BEFORE THE

GEORGIA PUBLIC SERVICE COMMISSION

In Re:	)	
Georgia Power Company's 2019 Integrated	)	
Resource Plan and Application for	)	
Certification of Capacity from Plant Scherer	)	
Unit 3 and Plant Goat Rock Units 9-21,	)	**Docket No. 42310**
Application for Decertification of Plant	)	
Hammond Units 1-4, Plant McIntosh Unit 1,	)	
Plant Estatoah Unit 1, Plant Langdale	)	
Units 5-6 and Plant Riverview Units 1-2	)	

And

In Re:	)	
Georgia Power Company's 2019 Application	)	**Docket No. 42311**
for the Certification, Decertification, and	)	
Amended Demand Side Management Plan	)	

Direct Testimony of Dr Joshua D Rhodes for Georgia Power Integrated Resource Plan (2019)

Senior Energy System Modeler & Analyst
Vibrant Clean Energy, LLC

On Behalf of
Southern Renewable Energy Association (SREA)

25th April, 2019

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I. Introduction and Summary

Q: Please state your name, occupation, and business address.

A: My name is Joshua D Rhodes. I am a Senior Energy System Modeler & Analyst for Vibrant Clean Energy, LLC, 6610 Gunpark Drive, Suites 200 B&C, Boulder, Colorado 80301-3460.

Q: Please summarize your academic background.

A: I received my Bachelor's and Master's in Mathematics from Stephen F. Austin State University and Texas A&M University, and my PhD in Civil Engineering from the University of Texas at Austin.

I have published almost two dozen peer-reviewed articles in academic journals such as Energy, Applied Energy, Renewable Energy, Solar Energy, and Energy Policy.

I have been invited to present on the topic of energy systems and energy transitions at numerous conferences, organizations, and universities; including Harvard, MIT, The United States Association for Energy Economics, The American Nuclear Society, and the American Geophysical Union.

Additionally, I am a full board member of The Texas Solar Energy Society, Pecan Street Data Board, and the Smart Grid subcommittee chair at ASHRAE.

My curriculum vitae is attached as Attachment JR-1.

Q: Please summarize your professional experience.

A: From 2014 – 2019, I was engaged as a Postdoctoral Research Fellow and later Research Associate at the Webber Energy Group and the Energy Institute at the University of Texas at Austin where I was the lead on multiple energy policy studies such as "The Full Cost of Electricity" and "The Energy Infrastructure of the Future" that sought to provide insight into the energy transition in the US. At the same time I also oversaw multiple graduate students and helped lead multiple grid modeling projects that looked at the ability of the Texas grid to integrate high levels of renewables, subject to stability constraints. From 2009 – 2014, I was a master's and then PhD student and wrote my dissertation on how to use data, particularly smart grid data, to better manage energy resources and identify system inefficiencies, particularly in the built environment.

Since May 2019, I have served as a Senior Energy System Modeler & Analyst for Vibrant Clean Energy, LLC ("VCE®"). The mission of VCE® is threefold: to support intelligent transmission and generation deployment for the modernized energy grid of the future; maximize returns from generation for the grid, the owners, and the developers; and provide technology/software (WIS:dom®) to facilitate efficient operation of generation, electricity grids, and markets. VCE® has provided detailed electric planning modeling services to a variety of clients including the Midcontinent Independent System Operator ("MISO"), Community Energy, Natural Resources Defense Council ("NRDC"), Sierra Club, the

McKnight Foundation, Environmental Defense Fund ("EDF"), Energy Innovation, Climate Policy Initiative, and well as others.

Q: On whose behalf are you testifying?

A: I am testifying on behalf of the Southern Renewable Energy Association ("SREA").

Q: Are you sponsoring any attachments?

A: Yes. I am sponsoring the following attachments:

- Attachment JR-1: Curriculum vitae of Dr Joshua D Rhodes, Vibrant Clean Energy, LLC.
- Attachment JR-2: The Coal Crossover: Economic Viability of Existing Coal Compared to New Local Wind and Solar Resources.
- Attachment JR-3: Minnesota's Smarter Grid: Pathways Toward a Clean, Reliable and Affordable Transportation and Energy System.

Q: What is the purpose of your testimony?

