Co-optimization Techniques & Results:
Generation & Transmission Planning

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Vibrant Clean Energy, LLC

Energy Systems Integration Group

Spring Technical Workshop: Virtual

April 6th, 2021

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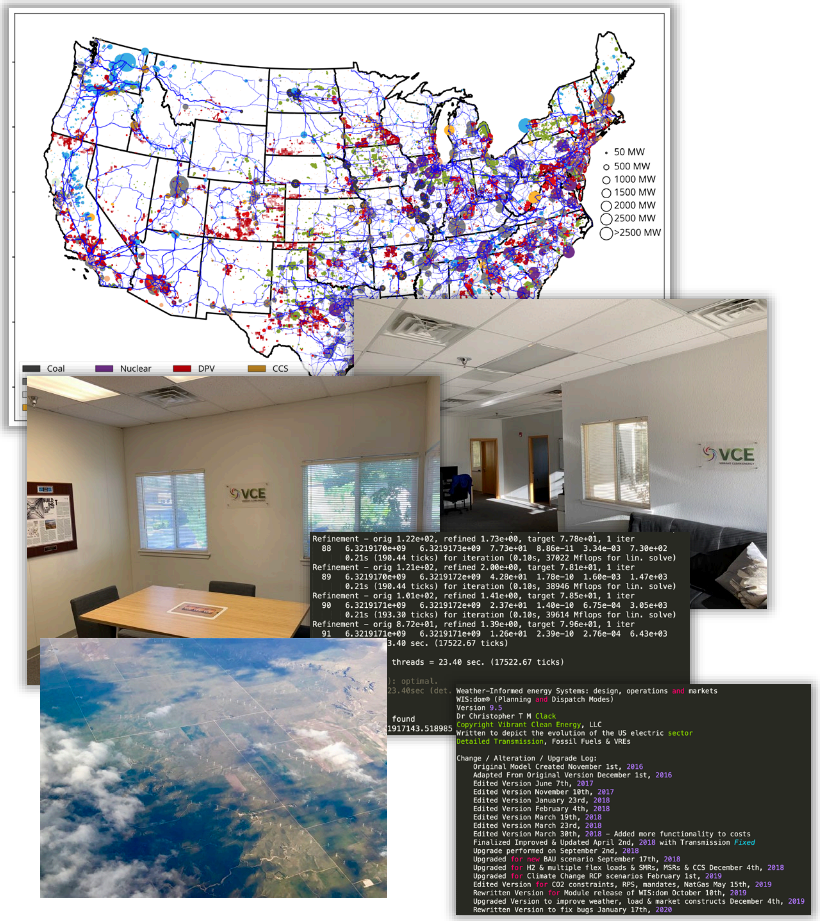

Purpose of Vibrant Clean Energy, LLC:

- Reduce the cost of electricity and help evolve economies to near zero emissions;
- Co-optimize transmission, generation, storage, and distributed resources;
- Increase the understanding of how Variable Generation impacts and alters the electricity grid and model it more accurately;
- Agnostically determine the least-cost portfolio of generation that will remove emissions from the economy;
- Determine the optimal mix of VG and other resources for efficient energy sectors;
- Help direct the transition of heating and transportation to electrification;
- ***License WIS:dom® optimization model and/or perform studies using the model;***
- Ensure profits for energy companies with a modernized grid;
- Assist clients unlock and understand the potential of high VRE scenarios, as well as zero emission pathways.

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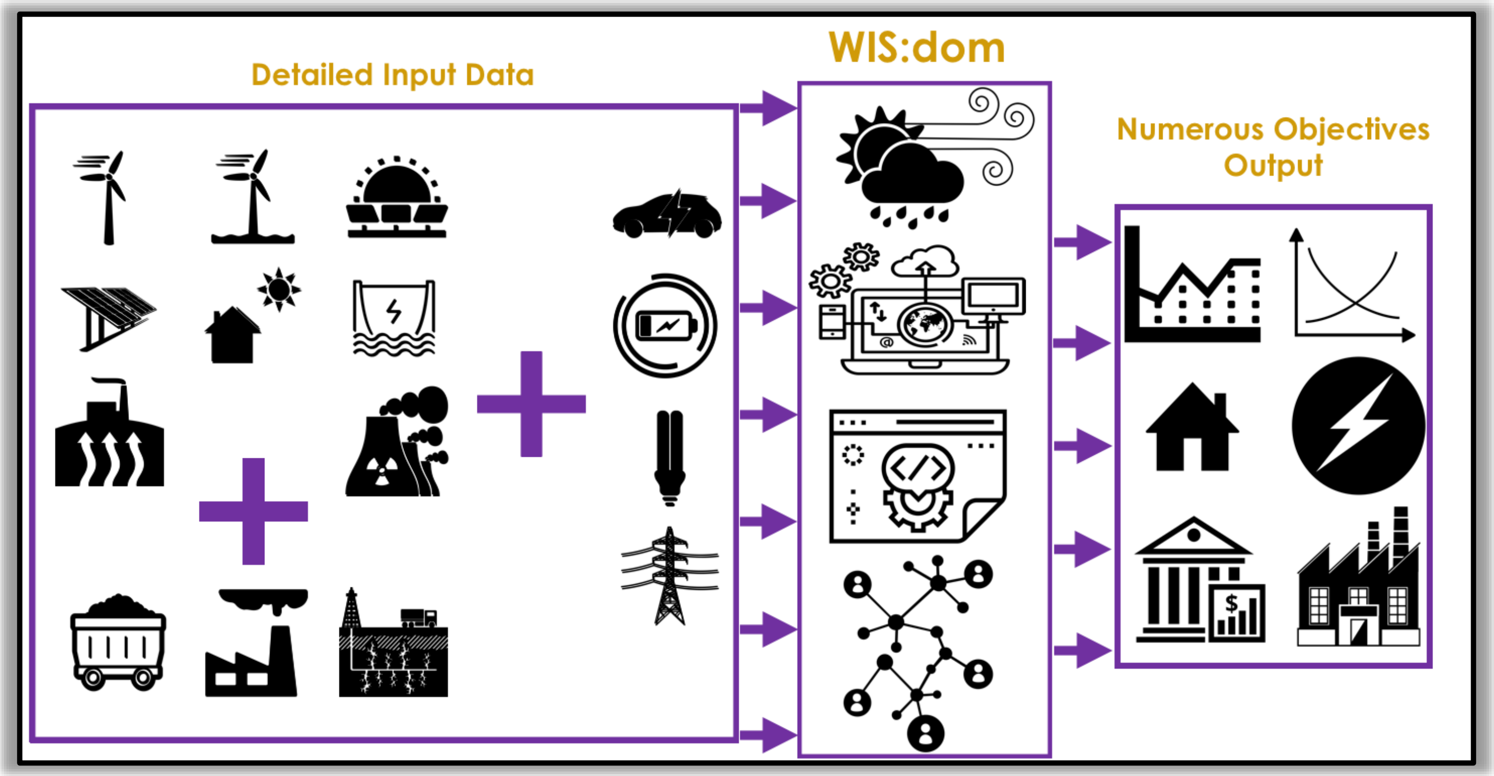
Techniques & Data

Co-optimization for Reliable, Robust, and Resilient Grid

To do this in the way we wanted we created a new model: WIS:dom®-P

- ***Capacity expansion includes:***
  - ✓ Continental-scale (globally capable) & spatially-determined;
  - ✓ Co-optimization of transmission, generation, storage and distributed resources;
  - ✓ ***Myopically perform investment periods from 2020 through 2050 (in five year periods);***
  - ✓ Transmission resolved at each 69-kV substation;
  - ✓ ***Generation siting resolved at 3-km spatial resolution;***
  - ✓ Existing policies, restrictions and incentives;
  - ✓ Detailed land-use screening for siting of technologies;
  - ✓ Future cost projections for technologies and fuels;
  - ✓ Detail accounting for retirement of generation assets;
  - ✓ Includes climate change data from CMIP-5 for possible future drivers of infrastructure stress;
- ***Production cost includes:***
  - ✓ Unit commitment;
  - ✓ Start-up & shutdown profiles of generators;
  - ✓ Ramp constraints, minimum up and minimum down times;
  - ✓ Transmission power flow, transmission dynamic line ratings, and transmission line losses;
  - ✓ Planning reserve margins and operating reserves, with detailed VRE accounting;
  - ✓ ***Distribution planning & hybrid optimization of the grid edge;***
  - ✓ Weather forecasting and physics of weather engines for resources and demands;
  - ✓ ***5-minutely temporal granularity***;
  - ✓ Zero loss of load at any time or location;
  - ✓ Detailed energy storage dispatch subroutines for arbitrage & transmission asset configurations;
  - ✓ ***Demand flexibility modeling based on granular weather drivers;***
  - ✓ Novel technology inclusion and integration (SMR, MSR, EGS, CCS, DAC, H_2, NH_3, CH_4, P2X);
  - ✓ Existing generator and transmission asset characteristics such as heat rates, power factor, variable costs, fixed costs, capital costs, ramp rate constraints, minimum up and down time, undepreciated value, fuel supply chain, and fuel costs.

