SPP Future Energy and Resource Needs Study (FERNS): Capacity Expansion Modeling Approach

SUMMARY FOR SPP STAKEHOLDERS

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Main Study Questions – FERNS Capacity Expansion Modeling

- What is the most cost effective future resource mix to meet system needs through 2050 under a range of electrification and carbon free generation pathways?
- 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?
- How could load management (e.g. through demand response) impact reliability and system costs in a high electrification future?

We will answer these questions by running GridSIM under the SPP-specified scenarios through 2050 for SPP and the surrounding areas.

The results from our expansion planning simulations can then be tested through SPP economic (nodal) and resource adequacy simulations.

Brattle has been coordinating with CPPTF, 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 efforts.

Scenario Specific Questions and Definitions

Additional study questions will be answered by modeling 5 core scenarios with varying levels of electrification and decarbonization, plus potential sensitivities

- What are the **resource adequacy and resilience** challenges in these scenarios? How can alternate resource adequacy frameworks impact the costs to procure a reliable resource mix? *(All)*
- How do the **future system costs** vary under different renewable generation shares and system electrification scenarios?
  - Under high renewable shares /high system electrification, as a high bookend? *(B3)*
  - Under moderate renewable shares and low system electrification, as a low bookend? *(A1)*
  - How do they rank between the bookends? *(A2, B1, B2)*
- How can **load management strategies** support reliability and mitigate system costs in highly electric and decarbonized future markets? *(B3 w/ sensitivity)*

Electrification and carbon-free resource shares will be pre-determined in each scenario

- Hourly demand will be consistent with the three FERNS Demand Electrification Modeling scenarios
- Carbon-free resource scenarios will be based on federal, state, and SPP member policies with “moderate” only including existing mandates and “high” also including new and aspirational goals

FERNS Study Scenarios

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

Source: FERNS scenario narrative

This study will focus on **three periods: 2020s, 2030s, and 2040s** to capture the non-linear system impacts of renewable development and electrification.

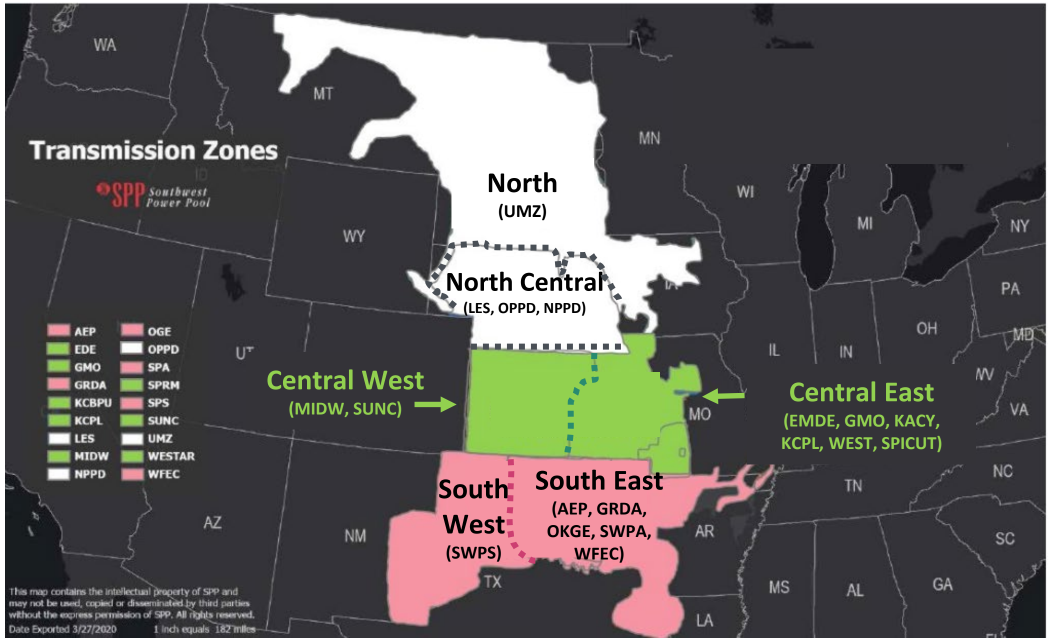
We will model select years through 2050, consistent with the FERNS low/moderate/high electrification load forecasts: 2023, 2025, 2029, 2034, 2040, 2050.

