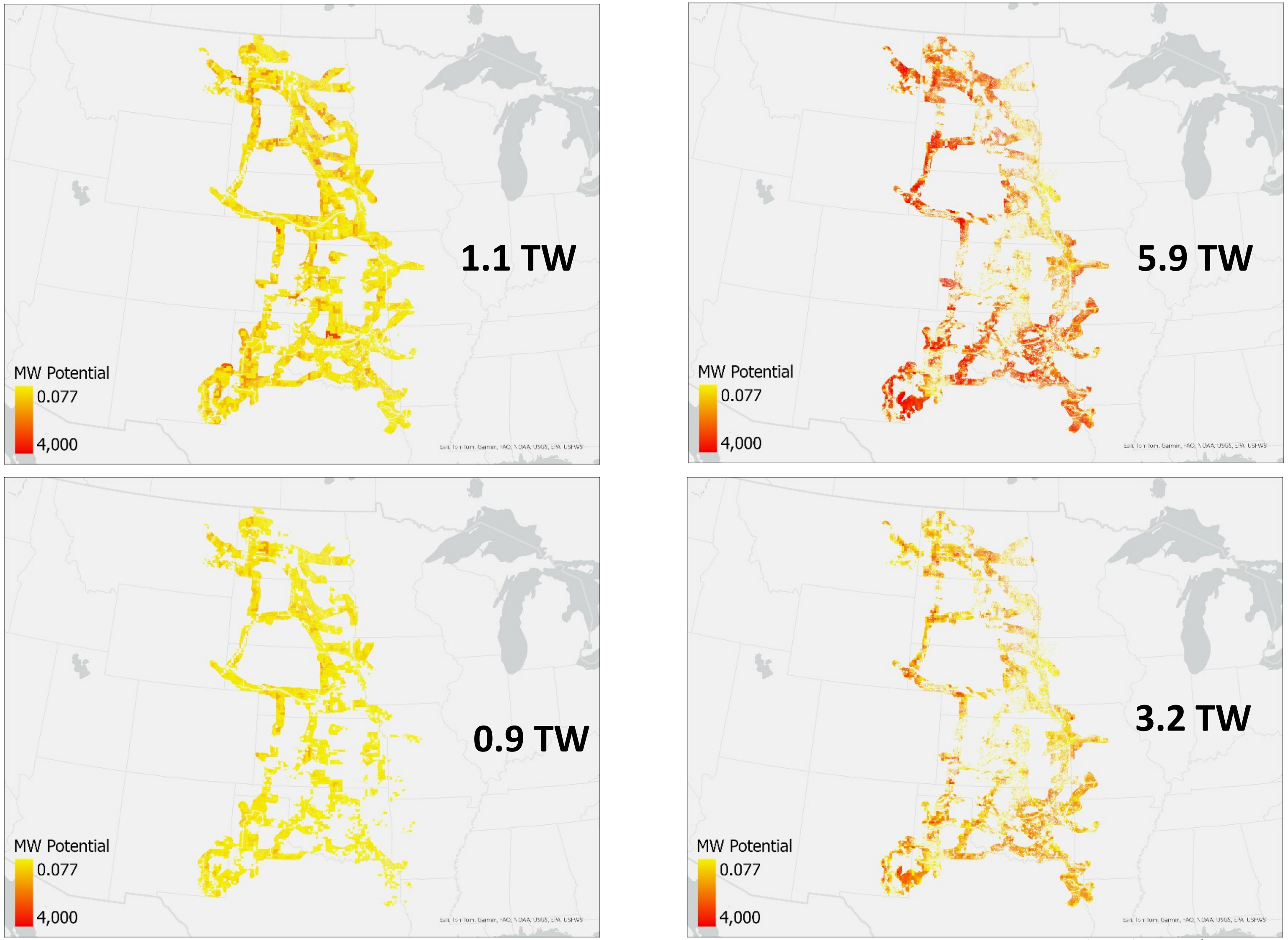
- The maps to the right show generation potential after removing sites farther than 20 km from existing transmission and are more restrictive versions of the previous maps
- Again, we show two NREL scenarios with the same TNC determined non-buildable areas removed
- Across SPP, generation potential is estimated to range between 0.9 GW and 1.1 TW for wind and between 3.2 TW and 5.9 TW for solar.
- Even when considering only low-impact land near infrastructure, ample amounts of generation potential exist!

Maps show generation potential for environmental threshold of <10 and social threshold <5.

Wind | **Solar PV**

NREL Reference Access

NREL Limited Access



Results by FERNS Zone – With Transmission Consideration

- After adjusting for low-impact land within 20 kM of 230+kV transmission, there is still at least 400 GW of solar and wind potential in each zone (6.8 TW for all of SPP)
- All FERNS capacity buildout scenarios will likely be well within these calculated low-impact potential estimates

Total GW of Generation Capacity by Zone and Proximity to Transmission

	Proximity to Transmission								
	10 KM			20 KM			30 KM		
SPP FERNS Zones	Wind	Solar	Total	Wind	Solar	Total	Wind	Solar	Total
Central East	52	301	354	82	483	566	101	613	714
Central West	45	180	225	81	327	408	109	431	540
North	193	1,144	1,337	317	1,832	2,149	402	2,258	2,660
North Central	73	308	381	121	509	631	158	687	845
South East	109	1,000	1,109	182	1,650	1,832	229	2,051	2,281
South West	96	681	777	150	1,085	1,235	185	1,330	1,515
Total SPP	**569**	**3,615**	**4,184**	**933**	**5,887**	**6,820**	**1,185**	**7,370**	**8,555**

For this table we use the NREL reference case for raw generation potential and TNC data filtered to below environmental values of <10 and social values of <5.