Co-optimization for Reliable, Robust, and Resilient Grid



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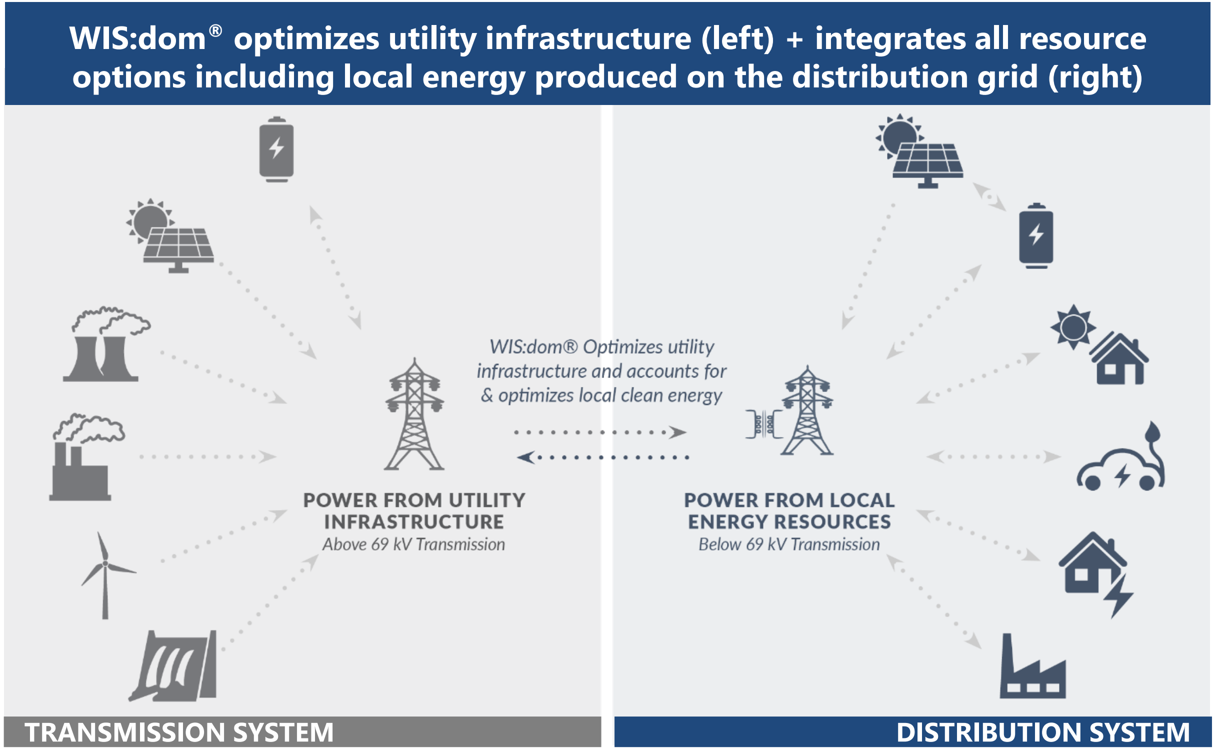
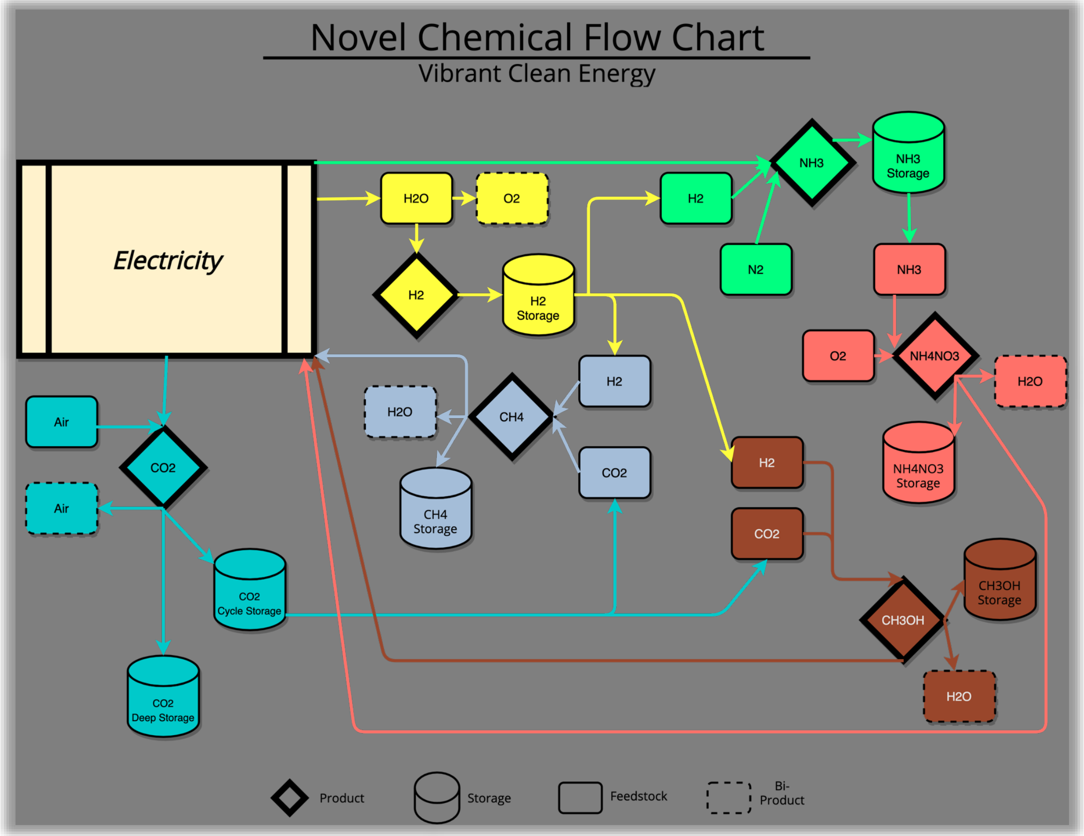
Co-optimization for Reliable, Robust, and Resilient Grid



Co-optimization for Reliable, Robust, and Resilient Grid



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Co-optimization for Reliable, Robust, and Resilient Grid

Equation (3.1) is the mathematical formulation of the objective function:

$$
\Gamma = \min \sum_{\mathcal{L}} \left\{ \begin{aligned}
&\sum_{\mathcal{T}} \left\{ \mathcal{C}^{\mathcal{G}}_{\mathcal{T}\mathcal{L}} \cdot x_{\mathcal{T}\mathcal{L}} + h \cdot \sum_{t} \left[\left(\mathcal{V}^{\mathcal{G}}_{\mathcal{T}\mathcal{L}t} + \left(\mathcal{F}^{\mathcal{G}}_{\mathcal{T}\mathcal{L}t} + \mathcal{V}^{c}_{\mathcal{L}} \cdot \mathfrak{F}_{\mathcal{T}\mathcal{L}} \right) \cdot \mathcal{H}^{\mathcal{G}}_{\mathcal{T}\mathcal{L}t} \right) \cdot p_{\mathcal{T}\mathcal{L}t} + \Delta \cdot \left(\mathcal{V}^{\mathcal{O}}_{\mathcal{T}\mathcal{L}t} \cdot o_{\mathcal{T}\mathcal{L}t} \right) \right] \right\} + h \cdot \sum_{t} \left(\mathcal{V}^{\mathcal{I}}_{\mathcal{L}t} \cdot \mathcal{I}_{\mathcal{L}t} \right) \\
&+ \sum_{\eta} \left[\sum_{\alpha} \left(\mathcal{C}^{\mathcal{S}}_{\alpha\eta\mathcal{L}} \cdot y_{\alpha\eta\mathcal{L}} \right) + h \cdot \sum_{t} \left(\mathcal{V}^{\mathcal{S}}_{\eta\mathcal{L}t} \cdot \mathfrak{D}_{\eta\mathcal{L}t} \right) \right] + \sum_{\mathfrak{B}} \left\{ \begin{aligned} &\sum_{\hat{\mathcal{L}}} \left[\frac{\mathcal{C}^{tr}_{\mathfrak{B}\mathcal{L}\hat{\mathcal{L}}} \cdot \mathcal{R}^{tr}_{\mathfrak{B}\mathcal{L}\hat{\mathcal{L}}} \cdot \mathcal{Q}^{tr}_{\mathfrak{B}\mathcal{L}\hat{\mathcal{L}}} \cdot z^{tr}_{\mathfrak{B}\mathcal{L}\hat{\mathcal{L}}}}{2} + h \cdot \sum_{t} \left(\mathcal{V}^{w}_{\mathfrak{B}\mathcal{L}\hat{\mathcal{L}}t} \cdot f_{\mathfrak{B}\mathcal{L}\hat{\mathcal{L}}t} \right) \right] \\ &\quad + \sum_{\beta} \left(\mathcal{C}^{\mathcal{N}}_{\mathfrak{B}\mathcal{L}\beta} \cdot n_{\mathfrak{B}\mathcal{L}\beta} \right) + h \cdot \sum_{t} \left(\mathcal{V}^{\mathcal{N}}_{\mathfrak{B}\mathcal{L}t} \cdot u_{\mathfrak{B}\mathcal{L}t} \right) \end{aligned} \right\} \\
&+ h \cdot \sum_{\mathfrak{D}} \sum_{t} \left(\mathcal{V}^{\mathfrak{D}}_{\mathfrak{D}\mathcal{L}t} \cdot r^{-}_{\mathfrak{D}\mathcal{L}t} \right) + \sum_{t} \left(h \cdot \mathcal{V}^{\mathcal{K}}_{\mathcal{L}t} \cdot \mathcal{W}_{\mathcal{L}t} + \mathcal{V}^{\mathcal{R}}_{\mathcal{L}t} \cdot q_{\mathcal{L}t} \right) + \Theta \cdot \left(\sum_{\mathcal{T}} \left(\mathcal{C}^{\mathcal{G}o}_{\mathcal{T}\mathcal{L}} \cdot x^{o}_{\mathcal{T}\mathcal{L}} + \mathcal{C}^{\mathcal{G}r}_{\mathcal{T}\mathcal{L}} \cdot x^{r}_{\mathcal{T}\mathcal{L}} \right) + \mathfrak{R}_{\mathcal{L}} \right) \\
&+ \Lambda \cdot \left\{ \mathcal{C}^{dp}_{\mathcal{L}} \cdot \left[\mathcal{E}^{p}_{\mathcal{L}} + \lambda_a \cdot \left(\mathcal{E}^{b}_{\mathcal{L}} + \mathcal{E}^{m}_{\mathcal{L}} \right) \right] + h \cdot \mathcal{C}^{de}_{\mathcal{L}} \cdot \sum_{t} \left(\mathcal{E}_{\mathcal{L}t} - \lambda_b \cdot \mathcal{I}_{\mathcal{L}t} \right) \right\}
\end{aligned} \right\} \tag{3.1}
$$

Due to scale we model compactifying variables is essential to solve the problem in a reasonable clock time!

