Siting Enhancement for MISO in High Penetration Levels of Wind, Solar, and Storage

Method, process & some high-level results

Prepared By:

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Prepared For:

Midcontinent Independent System Operator

November 28th, 2018

Disclaimer:

Study Scope

- Assess the transition of MISO electricity grid with increasing penetrations of variable generation, storage, and demand-side services:
  - Model MISO only with information to other regions removed;
  - Model MISO as part of a more interconnected Eastern Interconnection.
- Create a high temporal and spatial weather data set to use within the production cost portion of the WIS:dom optimization model. The dataset will cover three years and be at 3-km 5-minute resolution.
- Use the weather dataset to compute wind and solar power estimations for each 5 minutes over each 3-km grid cell in the Eastern Interconnection.
- Incorporate the power datasets within WIS:dom to facilitate high fidelity modeling of the evolution of the MISO grid when the generation, storage or demand-side resources are altered.
- Determine the capacity and transmission expansion via the WIS:dom optimization model.

Approach

- Typical modeling we perform involves **evolving time**. For example, we start in 2018 and the model evolves with time to 2020, 2025, 2030 and so on.

- For this study, we move away from this to **a paradigm of evolving constraints** on generation mix, capacities enforced, and transmission.

- We produced ten (10) iterations or evolutions of the MISO (and EI) electricity grids. The first iteration represents an estimate of the 2018 system. The remaining nine iterations evolve progressively towards to final state.

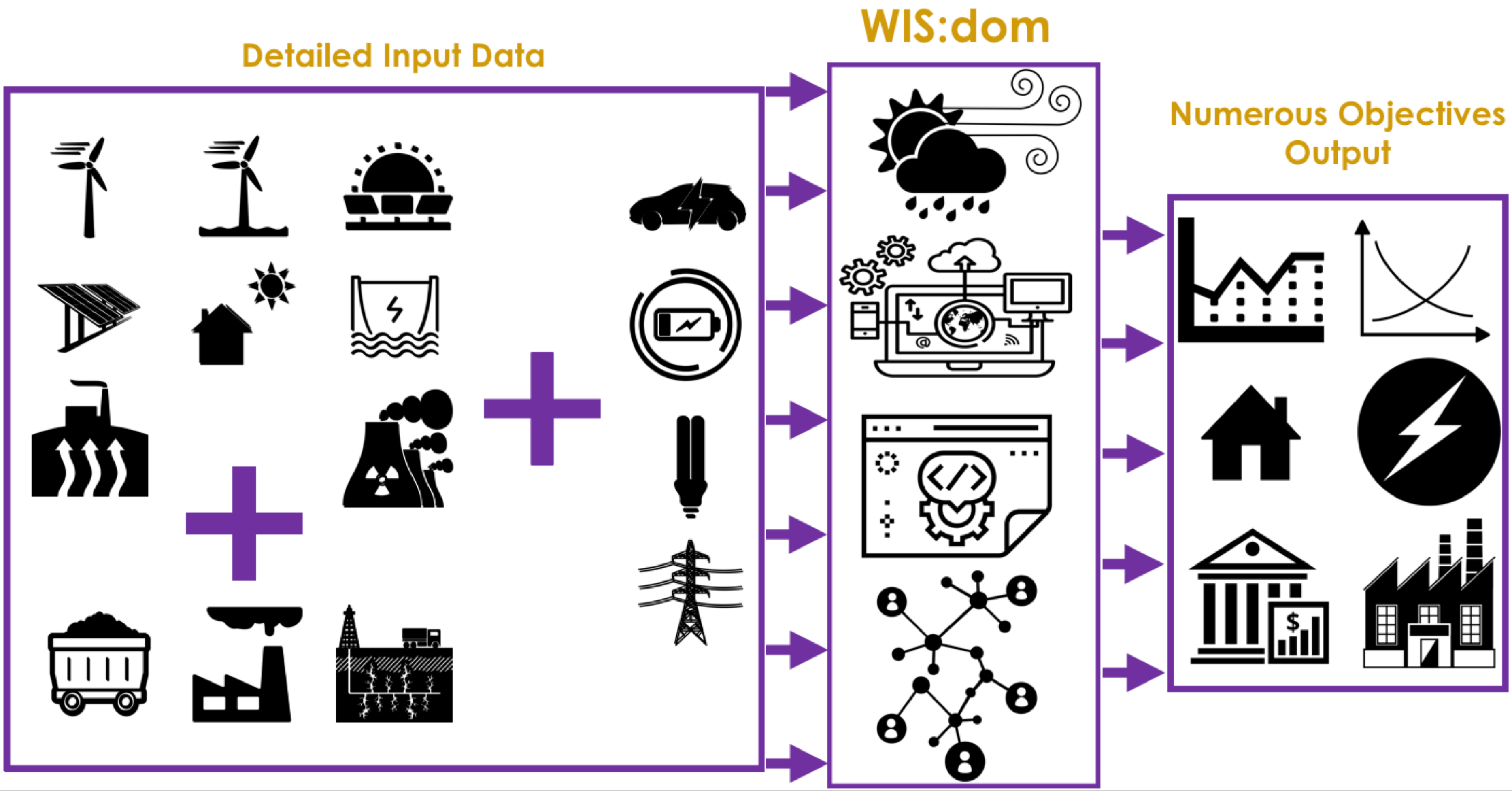
- For example, if a scenario is investigating 100% wind generation for MISO, iteration one would be today and iteration 10 would be 100%. The changes in between would be linear towards the target of 100%.

- The WIS:dom modeling tracked the installed capacities, retirements, generation, transmission build out, costs, emission, resource adequacy, capacity value, and other metrics.

Approach

- The entire system evolves with time to 2030. This facilitates the RPS policies in many States to be within compliance as well as federal policies to come to completion (PTC/ITC).
- The costs track the NREL ATB 2017 (mid) for national averages, and regional multipliers for capital and fuels.
- The 3-km 5-minute power datasets allows WIS:dom to dispatch the electricity grid while dealing with short-term variability.
- The weather dataset drives electric losses on transmission lines, demand changes, and EV requirements for charging.
- The WIS:dom optimization model considers strict land use constraints for the deployment of new generation.
- The model also co-optimizes distributed solar PV along with utility-scale generation. It further co-optimizes demand-side resources such as DSM, DR, BTM storage, and EVs.

WIS:dom Optimization Model



WIS:dom Optimization Model

WIS:dom is the ***only*** commercially available combined capacity expansion and production cost model. It combines:

- ✓ Continental-scale (globally capable), spatially-determined co-optimization of transmission, generation, storage, and demand-side resource expansion while simultaneously determining the dispatch of these sub systems at 3-km, 5-minutely resolution;
- ✓ Dispatch includes:
  - ➢ Individual unit commitments, start-up, shutdown profiles, and ramp constraints;
  - ➢ Transmission power flow, planning reserves, and operating reserves;
  - ➢ Weather forecasting and physics of weather engines;
  - ➢ Detailed hydro modeling;
  - ➢ High granularity for weather-dependent generation;
  - ➢ Chronological intervals for at least a full calendar year;
  - ➢ Existing generator and transmission asset attributes such as heat rates, line losses, power factor, variable costs, fixed costs, capital costs, fuel costs, etc.;
- ✓ Large spatial and temporal horizons;
- ✓ Policy and regulatory drivers such as PTC, ITC, RPS, RGGI, etc.;
- ✓ Detailed investment periods;
- ✓ Capable of including electrification of other sectors, hydrogen production, fuel price elasticity, Ammonia production, and carbon mitigation.

WIS:dom Optimization Model

Constraint ID	Equation Name	Equation Purpose	Impact Estimation
1	Total System(s) Cost Objective	To define the objective that is being minimized	**Critical** Other objectives may alter solutions significantly
2	Reliable Dispatch Constraint	Enforce WIS:dom meets demand in each region each hour without fail	**Critical** Strict enforcement of zero loss of load
3	Market Clearing Price Adjustment	Allowing WIS:dom to estimate the dispatch stack & attribute price vs cost	**Critical** Different market structures could impact deployment choices
4	DSM Balancing Constraint	Ensures that DSM providers can balance their demand	**High** Changing the description of DSM and costs could alter solutions
5	Transmission Power Flow Constraint	Produces the optimal power flow matrix and associated losses	**Critical** Transmission power flow significantly impacts dispatch and deployment
6	Transmission Capacity Constraint	Calculates the capacity of each transmission line	**Critical** Without this constraint, power flow could become artifically large
7	Planning Reserve Constraint	Ensure planning reserve margins are maintained	**High** Capacity credit for VREs can alter deployment decisions
8	Coal, NGCC, NGCT, Nuclear, Hydro, Geo Capacity Constraints	Maintain the capacity of generators above their peak production	**High** Without the constraints generations can be incredibly based on marginal costs alone
9	Storage Power & Energy Capacity Constraints	Complex equations & constraints to determine the utilization of storage	**Critical** Storage correctly modeled can change all investment decisions and dispatch
10	Coal, NGCC, NGCT, Nuclear, & Geo P_min Constraints	Constraints that force WIS:dom to adhere to P_min attributes for thermal generators	**Medium** P_min enforcement has lower impacts on decision
11	RPS & Emission Constraints	To enable WIS:dom to understand policy, regulatory and societal limitations	**Critical** When emissions enforced investment decisions are completely changed
12	Generator & Transmission Capacity Expansion Constraints	To require WIS:dom to keep investments in new generation & transmission to specific levels	**Low-Medium** Very tight enforcement could impact decisions, but realistic values do not substantial change solutions
13	Coal, NGCC, NGCT, Nuclear, & Geo Ramping Constraints	Describing the speed at which generators can alter their output for WIS:dom	**Medium** Faster ramping thermal generation is more favorable in lower emission scenarios, so this constraint impacts decisions in those cases
14	DER Deployment & Cost Constraints	Specifies to WIS:dom the amount of DERs to be constructed and/or cost to system of these assets	**Low** Has minimal impact on the overall system costs and investment decisions of utility scale generators
15	CIL & CEL Constraints	Describe the import & export limits between markets, countries, states, and interconnections	**Medium-High** Transmission expanding from existing lines & the addition of market impacts can dramatically alter decisions in some high emission reduction scenarios
16	Spatial Limitation Constraint	Allow WIS:dom to understand the space requirement for generators and competition for land use	**Medium** Without this constraint land use can be over used and over count the amount of generation in a location/site
17	Extraction Limits For VRE	Determines the limits to VRE extraction for nearby sites	**Medium** Impactful for wind siting considerations but much lower for solar PV siting
18	Nuclear & Hydro Dispatch Schedule	Informs WIS:dom that nuclear and hydro must conform to addition constraints regarding the water cycle, water temperature, and refuelling	**Low-Medium** Nuclear suffers a small amount due to offline times & hydro flexibility limited by constraint to assist with other VREs
19	Relicense / Repower Decision	Facilitates WIS:dom opting to relicense or repower an existing nuclear or VRE site	**Medium-High** Repowering can substantially improve existing sites at lower cost, while relicensing enable nuclear to remain within markets for longer
20	Load / Weather Forecast Error Estimator	Enables WIS:dom to detect regions with poor weather and/or load forecasts for consideration during investment decisions	**Low-Medium** Load & weather forecasts are small enough over EI markets that the invesments are not substantially altered. For WECC, the impact is much higher