Appendix

ADDITIONAL CAPACITY EXPANSION ASSUMPTIONS

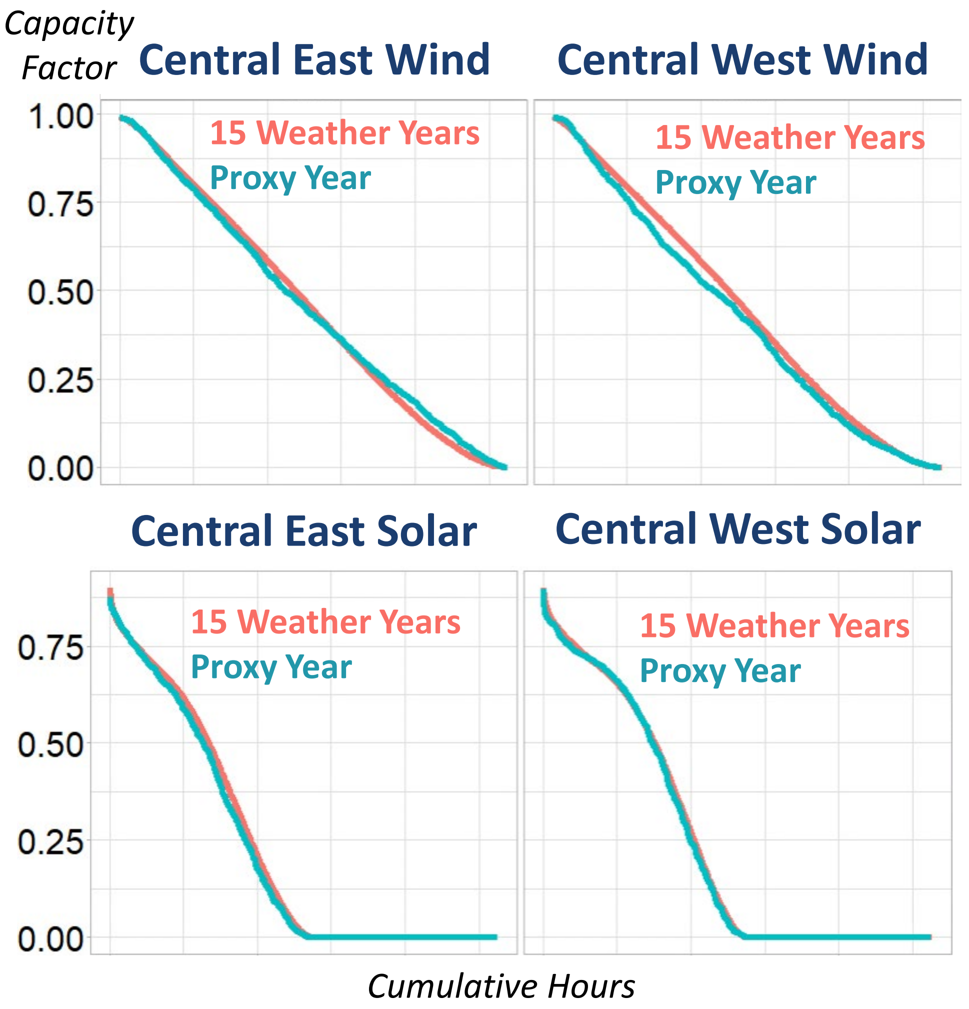
Summary of Modeling Inputs

Data Element	Description and Source Notes (may differ by year modeled)
Transmission Modeling Inputs	
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
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.
Demand-Side Modeling Inputs	
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
Supply-Side Modeling Inputs	
Existing Generator Data	SPP data (ITP 2025) for existing unit capacities, heat rates, and additional operational characteristics by region. Weather dependent thermal outages based on SERVM modeling and vary by weather year and zone
Scheduled Additions/Retirements (near term)	SPP data (ITP 2025) planning parameters reference case through 2034
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 prices from SPP IHS forecasts and other fuel prices consistent with ITP 2025 planning parameters
Market and Policy Inputs	
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 battery storage, assumed extended through study horizon

Renewable Resource Profiles

- 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)

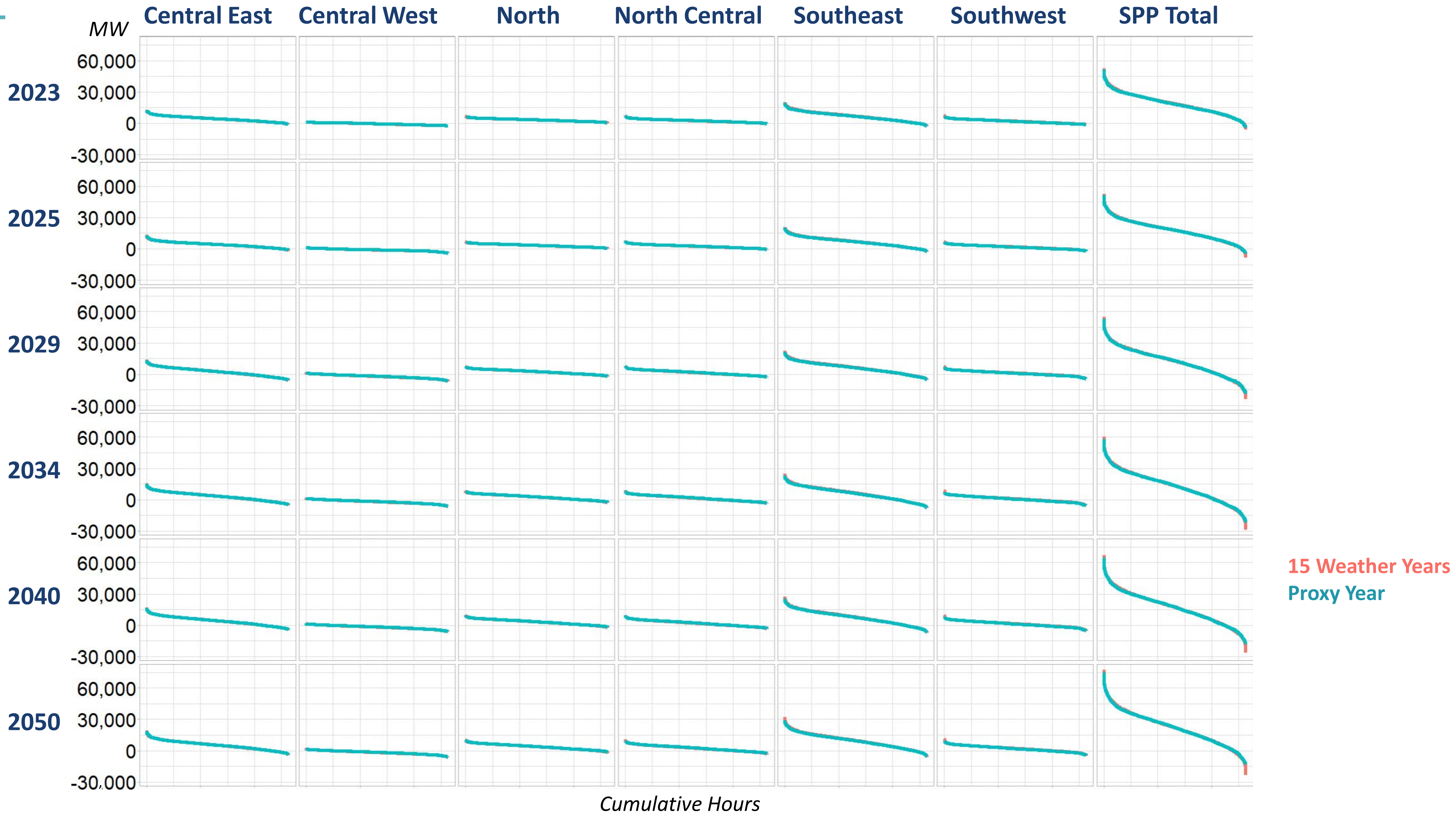
Example:
Wind & Solar in Central East and Central West