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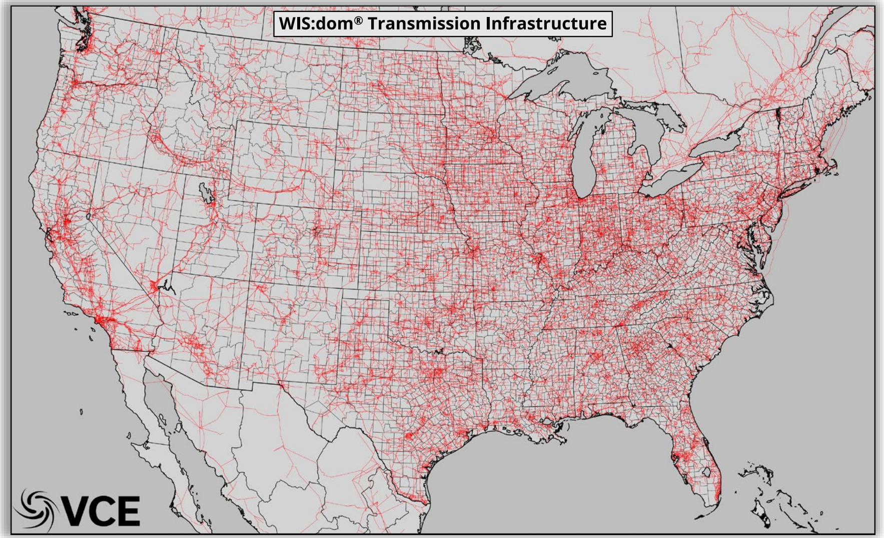
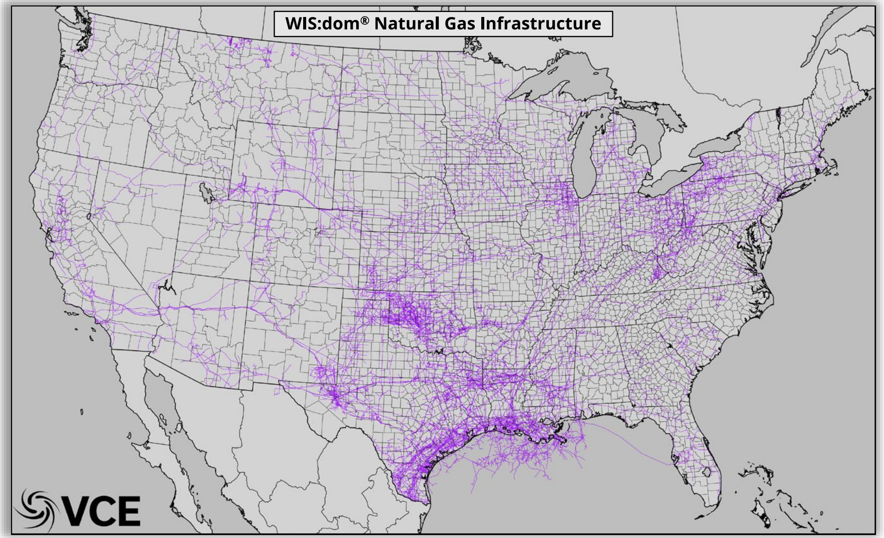
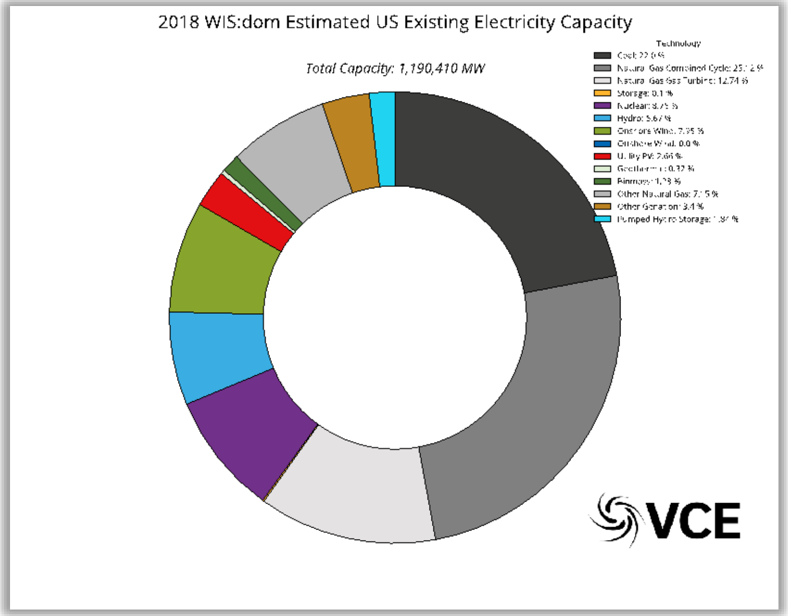
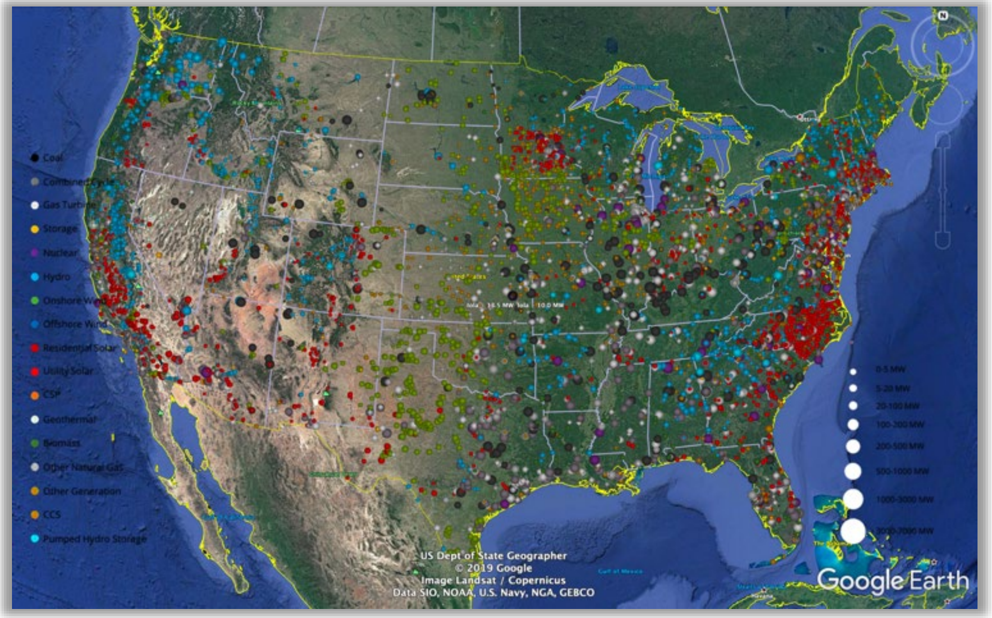
Data Requirements for G&T Planning (existing infrastructure)



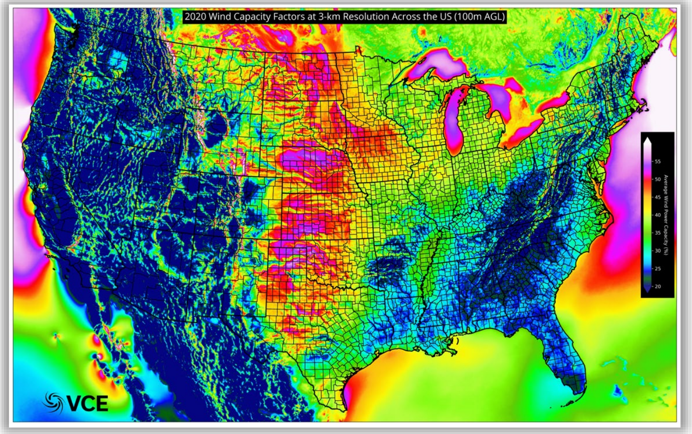


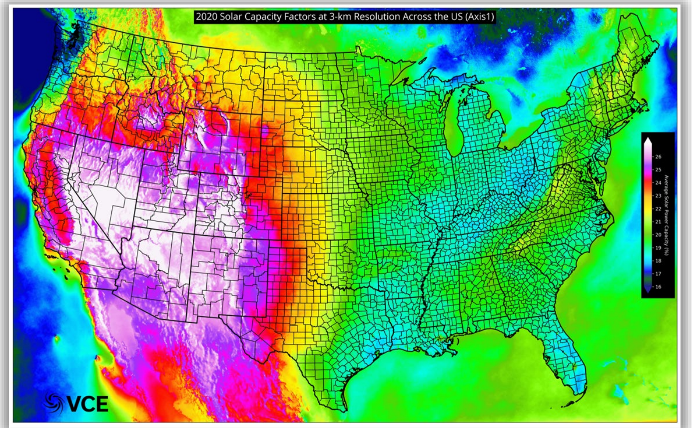
Data Requirements for G&T Planning (existing generation assets)

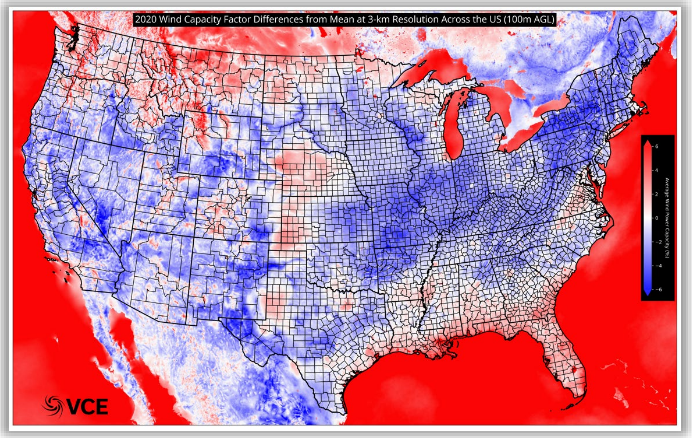


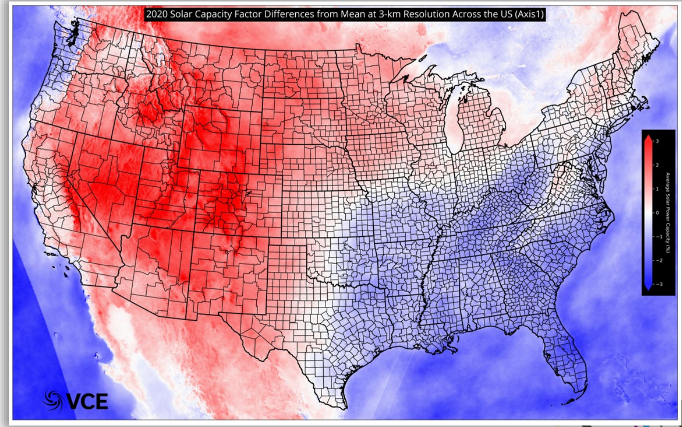


Data Requirements for G&T Planning (multi-year, granular datasets)









