100 Percent Study Kick-Off Meeting

August 25, 2021

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Today's Presentations

Study Overview

Workplan & Schedule

VCE Model

Assumptions and Key Inputs

Next steps

Study Scope

Scope based on requirements in the Clean Energy Jobs Act (CEJA) of 2019 and correspondence with State Senator Brian Feldman in February 2021

- Re-do selected portions of the Maryland RPS Study that PPRP submitted to the Maryland General Assembly in December 2019
- Assess the cost and benefits of a 100% RPS and a 100% clean energy standard by 2040
- Determine which industries and communities could be positively and negatively impacted
- Design mechanisms to alleviate any negative impacts for affected workers and communities
- Recommendations to change the Maryland RPS or recommendations for incorporation into future proposals for a Maryland clean energy standard

Working Group

- Membership -- Utilities, PJM, renewable energy developers/industry groups, other energy companies/industry groups, citizens, state agencies/orgs, county agencies/associations

- Role and Anticipated Focus Areas – provide feedback on standard scenario selection, sensitivity scenario selection, key input assumptions, and model run results

- Process – Presentations provided in advance; live input at Working Group meetings; follow-up comments

- Documentation – all presentations and comments will be posted on PPRP's website (https://dnr.maryland.gov/pprp/Pages/default.aspx)

- Communications – Primary POC – Fred Kelley, PPRP, frederick.kelley@maryland.gov

- ***Thank you in advance for making the time to share your expertise and perspectives. We know your input is vital to creating a robust final report.***

Today's Presentations

- Study Overview
- **Workplan & Schedule**
- VCE Model
- Assumptions & Key Inputs
- Next steps

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We'll be using Vibrant Clean Energy's WIS:dom Model

- Both a capacity expansion model and a production cost model
- Continental-scale, spatially-determined co-optimization of transmission, generation and storage expansion while simultaneously determining the dispatch of these sub systems at 13-km or 3-km, hourly or 5-minute 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;
  - Existing generator and transmission asset attributes such as heat rates, line losses, power factor, variable costs, fixed costs, capital costs, fuel costs, etc.;

Potential Scenarios

Initial Scenarios

- Base Case (50% RPS by 2030)
- 100% RPS by 2040
- 100% clean energy standard by 2040

Possible Sensitivity Scenarios

- Low Cost Renewables
- Electrification
- National Clean Energy Standard
- Climate Change
- High Transmission Costs
- PJM High Renewables/Clean Energy
- Retirement or Relicensing of Calvert Cliffs (depending on results of previous model runs)

Project Organization

- Budget is limited to 20 scenarios
- Project will largely be done sequentially
  - Will do production cost modeling first, then input-output modeling for determining employment and community impacts
  - Mechanism design to mitigate negative community and employment impacts, and recommendations/conclusions closes the project.

Preliminary Project Schedule

- August: Vet standard scenarios and input assumptions with working group
- September/October: Run model/analyze results; vet results with PPRP and working group, re-run model as needed
- November: Recommend sensitivity scenarios and vet with PPRP and working group, begin sensitivity model runs
- January: Finish sensitivity cases, analyze and share results with PPRP and working group
- February: Re-run sensitivity cases as needed
- March 2022: Finish modeling, use model output for input-output modeling

Project Schedule (2)

- May/June 2022: Finish input-output modeling, begin drafting report
- Winter 2022/Spring 2023: Finalize and issue report
- January 1, 2024: Final deadline for providing the report to the Governor per CEJA

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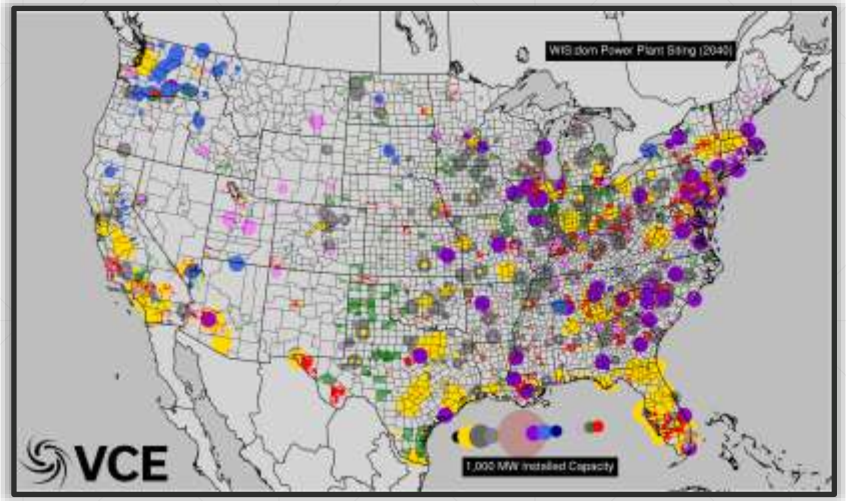
Who We Are: Vibrant Clean Energy



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.
- We have worked with ISOs (MISO), Cooperatives (Holy Cross and the Intermountain Rural Electric Association), the University of Texas, and various nonprofits and advocates.

The VCE® Team

Christopher T M Clack (lead, modeling, analysis, writing);

- Founded VCE® to democratize and expand modeling for clean energy futures,
- Wrote the original WIS:dom® model,
- Created all of the original datasets for the modeling platform,
- Delivered multiple dozens of studies and projects for clients in the academia, government and industry,
- At previous position created NEWS, helped with HRRR model, helped enhance WFP in WRF, assisted solar and wind forecast improvement projects, reviewed tens of DOE and ARPA-e proposals.

Aditya Choukulkar (modeling, grid topology, climate datasets, analysis, writing);

- Expanded all the climate datasets for use in WIS:dom® for higher fidelity,
- Enhanced the transmission topology datasets for ingestion into WIS:dom®,
- Helped create new derivatives of WIS:dom® for different tasks,
- Recomputed the weather datasets along with Bri to increase accuracy,
- Delivered several studies for clients using WIS:dom®,
- At previous position, investigated wind turbine effects and improved data for forecasting winds using LiDARs and assimilating the data into NWP. Also participated in numerous cross-discipline studies for improving weather and power forecasting.

Brianna Coté (generator datasets, standard inputs, weather datasets, validation, writing);

- Produces the weather and power datasets for WIS:dom® and licensing to clients,
- Validates the weather data to observations, SCED and other sources to QA/QC the production datasets,
- Creates and maintains the “standard” input datasets for WIS:dom®, including the existing generators, projected costs, parameters for existing and new generators, mandates and policies, as well as all forecast datasets,
- Manages projects for VCE® and liaises with clients,
- At previous position, maintained and used large datasets for energy markets across the United States as well as producing and delivering weather forecast data for commercial clients.

Sarah A McKee (input validation, potential screening dataset, analysis, writing);

- Assists with checking and validating all datasets for consistency and manages dataset archives,
- Performs logistics for VCE®, with respect to project deadlines and HR,
- Assisted creating the original transmission datasets, the resource potential datasets, and “standard inputs”,
- Provides assistance for documentation, graphic design and model execution,
- At previous position, was a scientific writer for the largest European Respiratory journal becoming a managing editor.

VCE® Tools & Data

- WIS:dom® variants:
  - ✓ ***WIS:dom®-P - The full planning version and our flagship model;***
  - ✓ ***WIS:dom®-D*** *- The full SCED version**;***
  - ✓ ***WIS:dom®-B -*** The baseload generation version that will be open source (waiting for publication);
  - ✓ ***WIS:dom®-T -*** The targeting version;
  - ✓ ***WIS:dom®-L -*** The local version;
  - ✓ ***WIS:dom®-H -*** The hybrid generation version;
  - ✓ **All modeling tools are available already for studies that VCE® performs**.

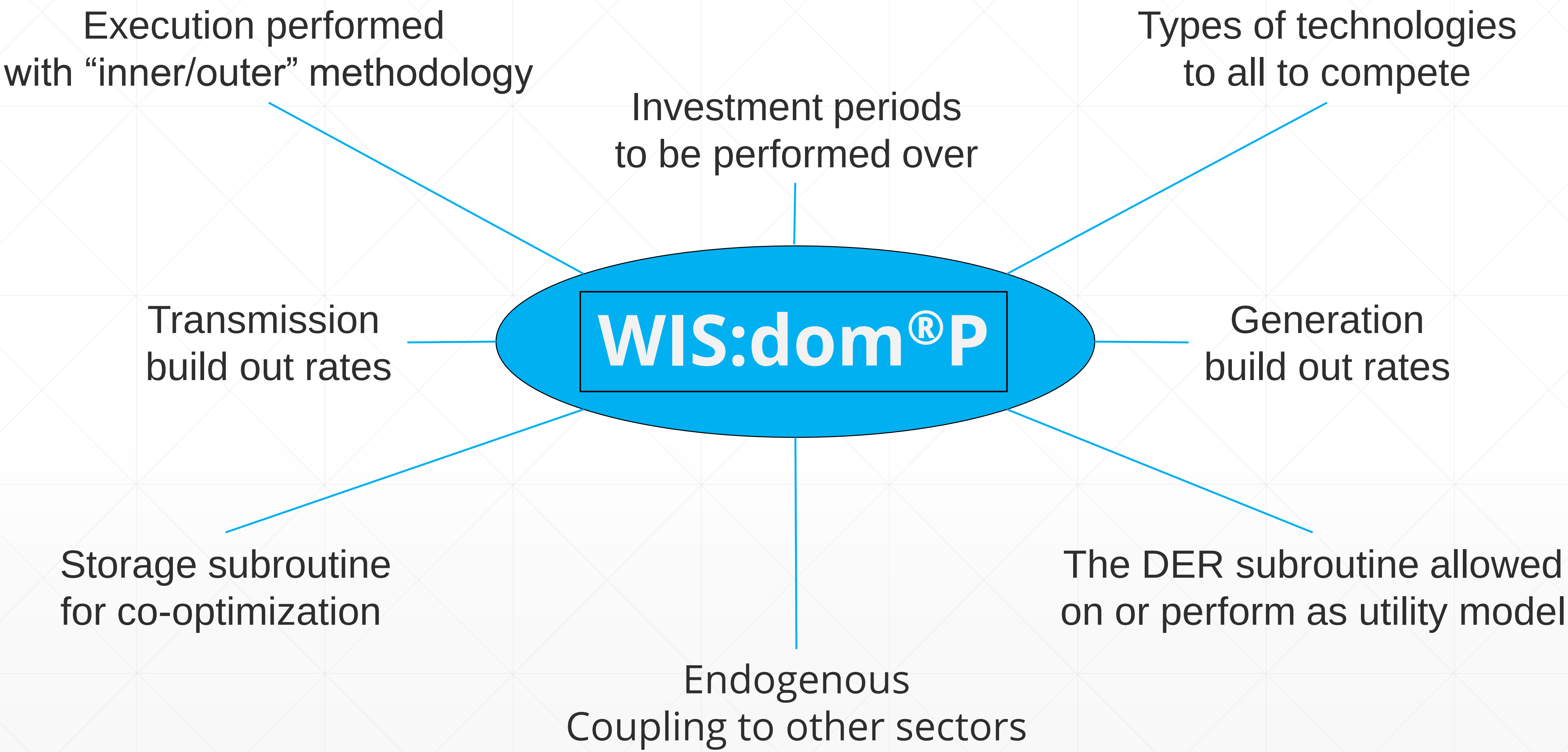
- ***Weather and power datasets for Variable Renewable Energy*** are ready to license to clients. The datasets are available at 3-km, 5-minute for the past 8 calendar years and are produced for numerous technologies (***2013 – 2020***). There are extension datasets at 13-km, hourly for the United States from ***2006 through 2016***. Clients can license all of the United States or single sites. By the end of Q3 2020, ***175 years of global weather data at 30-km, hourly*** will be available with all the same technology classes (testing and validation is currently ongoing). These are already used in VCE® studies.

- The ***existing grid topology*** is also available for license. It includes all generators, transmission (down to 69 kV) and technical potential build out sites. The standard datasets are also available, which include all existing policies, regional cost multipliers, cost projections, fuel elasticity, load projections, load profiles (weather aligned), and other grid parameters. These are already used in VCE® studies.

- The ***Climate Change stress*** on the grid infrastructure (2020 – 2100) is another dataset available from VCE®. It includes changes to wind, solar, hydro, thermal heat rates, transmission line ratings and losses, and demand profiles.

- Consulting studies allows for the most sophisticated WIS:dom® to be deployed without the client needing to invest in the hardware, rather VCE® does this as a service.

WIS:dom® Modeling Setup



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The WIS:dom® Model

WIS:dom®-P is a ***fully combined*** capacity expansion and production cost model.

- ***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 yearly 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.

The WIS:dom® Model

- ***Generation technologies includes:***
  - ✓ Coal power plants;
  - ✓ Natural gas combined cycle power plants;
  - ✓ Natural gas combustion turbine power plants;
  - ✓ Traditional nuclear (LWR & PWR) power plants;
  - ✓ Hydroelectric power plants;
  - ✓ Geothermal power plants;
  - ✓ Biomass power plants;
  - ✓ Onshore wind farms (80 m – 160 m hub heights);
  - ✓ Offshore wind farms (80 m – 240 m hub heights);
  - ✓ Distributed solar photovoltaic power plants;
  - ✓ Utility-scale photovoltaic power plants (multiple tracking, angles & types; including bi-facial);
  - ✓ Natural gas combined cycle with carbon capture and sequestration (pre- and post- combustion);
  - ✓ Enhanced geothermal system power plants;
  - ✓ Small modular reactor nuclear power plants;
  - ✓ Molten salts reactor nuclear power plants;
  - ✓ Hybrid VRE power plants;
  - ✓ Hydrogen turbines.

- ***Transmission, DERs & other technologies includes:***
  - ✓ Overhead AC transmission lines (down to 69-kV) for bands of voltages;
  - ✓ Spur line transmission for all generation to the nearest transmission substation;
  - ✓ Overhead & Underground (along interstate & railroad ROWs) HVDC transmission lines;
  - ✓ Distribution (69-kV) substations and parameterized distribution spur lines to demand;
  - ✓ Utility-scale electricity storage (traditional batteries, pumped hydro, redox flow batteries);
  - ✓ Distributed electricity storage (traditional batteries, demand flexibility, EVs, demand response);
  - ✓ Hydrogen production facilities;
  - ✓ Direct air capture facilities (combined with H_2 if required for P2X);
  - ✓ Haber process production facilities for ammonia production (typically for agriculture);
  - ✓ Sabitier & Fischer-Tropsch processes facilities for dense, synthetic hydrocarbon fuels.