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

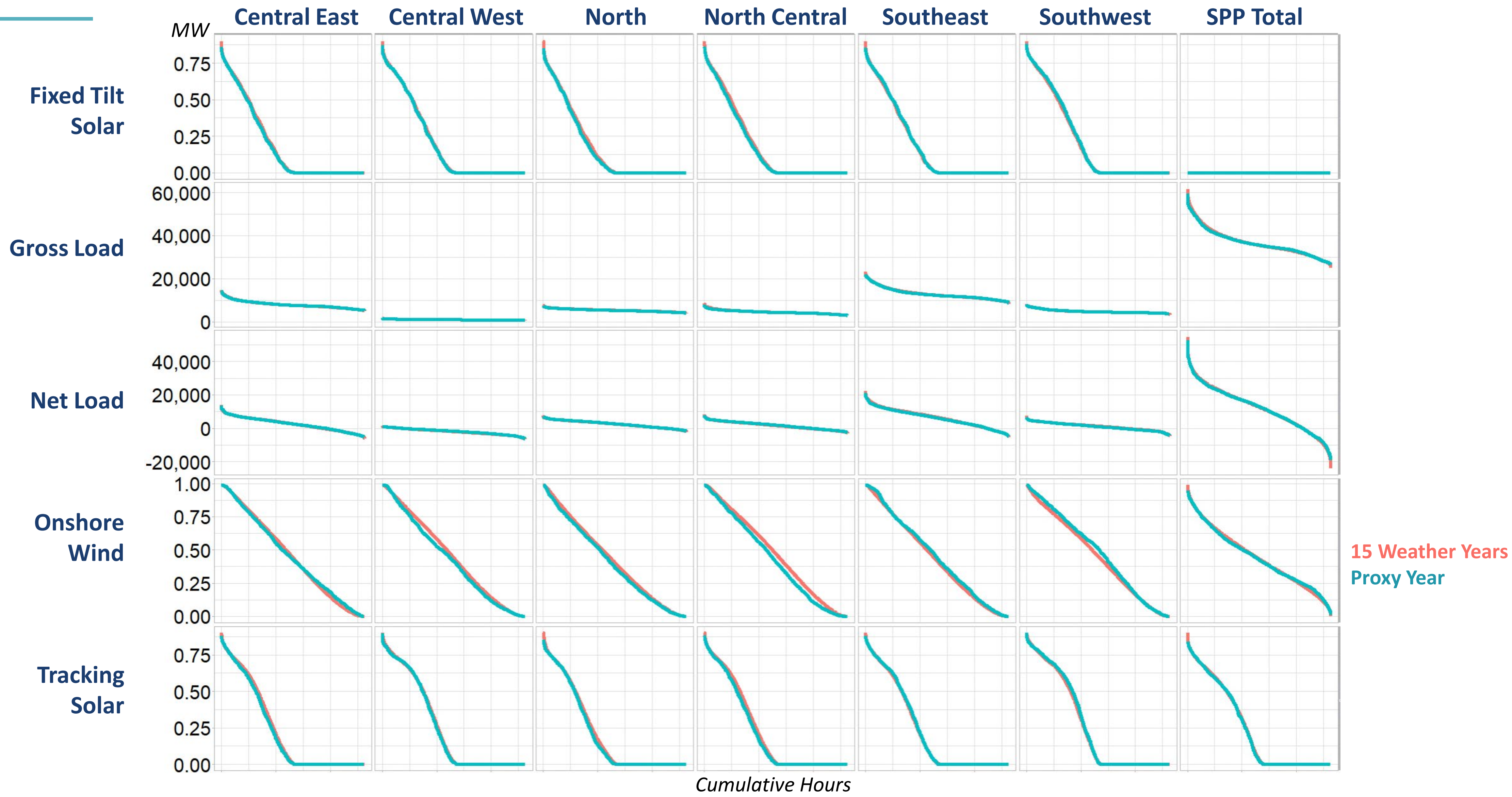
Preliminary draft.

2029 Medium Electrification Net Load: All Model Years



Preliminary draft.