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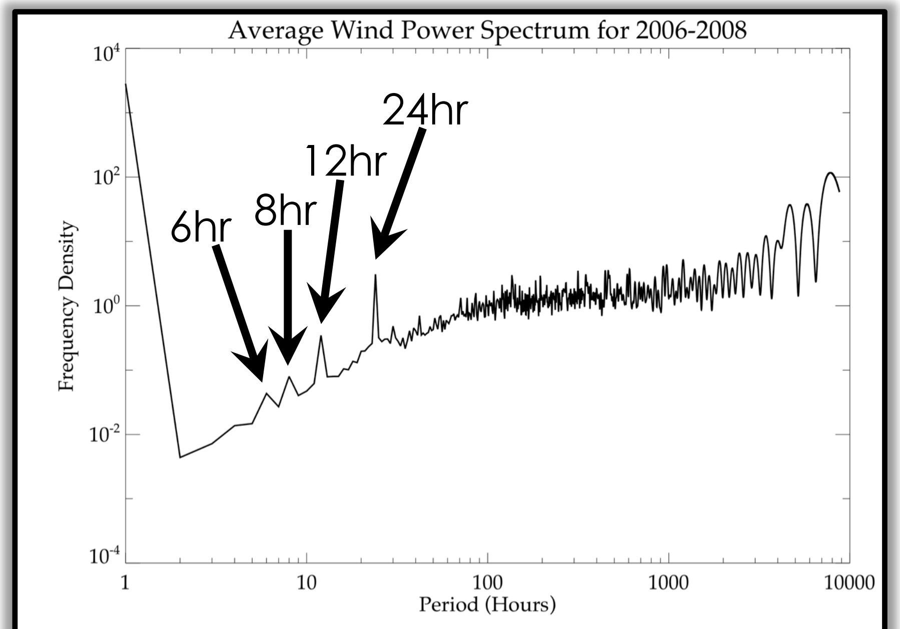
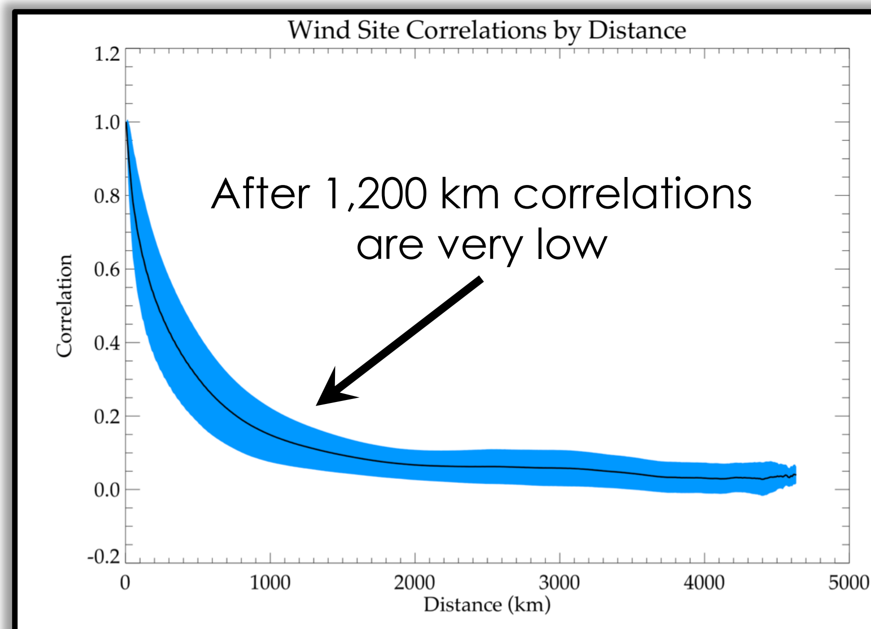
Weather-Informed Modeling

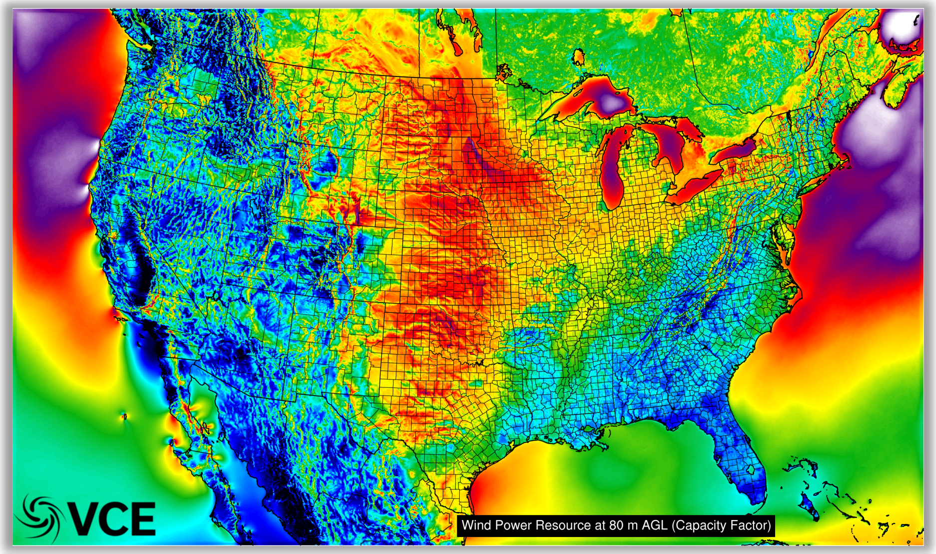
Renewable Generation Depends Upon Weather, thus co-optimizing around it will facilitate exploration of advantages and difficulties

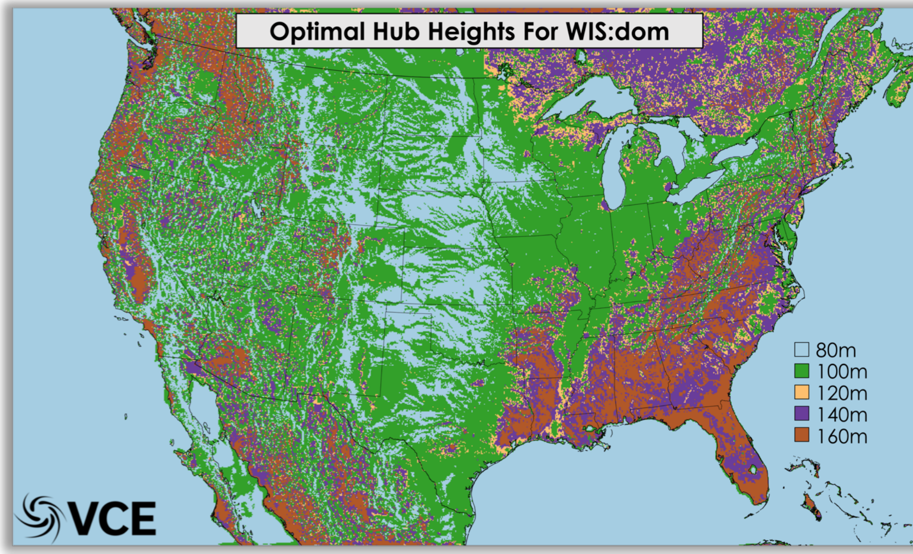


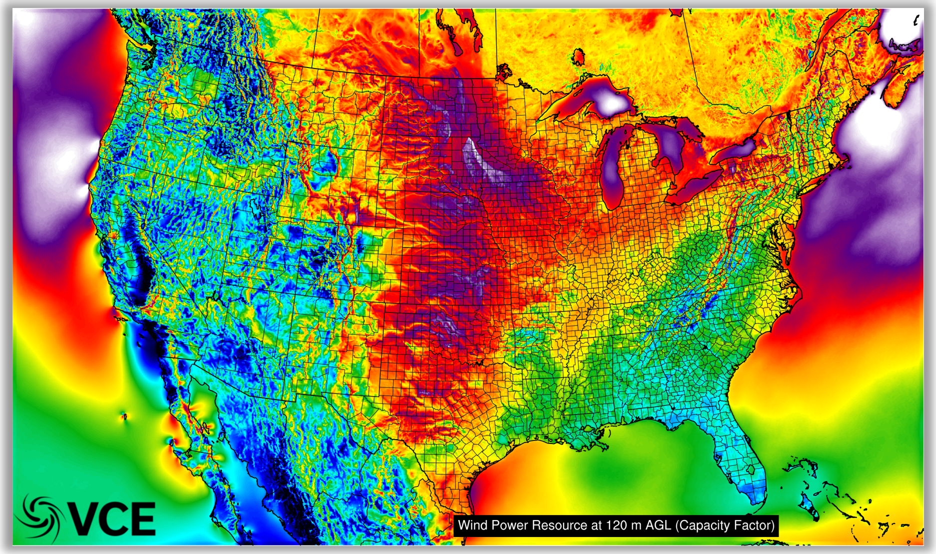


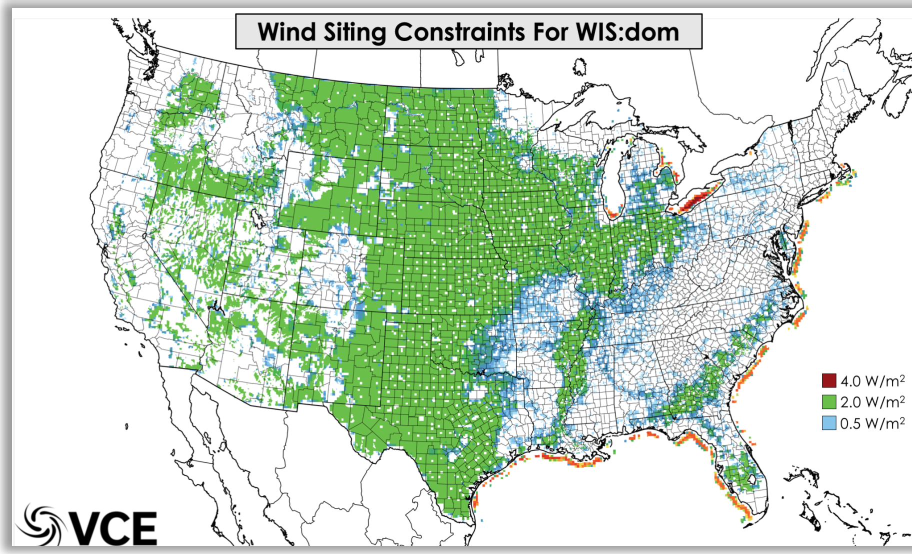
Energy Density Accumulates At Predictable Times & Sites Decorrelate Rapidly