Purple Highlights are available as advanced technologies options to use in studies/scenarios.

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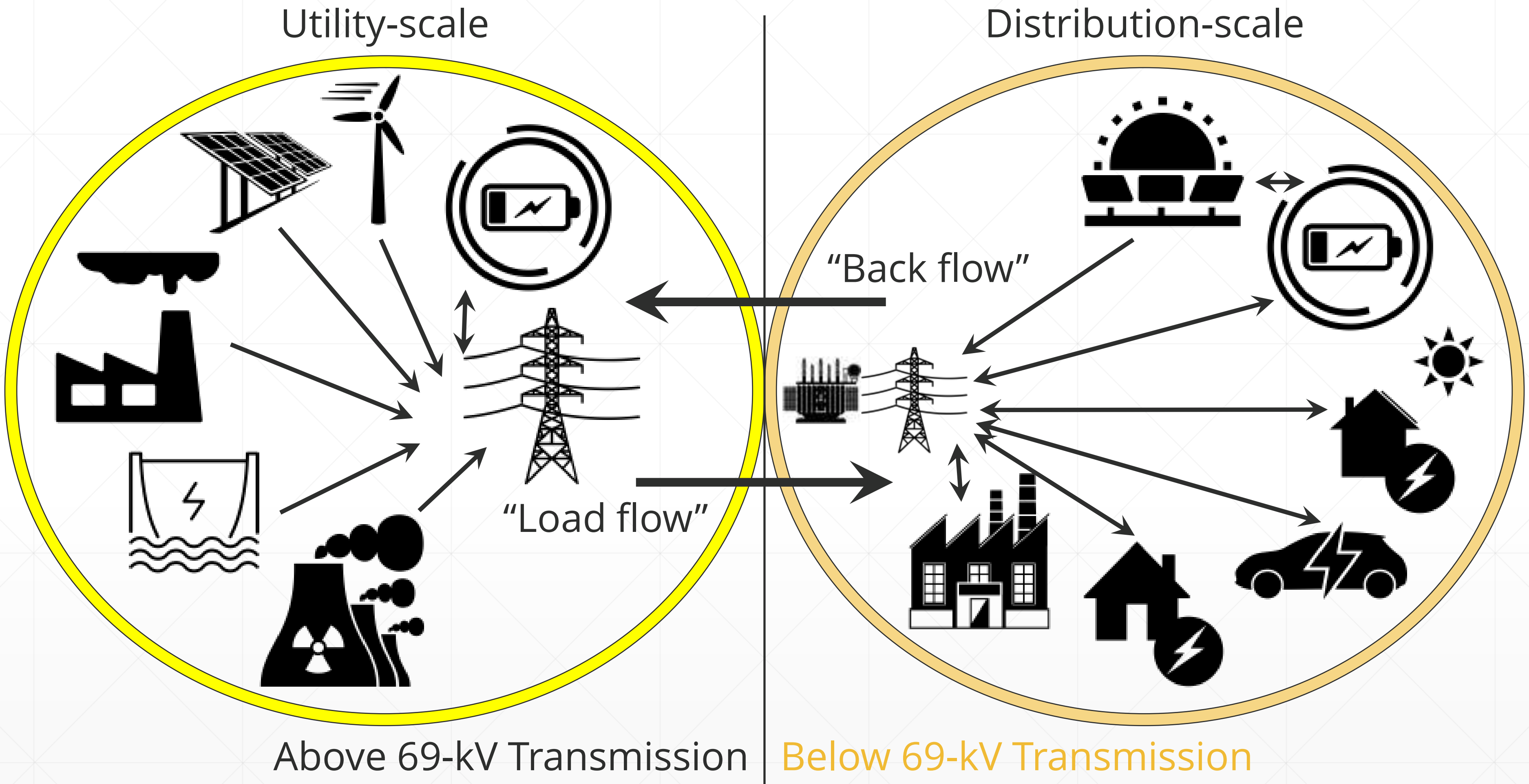
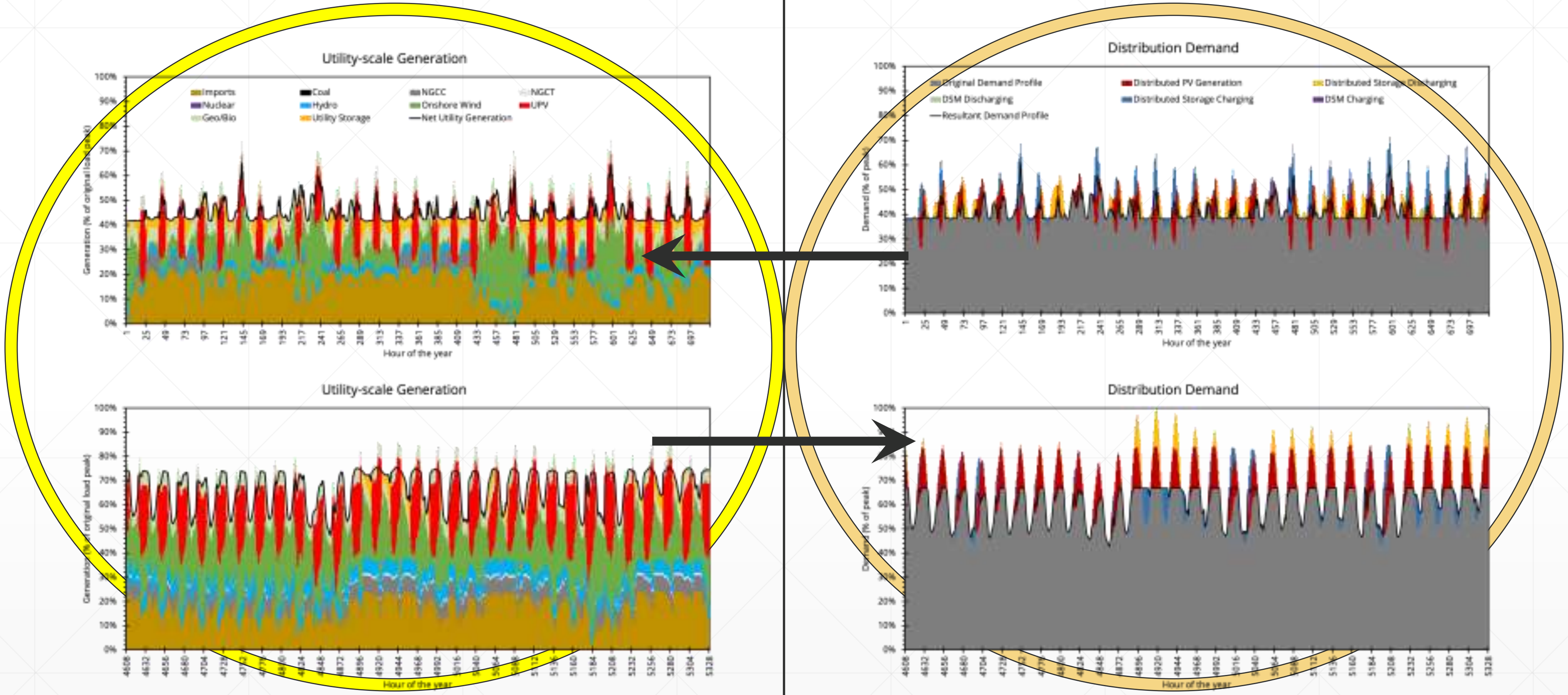
The WIS:dom®-P DER Subroutine



The WIS:dom®-P DER Subroutine

Utility-scale

Distribution-scale



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Datasets for WIS:dom® Modeling

Customizable and adaptable:
New sources easily introduced

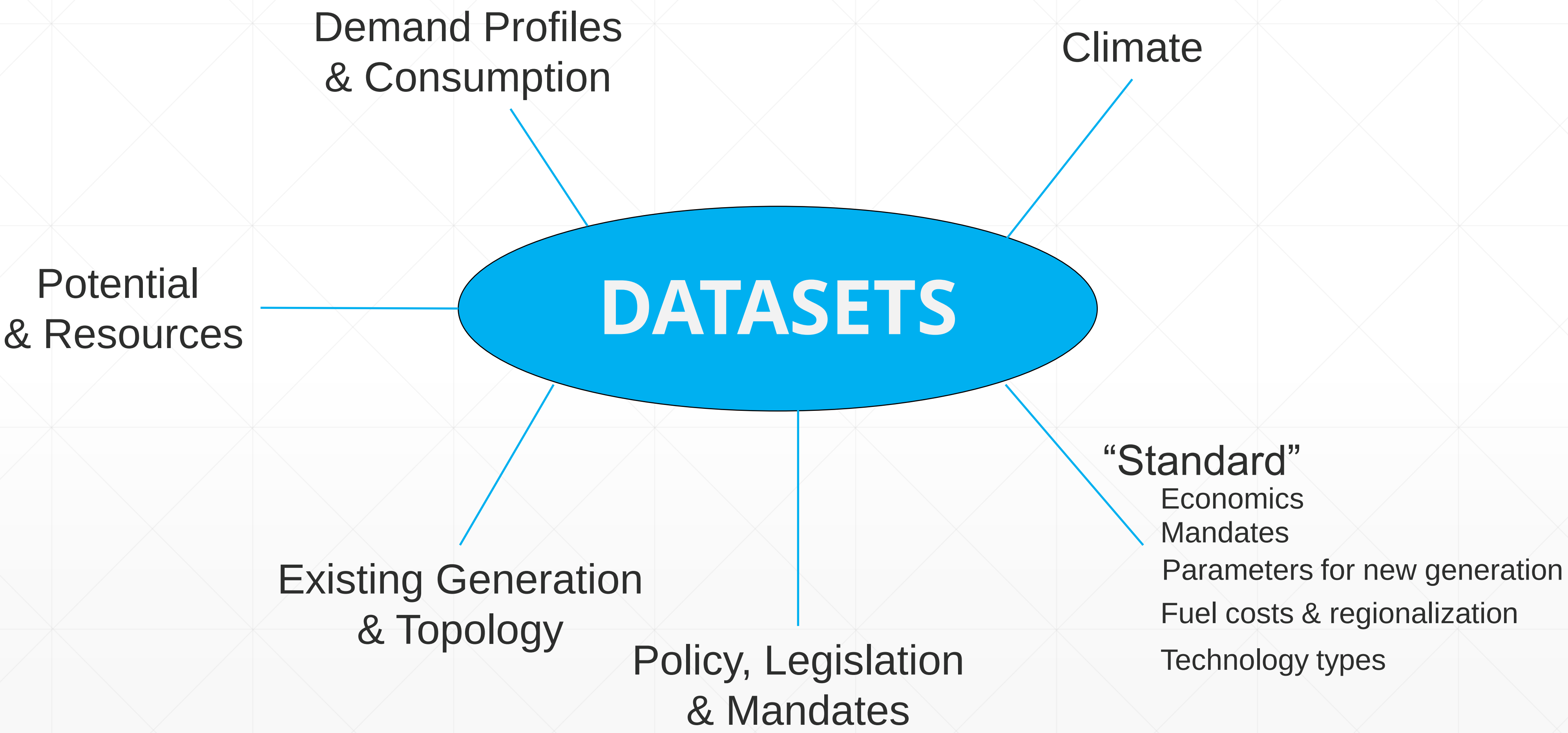
Regularly maintained and updated:
A change grid requirement

DATASETS

Direct Client Input:
Specific client insight can be incorporated

Transparency:
Client has access to all the data going into the model

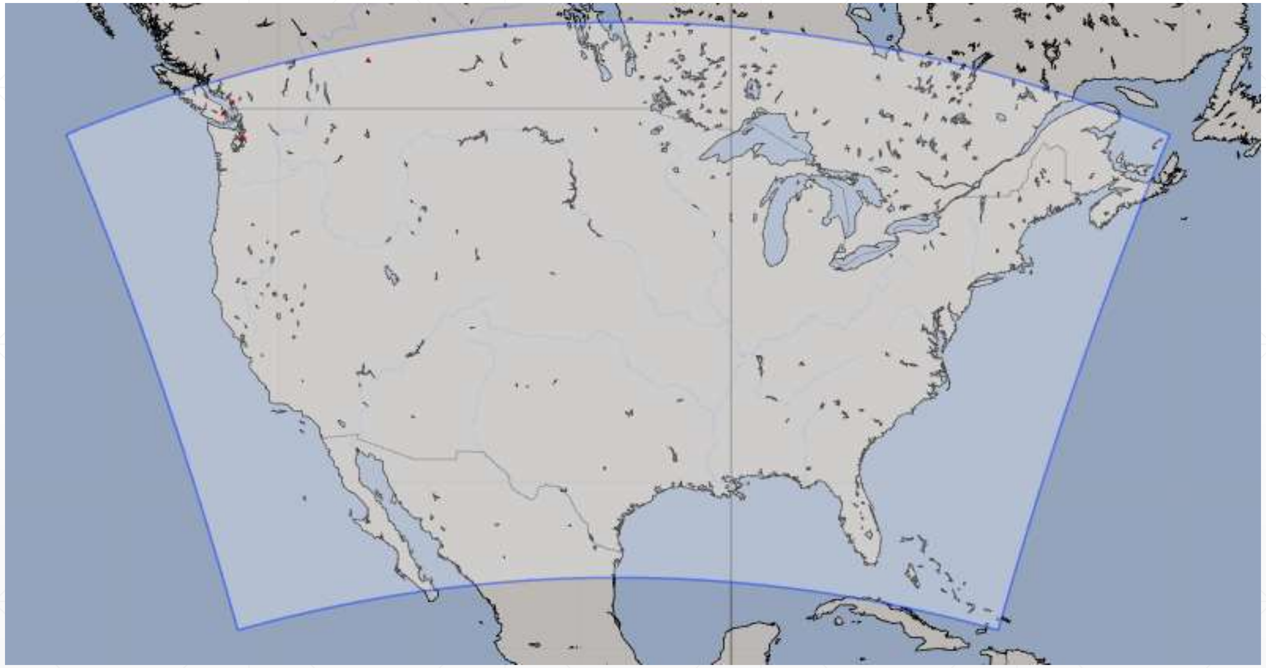
Datasets for WIS:dom® Modeling



Our 3km Grid

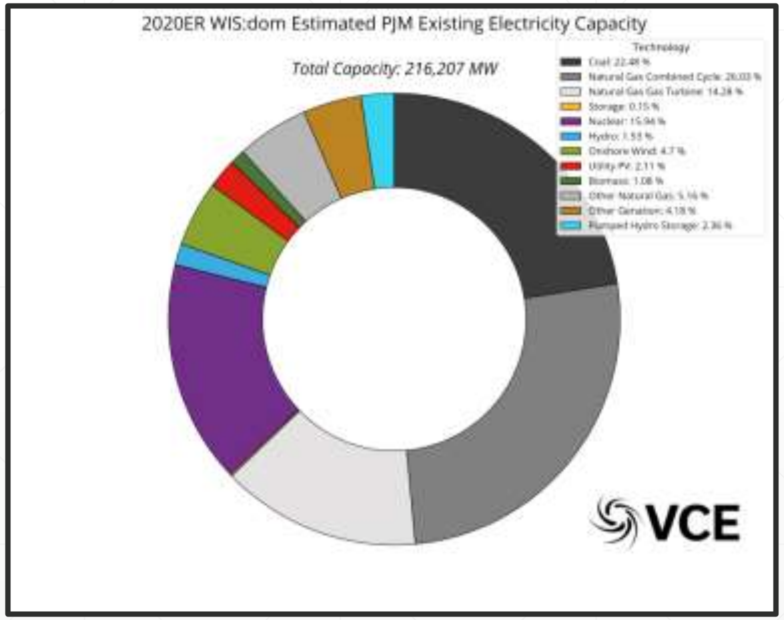
Alignment/Aggregating with HRRR (High-Resolution Rapid Refresh) grid:

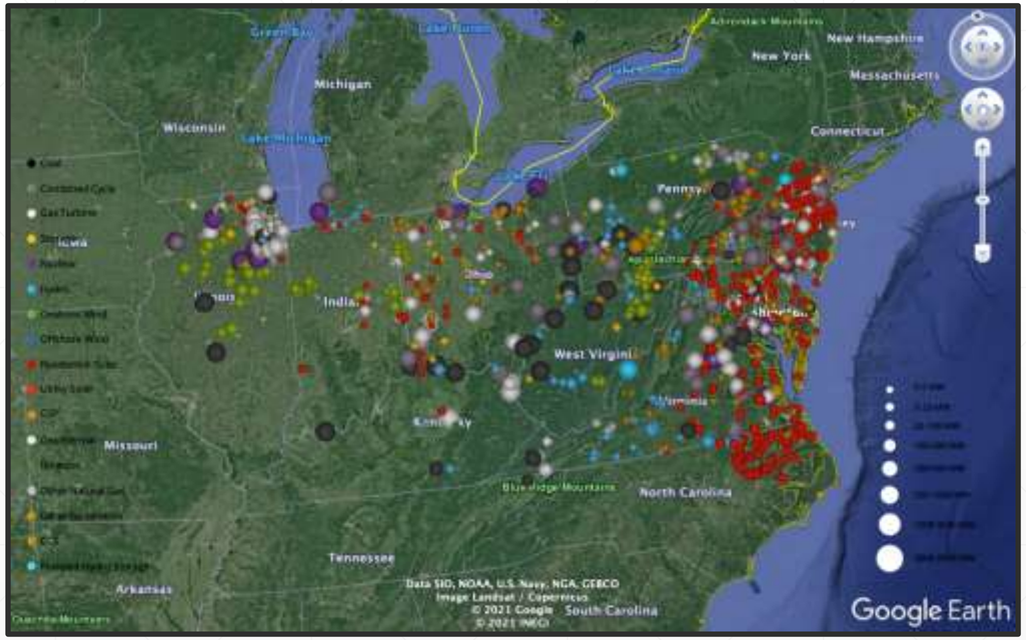
- The National Oceanic and Atmospheric Administration (NOAA) produces the HRRR model which VCE processes for energy applications.
- The HRRR weather model we use is a 5-min, 3-km resolution model. We align and aggregate many types of data into their closest/corresponding HRRR cells based on their location. An example of this is our input generator dataset.



Datasets for WIS:dom® Modeling
Input Generator Dataset Example - PJM

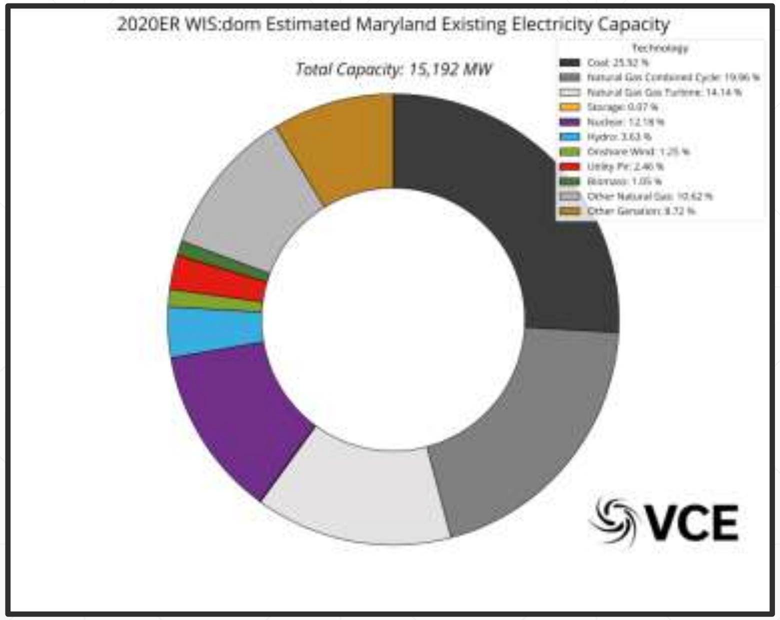
- Spatial view of 2020 Early Release Generator layout across PJM.
- The power plant units are identified and similar units (same technology) in the same 3-km grid cell are considered to be a single “WIS:dom® power plant”.
- Between investment periods, WIS:dom® recomputes the power plants based on retirement and additions.
- Inputs include: heat rates, power factors, minimum up and down times, unforced outage rates, undepreciated asset value, ramping rate constraints, retirement dates, and age.

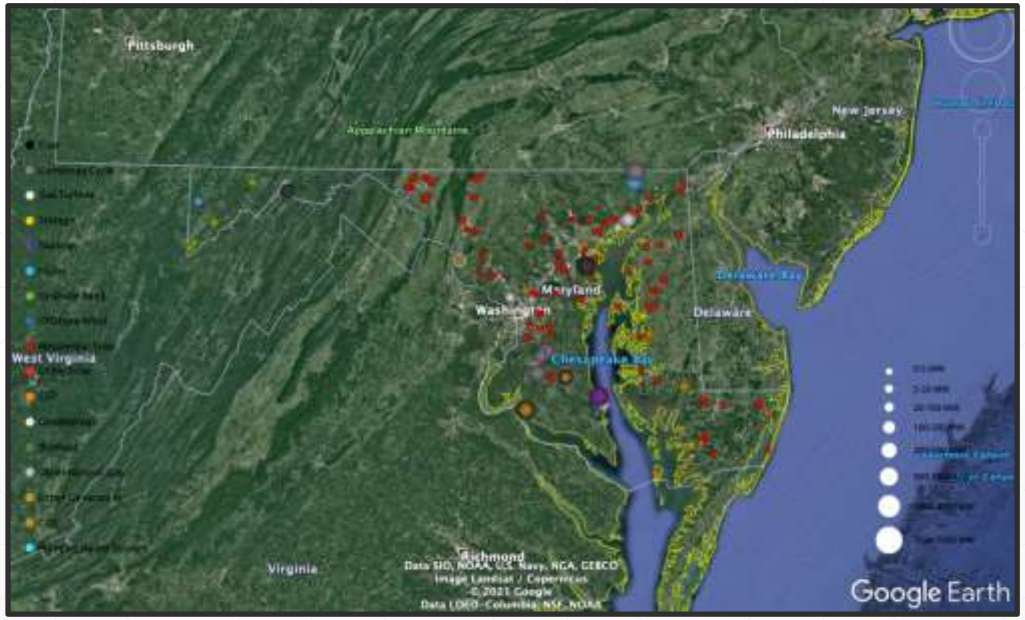




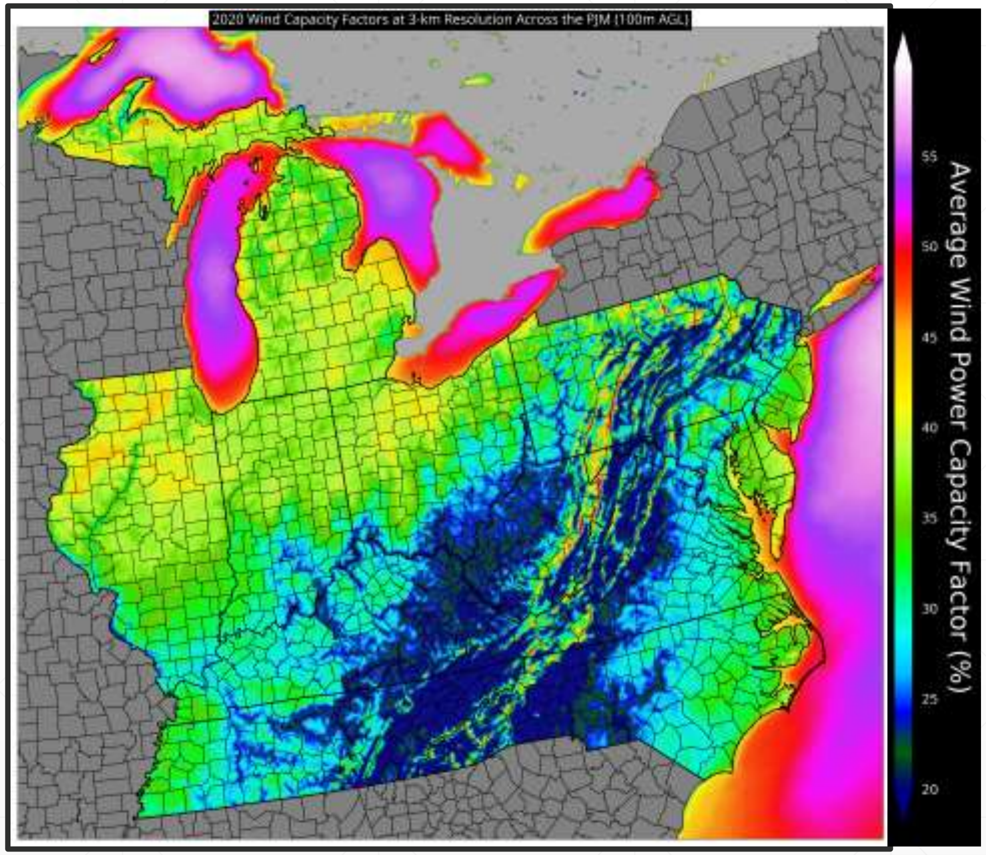
Datasets for WIS:dom® Modeling
Input Generator Dataset Example - Maryland

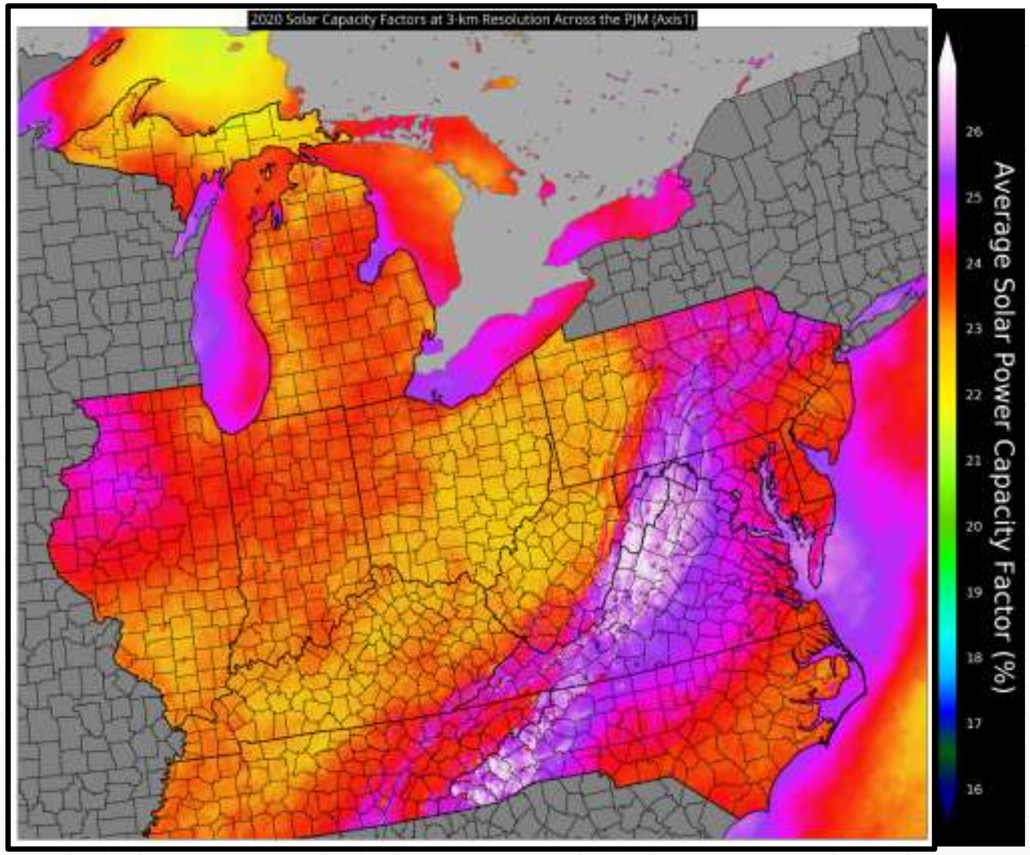
- Spatial view of 2020 Early Release Generator layout across the Maryland.
- VCE is actively working with Exeter to incorporate the PJM GATS data for Maryland (and PJM) and match this information with EIA 860. This will have most impact on distributed solar system representation.