2029 Medium Electrification: All Profiles

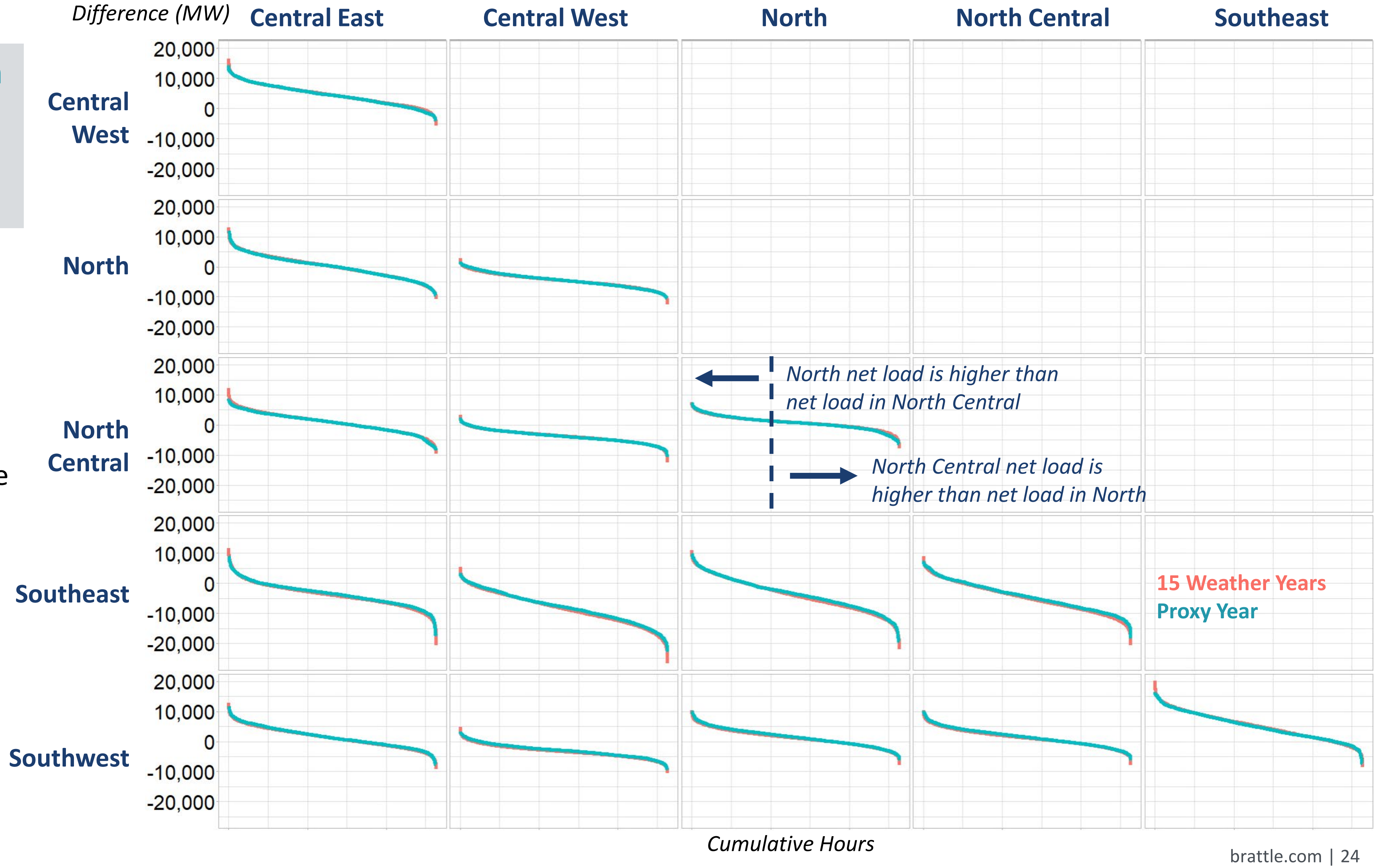


Note: Charts for renewables express hourly capacity factors on a scale of 0-1, as a fraction of installed capacity. Vertical axis scales differ across figures.