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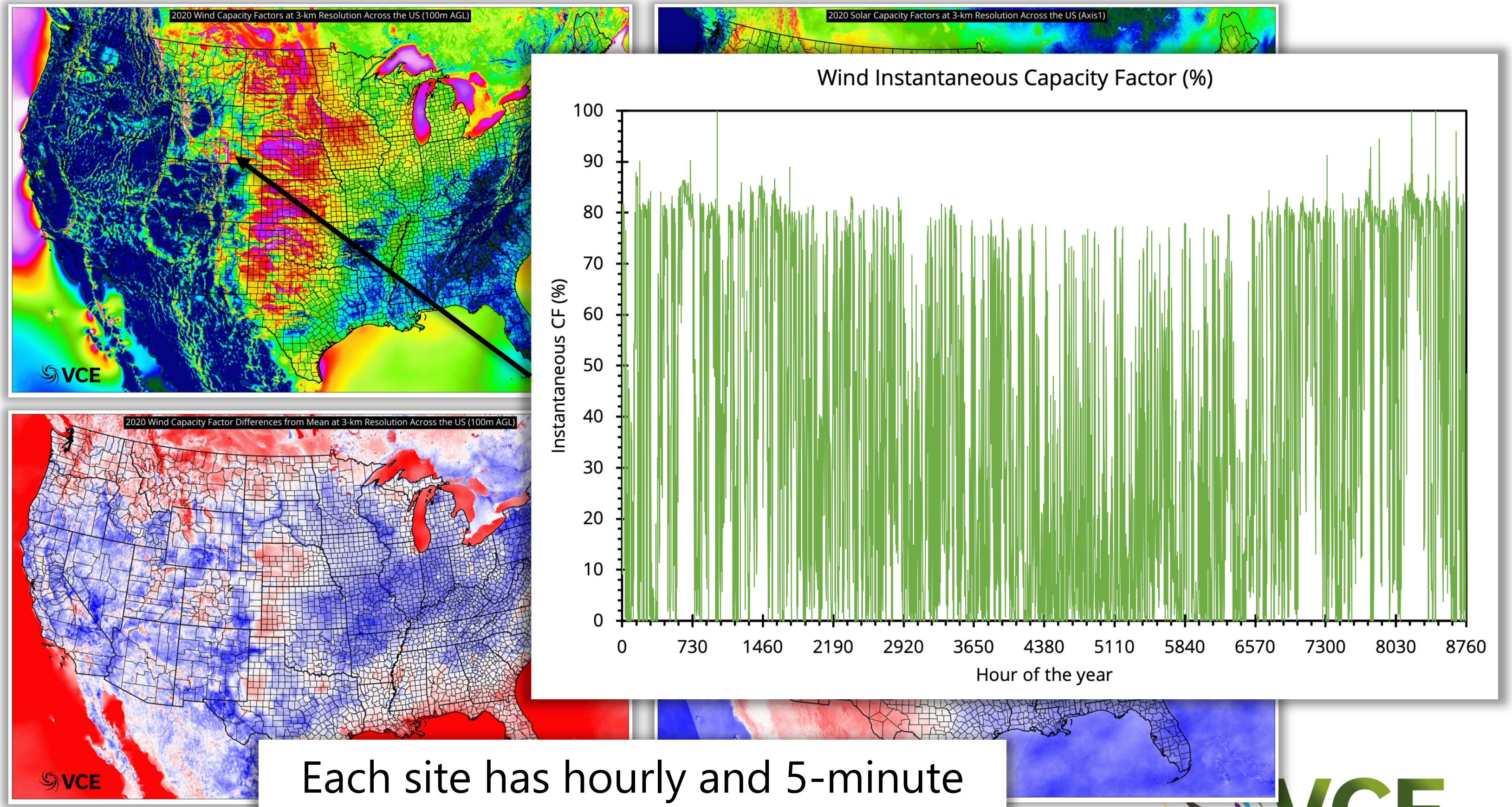
Data Requirements for G&T Planning (multi-year, granular datasets)



Each site has hourly and 5-minute data for each hub height. There are ~ 1 million unique sites.

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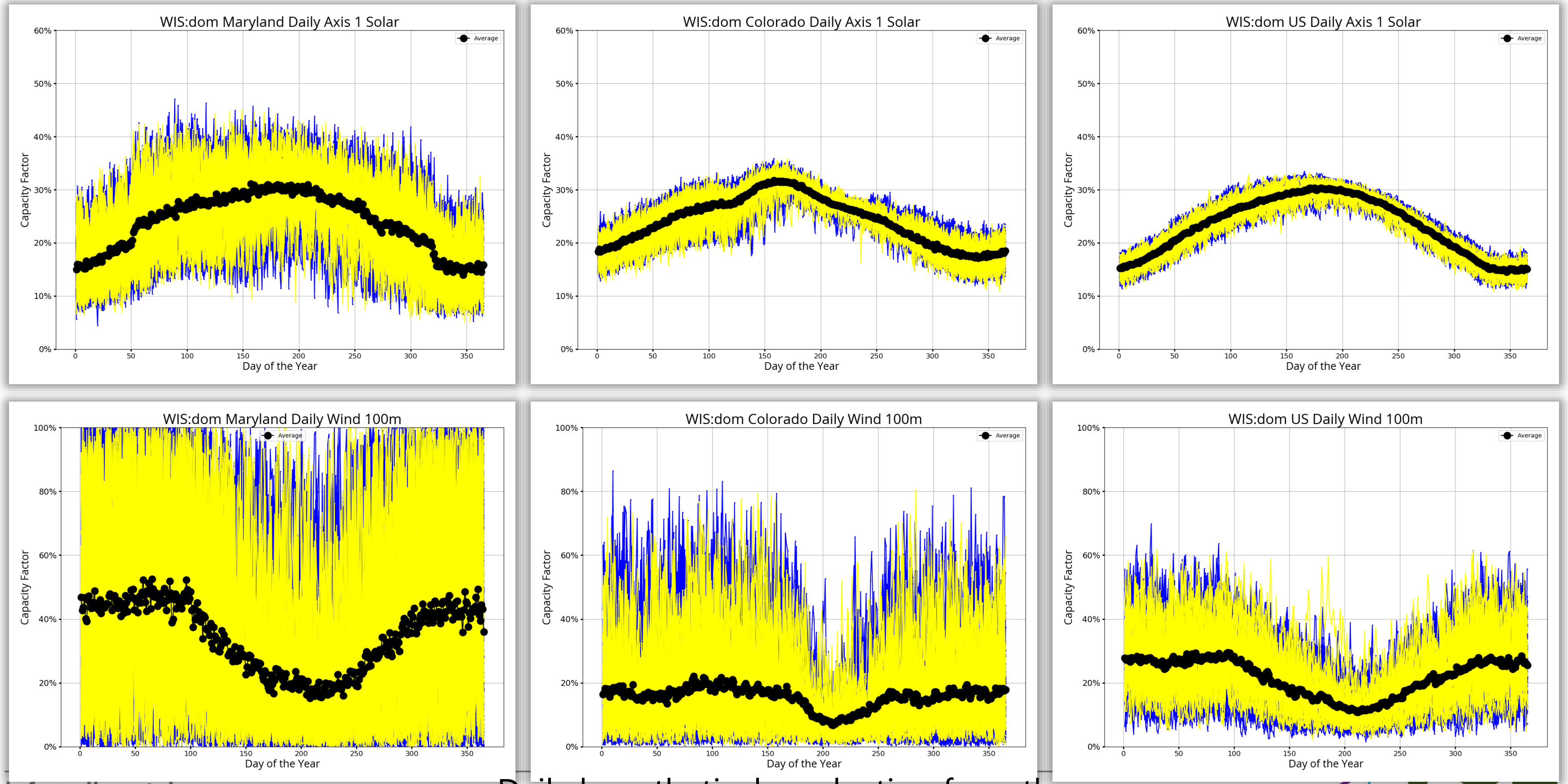
Data Requirements for G&T Planning (multi-year, granular datasets)



Daily hypothetical production from the VCE long-term dataset (1900-2015)

Data Requirements for G&T Planning (multi-year demand projections)

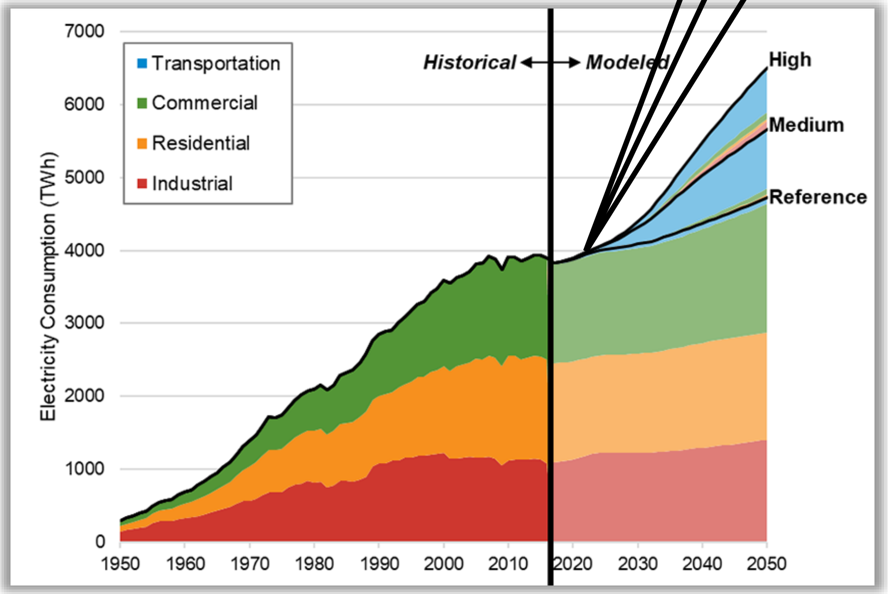
NOTE: In 2019 **29.4 PWh** of primary energy was consumed in the US. Of that **9.6 PWh** was productive for end uses (energy services). Source: LLNL

63% down	**15% up**
70% down	**7% down**
73% down	**19% down**

ZBF 2050 TWh with synthetic fuels & products (11 PWh)