Weather-Informed Modeling





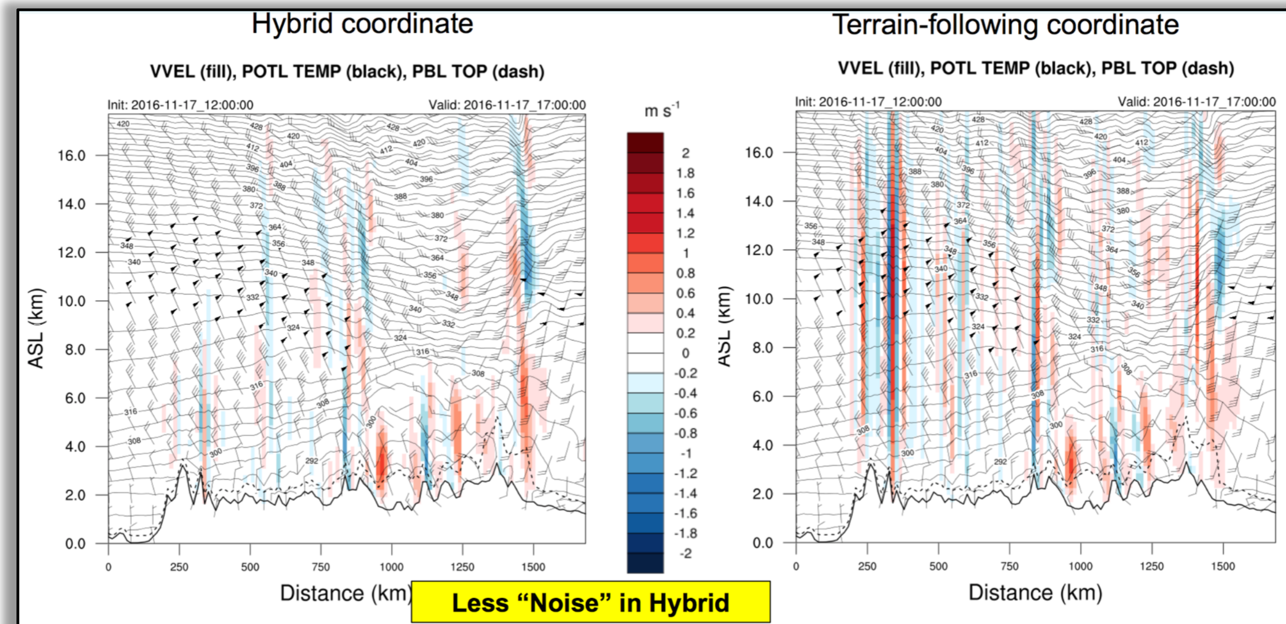




Weather-Informed Modeling

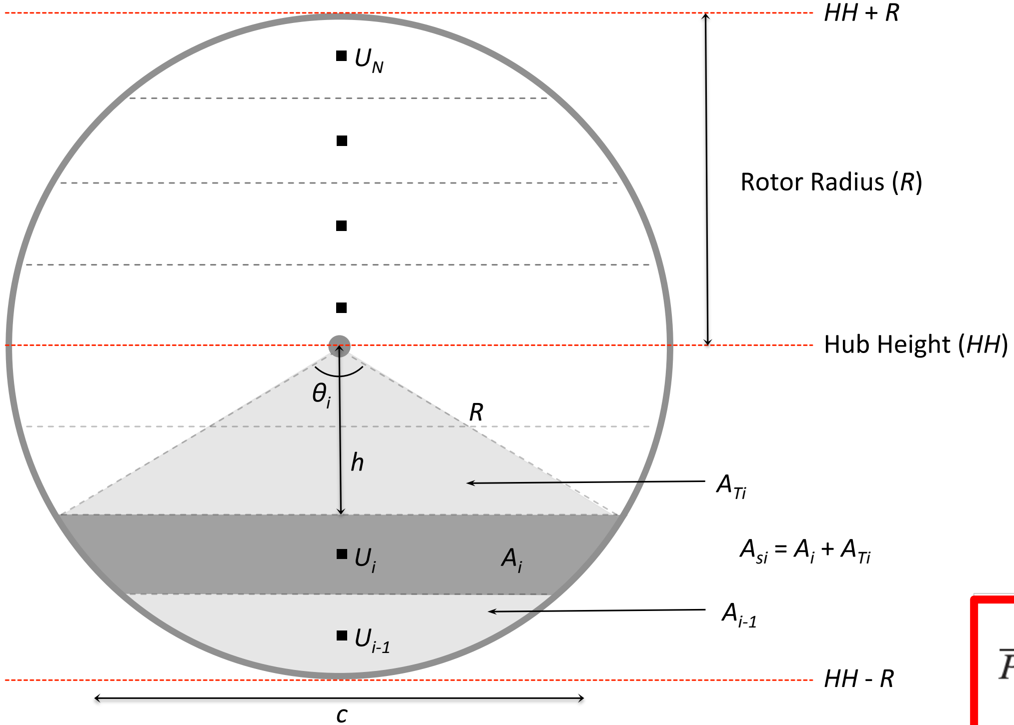
1. Use the ***3-km HRRR*** (High-Resolution Rapid Refresh) ***hourly*** data that includes 3-D volume of atmosphere over North America. Contains (1059 x 1799 x 51) data points for each variable

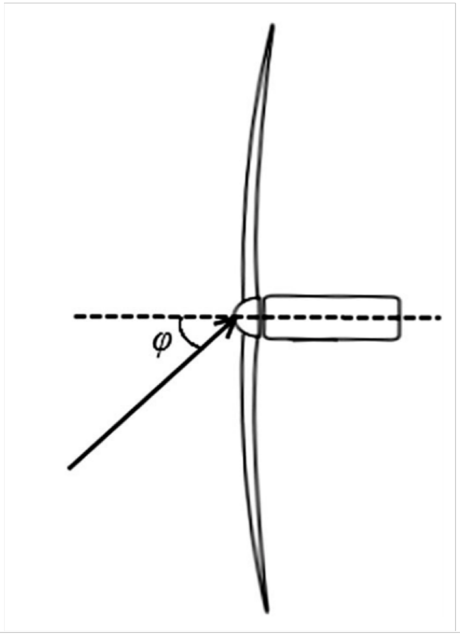
2. Extract the variables required for computation of wind power for WIS:dom. These variables include: ***Wind speed*** at 20m to 240m above ground level (in 10m increments), ***wind direction*** at each height, ***air density*** at each height, ***clouds*** at each height, ***turbulence*** at each height, ***hydrometeors*** at each height, ***temperature*** at each height, and the ***icing potential*** at each height. To compute these values at each height complicated atmospheric equations are interpolated between the ***hybrid-sigma coordinates*** at heights above ground.



From NOAA: *https://ruc.noaa.gov/ruc/ppt_pres/Alexander_WRFworkshop_2017_Final.pdf*

Weather-Informed Modeling





$$\overline{P}_{eq} = \frac{1}{2}\rho C_P \sum_{i=1}^{N} \overline{U}_i^3 \left(1 + 3\left(\frac{\sigma_{ui}}{\overline{U}_i}\right)^2\right)\left[1 - \frac{\overline{\varphi}_i^2}{2} - \frac{\sigma_{\varphi i}^2}{2}\right]^3 A_i$$

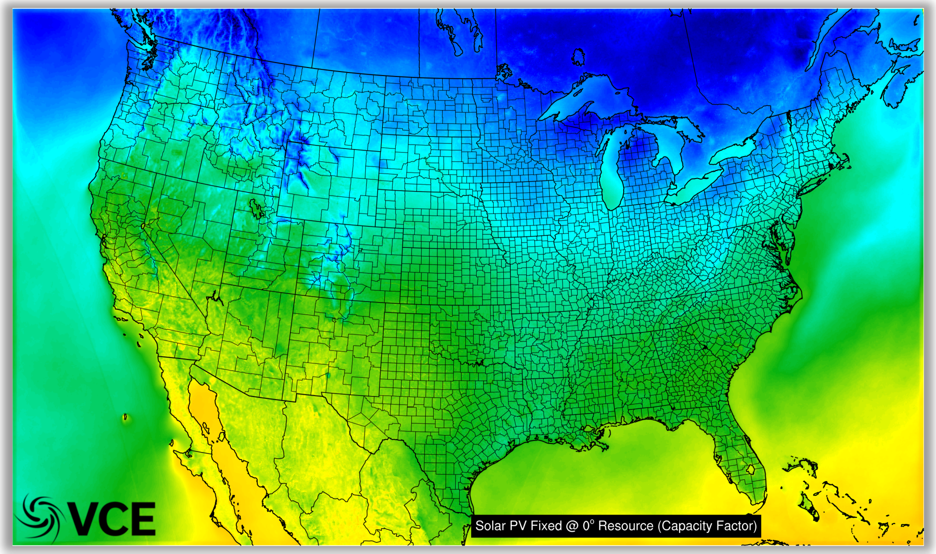
$$\alpha_i = \frac{A_i}{A} = \frac{(\theta_i - \sin\theta_i)}{2\pi} - \frac{1}{A}\sum_{j=0}^{i-1} A_j, \quad i \geq 1$$

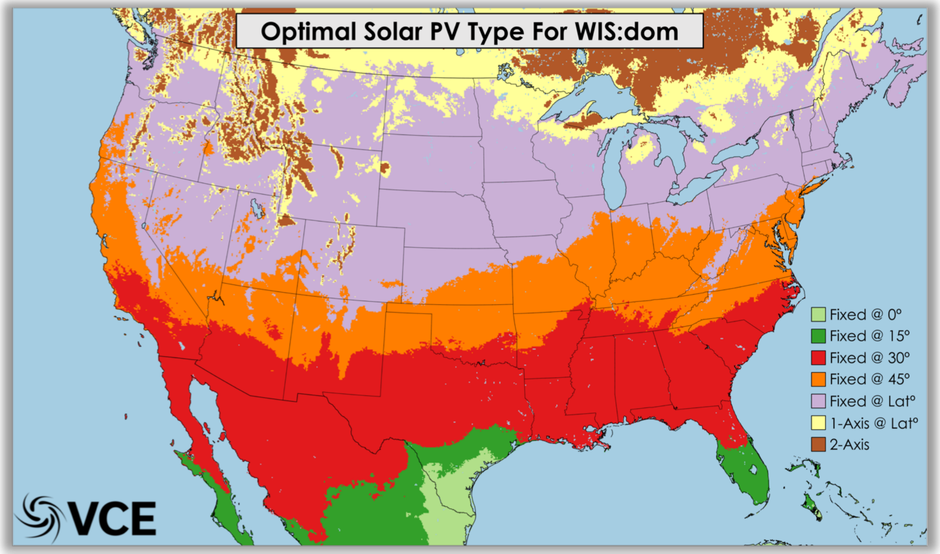
$$U_R = \sum_{i=1}^{N} \alpha_i \cdot U_i$$

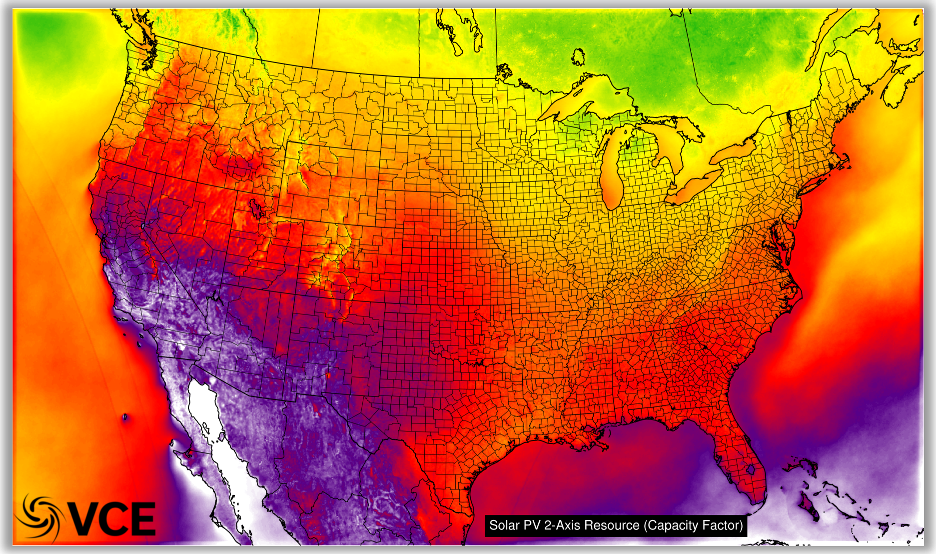
* We also perform the same technique to obtain the Rotor Equivalent Density, Temperature and Clouds