A: The purpose of my testimony is to analyze and summarize the results specific to Georgia from two studies (attachments JR-2 and JR-3) that VCE® completed. The first study (JR-2) analyzed all the coal-fired power plants in the United States and compared their marginal cost of electricity ("MCOE") to the levelized cost of electricity ("LCOE") of new wind or solar power plants within 35 miles. The second study (JR-3) used a much more sophisticated grid integration approach by utilizing the WIS:dom® optimization model to depict robust pathways for the Eastern Interconnection electricity system to 2050. My testimony shows that the Georgia Power footprint can accommodate much more renewables and storage that the current proposed integrated resource plan ("IRP") calls for. In addition, my testimony shows that the costs of the renewable and storage additions could be lower than alternatives. Finally, my testimony also illustrates the potential for wind and solar in Georgia based on different technologies for solar (angle, tracking or rooftop) and higher hub heights.

II. Summary of the Georgia Electricity System

Q: Please describe the current installed generation mix in Georgia.

A: According to the Energy Information Administration, the electric utility installed capacity in Georgia is 30,568 MW[1], comprising of 9,990 MW coal; 11,087 MW natural gas; 4,042 MW nuclear; 1,023 MW solar PV; 1,291 MW hydroelectricity; 837 MW petroleum; 2,297 MW pumped storage. The installed capacity is depicted in Fig. 1.

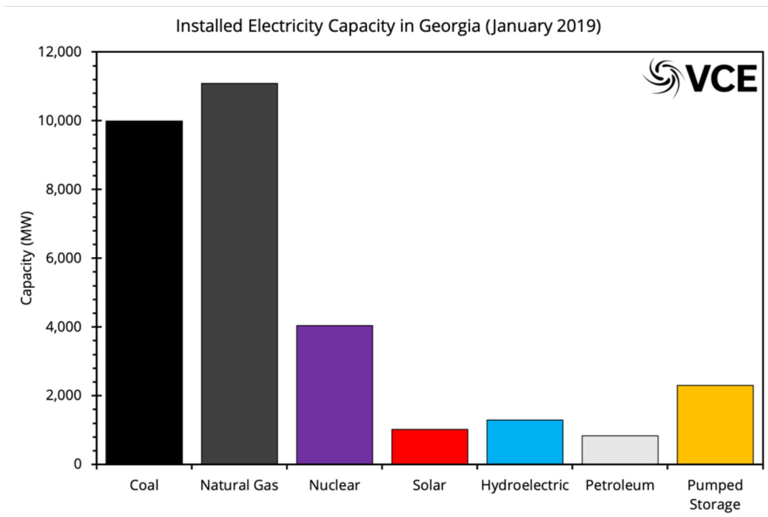

Figure 1: The installed electricity capacity in the state of Georgia (electric utility) in January 2019.

Q: Please describe the current generation mix in Georgia.

A: During 2018 the state of Georgia produced its electricity, according to the EIA[2], from coal (29.0%), natural gas (35.7%), nuclear (31.1%), solar (2.0%), hydroelectricity (2.1%) and other sources (0.1%). These numbers represent utility-scale electricity and smaller scale solar PV facilities. It

[1] https://www.eia.gov/maps/layer_info-m.php data retrieved 4/8/2019 (Power Plants shapefile).
[2] https://www.eia.gov/electricity/data/eia923/ data retrieved 4/19/2019 (2018 excel spreadsheet).

does not include self-generation numbers. The generation share is depicted in Fig. 2.

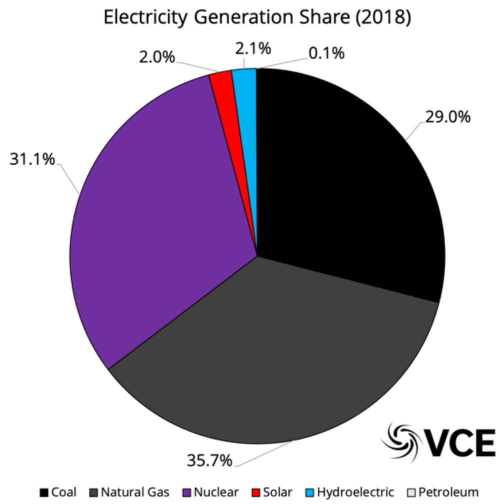

Figure 2: The electricity generation for the state of Georgia (electric utility) in 2018.

Q: What are the current trends in renewables across the United States?