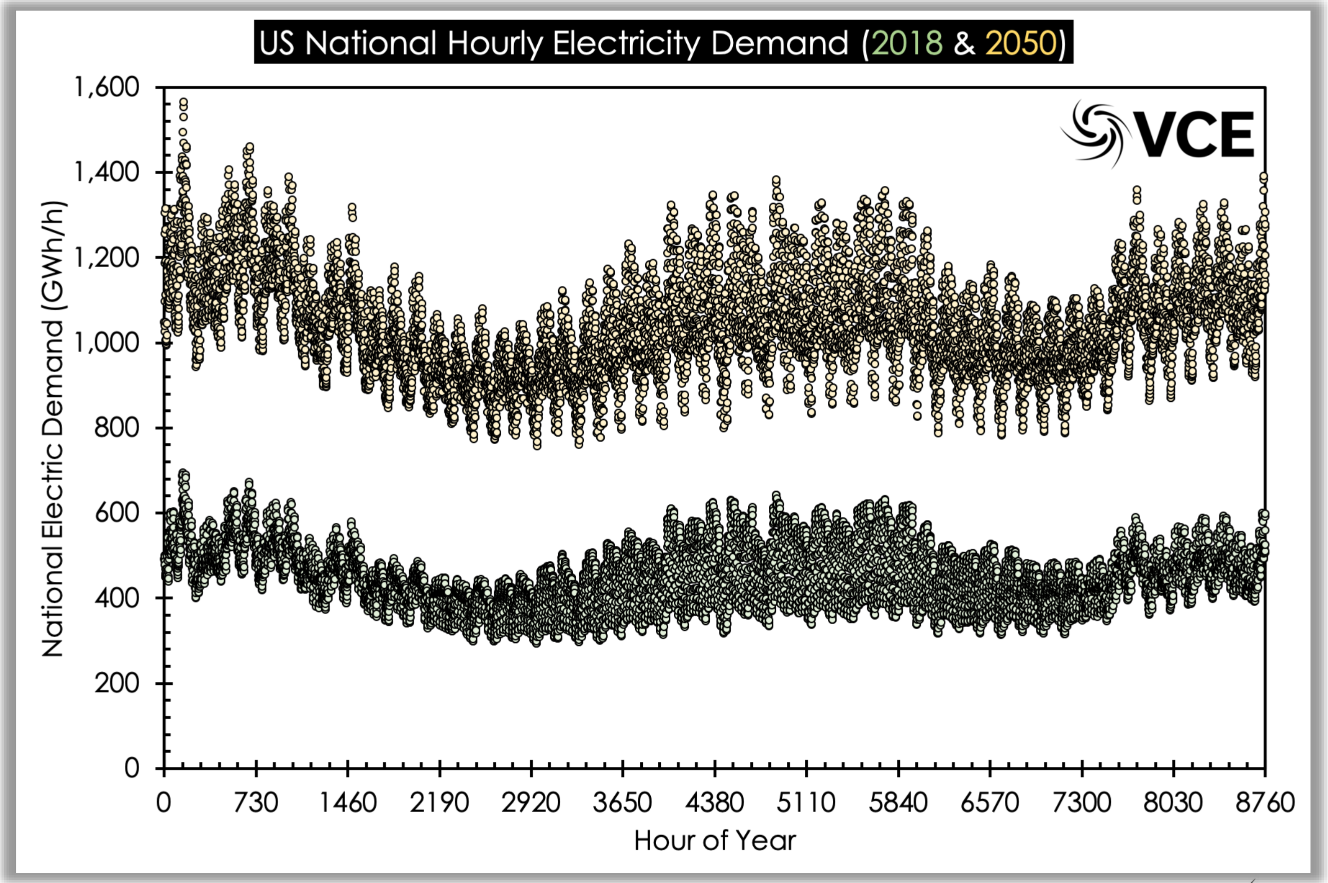
ZBF 2050 TWh with RCP4.5 climate change impacts (8.9 PWh)

ZBF 2050 TWh without climate change impacts (7.8 PWh)



https://www.nrel.gov/analysis/electrification-futures.html

Data Requirements for G&T Planning (multi-year demand projections)



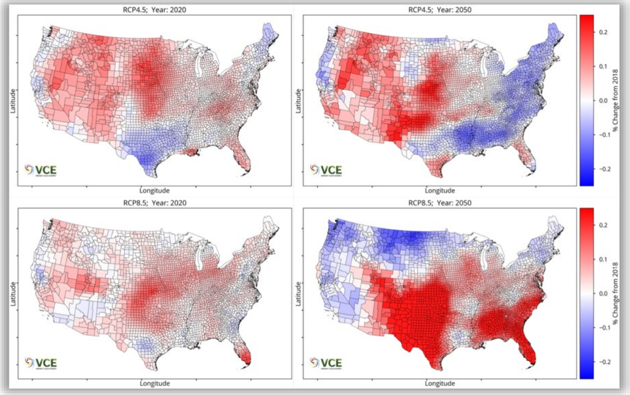
Data Requirements for G&T Planning (climate change projections)

The CMIP5 datasets allow WIS:dom® to incorporate the changing climate and its impacts on energy infrastructure.

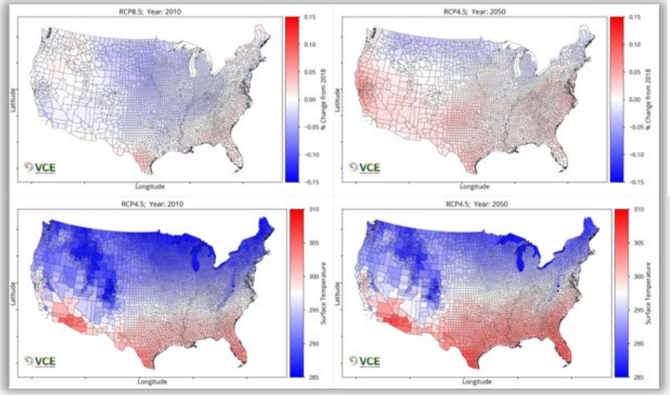
Currently this is achieved through:

- ✓ Changes to the demand profiles;
- ✓ Changes to the wind and solar power production;
- ✓ Changes to the water supply for thermal generation and hydroelectric power plants;
- ✓ Changes to the transmission line ratings and line losses via the dynamic line rating;
- ✓ Changes to the heat rates of the power plants due to thermal efficiency;
- ✓ Changes to the flexibility profiles for the demands.

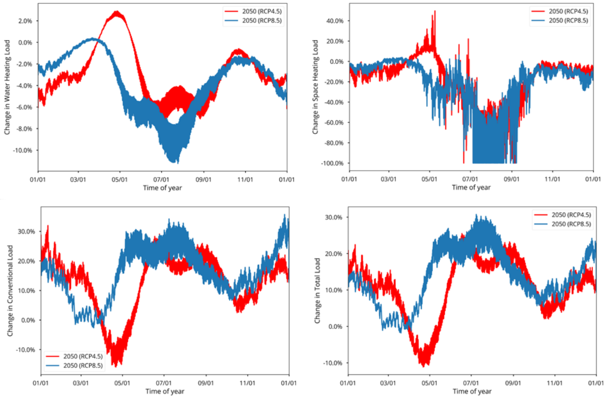
Data Requirements for G&T Planning (climate change projections)