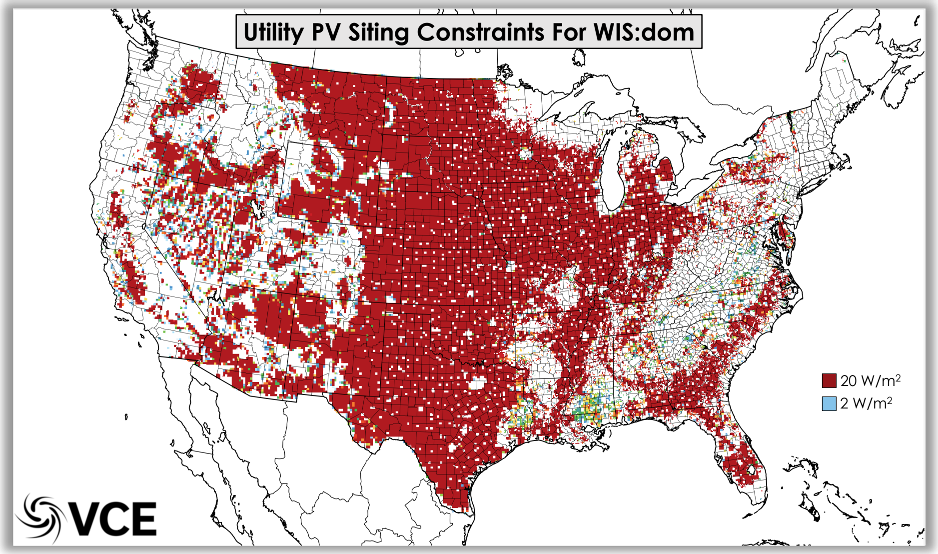
[Clack et al., *Wind Energy*, 2016](#)
[Choukulkar et al., Wind Energy, 2016](#)

Weather-Informed Modeling





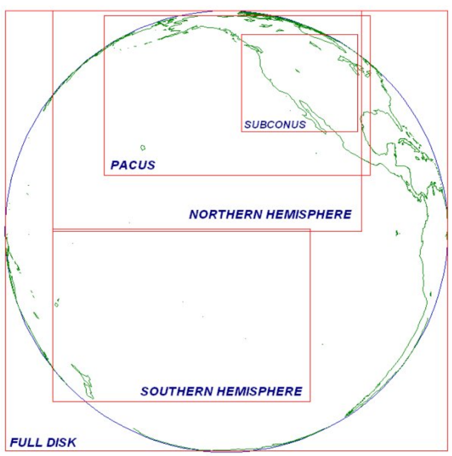


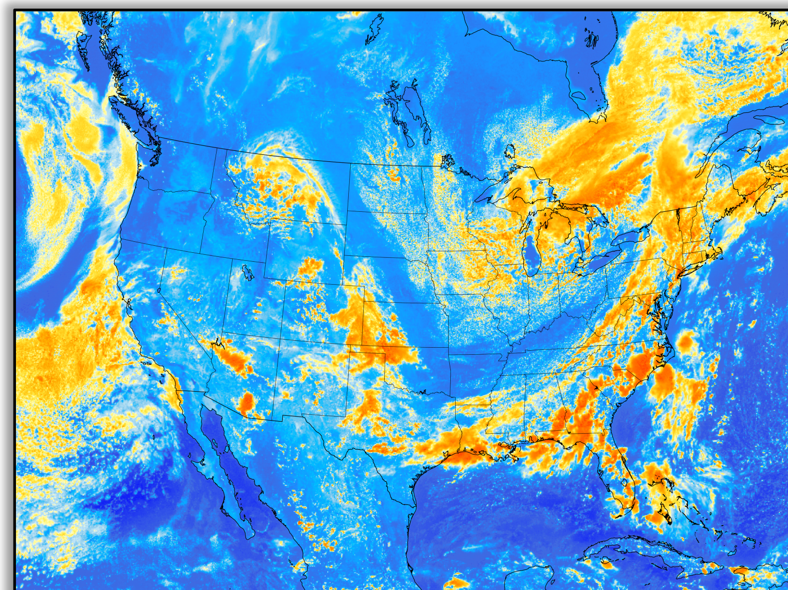


Weather-Informed Modeling

1. Use the ***3-km HRRR*** (High-Resolution Rapid Refresh) ***hourly*** data that includes 3-D volume of atmosphere over North America. Contains (1059 x 1799 x 51) data points for each variable.

2. Use the ***1- and 4-km GOES*** Satellite ***15-minute*** data for all of North America. The North America data is at a higher refresh rate that the full-disk scans. The reflectance values are for different wavelengths or "bands" – ***visible***, ***4-micron***, ***11-micron***, ***13-micron***, and ***water vapor***. VCE utilizes ***CONUS Ext***. and ***PACUS*** from the GOES satellites. Both are required to enable a stereographic view of the clouds for the multivariate regression to learn from.





Weather-Informed Modeling

$$Y_{n\times p} = Z_{n\times(r+1)}\beta_{(r+1)\times p} + \epsilon_{n\times p},$$

$$E(\epsilon_{(i)}) = 0, \quad \mathrm{Cov}(\epsilon_{(i)}, \epsilon_{(k)}) = \sigma_{ik} I, \quad i,k = 1,2,...,p.$$

3. We have p(=3) irradiance fields to calculate and n(=631,645) observation of each field. The observations are taken from 15 high quality measurement sites (NOAA SURFRAD & SOLRAD)

4. The regressors (β) are the satellite data (5 wavelengths), the HRRR weather variables (SW, LW, temperature, wind, elevation, etc.), the top of atmosphere irradiance, the zenith angle, the azimuth angle, and the declination angle.

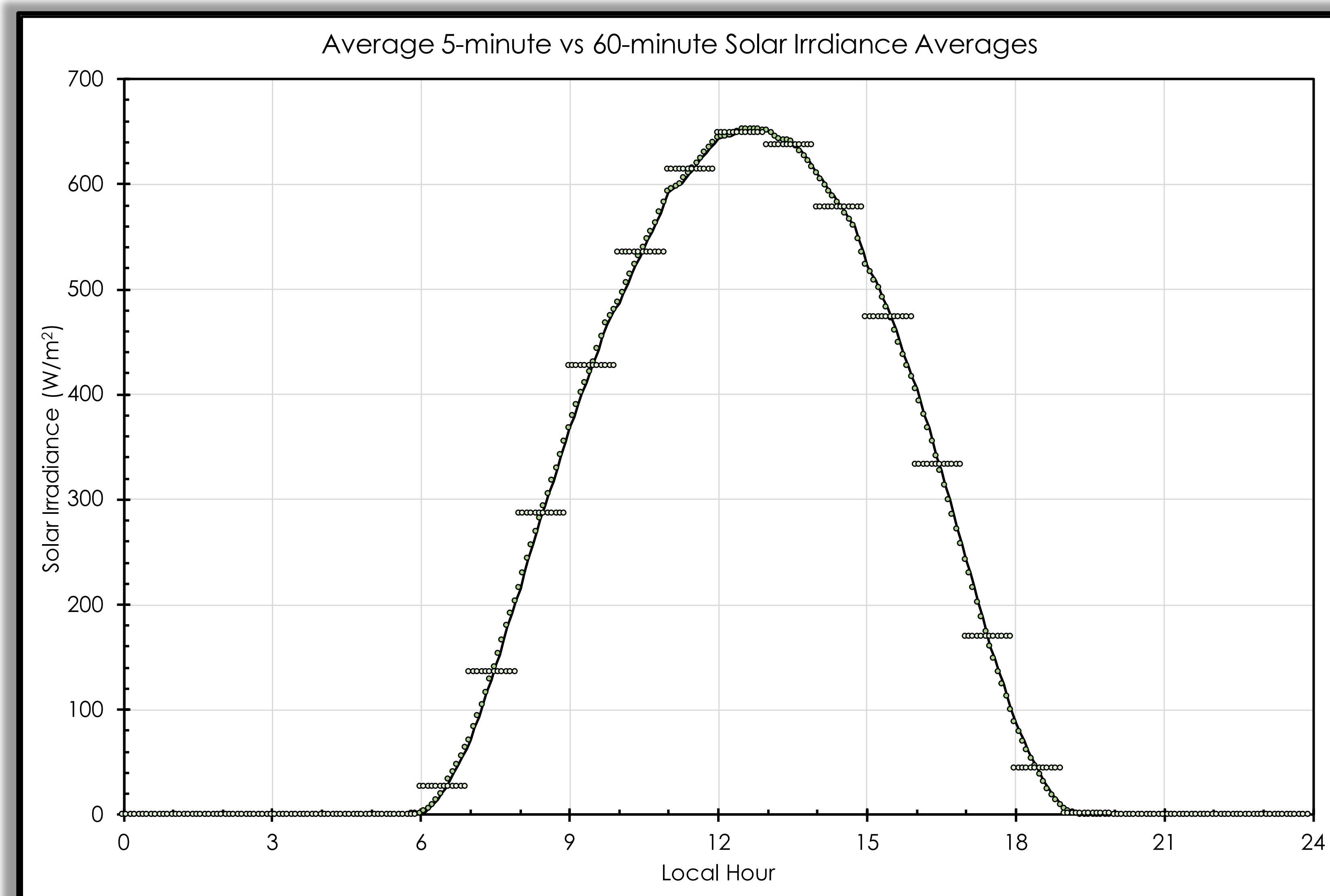
5. The measurements are taken for each of the weather years, the closest 5-minute interval and aligned to the correct UTC time

6. The data is quality controlled, and all night-time measurements were removed. The regression is trained at sites that are dispersed across the USA.

7. Separate regressions are performed with and without satellite data, so that when no satellite is available an approximation is made.