A: During the calendar year of 2018 the United States added 7,852 MW of utility-scale wind, 5,649 MW of utility-scale solar PV, and 3,374 MW of distributed solar PV. These additions (along with 330 MW of hydroelectricity and geothermal) accounted for approximately half of the added capacity in 2018. These numbers represent wind adding 9% to its total capacity (up to 95,900 MW), utility-scale solar PV adding 21% to its total installed capacity (up to 32,800 MW) and distributed solar PV increasing its capacity by 19% (up to 19,522 MW). Renewables now account for nearly one quarter (24%) of the total installed electricity capacity in the United States. The growing renewable capacity is happening while the installed capacity of coal-fired power plants fell by nearly 6% during 2018; reducing by 15,744 MW (to 264,864 MW). The installed capacity of natural gas grew by 3% in 2018 to 541,596 MW[3].

Q: What does the EIA estimate for the interconnection queue in Georgia?

A: According to the Electric Power Monthly (EIA-860M) of the EIA[4] there is 24,624 MW of wind, 15,415 MW utility-scale solar PV, 942 MW battery storage, and 522 MW of hydroelectricity either under construction or in the final stages of planning across the United States. Yet, in Georgia there is only 972 MW of planned utility-scale solar PV, zero wind, and zero battery storage. There is approximately 2,200 MW of nuclear power under construction in Georgia (Vogtle). Nationally, there are 21,476 MW of coal-fired and 13,759 MW of natural gas power plants scheduled for retirement. However, there are none for the state of Georgia. There is a single planned coal-fired power plant at 850 MW in Georgia, which has not yet been approved.

According to the OASIS active generation interconnection requests for Southern Company[5] there are 835 MW of solar PV in Georgia with draft or executed Generator Interconnection Agreements (GIA). There is a further 6,584 MW of solar PV in different stages of study for interconnection.

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[3] All data retrieved from the EIA 860, 860M, 861, 861M in April 2019. Includes all electricity generation sources.
[4] https://www.eia.gov/electricity/monthly/ data retrieved in April 2019. Data from Tables 6.05 and 6.06.
[5] https://www.oasis.oati.com/woa/docs/SOCO/SOCOdocs/Active-Gen-IC-Requests.pdf (version accessed: March 27th, 2019 update).

III. Wind and Solar Resources for Georgia

Q: What wind resources are available to the state of Georgia?

A: The state of Georgia has substantial resources when it comes to wind power. The state can procure wind energy from outside of its border from neighboring states that have a higher capacity factors at the typical 80m above ground level (AGL) hub height. This would require interconnection using transmission to states from the north. Alternatively, Georgia could construct wind farms within the state at higher hub heights (100m or 120m) to capture stronger winds aloft. Doing so would substantially increase the wind resource potential and lower the cost of electricity from wind. Figure 3 shows the VCE® wind resource map for Georgia and the nearby regions. It shows the wind potential at 80m, 100m, and 120m AGL.

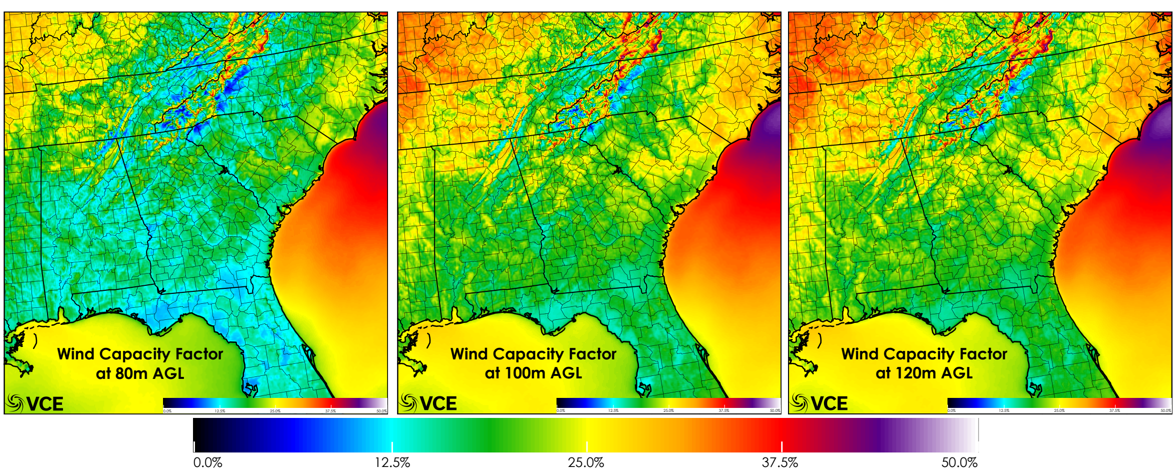

Figure 3: The wind potential for Georgia and surrounding regions. Left is for 80m, middle is for 100m, and right is for 120m AGL.