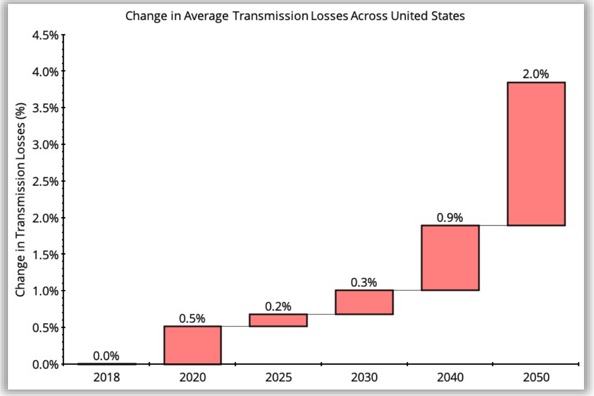
Wind



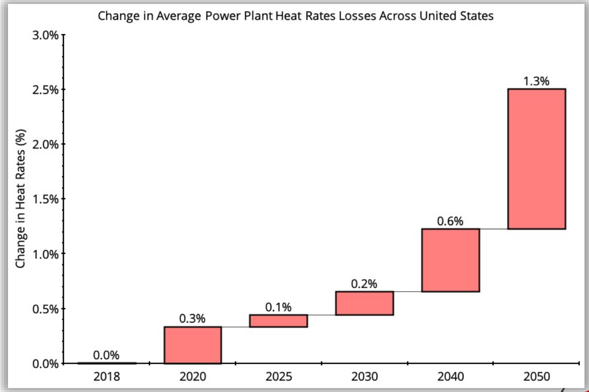
Solar



Demands



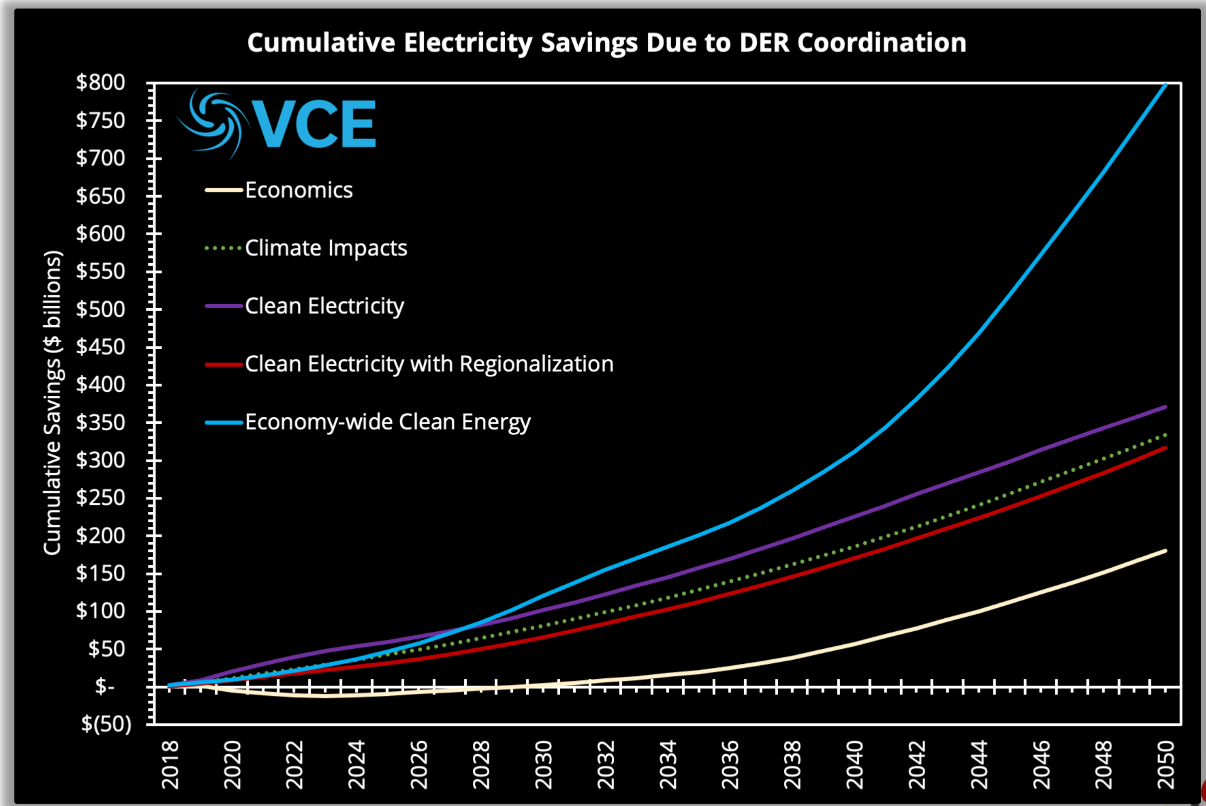
Tx Losses



Heat rates

Results

Cumulated Savings with Co-optimized Planning



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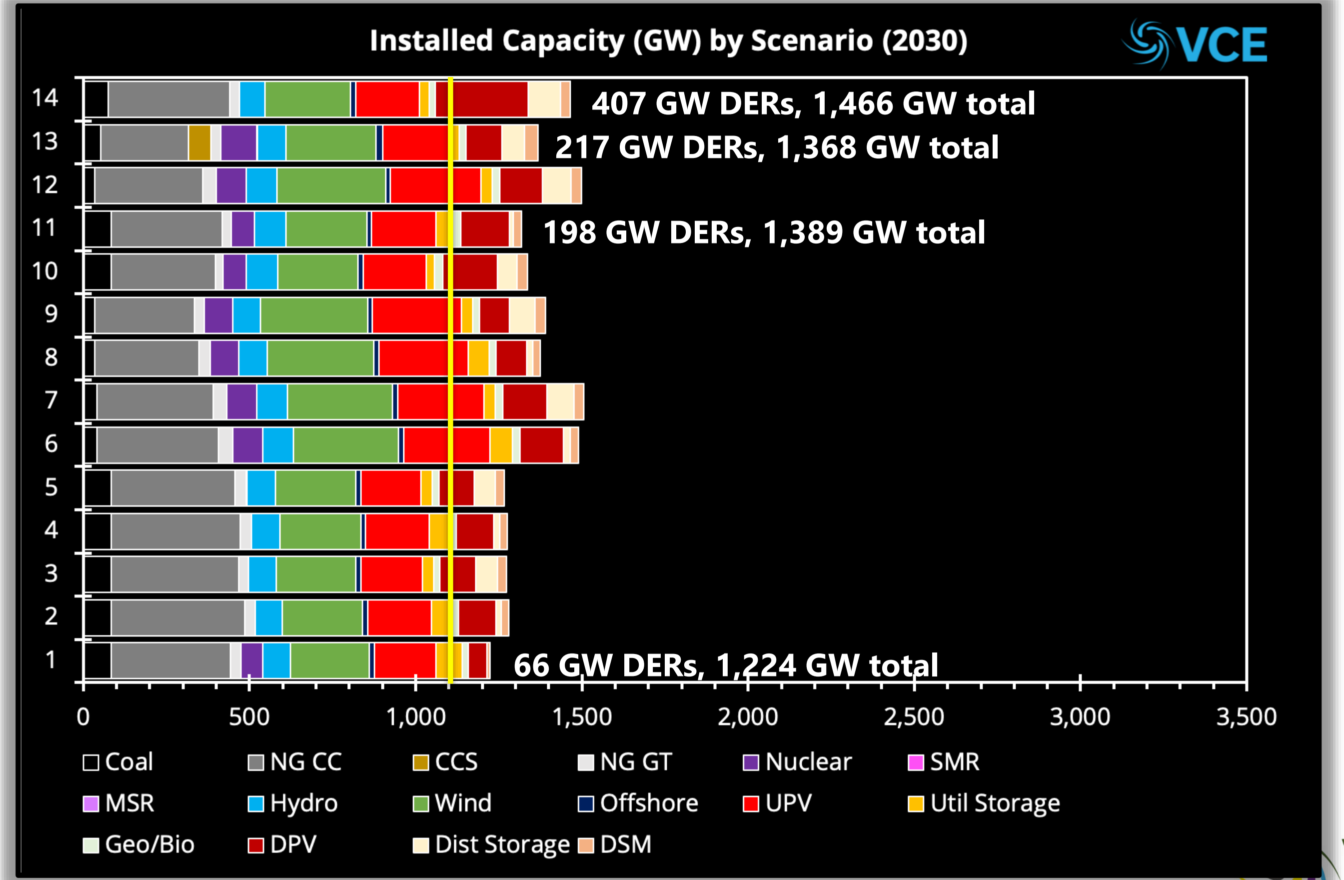
Generation Buildout with Co-optimized Planning



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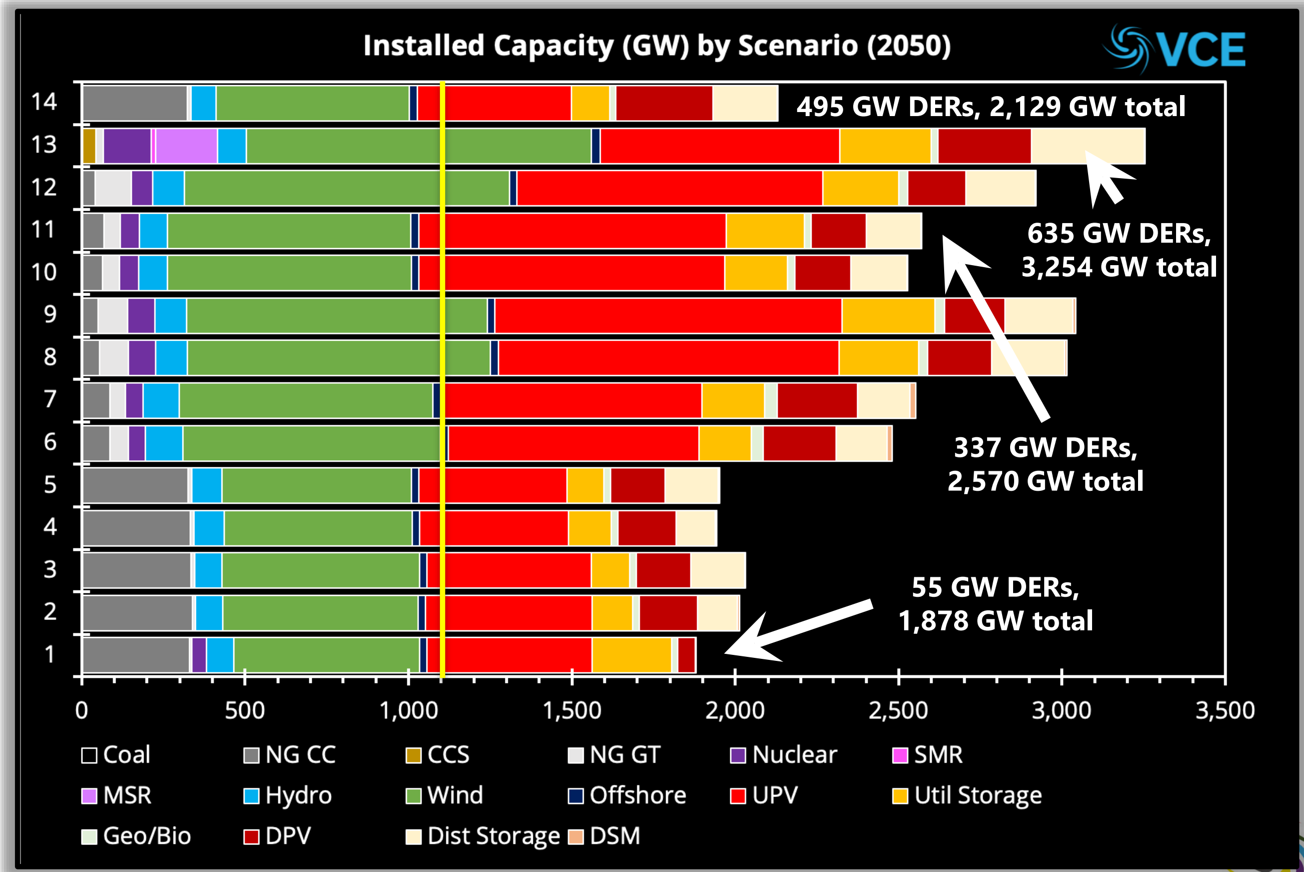
Generation Buildout with Co-optimized Planning



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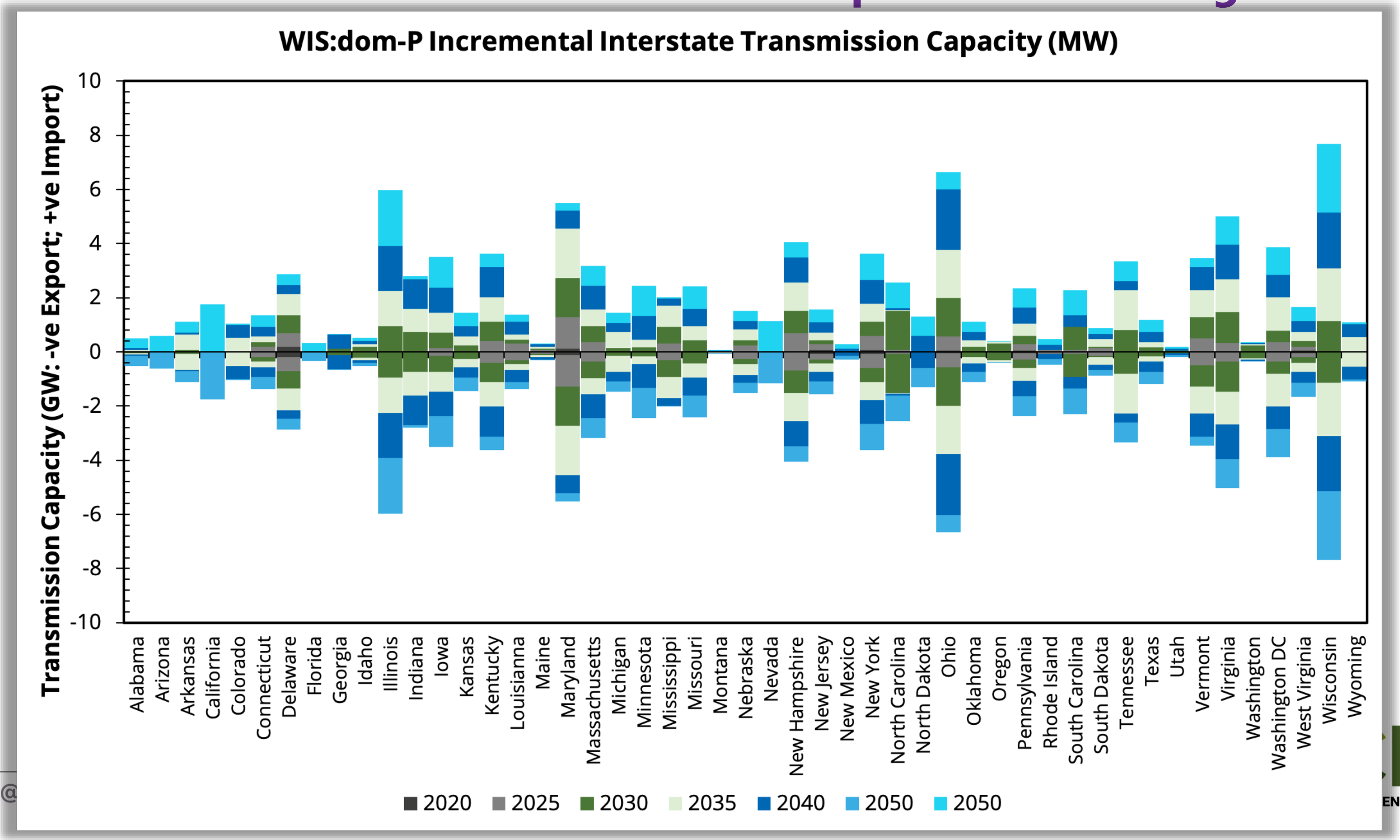
Transmission Buildout with Co-optimized Planning