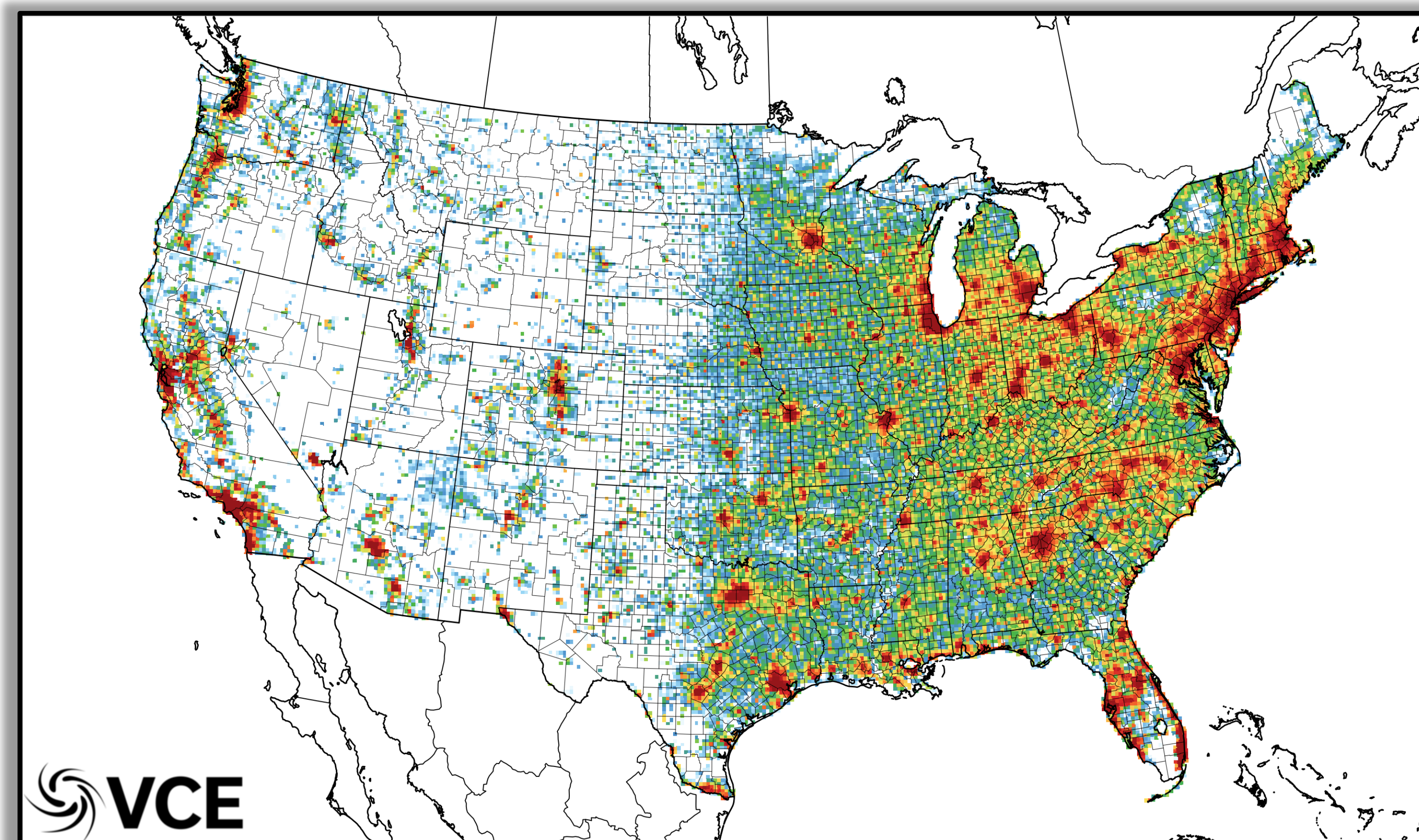
Clack, JAMC, 2017

Weather-Informed Modeling



Weather-Informed Modeling

Note: Logarithmic Color Scale



Maximum
2.5 W/m^2

Minimum
2.5x10^{-5} W/m^2

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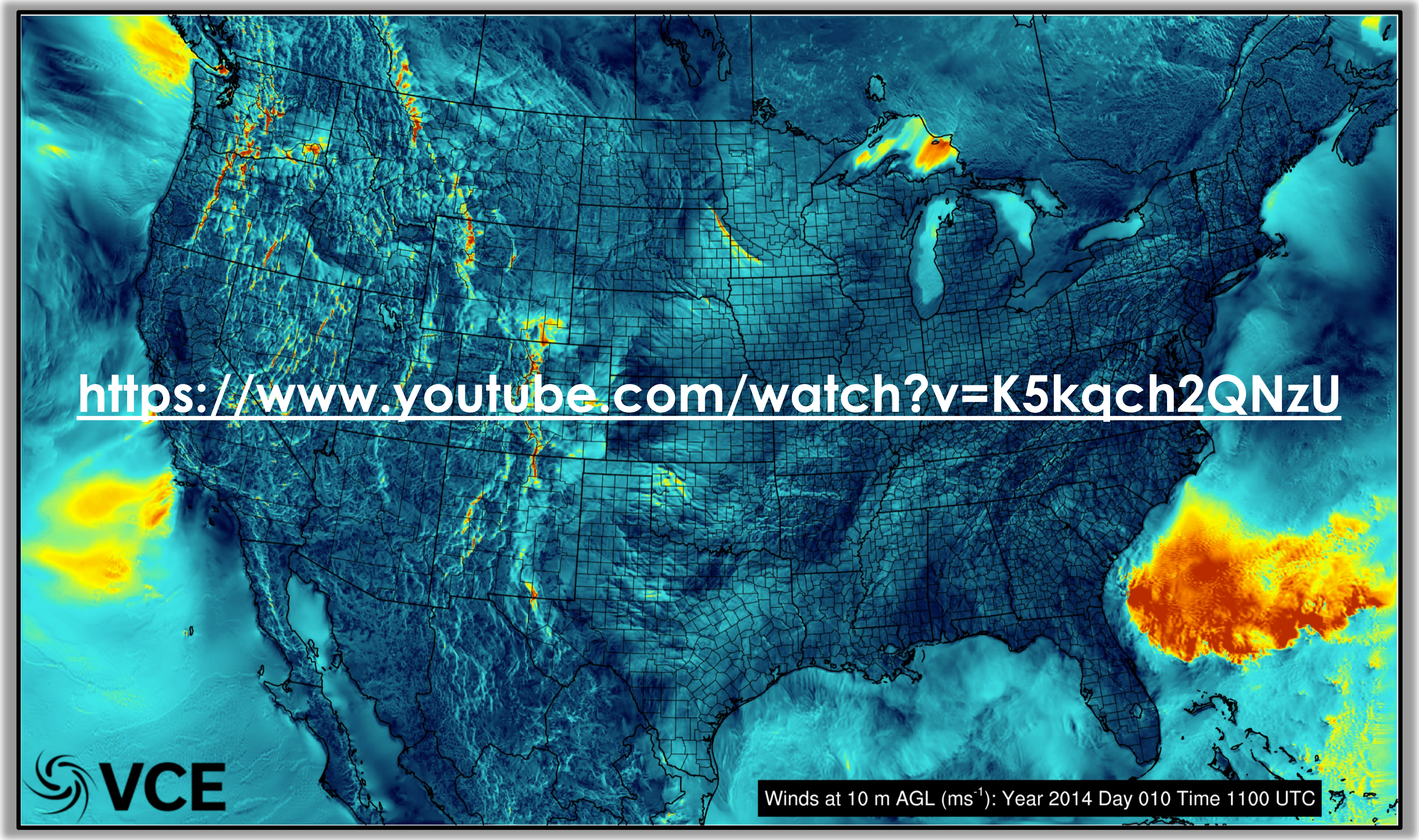
Wind Speed From 3-km, 5-min Dataset



https://www.youtube.com/watch?v=K5kqch2QNzU

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PV Power From 3-km, 5-min Dataset

The Study Scenarios

Scenario	Target / Purpose	Wind %	Solar %	Distr. PV %	Storage %	DS %	EV %	Trading	Tx. Expansion
1	Optimal MISO Expansion							None	
2	Optimal Wind Siting	100						None	
3	Optimal Solar Siting	100						None	
4	Optimal Wind & Solar Siting	100						None	
5	Equal Wind & Solar Siting	50	50					None	
6	Optimal Distr. PV Siting			10				None	
7	Optimal Siting with Storage				2			None	
8	Optimal Siting with DS					10		None	
9	Optimal Siting with EVs						10	None	
10	Optimal EI Expansion								
11	Optimal MISO Expansion							Current	Current
12	Optimal Wind & Solar Siting	50		10	0.1	10	10	Current	Current
13	Optimal Wind & Solar Siting	50		10	0.1	10	10	Expand	Expand
14	Optimal Wind & Solar Siting	75		20	0.2	20	20	Current	Current
15	Optimal Wind & Solar Siting	75		20	0.2	20	20	Expand	Expand
16	Optimal Wind & Solar Siting	90		30	0.3	30	30	Current	Current
17	Optimal Wind & Solar Siting	90		30	0.3	30	30	Expand	Expand
18	Optimal Wind & Solar Siting	100		30	0.4	30	50	Current	Current
19	Optimal Wind & Solar Siting	100		30	0.4	30	50	Expand	Expand
20	Dealer's Choice								

Not constrained
MISO Only
Eastern Interconnection

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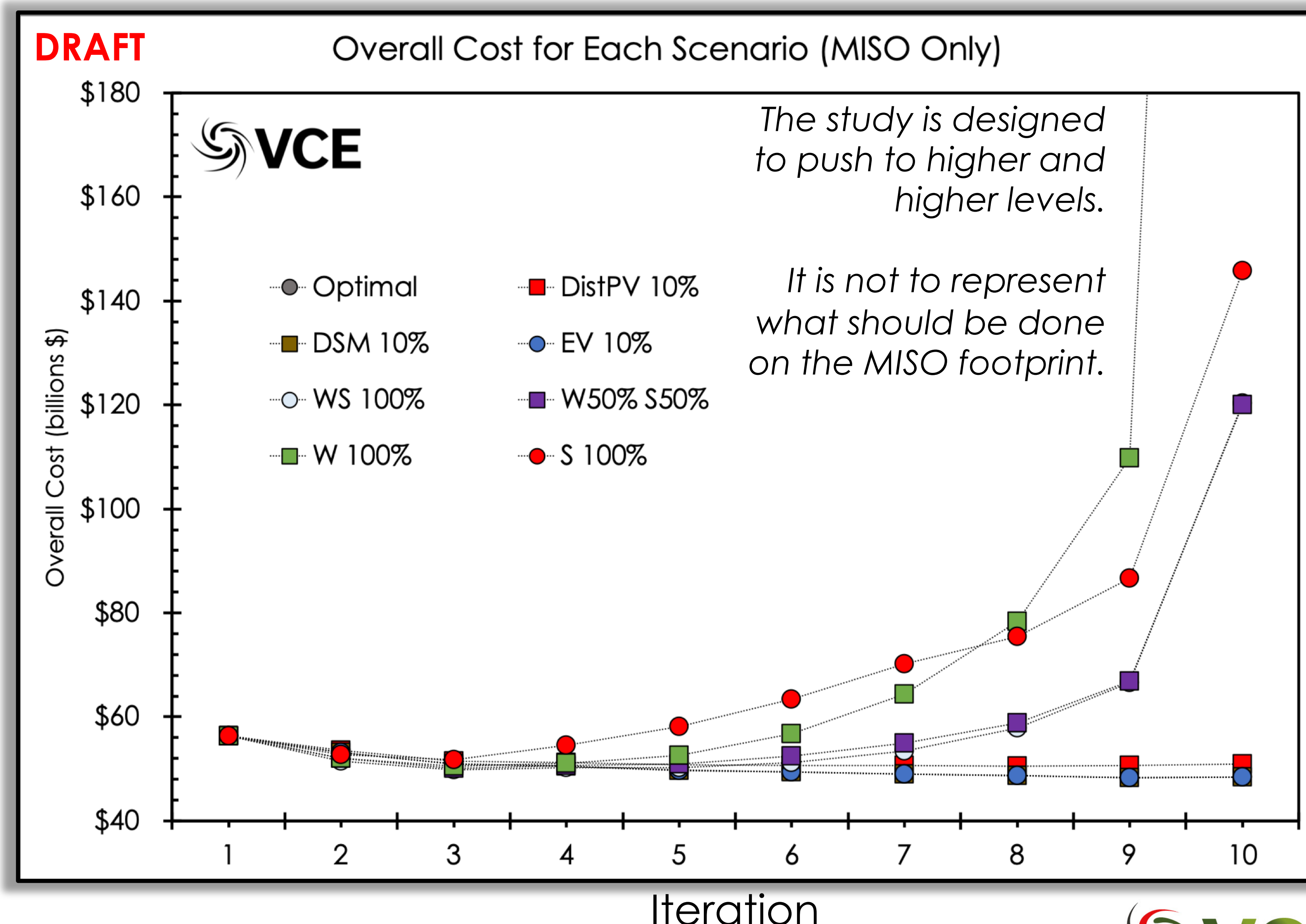
Some Results (illustrative)