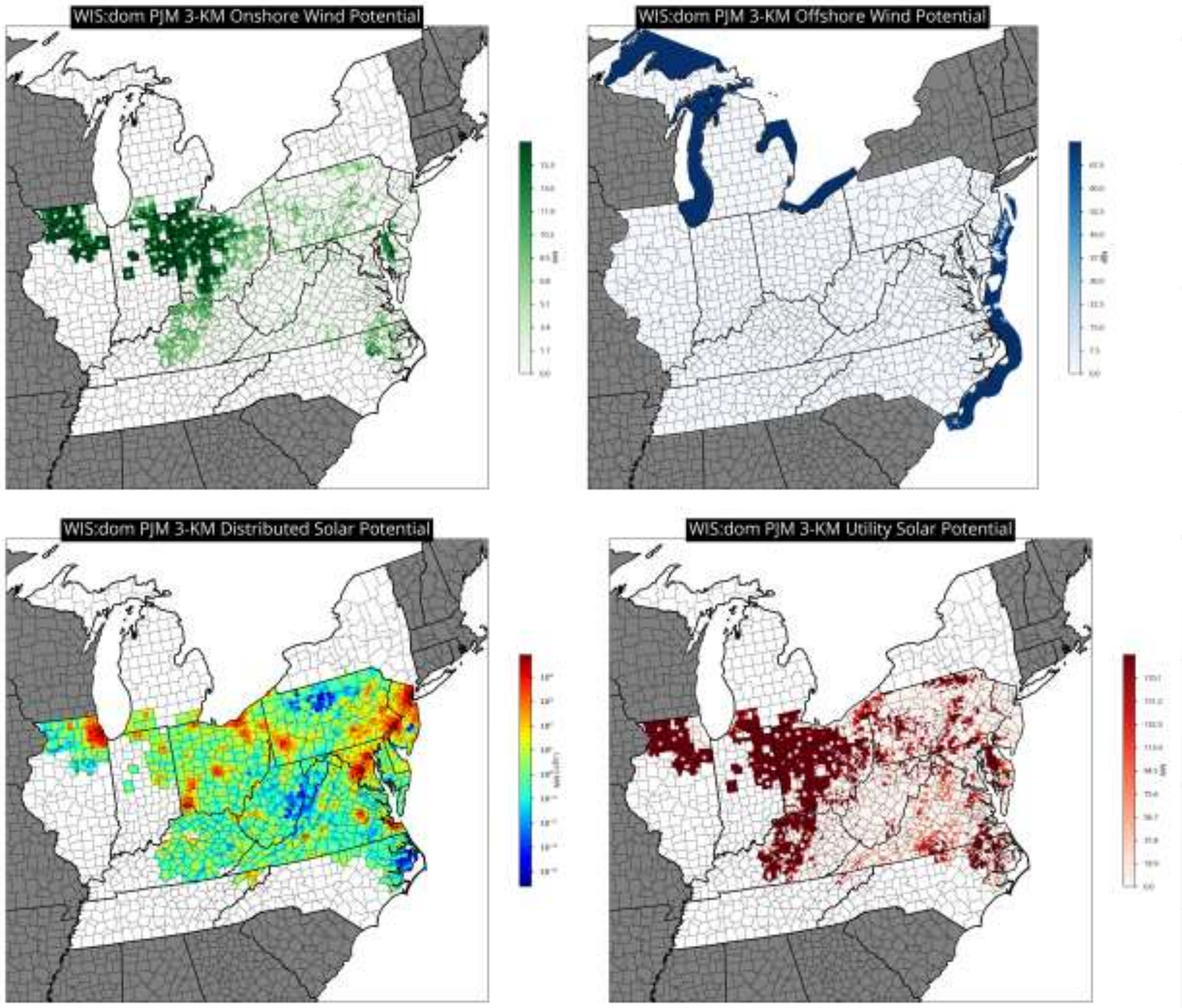


Datasets for WIS:dom® Modeling
Weather Data





Datasets for WIS:dom® Modeling Potential Data



- VCE® performs an extensive screening procedure to determine the siting potential of new generators across the contiguous US. This ensures that the WIS:dom® model has constraints on where it can build new generation.
- USGS Land Use Application
- Example: Remove military sites, land that is too sloped, protected lands such as National Parks.

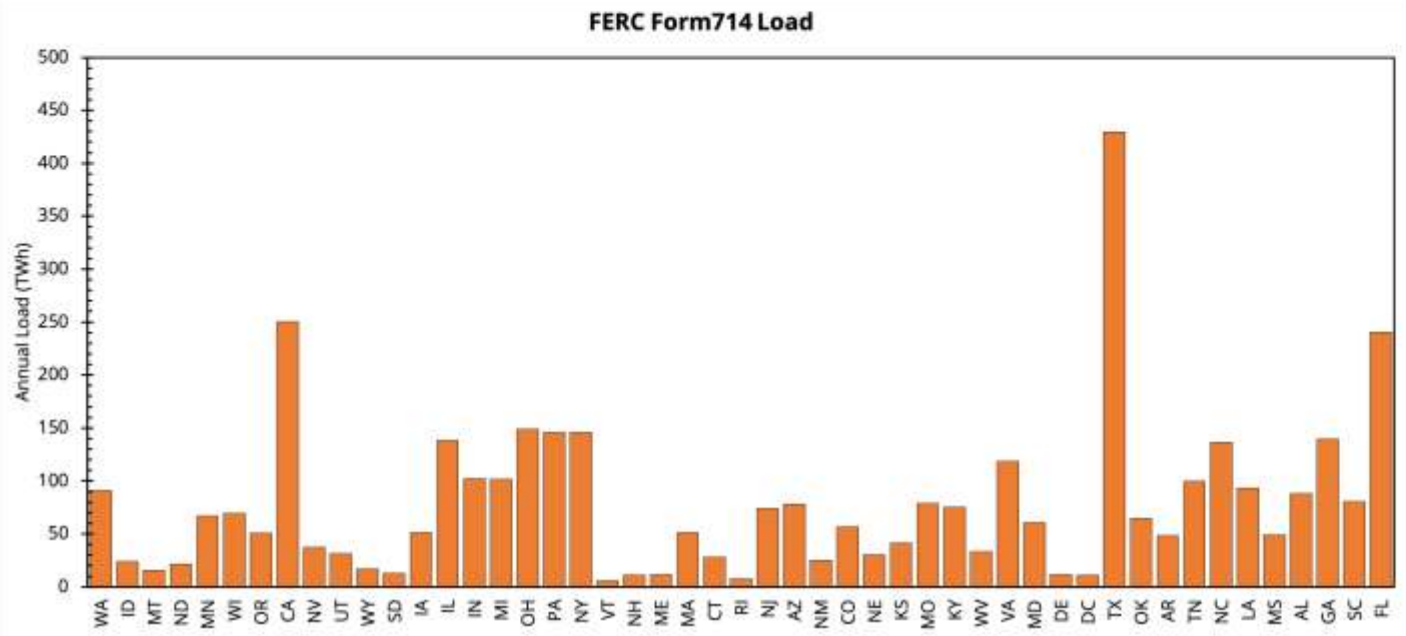
WIS:dom-P Load Dataset

- The WIS:dom-P model by default is run with Load Datasets that are created by VCE.
- This data can also be updated by the client.
- For this Maryland study, we have been in touch with E3 to find out more information about the loads used in the Greenhouse Gas Emissions Reduction Act (GGRA) Plan Study. This information, if it can be provided at a certain granularity, may be used in the WIS:dom-P model.
- The table below compares VCE BAU Loads with the Reference Scenario form the GGRA study. There is significant parity.

	Reference Scenario GGRA Maryland Total Load (TWh)	VCE Maryland Total BAU Load (TWh)
2020	58	61
2025	57	60
2030	59	61
2035	61	61
2040	64	63
2045	66	66
2050	68	68

WIS:dom-P Load Dataset

- The load dataset in WIS:dom-P is divided into the following categories
  - Conventional or traditional electric load
  - Space heating load
  - Water heating load
  - Transportation load
  - Hydrogen production load



- The load dataset is created using a combination of FERC 714 data and the weather dataset.

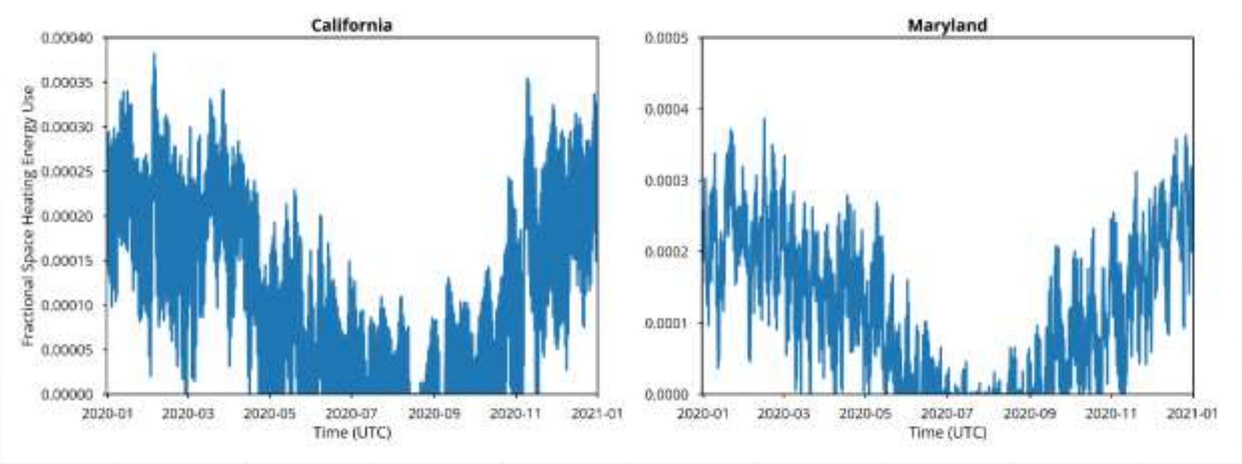
$$L_{j,h} = \sum_{i=1}^{n} BA_{i,j,h} \times \frac{L_{j,act}}{\sum_{h=1}^{8760} \sum_{i=1}^{n} BA_{i,j,h}}$$

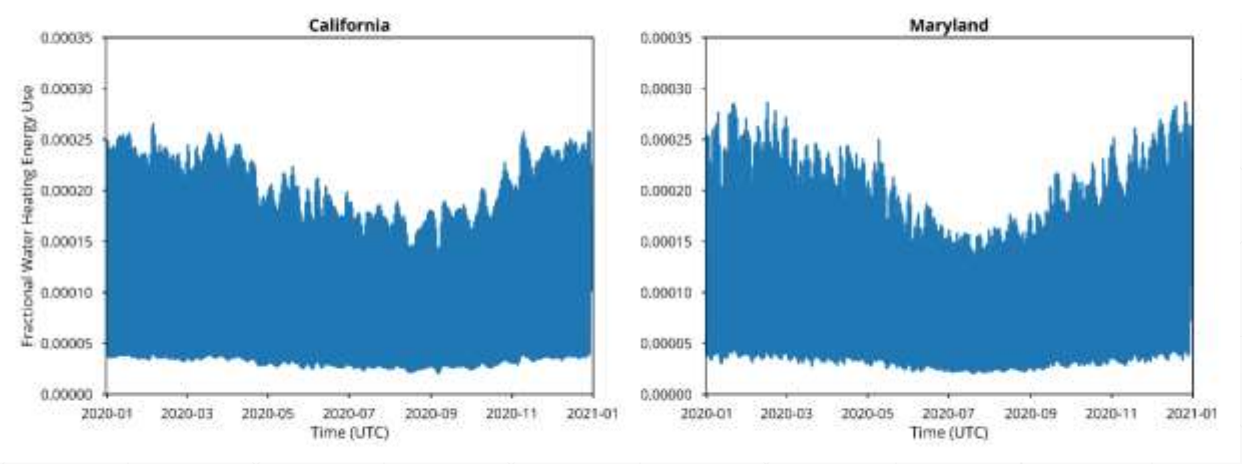
Space and Water Heating Load

- Space heating demand depends on local climate and variability in temperature over a year.
- Space heating load is calculated assuming that the ideal indoor temperature (T_{ideal}) for the building stock is 72 ^{o}F.

$$\Rightarrow Q_{ideal}(t) = \frac{T_{ideal} - T_{out}(t)}{\sum_t \left(T_{ideal} - T_{out}(t)\right)}$$

- Water heating is modelled similar to the space heating.
- It is assumed that the ideal water temperature to be maintained is 140 ^{o}F with average residential water heater usage overlaid.
- It is assumed that the incoming water temperature is correlated to the outside air temperature.

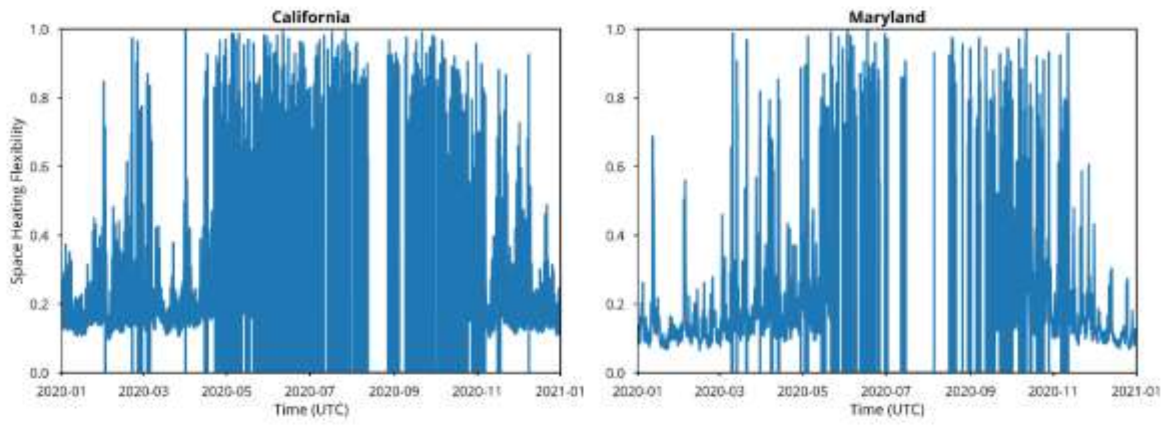




Space and Water Heating Flexibility

- To calculate flexibility in space heating load, it is assumed that the ideal indoor temperature can be allowed to drop to 68 ^oF (T_{flex}) for short periods.

$$flex(t) = 1 - \phi \frac{Q_{flex}(t)}{Q_{ideal}(t)}$$



- Water heating flexibility needs to ensure that hot water needs are satisfied at every timestep.
- Water heater is allowed to overheat (max 150 ^oF) or underheat (min 120 ^oF).