Zonal Topology and Transmission Limits

GridSIM uses a pipe-and-bubble representation of the SPP footprint, aggregating generators and loads into a multi-zonal energy model

- We propose to model 6 zones in SPP, consistent with the 2023 Draft LOLE zones, aggregated up from transmission pricing zones
  - North, North Central, Central East, Central West, Southeast, Southwest
  - The southern and central zones are split between east and west to capture congestion and transmission needs between the renewable-rich load-rich portion of these zones
- Zones allow us to capture congestion, which requires the definition of inter-zonal transmission limits, and (optional) expansion costs
  - SPP inter-zonal transmission limits from SPP 2023 LOLE study between each zone and the rest of SPP that define forward and reverse flow limits
  - We propose to allow the model to economically expand the transmission limits between zones (co-optimized with building resources within the zones to achieve lowest total costs)

Proposed Zones for FERNS Study

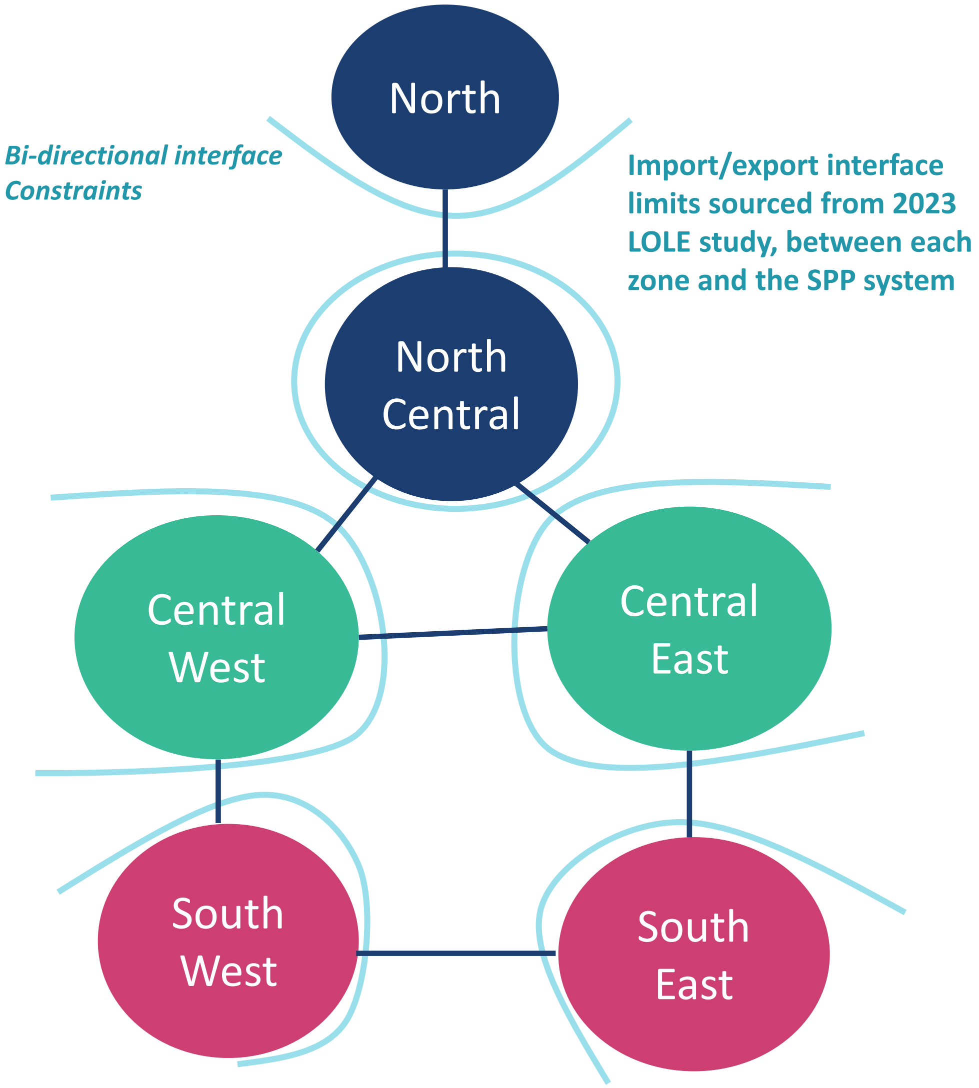


Base map source: SPP

Zonal Loads, Generation, and Internal Transmission Limits

- SPP load data from FERNS Demand Electrification Modeling scenarios for 15 weather years
- Existing generator data (Integrated Transmission Planning 2024) will be aggregated into the 6 zones shown at right
  - Will include already-planned generation additions and retirements (e.g., through 2030) as model input; model-based economic decisions after that
- 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
- Zonal import/export limits ones can be expanded based on proxy ($/MW) expansion costs
  - Expansion costs will be sourced from SPP transmission teams and public studies
- Renewable costs, generation profiles, and technical potential will vary by zone
  - Renewable profiles will be weather consistent with 15 years of load data and vary by zone, to capture renewable drought variability in SPP footprint
  - Increasing zonal transmission/interconnection costs at higher renewable shares will be sourced from SPP generation interconnection studies and modeled as increasing transmission cost adders to renewable generation supply curves