Capturing Geographic Diversity

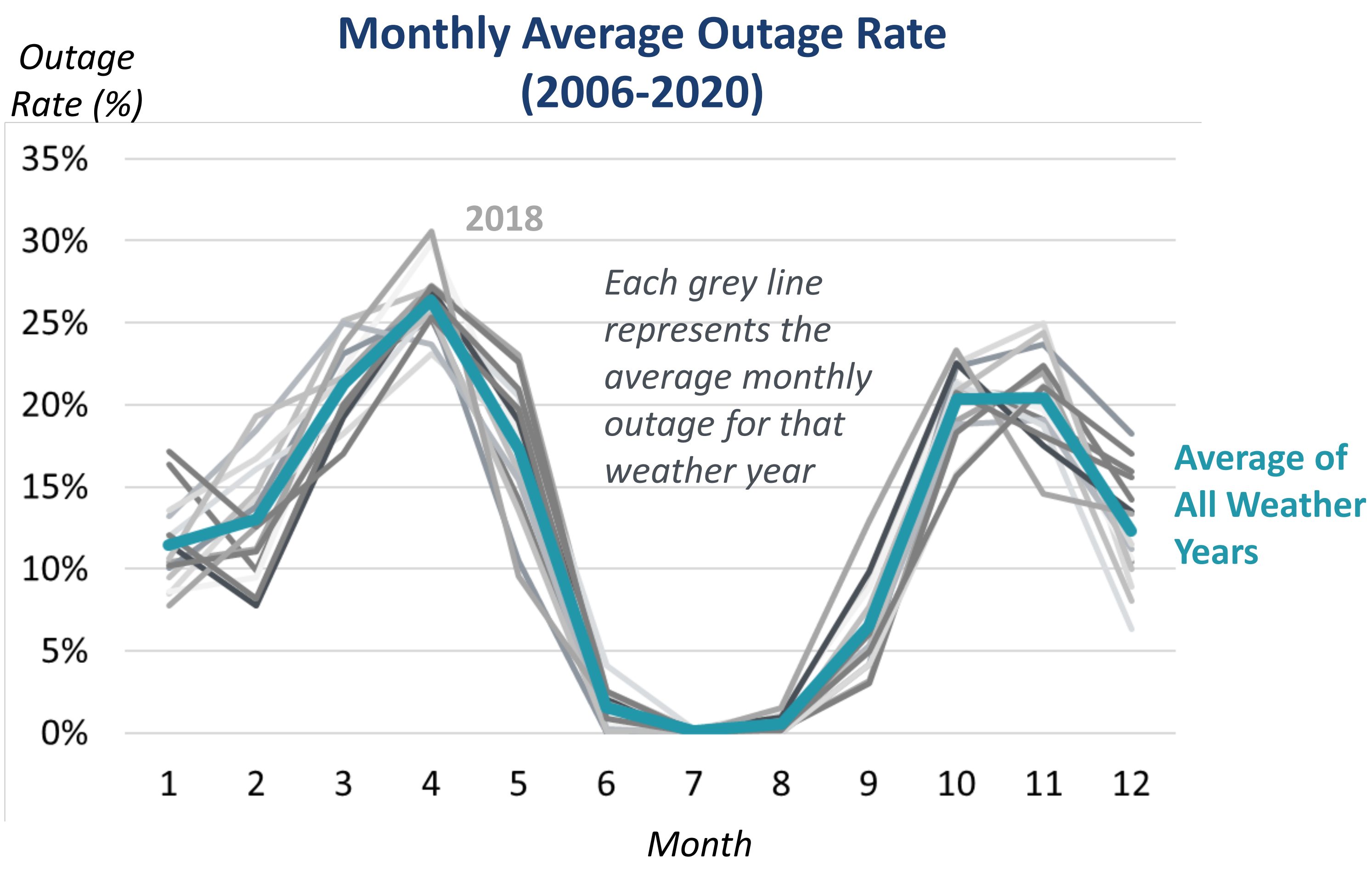
Difference between Column Region vs. Row Region
(2029 Medium Electrification, Net Load)

- 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's region



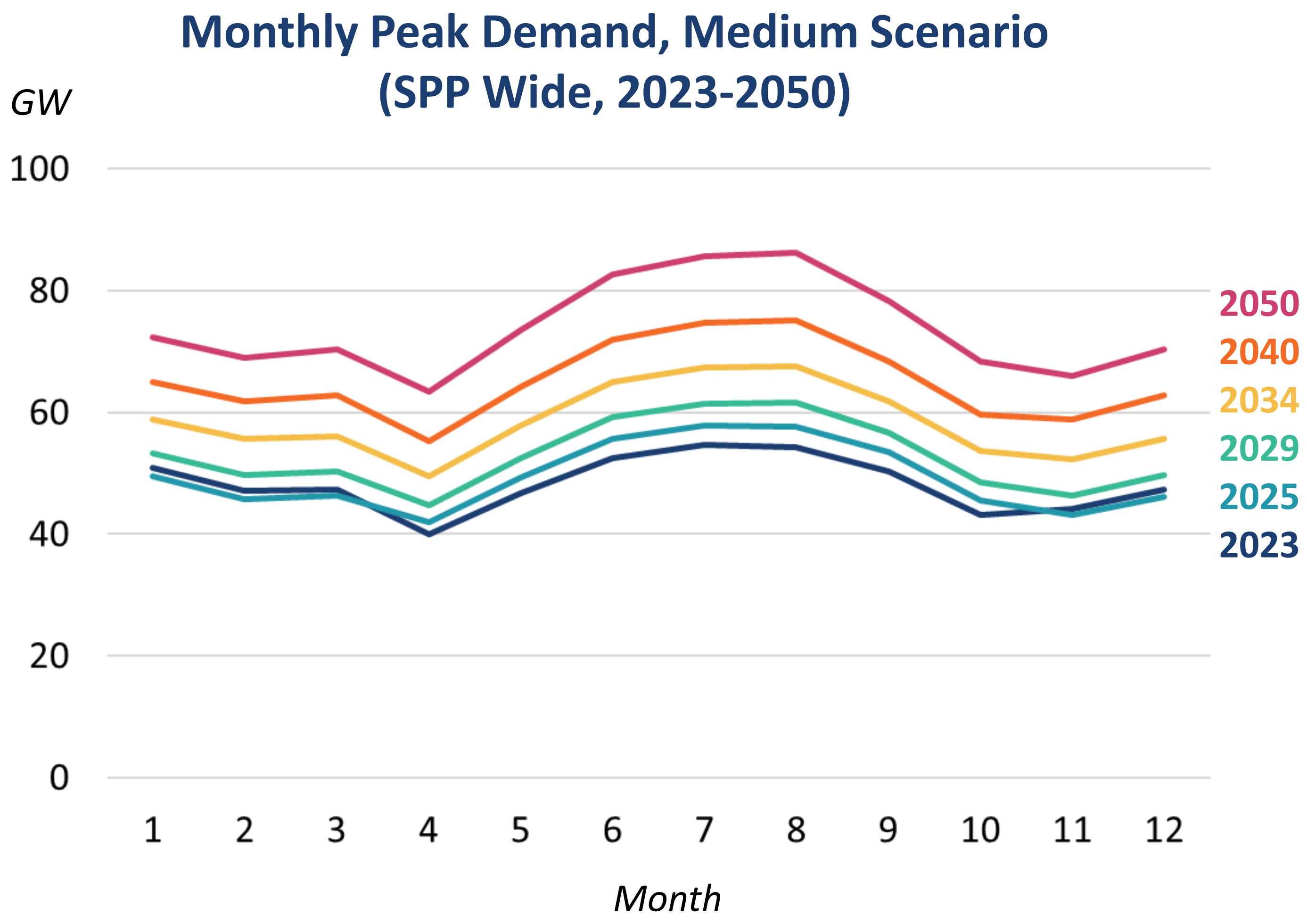
Planned & Maintenance Outages

- 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.