$$Q_{avail}(t) = Q_{avail}(t-1) + Q_{WH}(t) - Q_{ideal}(t) - Q_{Loss}(t)$$

$$T_{WH}(t) = \frac{(T_{WH}(t-1) + Q_{WH}(t))}{H(t)}$$

$$H(t) = \rho \dot{V} C_P (T_{WH}(t) - T_{out}(t))$$

$T_{WH}(t) \leq T_{max}$ Set to 150 ^oF

$T_{WH}(t) \geq T_{min}$ Set to 120 ^oF

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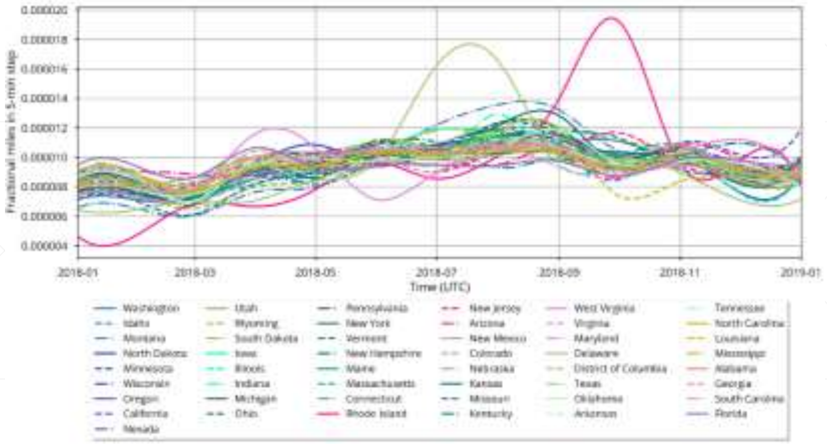
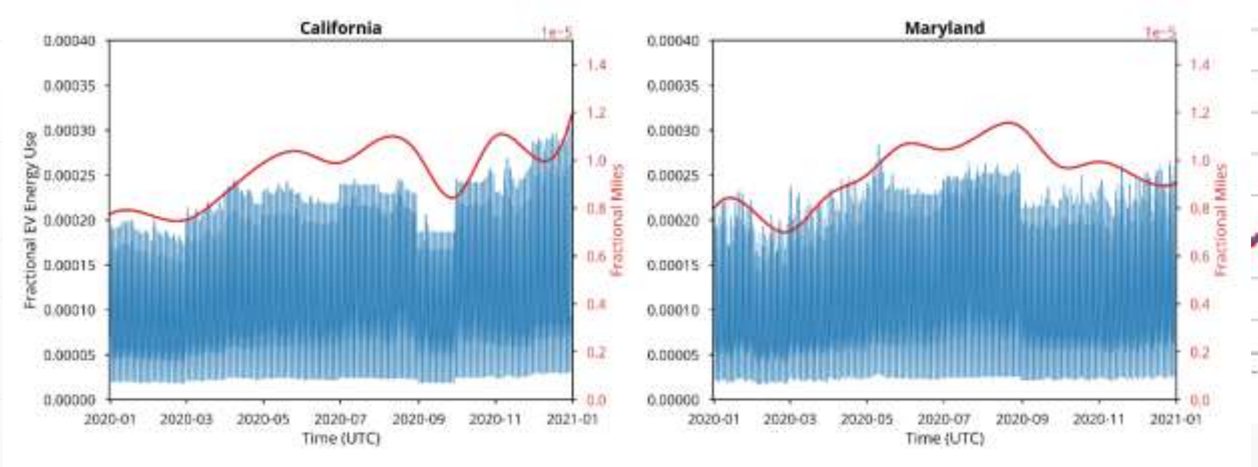
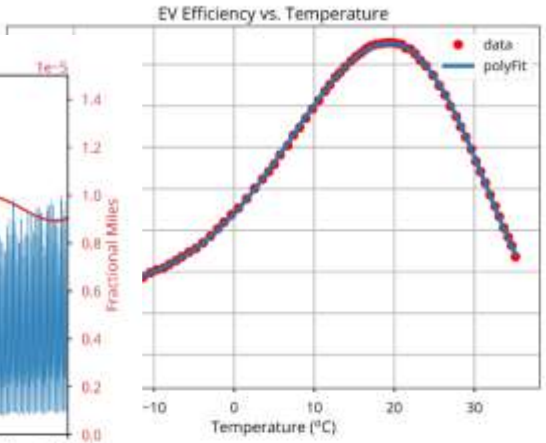
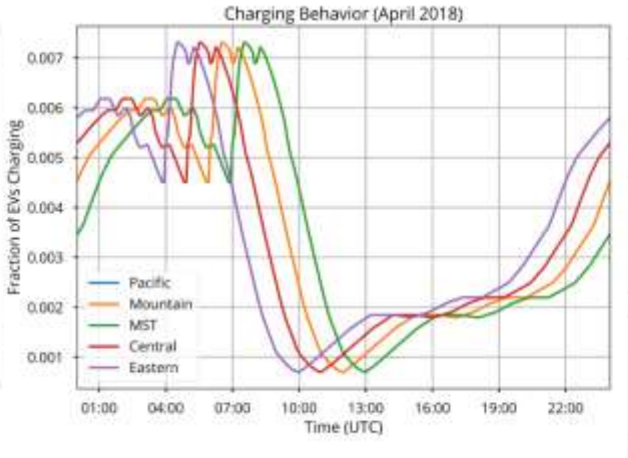
Transportation Load

- Energy used by electric vehicles can be broadly divided into two components:
  - energy used for cabin heating/cooling and
  - energy used for driving.









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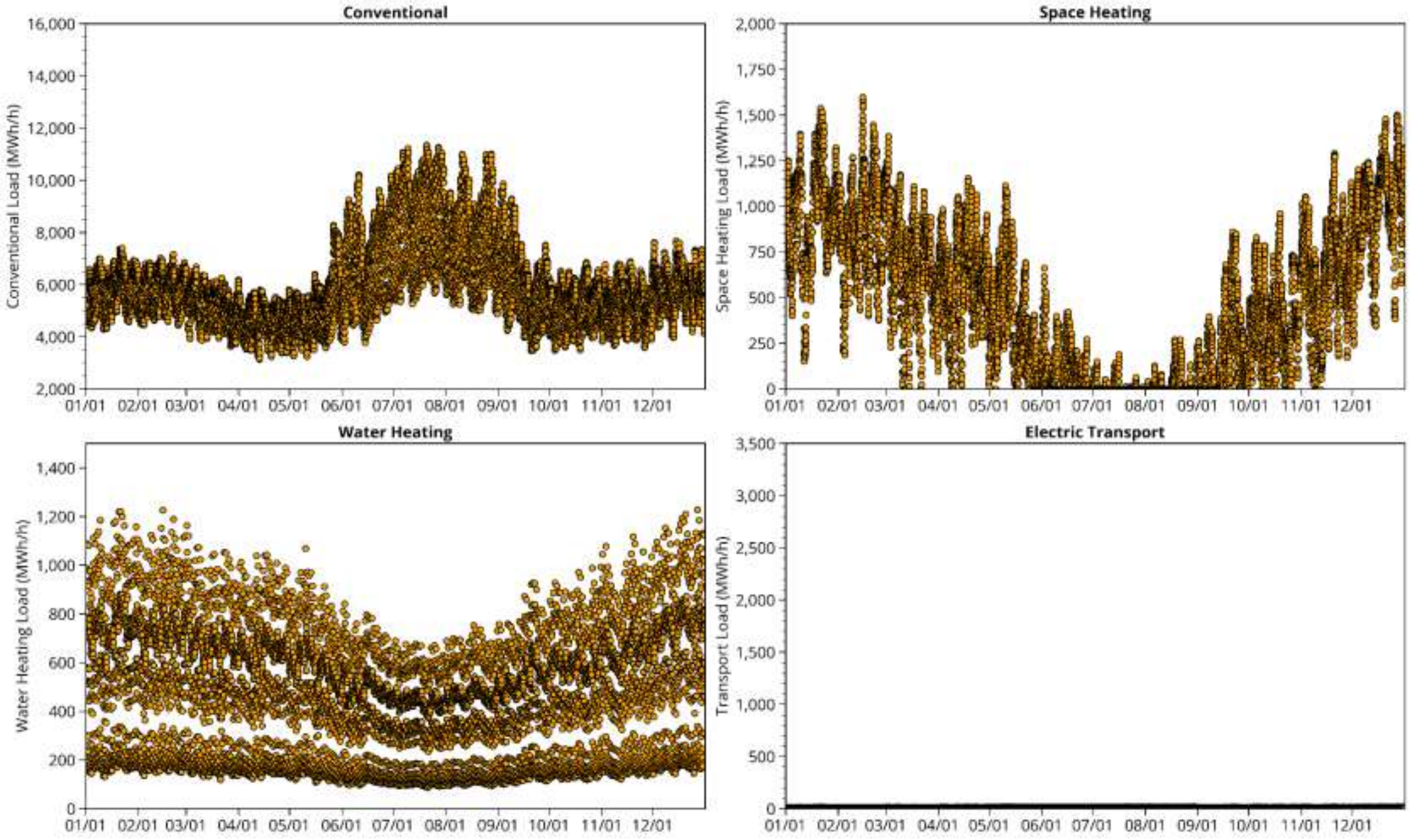
Maryland Load Shapes

BAU 2020



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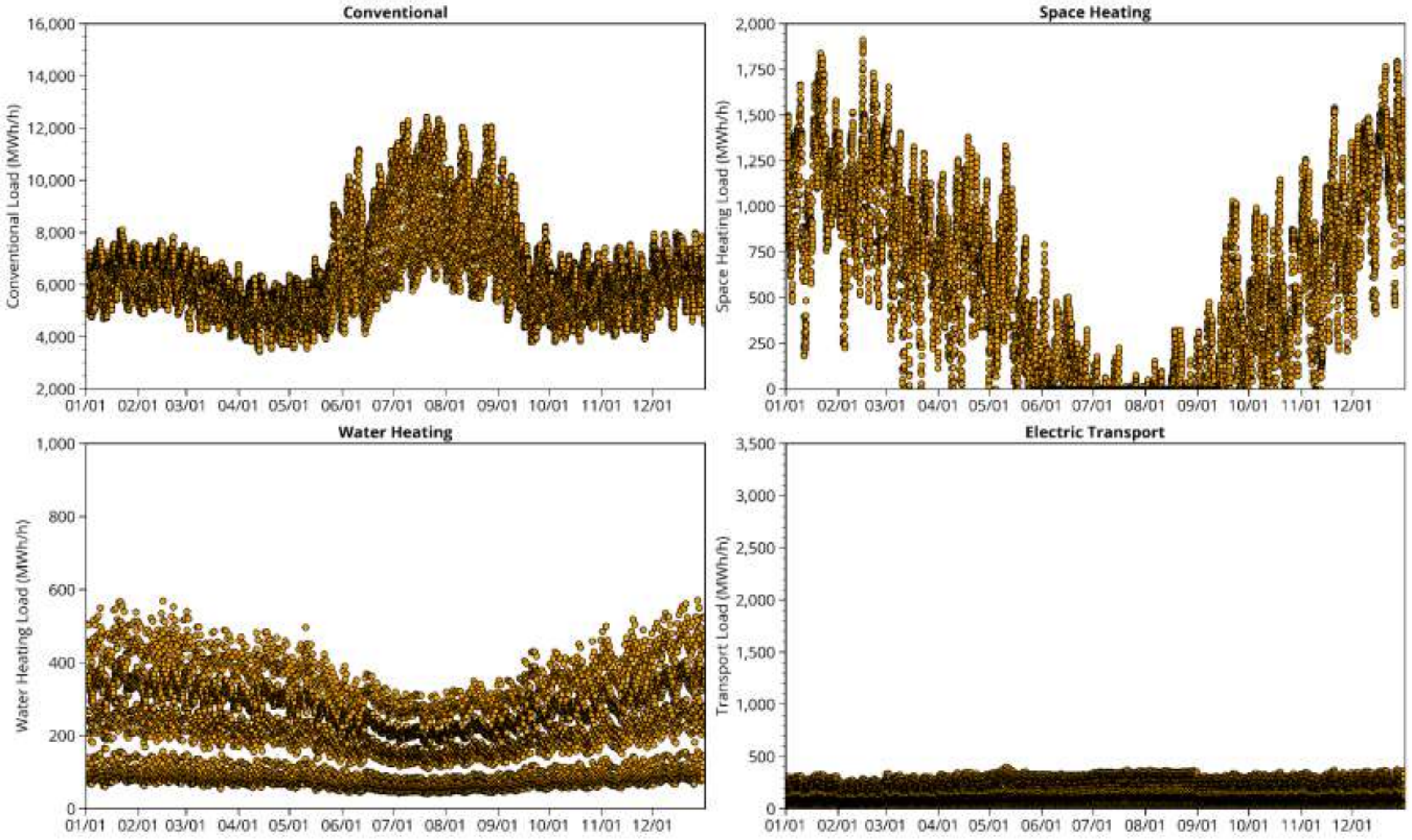
Maryland Load Shapes

BAU 2050



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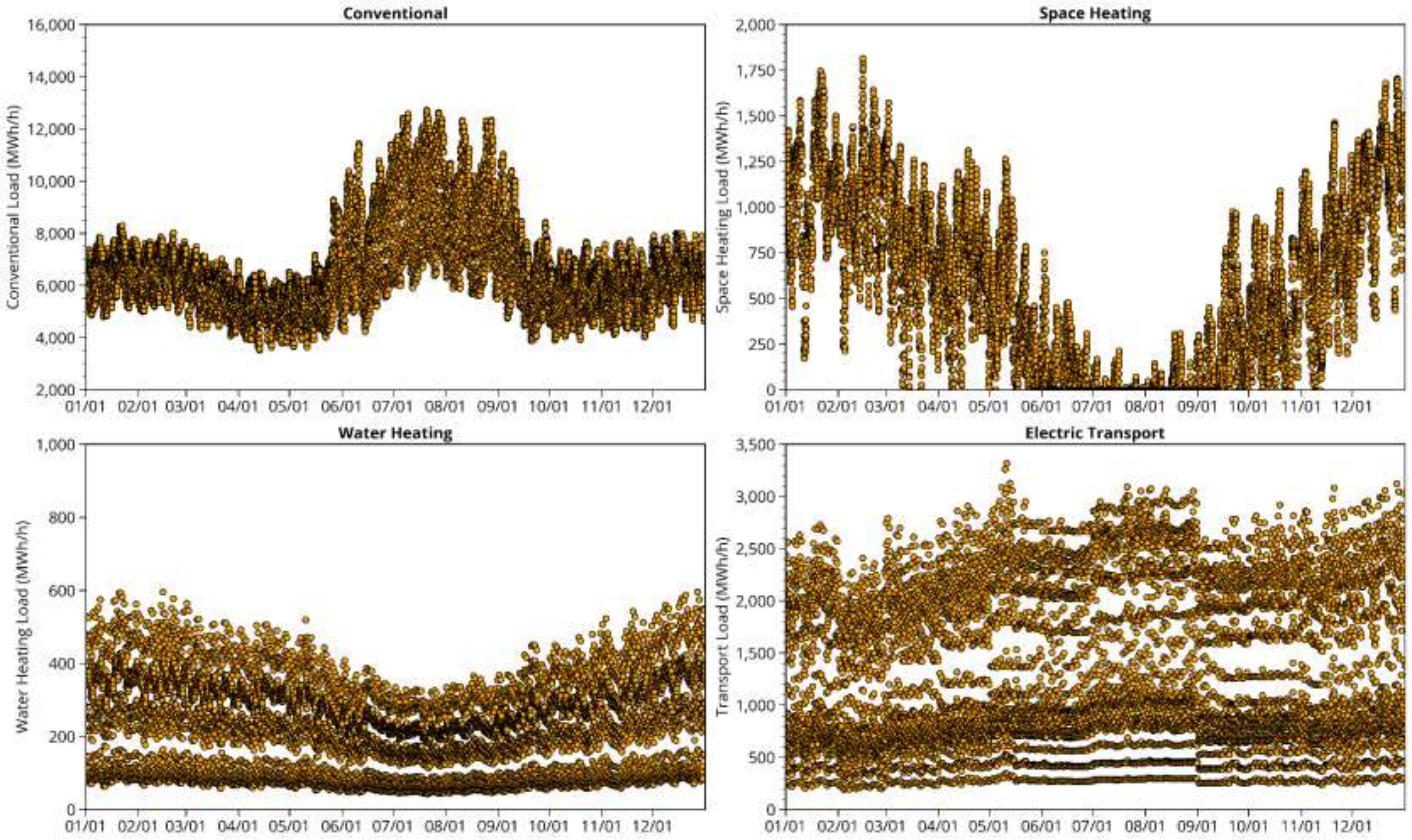
Maryland Load Shapes