Modeled SPP Transmission Zones



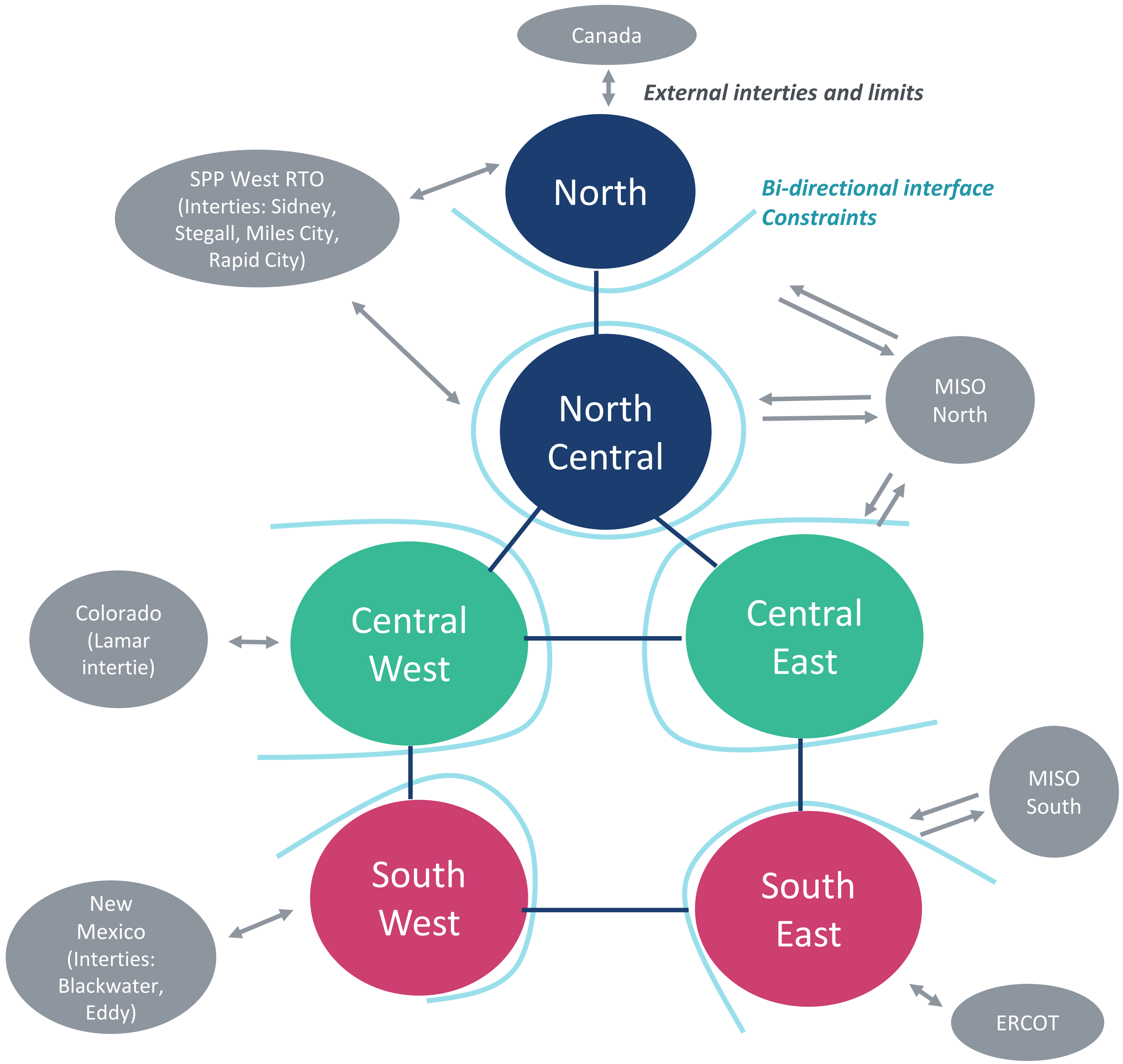
External Zonal Topology

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

- Intertie limits provided by SPP in import and export direction (possibly use pro-rata allocation to interconnected SPP zones)
- Each external zone will be modeled with simplified aggregate load and resources, but reflecting differences net-load variance to capture geographic diversity.
- Future expansions of external resource capacity and transmission capabilities will be an input assumption (i.e., not optimized by the model)
  - Load and resource mix to evolve consistent with FERNS scenarios, based on data from NREL studies (Cambium)

How do stakeholders anticipate the existing intertie capacities will increase?