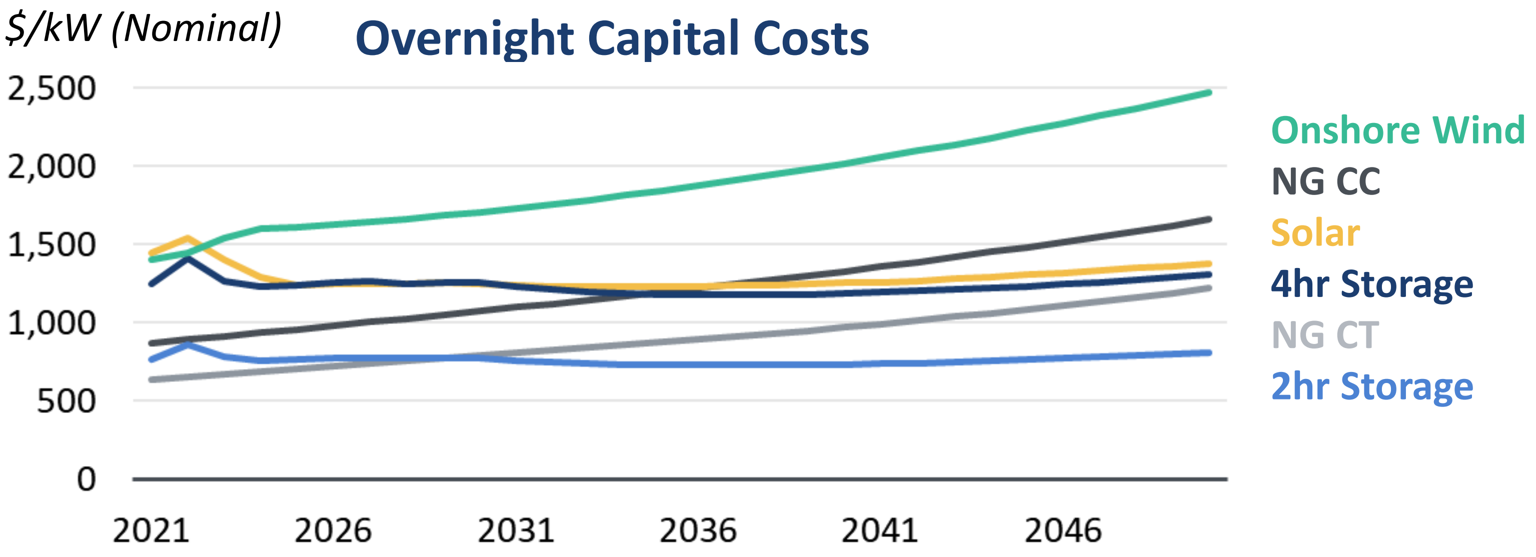
- Most planned outages occur during shoulder seasons leaving most capacity available during summer and winter months
- Based on forecasted load growth from EER, peak demand conditions will follow a similar monthly trend as today
- Planned outages could be scheduled in other months, if load conditions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

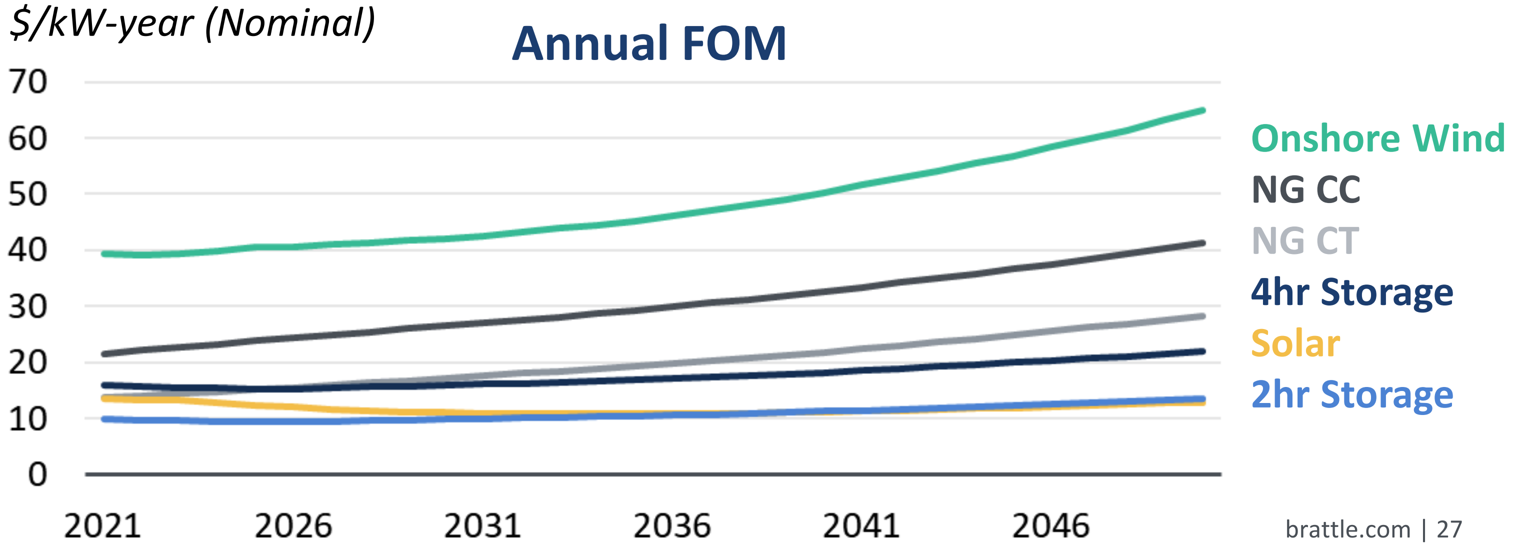


Note: Data shows the maximum monthly peak value based on all 15 weather years of data.