System Costs For MISO



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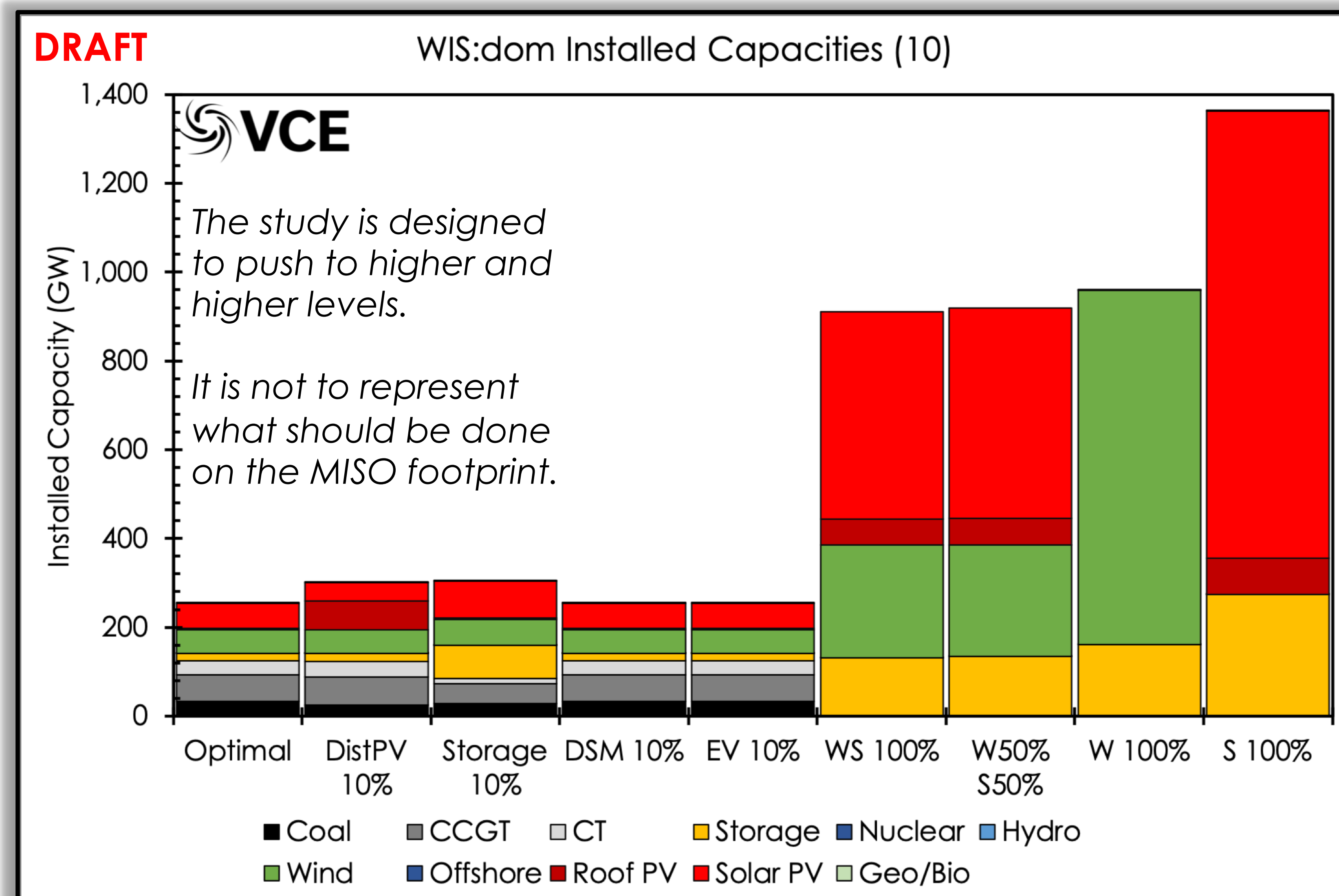
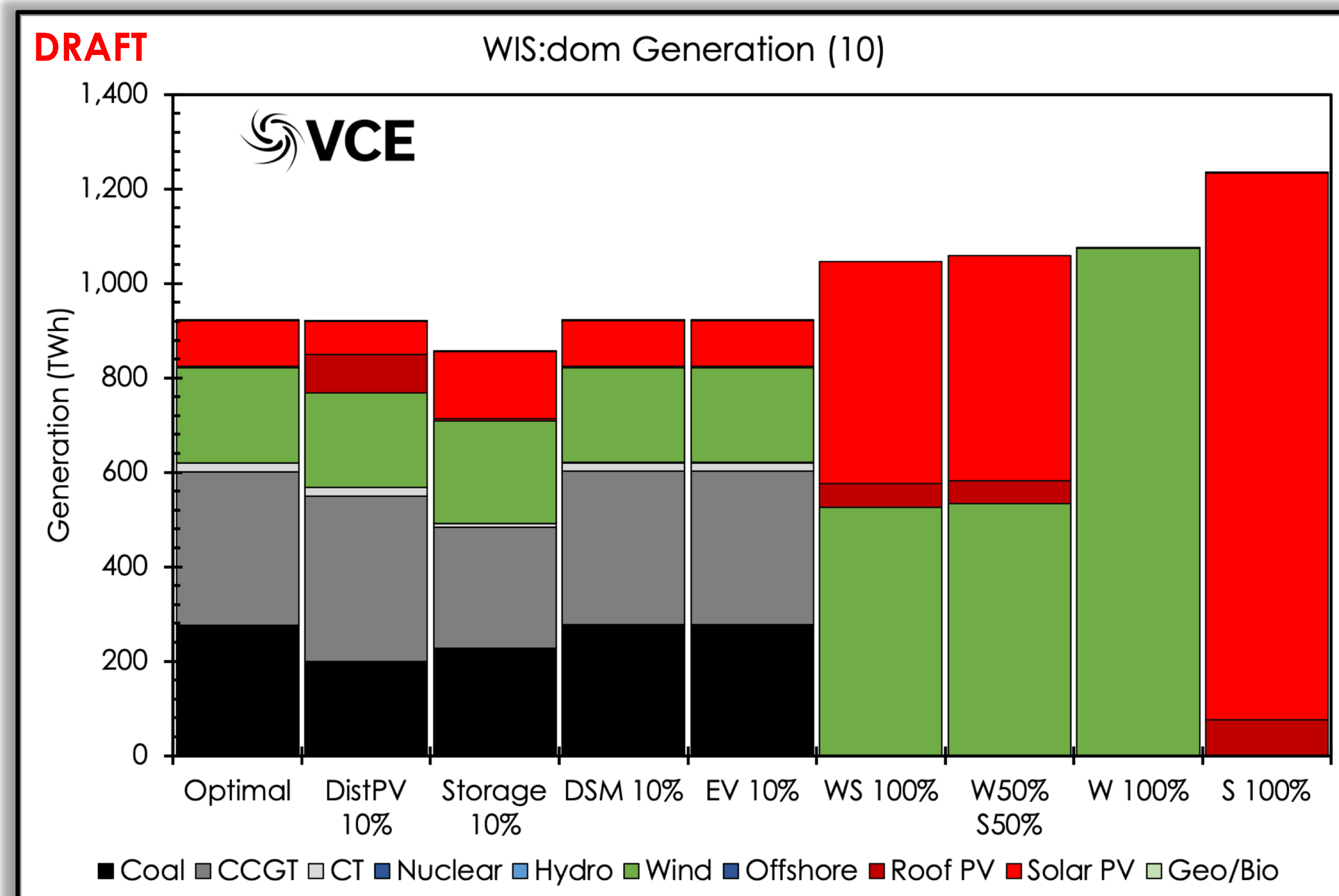
Installed Capacities For MISO



Generation For MISO



The study is designed to push to higher and higher levels.
It is not to represent what should be done on the MISO footprint.

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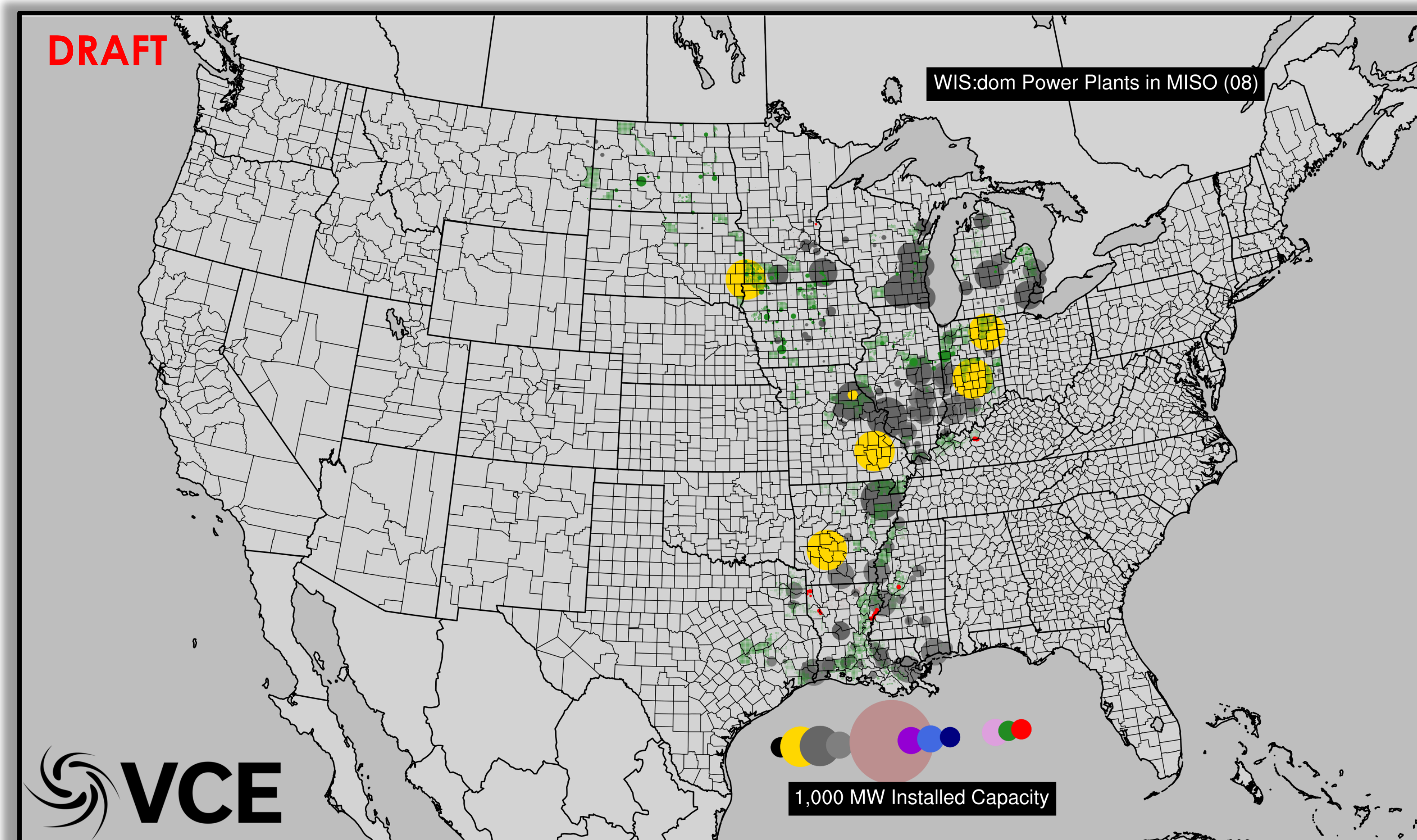
Siting For MISO – Wind