SPP Zones and Interties to Neighboring Systems



Resource Adequacy Approach

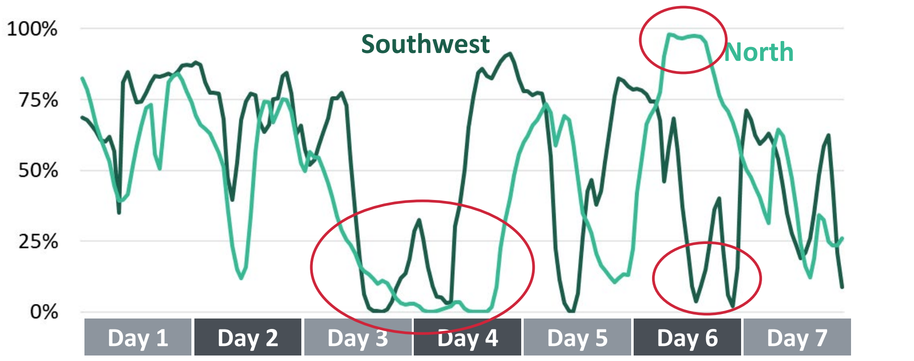
Conventional approach to considering resource adequacy in expansion modeling:

- 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

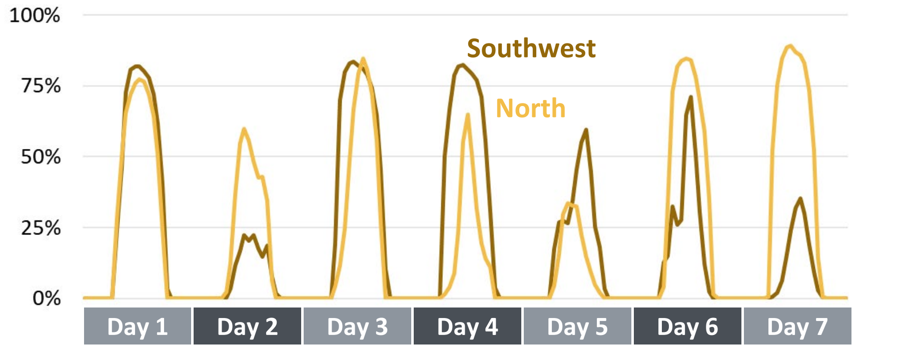
Proposed "dynamic" approach to resource adequacy

- 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 chose 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.

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, 2024) for existing unit capacities, heat rates, and additional operational characteristics by region
Scheduled Additions/Retirements (near term)	SPP data (ITP, 2024) or Velocity Suite, ABB Inc. and public announcements for near-term plant developments and retirements (capacity, location, date) to force into the model
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 (if available for use in FERNS study), otherwise will source from NREL Annual Technology; 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 sensitivities used in 2024 and 2025 ITP parameters (if available for use in FERNS study), otherwise will source from S&P Global and other public sources
	Market and Policy Inputs
Reserve Margin/RA framework	The conventional approach would be to mode 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

Appendix

GridSIM: Brattle's capacity expansion model

Basics

- **Optimization model** that minimizes system investment and operation costs, providing optimized power system build-out and dispatch for given scenario conditions
- **Co-optimized** modeling and pricing of energy and RA markets (with endogenous inter-zonal transmission optimization)
- **Zonal representation of SPP system**, transmission limits, and resource adequacy constraints mimic power systems and markets
- **Chronological commitment and dispatch** to model storage and demand response; representative days with hourly detail, including option to include multiple days with challenging system conditions (heatwaves, coldsnap, renewable drought).
- **Models any applicable decarbonization policies** in a variety of ways, via clean energy goals requirements, technology mandates, and/or carbon prices

Outputs

- **Least-cost capacity expansion, retirement, and dispatch** to meet demand for energy/capacity subject to environmental and transmission constraints
- **System costs**
- **Market prices for energy, RA, emissions, etc.**
- **Emissions**
- **Resource adequacy information**

Brattle "owning of the code" *enables great flexibility for tuning the model to the needs of each study and market (market design, constraint specifications, algorithms, input structures, output content, etc.)*

GridSIM Inputs, Optimization and Constraints, and Outputs

INPUTS

Supply
- Existing resources
- Fuel prices
- Investment/fixed costs
- Variable costs

Demand
- Representative days (hourly chronology)
- Capacity needs

Transmission
- Zonal limits
- Intertie limits (and expansion costs)

Regulations, Policies, Market Design
- Capacity market
- Carbon pricing
- State energy policies and procurement mandates

GridSIM OPTIMIZATION ENGINE

Objective Function
- Minimize NPV of Investment & Operational Costs

Constraints
- Market Design and Co-Optimized Operations
  - Capacity
  - Energy
- Regulatory & Policy Constraints
- Resource Operational Constraints
- Transmission Constraints

OUTPUTS

Annual Investments and Retirements (optional transmission expansion)

Hourly Operations

Market Shadow Prices (Energy and resource adequacy)

Emissions and Clean Energy Additions