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

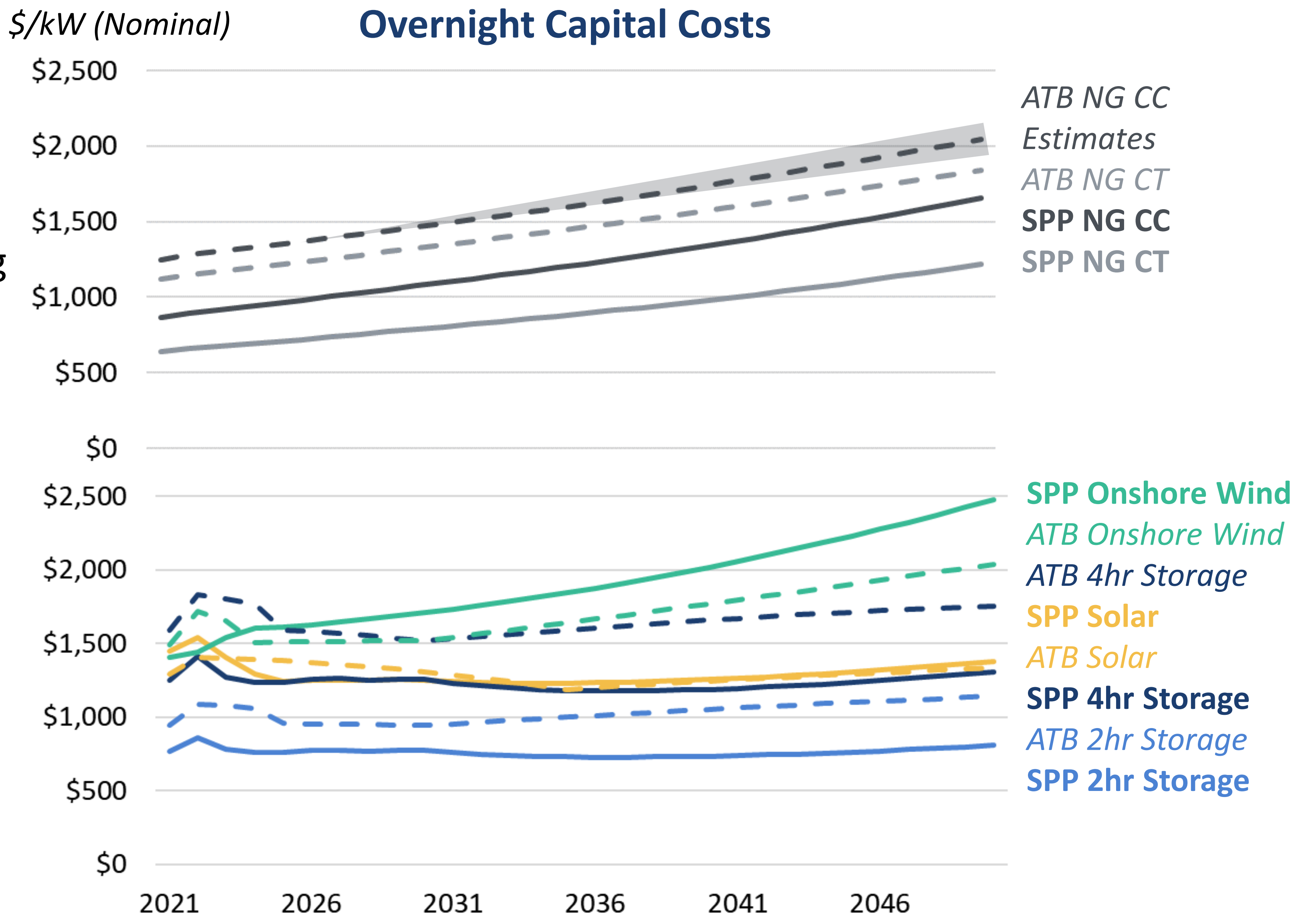




Note: Vertical axis scales differ across figures.

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.