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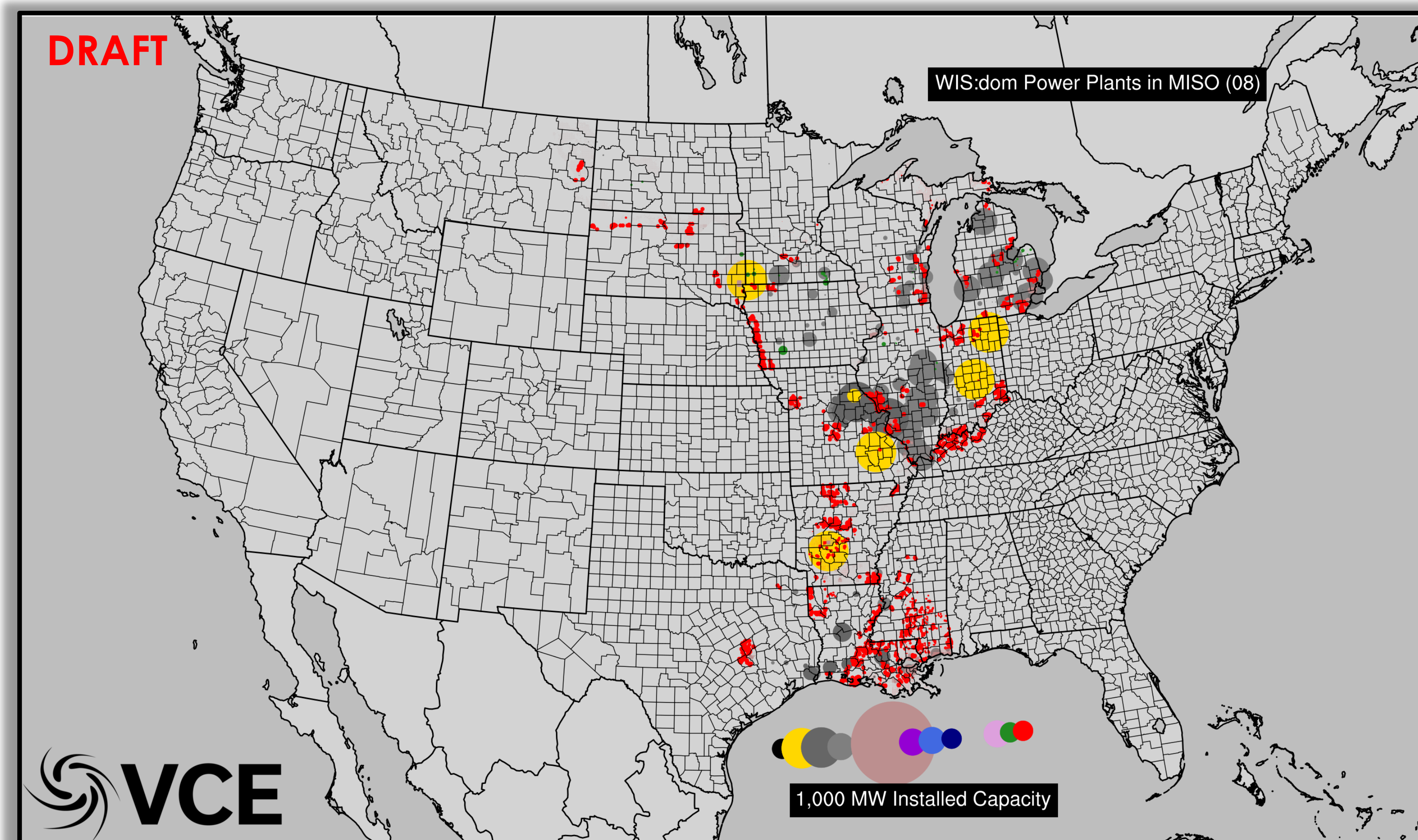
Siting For MISO – Solar



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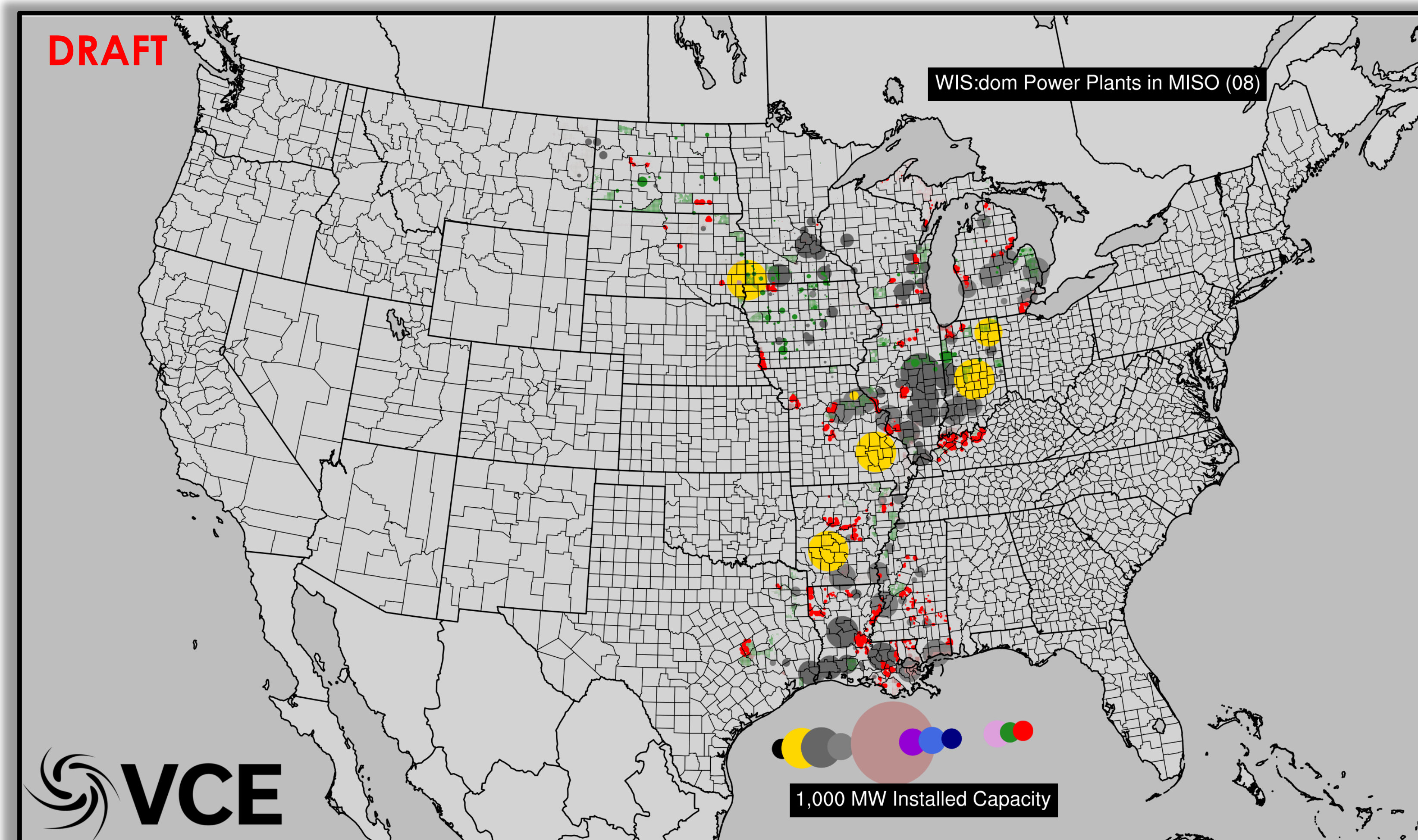
Siting For MISO – Wind & Solar



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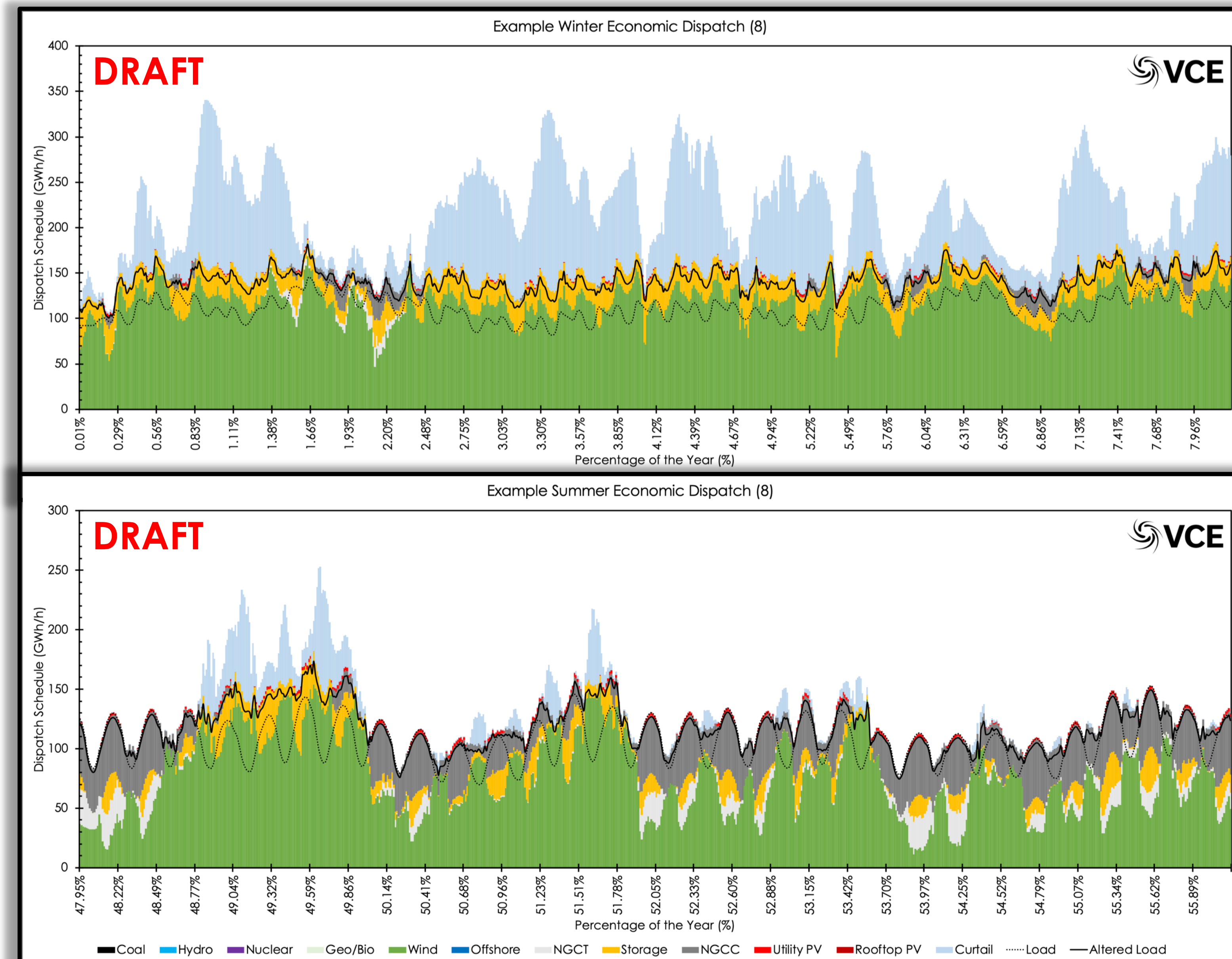
Dispatch For MISO – Wind