High Electrification 2050



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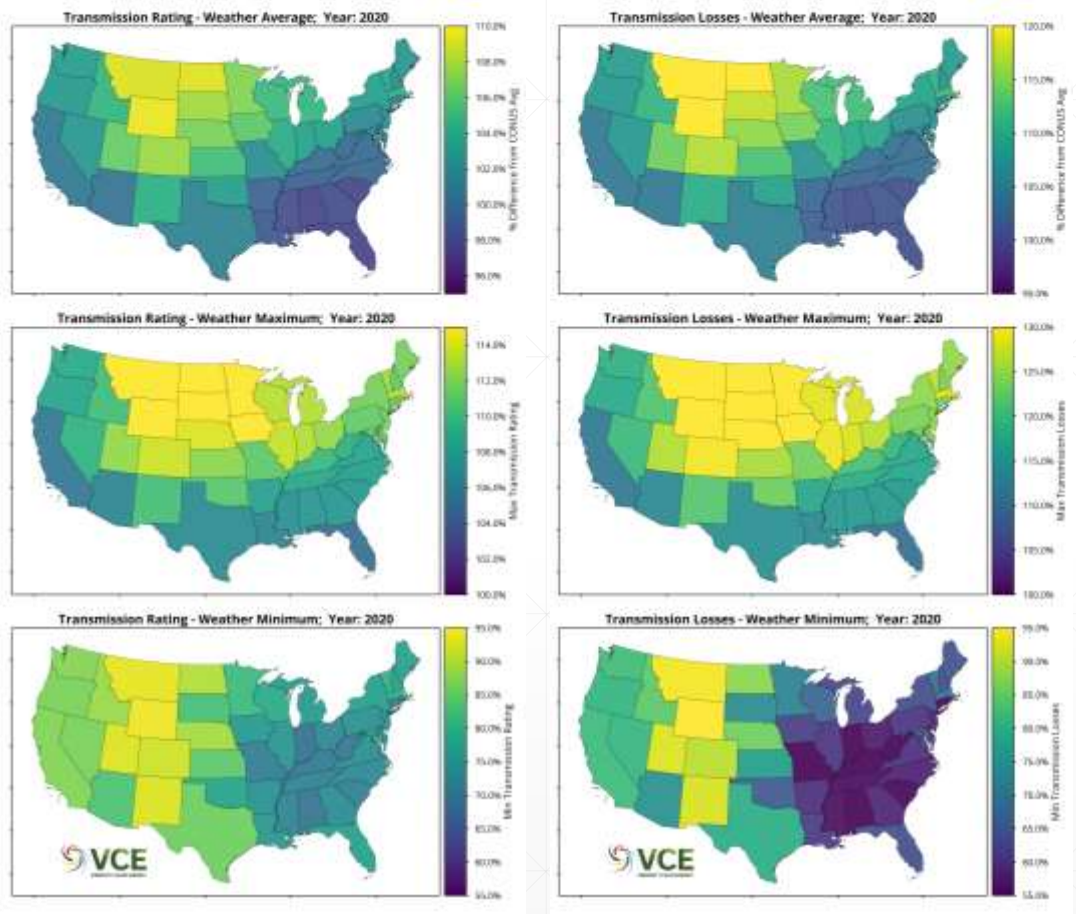
Transmission Line Rating and Losses

- Change in ambient temperature dictates transmission line rating to ensure safe operation.
- Change in line rating and conductor temperature affect losses due to change in resistance and resistive heating.

$$I = \sqrt{\frac{\pi * h * D * (T_{cond} - T_{air}) + \pi * \varepsilon * \sigma * D * \left(T_{cond}^4 - T_{air}^4\right) - \delta * \pi * D * a_s}{R(T_{cond})}}$$

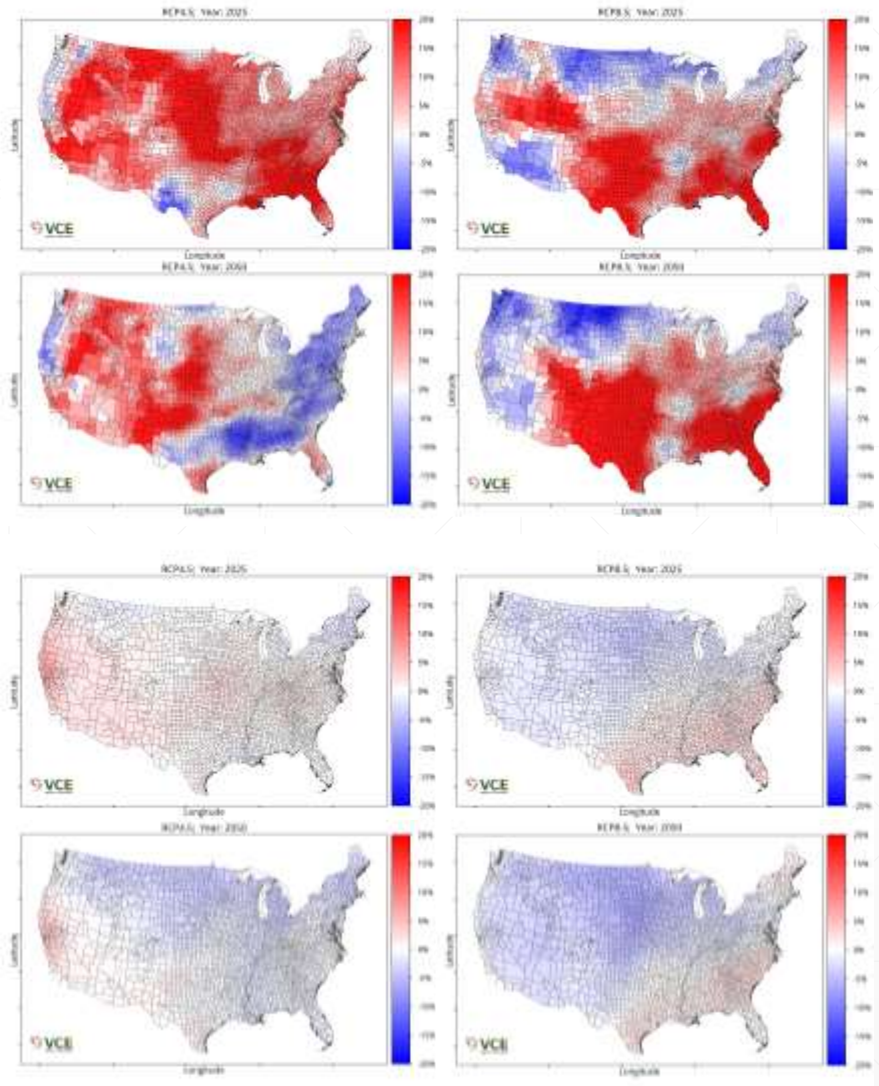
$$T_{core} - T_s = \frac{I^2 R\left(T_{avg}\right)}{4\pi k_{th}}$$

$$Loss_{change} = \frac{I(t)^2 R(t)}{I_{avg}^2 R(75^o C)}$$



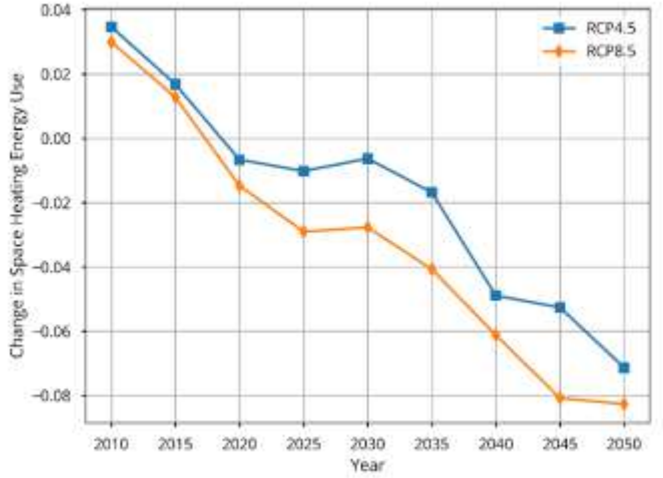
Impact of Climate Change

- Climate change impacts on wind speed (80 m), 2-m temperature, short-wave radiation and precipitation are extracted from the Climate Model Intercomparison Project – V (CMIP5) database for various scenarios.
- Climate impacts will be turned OFF for the "Reference Case (i.e., BAU) " scenario.
- Climate data is used to calculate change in:
  1. Wind power capacity factors
  2. Solar power capacity factors
  3. Heat rates of conventional generators
  4. Transmission line rating and losses
  5. Space and water heating energy use
  6. Space cooling energy use
  7. EV energy use

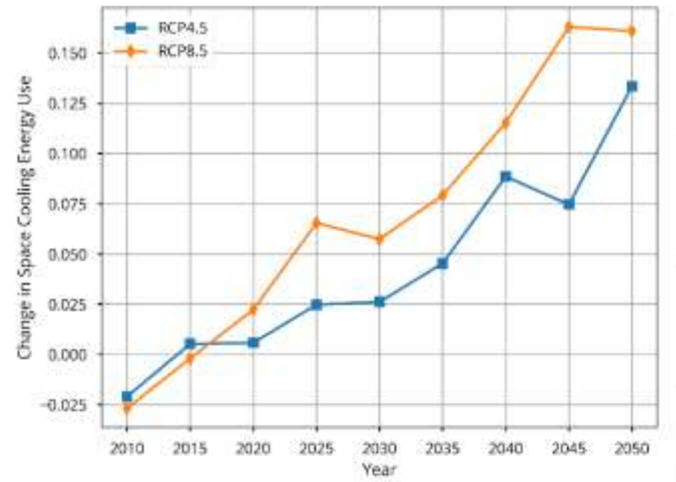


Impact of Climate Change

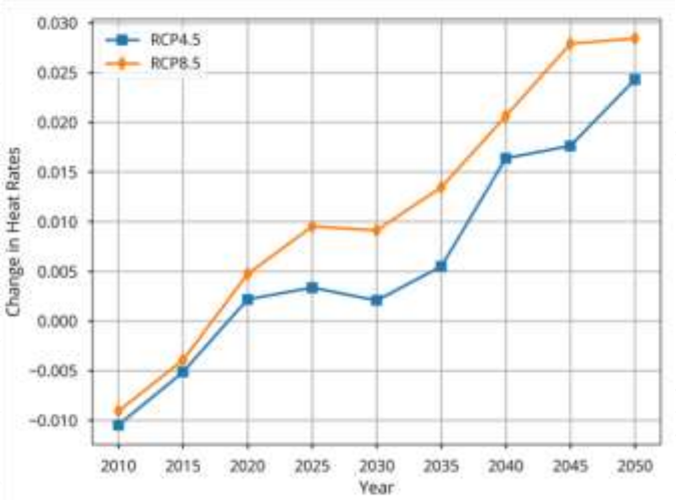
Space Heating



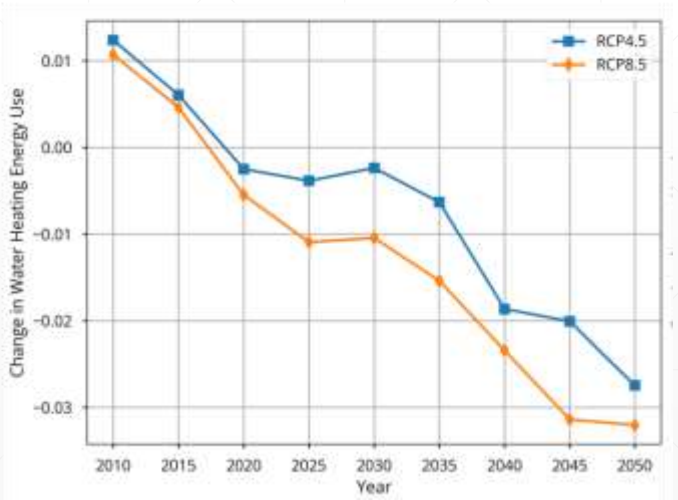
Space Cooling



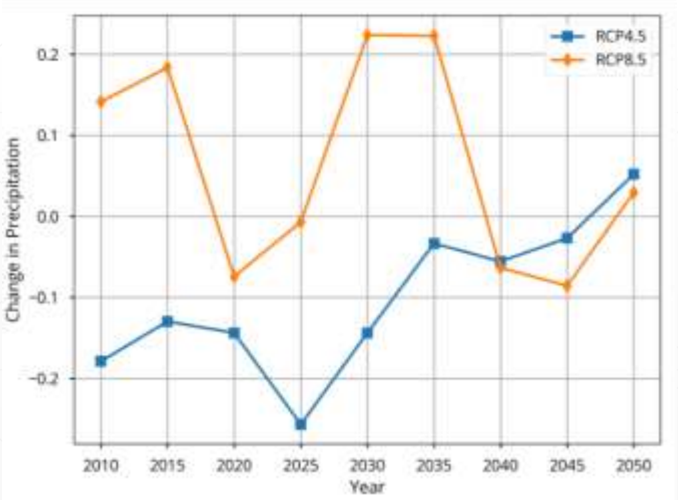
Heat Rates



Water Heating



Precipitation



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Today's Presentations

Study Overview

Workplan & Schedule

VCE Model

Assumptions and Key Inputs

Next steps

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http://commons.wikimedia.org/wiki/File%3APower_Lines_DSC1993w.jpg