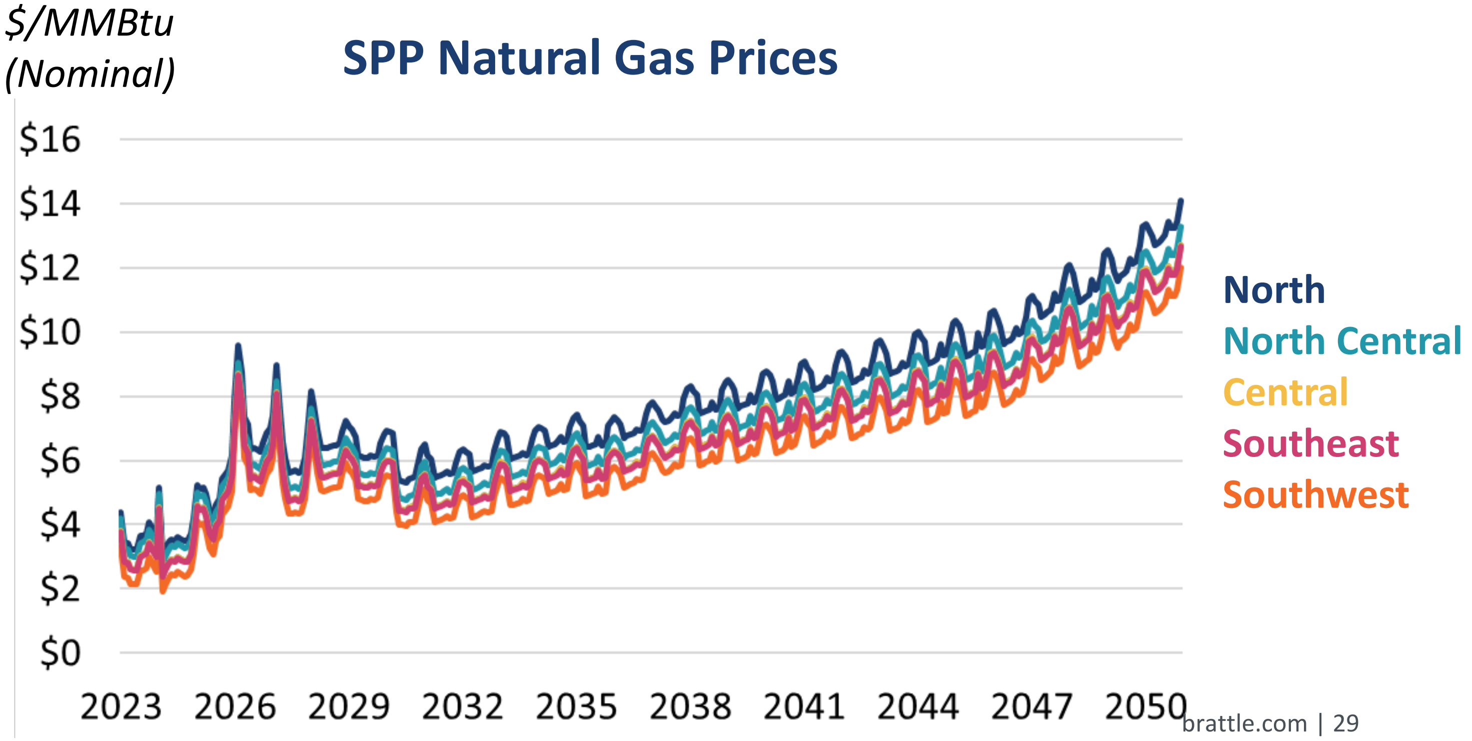
Natural Gas Prices

- 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

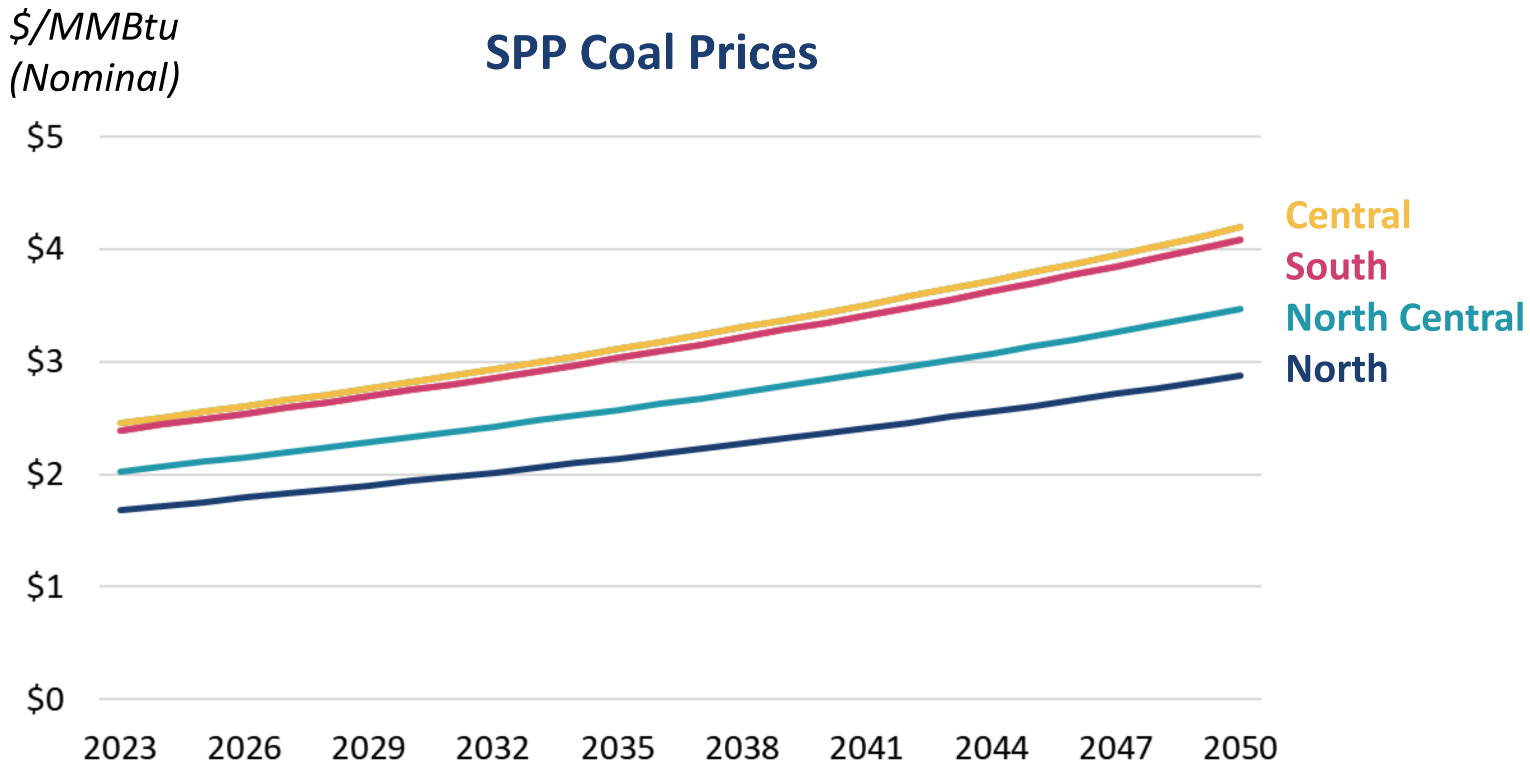
Zones	Gas Price Hubs
North	NG Dakotas
North Central	NG Nebraska
Central West	NG KSMO
Central East	NG KSMO
Southwest	NG West SPP
Southeast	NG Oklahoma

SPP Natural Gas Prices



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%