Figure 3 shows that increasing the hub height of wind turbines to 100m or 120m would provide Georgia with much improved wind resources that can compete with neighboring regions. Figure 4 illustrates the levelized cost of electricity (LCOE) of new wind in Georgia and surrounding regions taken from the data provided by the report in attachment JR-2.

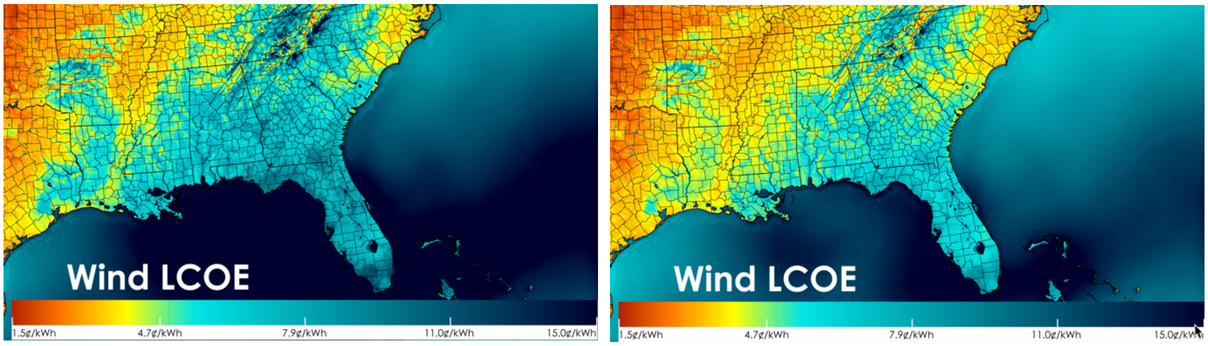

Figure 4: The LCOE of new wind in Georgia for 2018 (left) and 2025 (right). The images also depict the surrounding regions.

Figure 4 shows that Georgia could construct wind within its borders at $40–$65/MWh as of 2018; by 2025 that cost would reduce to $35-$55/MWh. The cost of construction is taken from the National Renewable Energy Laboratory (NREL) Annual Technology Baseline (ATB) 2018 midline values for 2018 and low values for 2025[6]. It also shows that Georgia could procure wind energy for a much lower cost from neighboring states and transmit the power to within its borders. The LCOE costs take into account the Production Tax Credit (PTC) and their current phaseout.

Using VCE® screening algorithms, it is estimated that within the state of Georgia 140,054 MW (140 GW) of onshore wind potential sites exist and 8,808 MW (9 GW) of offshore wind potential sites exist. Of that 150 GW, there is currently 1,000 MW with an LCOE below $50/MWh. The cost of wind for the wind regimes encountered in the south east are expected to continue to fall dramatically over the next few years.

[6] https://data.nrel.gov/files/89/2018-ATB-data-interim-geo.xlsm.

Q: What solar resources are available to the state of Georgia?

A: The state of Georgia has even more solar PV power potential than it does wind power potential. In addition to utility-scale solar PV, Georgia has substantial space for residential, commercial and industrial distributed solar PV. Figure 5 displays the VCE® estimated available siting for rooftop and utility-scale solar PV.