Assumptions in VCE Model – Ref Case (Current RPS)

Year	Total MD RPS Requirement %	Solar %	Offshore Wind MW	Geothermal %	Tier 2 %
2021	30.80	7.50	0	0	2.50
2022	30.10	5.50	0	0	2.50
2023	31.90	6.00	0	0.05	2.50
2024	33.70	6.50	270	0.15	2.50
2025	35.50	7.00	270	0.25	2.50
2026	38.00	8.00	790	0.50	2.50
2027	41.50	9.50	790	0.75	2.50
2028	43.00	11.00	1190	1.00	2.50
2029	47.50	12.50	1190	1.00	2.50
2030	50.00	14.50	1590	1.00	2.50

Assumptions in VCE Model – 100% RE Scenario

100% RPS Scenario						
Year	MD RPS Requirement	Solar	Offshore Wind (MW)	Geothermal	Tier 2	
2021-2030	Same as Ref Case					
2031	55.00	14.50	1590	1.00	2.50	
2032	60.00	14.50	1590	1.00	2.50	
2033	65.00	14.50	1590	1.00	2.50	
2034	70.00	14.50	1590	1.00	2.50	
2035	75.00	14.50	1590	1.00	2.50	
2036	80.00	14.50	1590	1.00	2.50	
2037	85.00	14.50	1590	1.00	2.50	
2038	90.00	14.50	1590	1.00	2.50	
2039	95.00	14.50	1590	1.00	2.50	
2040	100.00	14.50	1590	1.00	2.50	

Assumptions in VCE Model – 100% Clean Energy Scenario (CARES Act)

Year	Total	Solar	Offshore Wind (MW)	Clean Energy Tier	
2022	58.1	8.5	0	3.3	
2023	60.4	9.5	0	4.2	
2024	62.7	10.5	270	5.0	
2025	65.0	11.5	270	5.8	
2026	67.5	12.5	790	6.7	
2027	70.5	13.5	790	7.5	
2028	72.5	14.5	1190	8.3	
2029	74.5	14.5	1190	9.2	
2030	75.0	14.5	1590	10.0	
2031	77.5	14.5	1590	12.0	
2032	80.0	14.5	1590	14.0	
2033	82.5	14.5	1590	16.0	
2034	85.0	14.5	1590	18.0	
2035	87.5	14.5	1590	20.0	
2036	90.0	14.5	1590	22.0	
2037	92.5	14.5	1590	24.0	
2038	95.0	14.5	1590	26.0	
2039	97.5	14.5	1590	28.0	
2040	100.0	14.5	1590	30.0	

Assumptions in VCE Model and other Key Assumptions

Topic	Assumptions
Energy and Peak Demand Forecast	The VCE default BAU loads will be used for the initial scenarios. Both Exeter and VCE are in contact with E3 to see if the loads from the GGRA Plan are available at granularities necessary for WIS:dom-P. If that is the case, the E3 loads could be used instead. The VCE BAU and E3 Reference loads from GGRA are in close parity.
Locational Multiplier	Locational multipliers (LMs) ranging from 0.95% to 1.175% for each state across the US. These are applied to capital costs, depending on technology. LMs ranging from 1.0% to 1.5% are applied to fuel costs, depending on fuel type and state.
Fuel Costs	Fuel costs are based on the EIA Annual Energy Outlook (AEO) 2021 High Oil and Gas Supply (HRT) scenario. For example, average natural gas prices are projected to increase from approximately \$2.49/MMBtu in 2021 to approximately \$2.92/MMBtu in 2040.

Assumptions in VCE Model and other Key Assumptions (2)

Topic	Assumptions
Capital Costs	All capital costs are based on NREL's Annual Technology Baseline (ATB) 2021 middle cost assumptions. For example, selected capital costs for the year 2021 are as follows: natural gas CC - $966/kW; natural gas GT – $850/kW; nuclear - $6,288/kW; hydro - $5,212/kW; on-shore wind - $1,309/kW; off-shore wind - $2,539/kW; utility scale PV - $975/kW; residential PV - $2,118/kW; utility scale storage - $111/kW and $263/kWh*; CSP – $1,318/kW; geo/biomass - $5,862/kW. Carbon Capture Systems ($2328/kw), Small Modular Reactor Nuclear ($6,288/kW), Molten Salt Reactors ($6,288/kW). These will not be in the BAU and 100% Renewable scenarios. These will be used in the 100% Clean Scenario. Hydrogen and other novel technologies are also in VCE's model to potentially be used beyond the first runs. *Energy storage fixed and variable costs based on an industry partner, not NREL's ATB. Storage duration is left to be determined by the model.

Assumptions in VCE Model and other Key Assumptions (3)

Topic	**Assumptions**
Financial Assumptions	By default, the NREL ATB market factor and real Weighted Average Cost of Capital rates are used. These rates vary by technology. The debt fraction also varies by technology.
Renewable Energy Portfolio Standard/Clean and Renewable Energy Standard	It is assumed that Maryland will meet the requirements of the Maryland RPS or CARES, including carve-outs, through the retirement of Renewable Energy Credits, Ocean Renewable Energy Credits or Clean Energy Credits, as applicable (as opposed to alternative compliance payments).
Environmental Regulations	EPA's existing regulations (the Cross-State Air Pollution Rule, the Mercury and Air Toxics Standard, and New Source Performance Standards) are integrated into the model. Additionally, the model recognizes the Regional Greenhouse Gas Initiative. GGRA target (40% reduction in GHG emissions from 2006 levels by 2030) is not treated as a binding constraint.

Assumptions in VCE Model and other Key Assumptions (4)

Topic	**Assumptions**
Wind Power Capacity Factors	On-shore and off-shore wind turbines are assumed to operate with capacity factors calculated using weather data from NOAA's HRRR model that are at 3-km, 5-minute resolution. The average wind power capacity factor across PJM is 30%. The average wind power capacity factor across Maryland is 34%.
Solar Power Capacity Factors	Utility-scale, community, and residential photovoltaic (PV) systems are assumed to operate with capacity factors calculated using weather data from NOAA's HRRR model that are at 3-km, 5-minute resolution. The average solar power capacity factors across PJM are 24%, 18% and 18%, respectively. The average solar power capacity factor (assuming an inverter load ratio of 1.25) across Maryland are 25%, 19% and 19%, respectively.
Existing Power Plants	All planned retirements and plants in operation as of August 2021, will be reflected in the model.

Assumptions in VCE Model and other Key Assumptions (5)

Topic	**Assumptions**
Calvert Cliffs	Assume Calvert Cliffs is relicensed if the model determines it is economic to do so. A sensitivity scenario on the opposite of the initial model run (relicensed, or not relicensed) will be conducted.
Transmission Infrastructure	The transmission infrastructure includes all PJM transmission lines (>69kV), and transmission lines in other regions, in place in June 2020.

Today's Presentations

- Study Overview
- Workplan & Schedule
- VCE Model
- Relevant Legislation & Key Inputs
- **Next Steps**

Photo Credit: Peter Haas via Wikimedia Commons
http://commons.wikimedia.org/wiki/File%3APower_Lines_DSC1993w.jpg

Next Steps

- Working Group send comments on Standard Scenarios and input assumptions by September 8th. The comments will be posted on PPRP's web site
- Exeter/VCE to refine assumptions for Base Case, 100% RE, 100% CARES scenarios based on feedback from the Working Group
- VCE conduct initial models runs
- Working group review of initial model results in October

Appendix

Maryland Renewable Portfolio Standard

- Enacted in 2003 and revised multiple times since then.
- 50% of electricity sales by 2030 (47.5% Tier 1, 2.5% Tier 2)
  - Tier 1—biomass
    - Methane from landfills or wastewater plants, poultry litter, waste-to-energy, thermal energy from animal manure or poultry litter, raw or treated wastewater used as a heat source or for heating and cooling, and refuse-derived fuel
    - ocean, hydro <30 MW, geothermal, wind, solar, solar heating and cooling
    - Black liquor removed as an eligible source earlier this year
  - Tier 2—hydro >30 MW, excluding pumped storage.
- Eligible resources inside PJM, and resources outside PJM but transmitted into PJM, are eligible for the Maryland RPS.

Maryland RPS Tier 1 Carve-outs

- Solar, 14.5% by 2030 (in-state)
  - Municipal utilities and rural electric cooperatives have a 2.5% solar carve-out
  - Munis/coops account for 8.5% of state-wide electricity sales in 2019
- Offshore wind
  - Two rounds. Round 1 is 368 MW of offshore wind previously approved by the Maryland Public Service Commission
  - Second round: 400 MW by 2026, 800 MW by 2028, 1200 MW by 2030. Maryland PSC is reviewing bids from recent offshore wind RFP
  - % amount set by the Maryland PSC. Specified at no more than 10% in 2025 but unspecified in any other year
  - Located between 10 and 80 miles off the coast of Maryland

Maryland RPS Tier 1 Carve-outs, cont.

- Newly established Tier 1 carve-out for geothermal heating and cooling
  - For closed- or open-loop installations beginning on January 1, 2023
  - Starts at 0.05% in 2023 and increases to 1% in 2028
  - At least 25% set aside for low- to moderate-income housing (single or multifamily), or to institutions that serve such customers (e.g., hospitals and schools)
  - Systems rated at 360,000 BTU or higher must meet labor standards
- ***We're assuming non-carve-out Tier 1 is 47.5% minus the solar and geothermal carve-outs, and the offshore wind carve-out as determined by the PSC***

Various Cost Cap and Exemption Provisions

- Industrial Process Load >300,000 MWh exempt (~2% of annual electricity sales)
- Rate impact of Round 1 offshore wind projects limited to $1.50/month for residential ratepayers and 1.5% of nonresidential annual electric bills. OREC prices cannot exceed $190 (all 2012 $)
- Rate impact of Round 2 offshore projects limited to $0.88/month for residential ratepayers and 0.9% of nonresidential annual electric bills (all 2018 $)
- Industrial customers with annual consumption >75,000 MWh and agricultural landowners with monthly consumption >3,000 MWh exempt from offshore wind requirement

Other Recent and Noteworthy Legislative Changes in Maryland

- Net metering cap raised from 1,500 MW to 3,000 MW
- Maximum size of individual net metering facility raised to 5 MW

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Proposed Clean and Renewable Energy Standard (CARES)

- Sponsored by the Governor (2020) and the Maryland Energy Administration (2021) ***but not enacted***
- Would create a clean energy resource tier consisting of combined heat and power, hydro > 30 MW, nuclear power (including small modular reactors), natural gas or biomass with carbon capture as a clean energy resource, and Tier 1 renewables. All would have to be located in-state
- For hydro >30 MW:
  - Clean energy resource credits would be assigned to the Maryland PSC, who would then sell them
  - Revenues would go into a hydro environmental impact remediation fund

Proposed Clean and Renewable Energy Standard (CARES), cont.

- The Maryland PSC could add “[an] emerging net-zero carbon technology, including energy storage or microgrids,” as clean energy resources, by regulation
- Combined Heat and Power plants have to meet certain efficiency requirements
  - For a full “clean energy resource credit”, CHP must have an efficiency level of 90% or more
  - ¾ clean energy resource credit for efficiency levels between 75% and 90%
  - ½ clean energy resource credit for efficiency levels between 60% and 75%
- Combined Heat and Power and nuclear power eligible if installed after January 1, 2022

Proposed Clean and Renewable Energy Standard (CARES), cont.

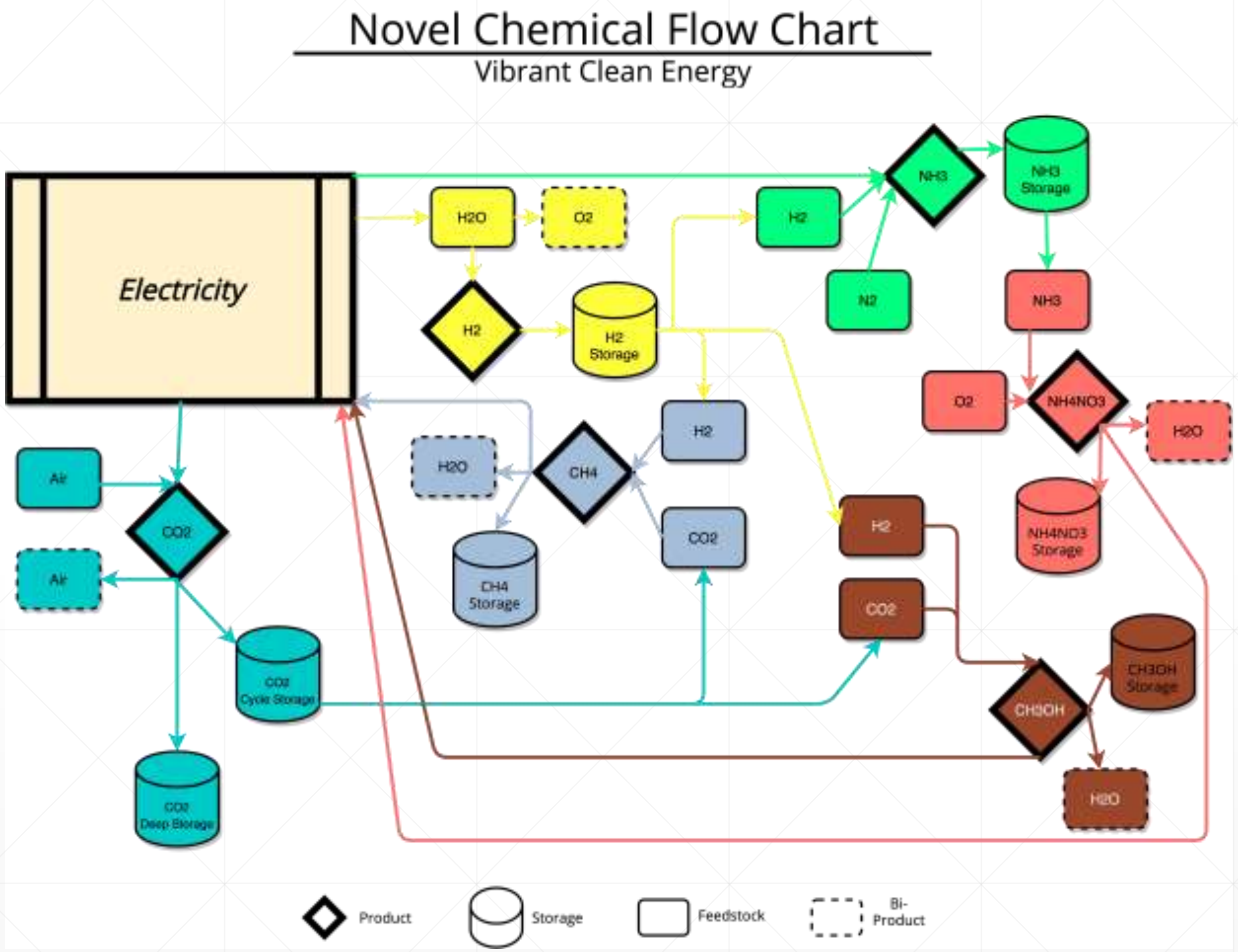
- Solar and off-shore wind carve-outs are unchanged
- Starts at 58.1% in 2022 (3.3% from clean energy resources) and goes to 100% by 2040 (30% from clean energy resources)
- Annual % requirement reduced by this calculation: average nuclear generation in Maryland over the past three years (Calvert Cliffs) divided by average electricity retail sales, also over the past three years)
  - Would reduce annual requirement by ~25%
  - Unit of Calvert Cliffs scheduled to retire by 2034, Unit 2 by 2037 (unless Exelon petitions the NRC for another license extension)