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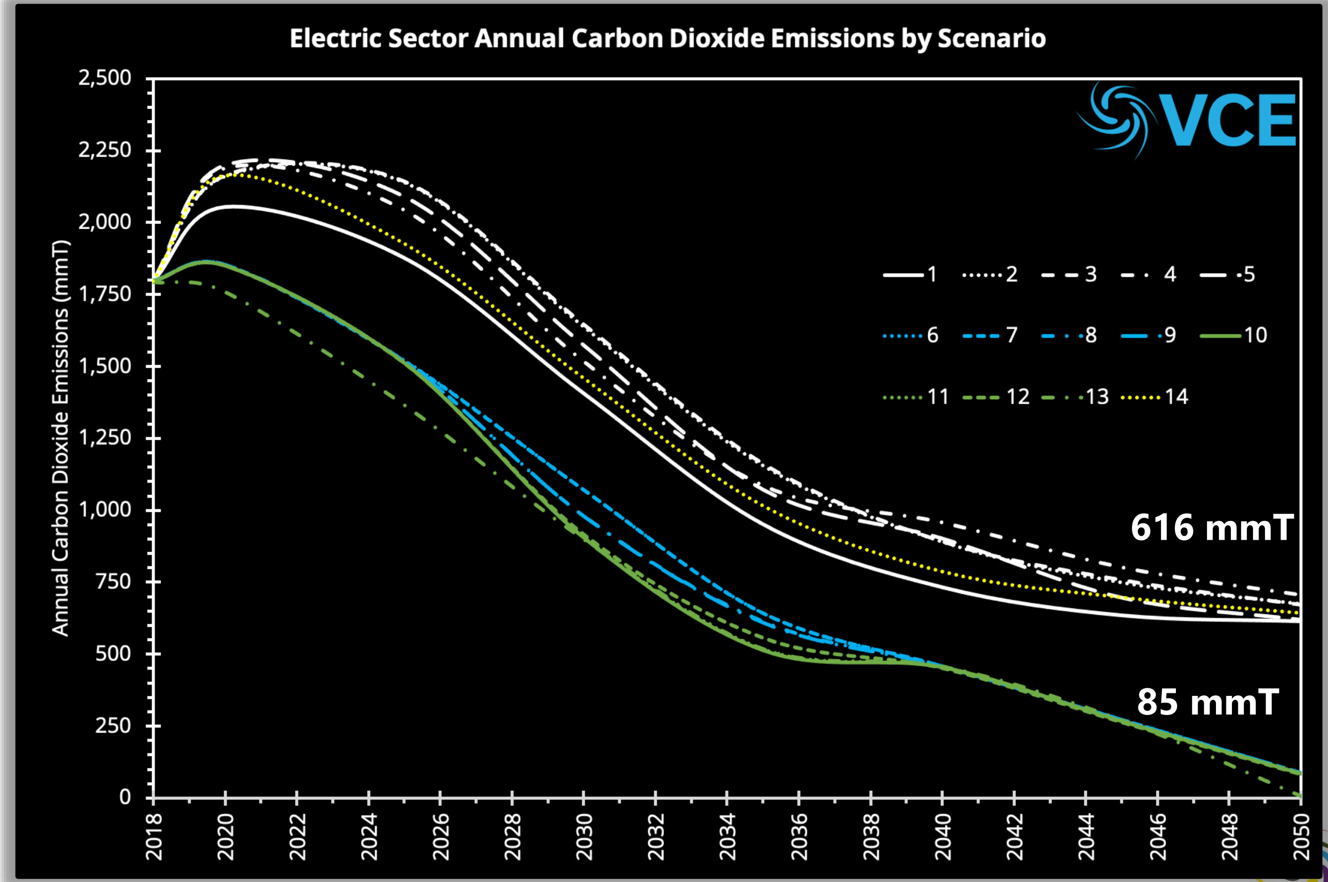
Emission Changes with Co-optimized Planning



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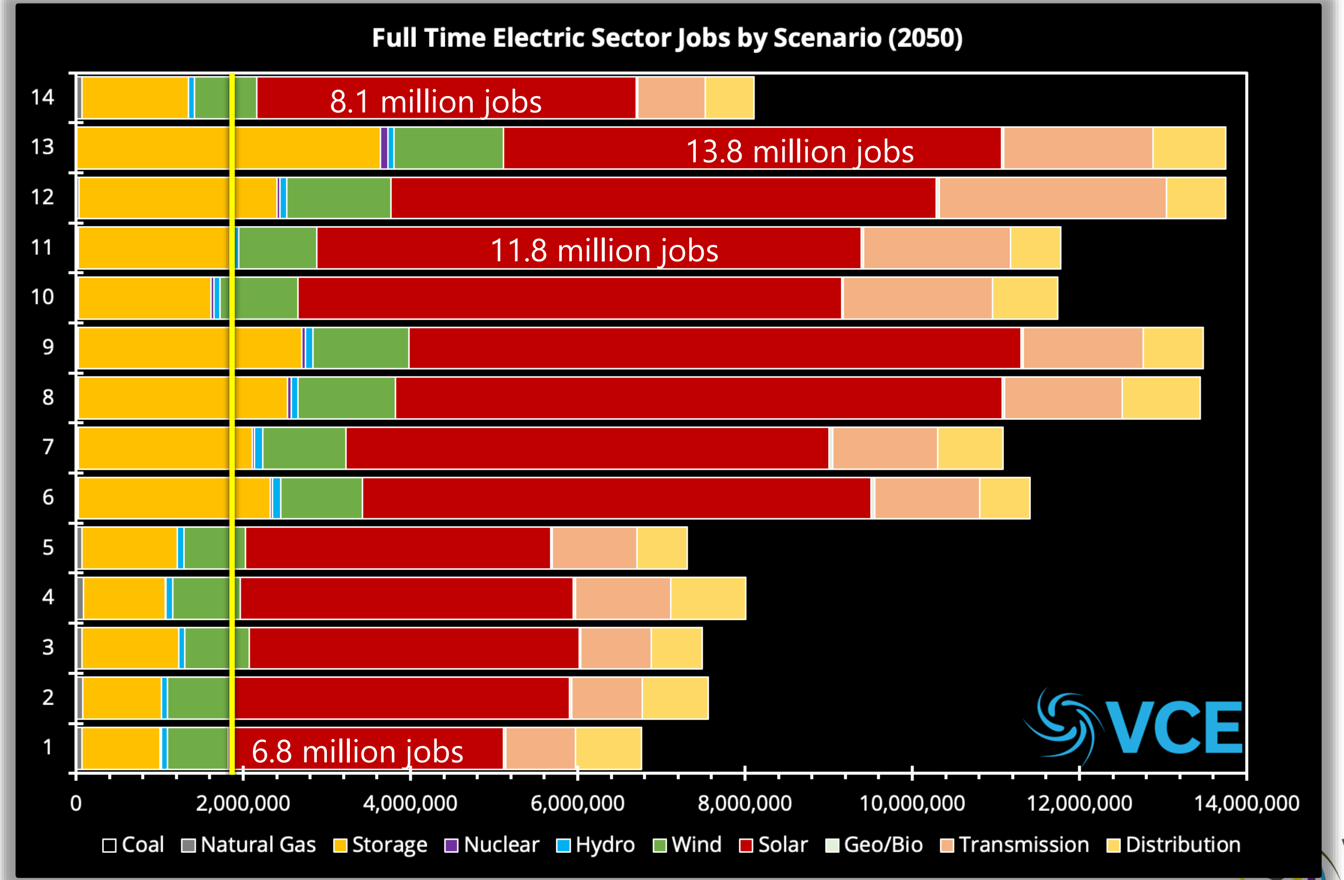
Electricity Sector Jobs with Co-optimized Planning



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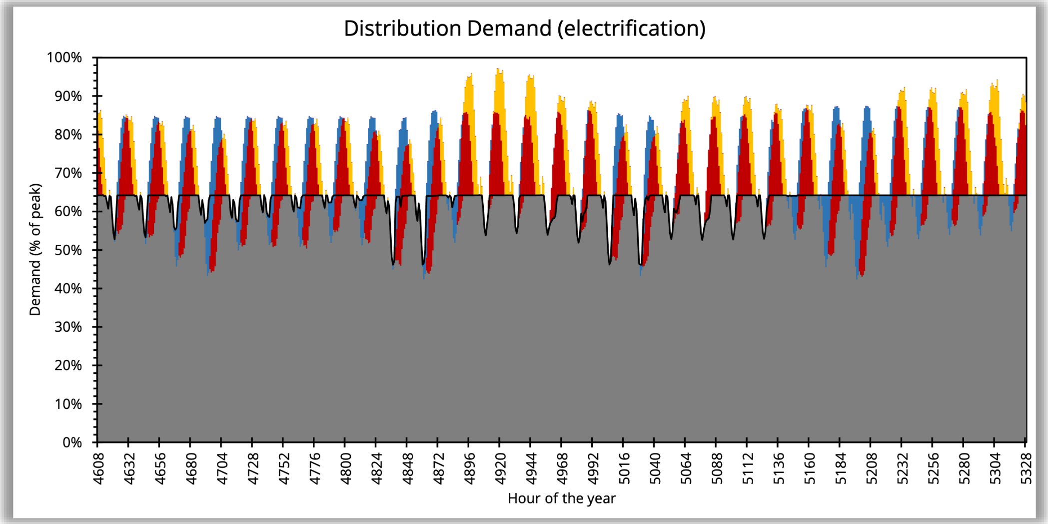
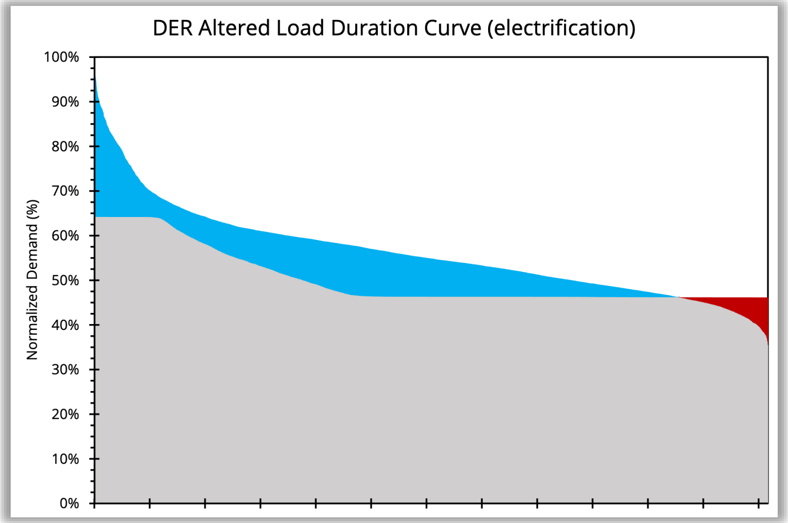
Electrification Enhances DERs Ability to Reduce Supply Pressure