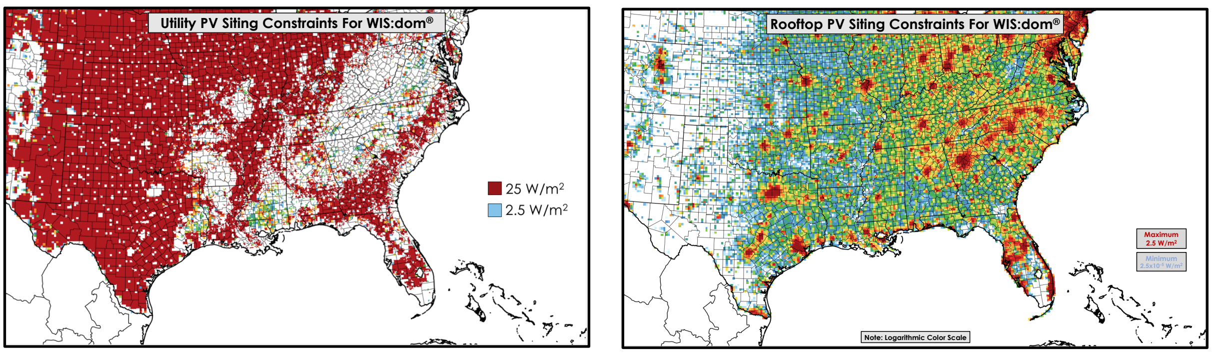

Figure 5: The WIS:dom® potential sites for utility-scale PV and rooftop PV for the South East, including Georgia.

VCE® estimates that Georgia has at least 71,590 MW of distributed solar PV and 494,893 MW of utility-scale solar PV potential resource available that can technically be deployed. It is not proposed that Georgia would ever build out all those resources, but the magnitude of the available resource potential illustrates the vast un-tapped development opportunity that exists. For Georgia, there exists today 1,000 MW of utility-scale solar PV at an LCOE below $29/MWh. Due to the similarity of the utility-scale solar PV resource across Georgia, there is in excess of 15,000 MW of sites with an LCOE below $30/MWh. In addition, there is 1,000 MW of distributed solar PV at an LCOE below $72/MWh. These costs are also expected to fall substantially in the near future.

The available potential resource space is one component, the other is the resource quality. For solar PV the south east (including Georgia) has one of the highest quality solar resources in the entire USA. There are different technologies for solar PV that can help increase the potential, but the biggest difference comes from installing the panels at different angles. Figure 6 displays capacity factor maps for Georgia and the surrounding regions. It shows the fixed axis (horizontal) utility-scale PV and single axis tracking utility-scale PV potential capacity factors.

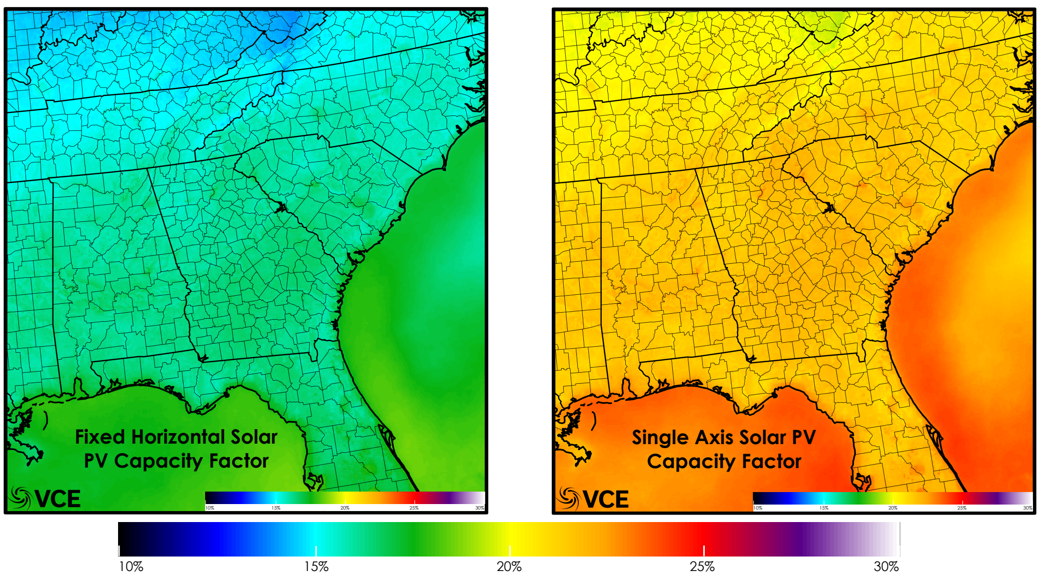

Figure 6: The utility-scale PV fixed (left) and single axis tracking (right) resource potential for the South East, including Georgia.

The plots in Fig. 6 show that solar PV has a much more homogeneous resource potential across Georgia than wind; however, the capacity factors are lower for the fixed axis. For the single axis tracking, the capacity factor of solar PV is similar to that of wind at 80m AGL. The cost of solar PV has been in a dramatic decline for several years and Fig. 7

displays the LCOE of new solar PV in Georgia and the surrounding region taken from the data provided in the report in Attachment JR-2.