Previous Work

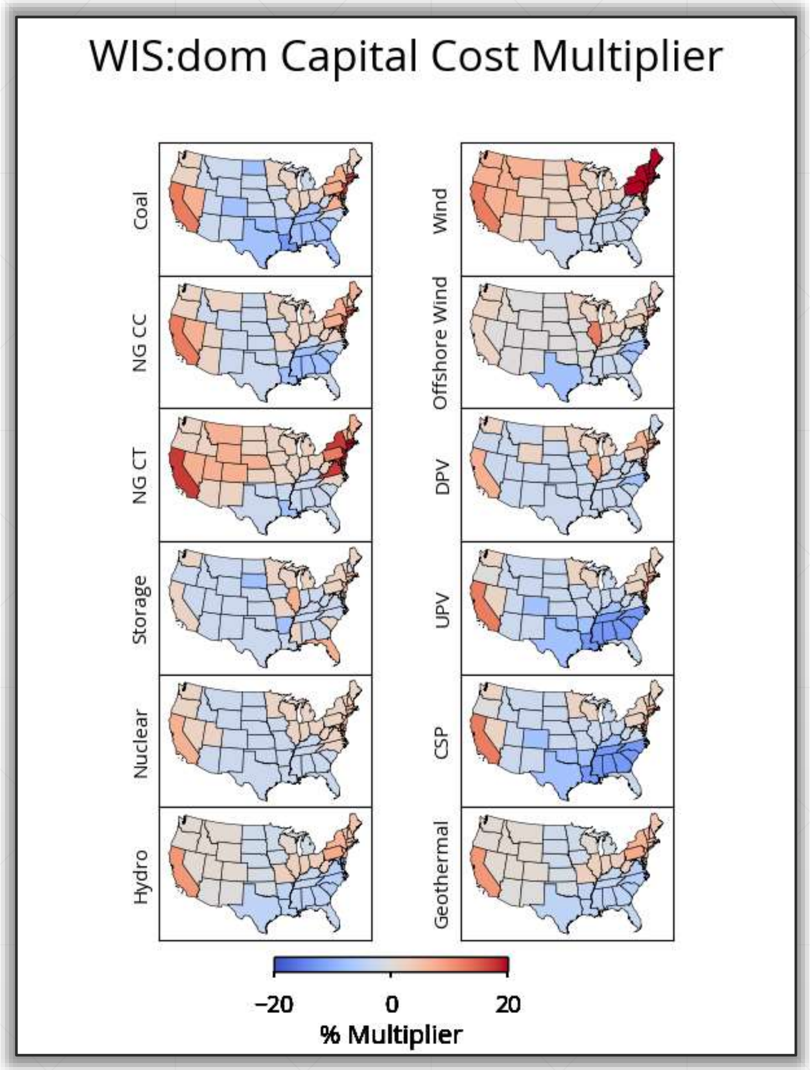
A few links to previous studies:

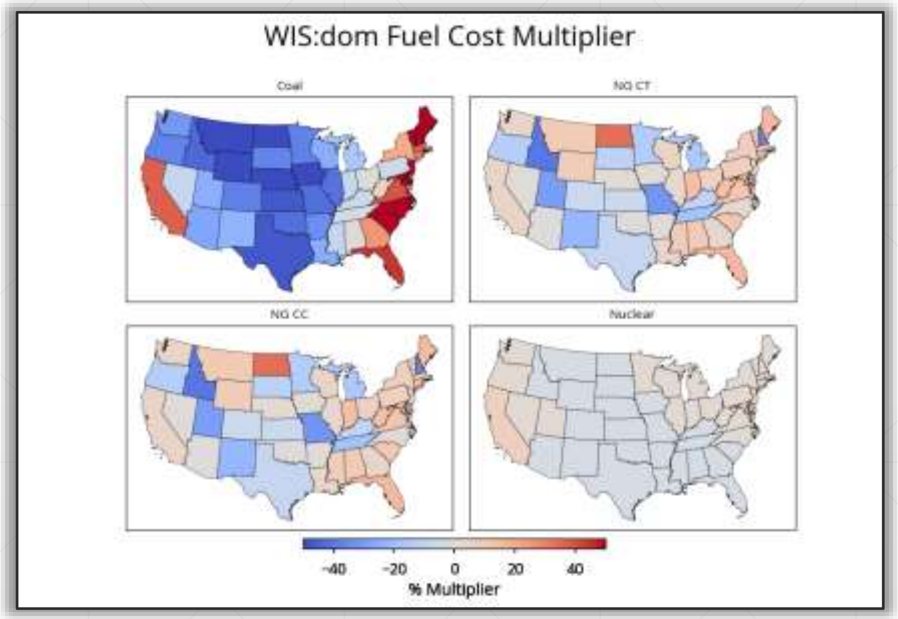
- https://www.vibrantcleanenergy.com/wp-content/uploads/2021/04/2018%20VCE%20Study_Results536959.pdf
- https://www.vibrantcleanenergy.com/wp-content/uploads/2020/10/CO-EIM-Options-Report.pdf
- https://www.vibrantcleanenergy.com/wp-content/uploads/2021/02/VCE-CUB-XcelIRP-ModelingResults.pdf
- https://www.vibrantcleanenergy.com/wp-content/uploads/2018/07/Minnesotas-SmarterGrid_FullReport.pdf

Novel Technologies



Datasets for WIS:dom® Modeling
Locational Cost Multiplier Example





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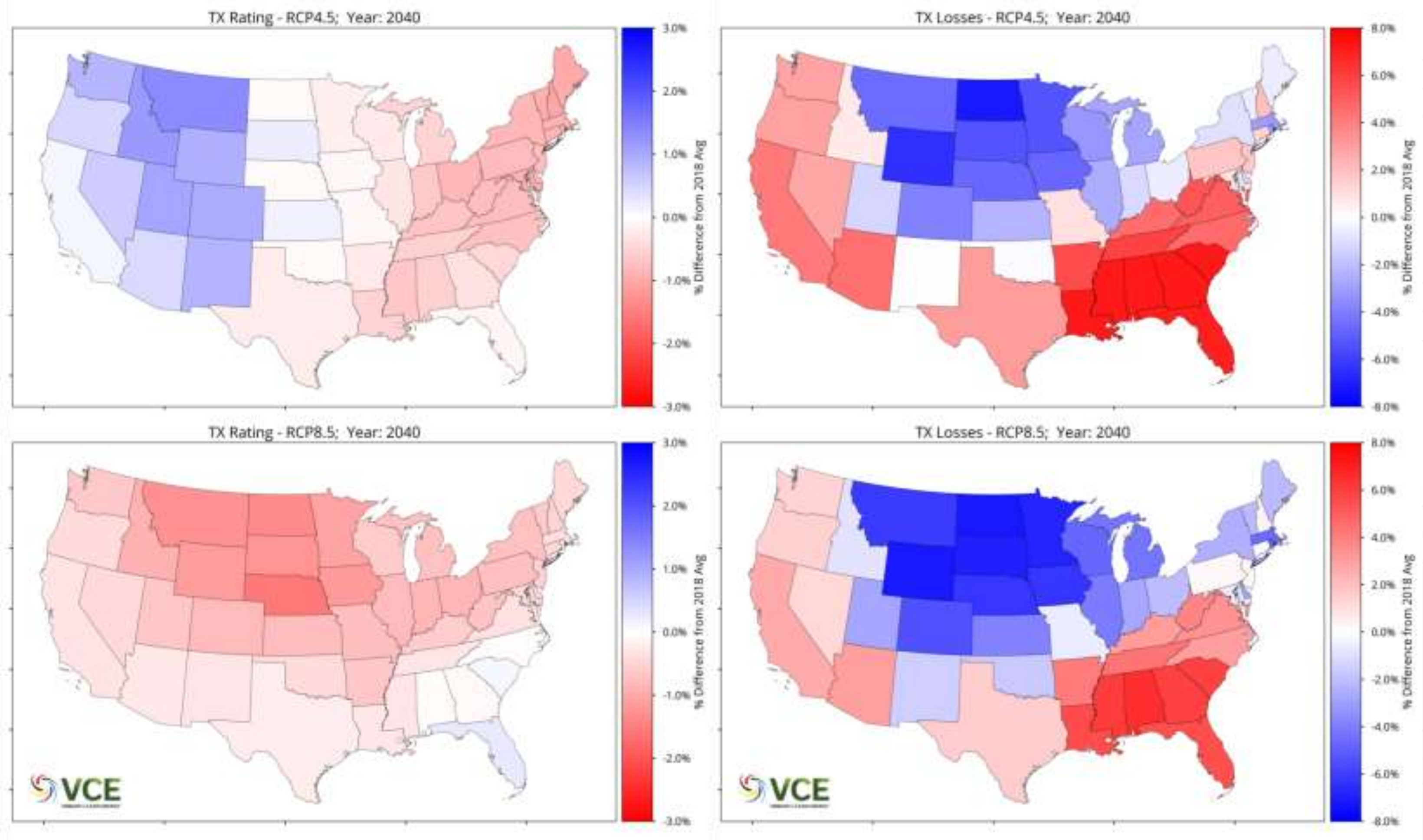
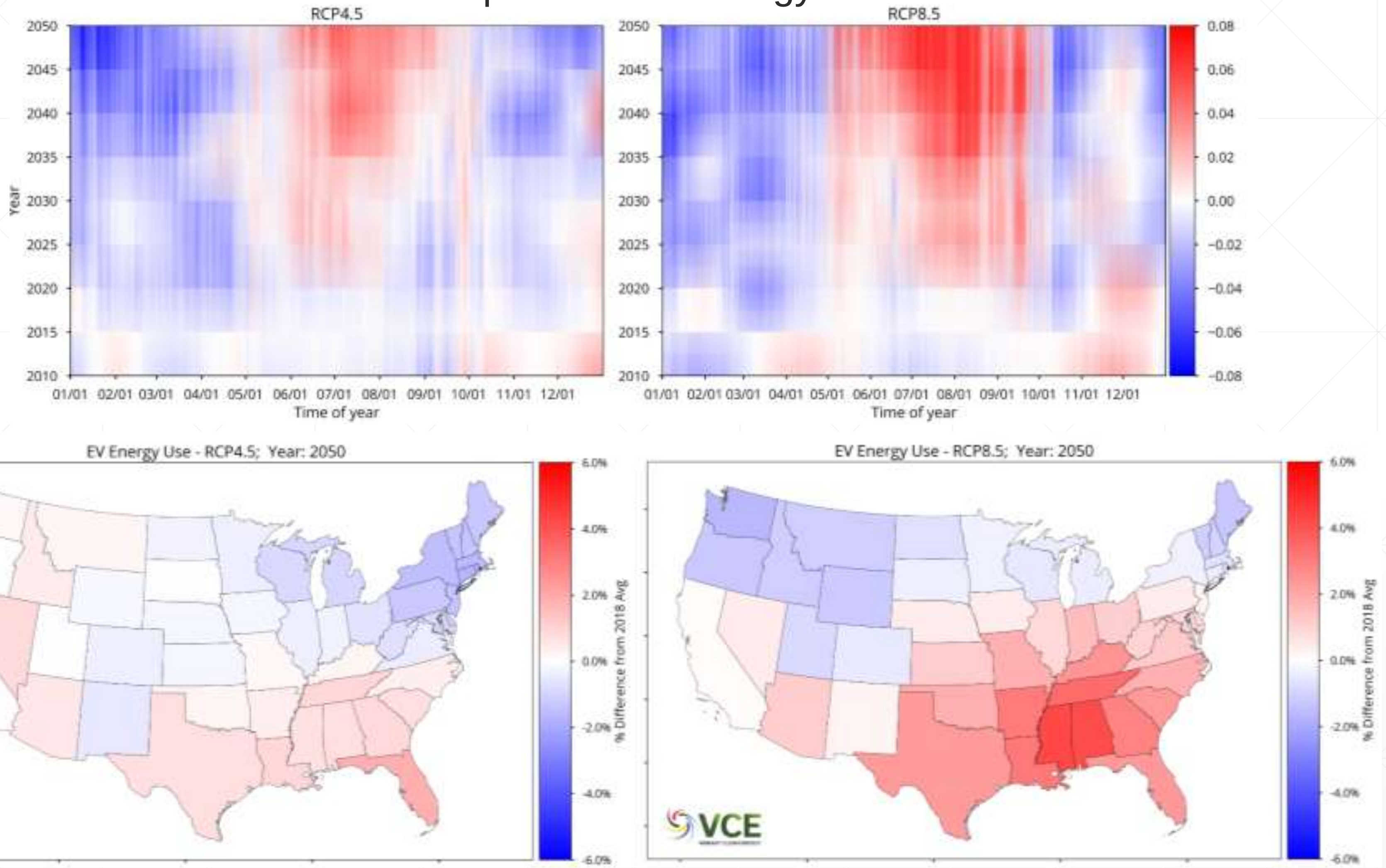
Impact of Climate Change

Transmission Line Rating and Losses



Impact of Climate Change

Impact on EV Energy Use



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