Hydrogen storage and combustion or fuel cells can add additional flexibility for the system, with minimal additional cost

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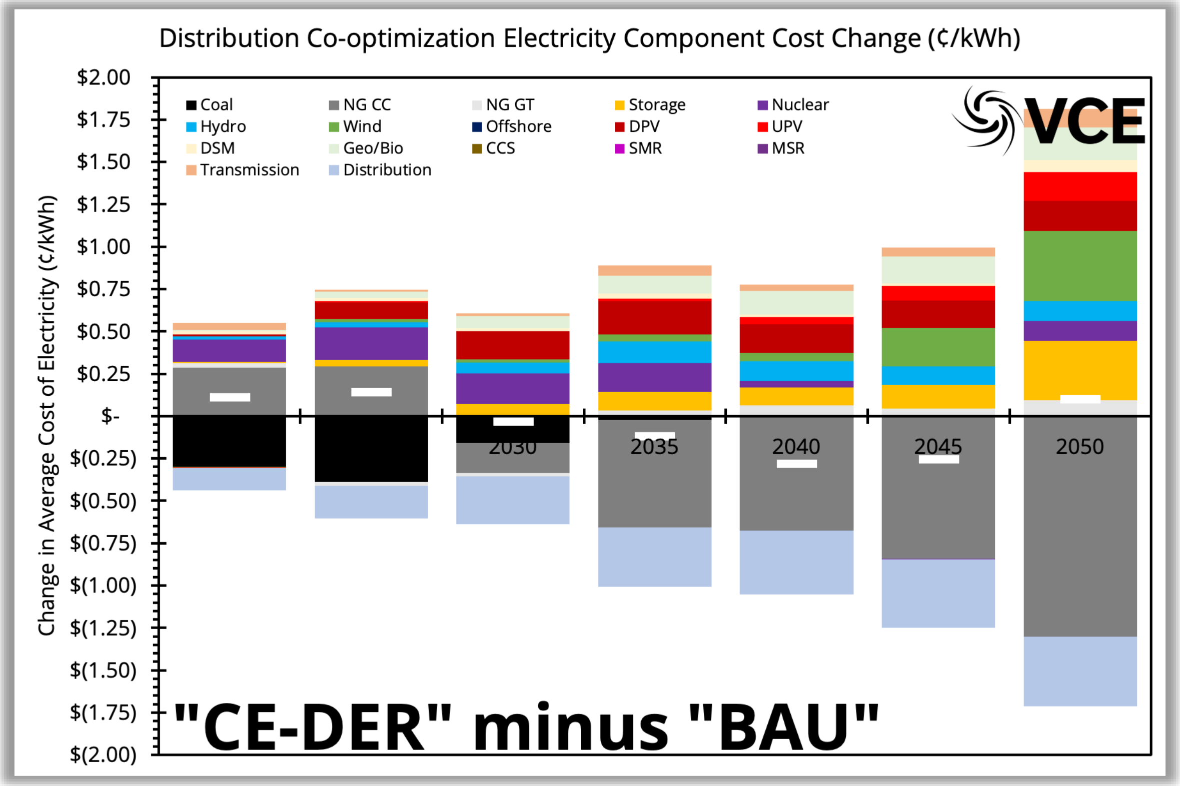
The Cost Change With Clean Electricity Beats "BAU"



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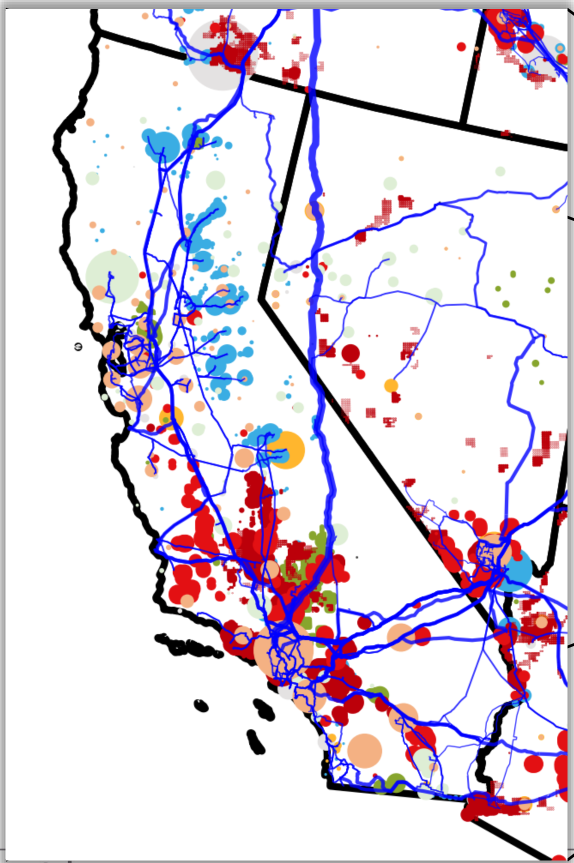
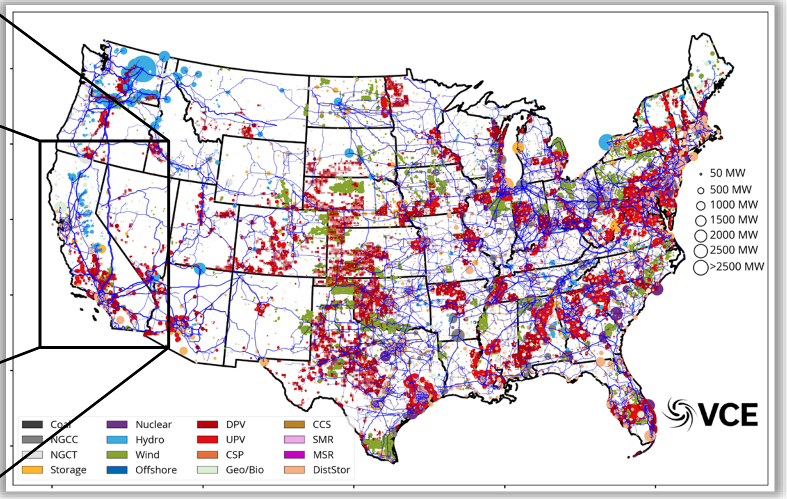
Clean Electricity Locally & Nationally





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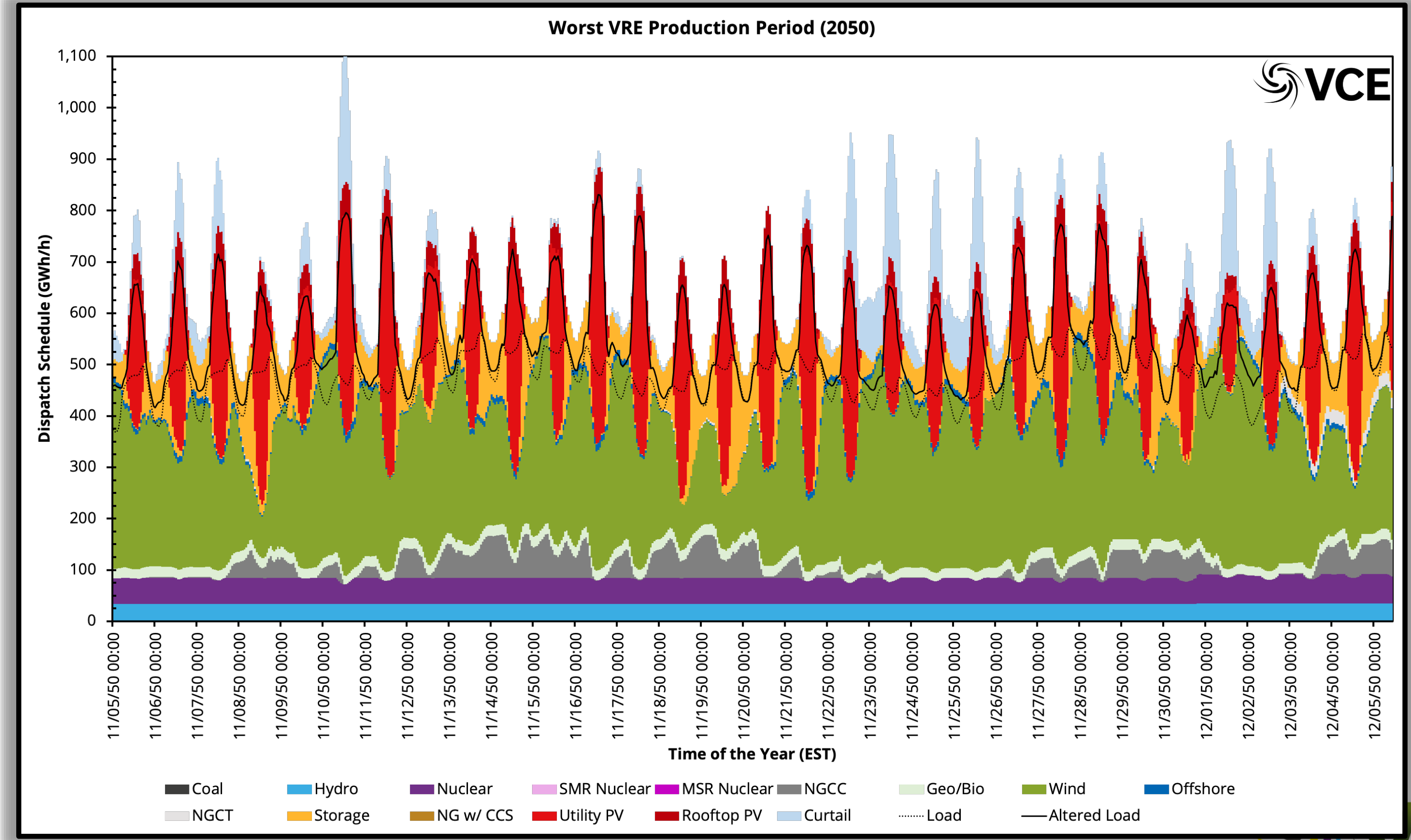
The “Highest Strain” Periods Are Met with Combined Resources



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The Whole Co-optimized System Operating (w/o HVDC)

Thank You

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