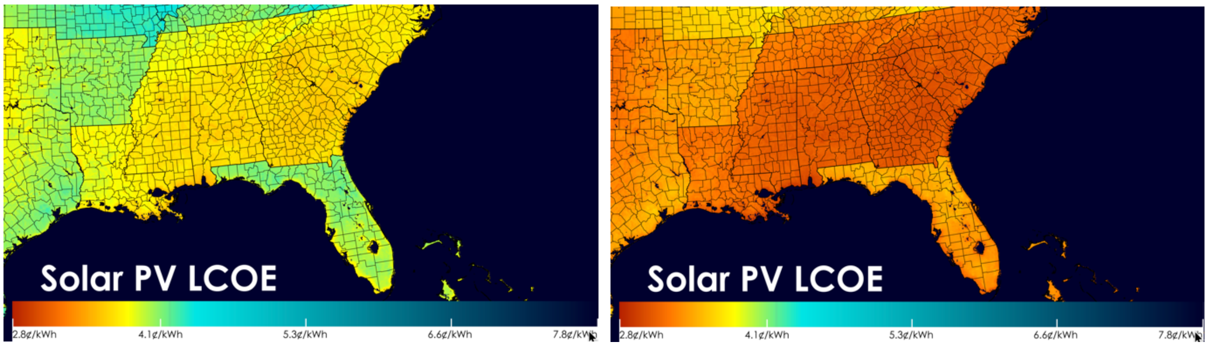

Figure 7: The LCOE of new utility-scale solar PV in Georgia for 2018 (left) and 2025 (right). They also depict the surrounding regions.

Figure 7 shows that new utility-scale PV in Georgia has an LCOE less than $35/MWh and by 2025 that could fall to less than $28/MWh. These LCOEs are based upon the analysis provided in Attachment JR-2. It can be seen that the surrounding south east is similarly low-cost.

Since solar PV only produces power in daylight hours, but its LCOE is lower than wind, there is an opportunity to pair with battery storage to make the solar PV dispatchable. The benefit of pairing solar PV with storage is increased by the availability of the Investment Tax Credits (ITC) for directly paired facilities. The cost of battery storage is rapidly falling and by 2025, VCE® expects utility-scale storage to cost less than $100/kW and $175/kWh[7], making the combined cost of a 4-hour battery less than $800/kW or $200/kWh.

In summary, Georgia has substantial wind and solar PV resources (including distributed solar) that could theoretically cover a significant portion of the electricity demand within the state. Further, Georgia has

[7] Internal calculations used for the WIS:dom® optimization model.

neighbor states that also have wind and solar that could be transmitted into the state at a cost lower than alternatives. These resources could be paired with batteries to facilitate dispatchable, low-cost renewable generation for the state of Georgia without a loss of reliability. The integration of these renewables would require study to ensure that they can function in the existing electricity system. I will go into this in more detail in Section V, drawing from the VCE® report in Attachment JR-3, where a detailed modeling exercise was carried out for the entire eastern interconnection.

IV. Analysis & Summary of Coal Crossover Report

Q: What is the Coal Crossover Report?

A: The coal crossover report was a joint report between VCE® and Energy Innovation, LLC. The report is Attachment JR-2. The report was produced by VCE® modeling every possible wind and solar location in the contiguous United States (CONUS) and comparing the cost to build new generation against the existing coal power plants running costs (or MCOE). The new wind or solar was constrained to replace all the Megawatt hours (MWh) of each coal plant before the algorithm was allowed to complete. The replacement of the coal plants was made from the existing site and spread outwards until all of the coal plant generation was covered by wind or solar. The maximum radius away from the existing coal plant was 35 miles.

The VCE® model for the coal crossover report did not include the matching of the temporal output of the coal-fired power plants, but simply matched the annual generation. The report designated that a coal-fired power plant was at risk if the LCOE of either wind or solar was lower cost than the MCOE of the coal plant. The report highlighted coal-fired power plants at substantial risk if the LCOE of the new wind or solar power plants were 25% cheaper than the MCOE of the coal plant.