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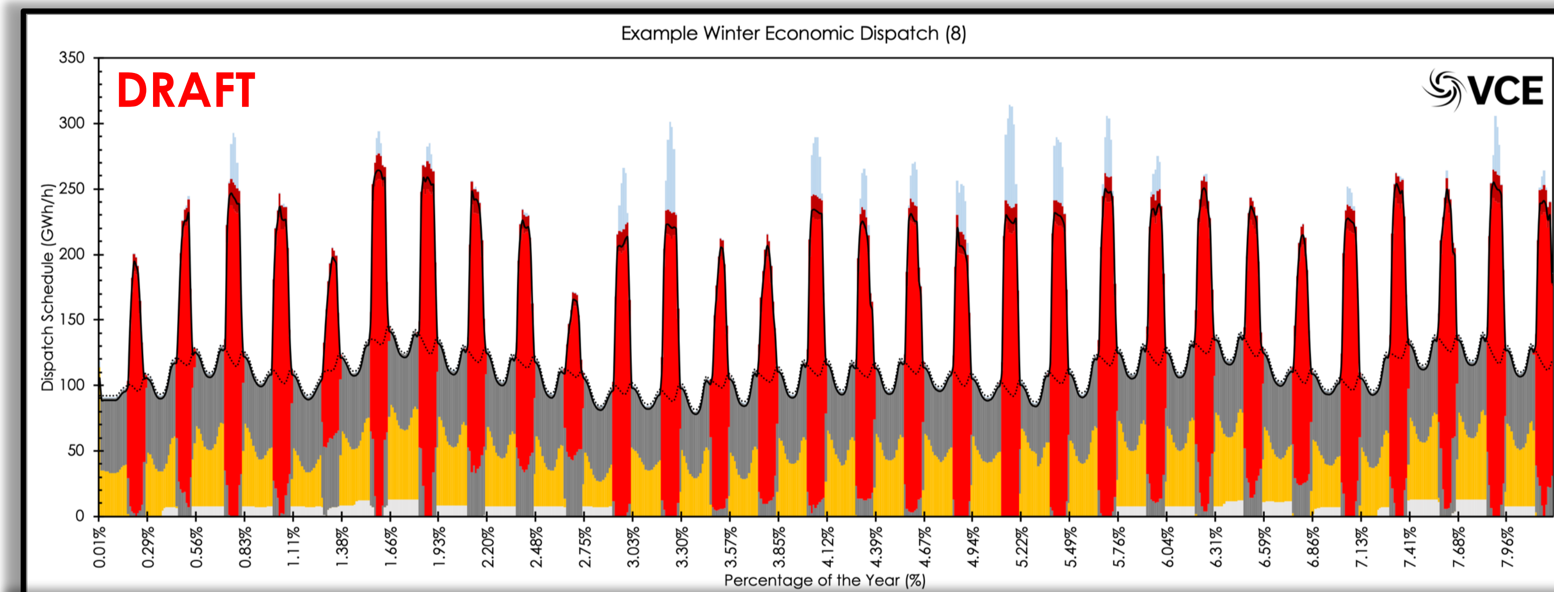
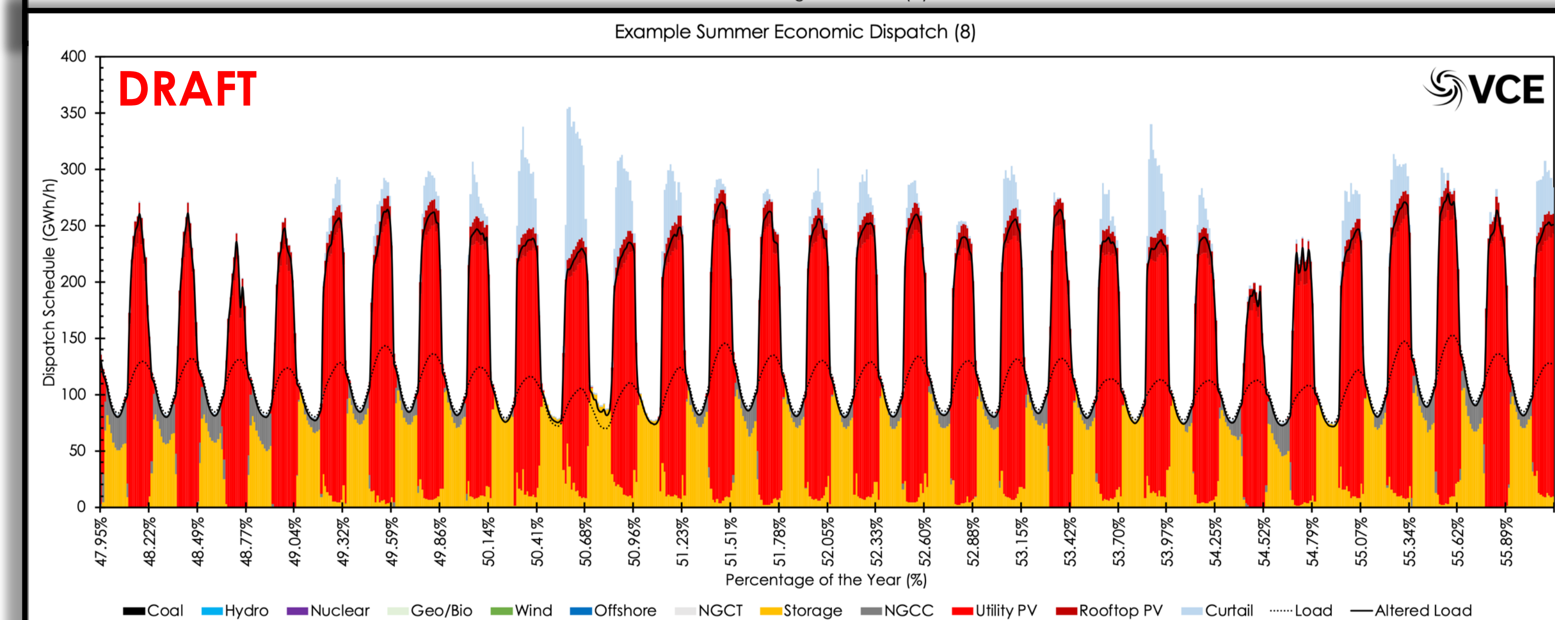
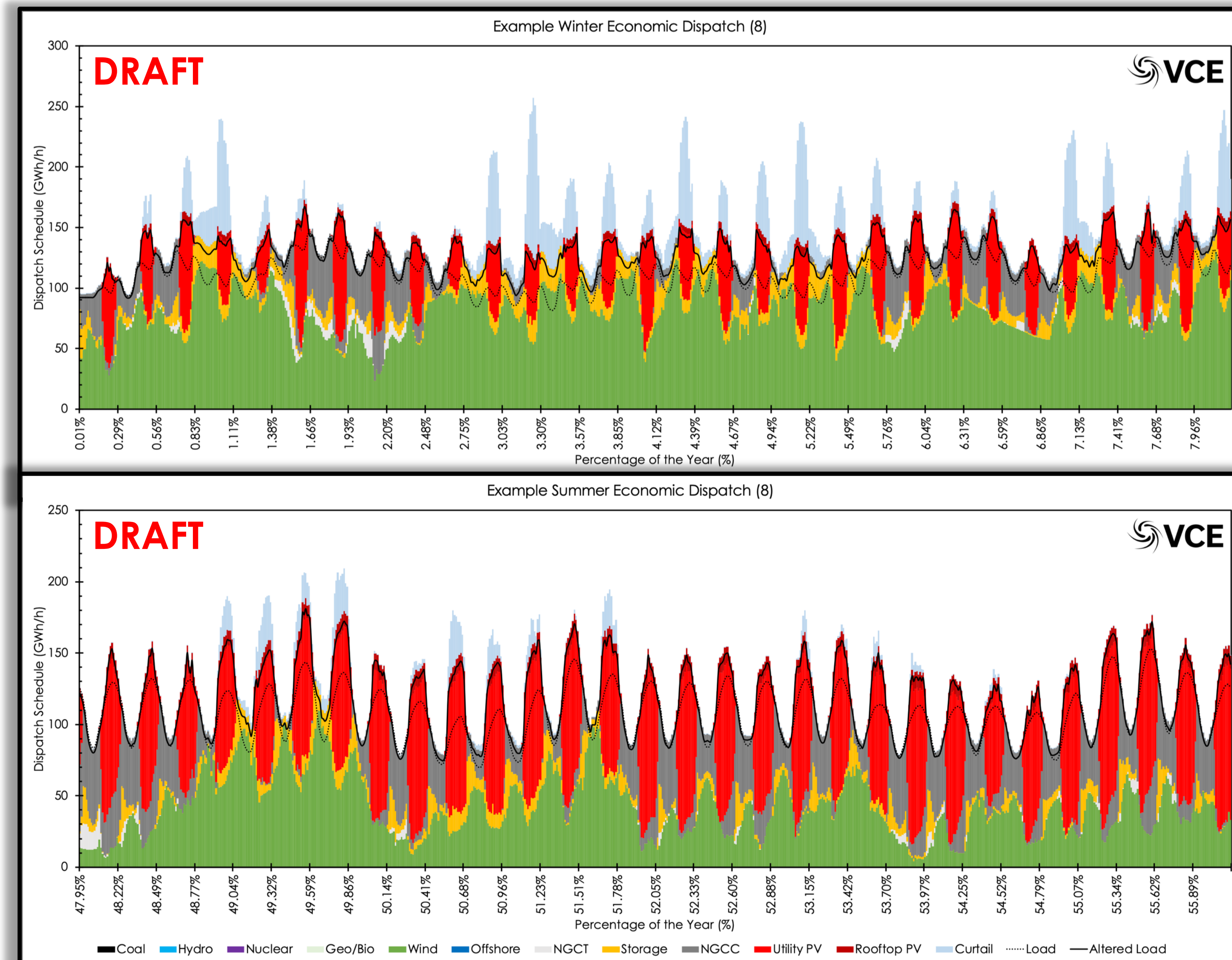
Dispatch For MISO – Solar





Dispatch For MISO – Wind & Solar



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General Findings (Preliminary)

- MISO is capable (in theory) of evolving into numerous future states that can range from high thermal generation to highly specialize systems for variable generation of a single type.

- The MISO grid is big enough that with transmission expansion can find adequate siting for VREs that can manage capacity value decline with increasing shares of renewables.

- The demand-side resources does not dramatically alter the siting prospects for VREs (when considering DSM and EVs). Heating would likely create a more localized wind correlation to demand; reducing burden on new transmission.

General Findings (Preliminary)

- The 5-minute, 3-km power data for wind and solar makes integration of new VREs more difficult, particularly for utility solar PV; however, with a small amount of storage and MISO's large footprint these short-timescale fluctuations are overcome without significant cost increases.

- The co-optimization of generation, transmission, storage and demand-side resources creates emergent phenomena:
    1. The transmission and storage act in unison to shift VREs in space and time simultaneously. This allows better line utilization and lower losses;
    2. Demand-side resources competing along with generation allows better capacity factors for generation, reduces some need for transmission, and lowers costs for customers;
    3. The competition and cooperation between generation sources results in siting moving from simple lowest cost generation to greatest system value siting. This manifests with VREs beginning to back each other up on shorter timescales; and on longer timescales, the storage, DSM and thermal generation can fill the gaps.

- Larger footprints alters the highest quality resources for siting when the model pushes to higher levels of VREs. More on this to come.

Thank You

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