VCE® and Energy Innovation, LLC made the existing coal power plant, wind LCOE and solar PV LCOE datasets available to the public along with the full report. The full coal-fired power plant dataset can be found on the VCE® website[8]. The wind[9] and solar PV[10] LCOE datasets for the entire CONUS are also available for free from the VCE® website. The wind and solar potential generation are based on the VCE® 3-km, 5-minute power datasets created from the National Oceanic and Atmospheric Administration (NOAA) High Resolution Rapid Refresh (HRRR). The NOAA HRRR was used to produce the power potentials for wind and solar PV because of the high number of observations (ground-based, aircraft, balloons, satellites, and radar) that are assimilated every hour for the operational weather forecasts.

The coal crossover report dataset was updated in April, 2019 and the refined numbers imply that 66% of the 263,278 MW of existing coal-fired power plants were at risk from wind or solar PV in 2018. This figure rises to 77% by 2025. The coal-fired power plants that are at substantial risk were 27% in 2018 and rises to 42% by 2025. These numbers represent local wind or solar PV (within 35 miles) and do not account for the complications of grid integration. However, the figures do illustrate the low-cost of new wind and solar power plants. At a minimum the fact that these new wind and solar PV generators are lower cost than the running

[8] https://vibrantcleanenergy.com/wp-content/uploads/2019/03/LCOE-Mapping/ExistingCoal_vs_NewWindSolar_17April2019.xlsb.
[9] https://vibrantcleanenergy.com/wp-content/uploads/2019/03/LCOE-Mapping/WindLCOE_Data.zip.
[10] https://vibrantcleanenergy.com/wp-content/uploads/2019/03/LCOE-Mapping/SolarLCOE_Data.zip.

costs of existing coal should elicit more scrutiny around the continued operation of the coal-fired plants that are at substantial risk. This is because the coal-fired power plants are 25% more expensive to operate than construct and operate new wind or solar within 35 miles. Figure 8 shows the installed capacity of each state in the CONUS broken down by the risk categories outlined in the Attachment JR-2.

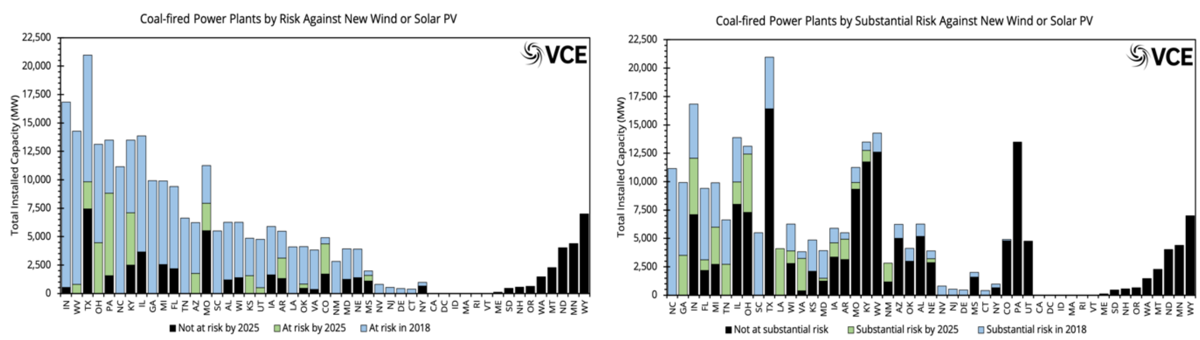

Figure 8: The coal-fired power plant installed capacities for each state disaggregated into capacity at risk in 2018 and by 2025. Left panel is for the "at risk" category and the right panel is for the "at substantial risk" category.

The left panel of Fig. 8 shows that 172,772 MW of coal-fired power plants were at risk in 2018 and this rises to 203,846 MW by 2025. The right panel shows that 71,992 MW of coal was at substantial risk in 2018 and this rises to 109,441 MW by 2025.

Q: What does the report show about coal-fired power plants in Georgia?

A: The coal crossover report (Attachment JR-2) suggests that all of the coal-fired power plants (~10 GW) in Georgia were at risk from new local wind or solar PV in 2018. It can be seen in Fig. 8 that the coal fleet in Georgia is at risk, and 65% of the fleet was at substantial risk in 2018, with the remaining 35% becoming substantially at risk by 2025. With such high numbers of the coal-fired power plants being at substantial risk, it is hard to understand why there is not more renewables within the generation queue. There is nearly 10,000 MW of coal-fired power plants in Georgia that are causing customers to pay more than they would if new replacement wind or solar PV was built. Clearly, there is integration concerns that would require solving, but pairing solar PV with storage could overcome many of these at costs that could be comparable with the existing coal-fired power plants.

Q: What are your recommendations?

A: The state of Georgia should carefully evaluate whether renewables could be used to replace some or all of the existing coal-fired power plant fleet at costs that are lower than keeping those plants running. The coal crossover analysis only considered local renewables; however, as I discussed in earlier sections, Georgia has neighbors with wind and solar PV at low cost that could also reduce the cost of replacing the coal-fired power plants further.

The integration issue might not be as large of an issue for Georgia as other regions because it has over 2,000 MW of pumped storage that could be used to accommodate the peak solar PV when excess generation occurs. Further, battery storage costs are declining at a rapid pace, which suggests pairing new solar PV would be economically competitive against other sources. Simply replacing the coal-fired power plants in the state of Georgia supports targeting 10,000 – 15,000 MW of renewable deployment by 2025.

Figure 2 illustrates that replacing the coal-fired power plants with renewables would account for 29% of the generation within the state, and therefore, approximately 60% of the generation would remain as synchronous generation. In addition, Georgia Power is constructing 2,000 MW of nuclear power that would add to this inertia-enabling generation.

The 10,000 – 15,000 MW of renewables would only account for 1.4 – 2.1% of the available renewable resource in Georgia. The state could cover the whole deployment with distributed solar PV if it desired; however, a diverse portfolio of utility-scale wind and solar PV along with distributed solar PV would provide the most equitable mix of generation for Georgia.

A substantial portion of the new wind and solar PV could be paired with storage; however, typically, solar PV is more suited to the current battery storage chemistry. The added incentive would be the ITC being applied to solar PV and storage directly paired. This was not analyzed in the coal crossover report (Attachment JR-2), but much more discussion of this option is made in the next section. Further, the coal crossover study limited itself to only comparing coal-fired power plants with local wind or solar, and more remote renewables could cost effectively replace these plants with further savings.

V. Analysis & Summary of MN Smarter Grid Report

Q: What is the MN Smarter Grid Report?

A: In July 2018, VCE® released a detailed report studying the electrification and decarbonization of the energy economy for Minnesota for the McKnight Foundation. The report is Attachment JR-3. To model Minnesota accurately, VCE® decided that the entire eastern interconnection should be modeled, so that the changing conditions across the entire interconnection can be experienced by Minnesota as its generation mix evolves. The modeling used WIS:dom® the state-of-the-art combined capacity expansion and production cost optimization model.

The MN smarter grid study dispatched the entire eastern interconnection at 3-km, 5-minute resolution, while determining the least-cost capacity expansion of generation, transmission and storage to fulfill the evolving electricity demands. The study (Attachment JR-3) performed thirteen (13) scenarios for the entire eastern interconnection. The main changes were to investigate how the Minnesotan electricity grid responded; however, results for every state in the eastern interconnection are available for download[11] from VCE®. Many of the scenarios are repetitive for eastern interconnection outside

[11] Data for the MN Smarter Grid study (Attachment JR-3) are available here: https://drive.google.com/drive/folders/1yUnLVDTXC7dIgbljJ1_VFGeOPNnyF-su.

of Minnesota. The three most different scenarios for the eastern interconnection are A1, A2 and E1.

Scenarios A1 and A2 in the MN Smarter Grid study (Attachment JR-3) are considered the baseline scenarios. The whole of the eastern interconnection evolves based purely on economics and existing policies / regulations. The difference between A1 and A2 is the ability for WIS:dom® to build interstate transmission lines: A1 allows the construction while A2 does not. Scenario E1 studies the impact of carbon emission limitations for the whole economy of the eastern interconnection. The study described pathways for the electricity sector to the year 2050.

In general, the MN Smarter Grid study suggests that the eastern interconnection can accommodate much more renewable energy than is currently installed. In adopting more renewable energy, the cost of electricity can be reduced because they are much lower cost than alternatives. The MN Smarter Grid study includes detailed reserve modeling, power flow modeling, dispatch of generation and incorporates historical weather patterns to drive renewable generation at the 3-km, 5-minute resolution.

For the baseline scenario (A1) the eastern interconnection adds approximately 22,000 MW of wind; 87,000 MW utility-scale solar PV; 9,400 MW of distributed solar PV; and 31,000 MW of electric storage by

2030. The added capacity is balanced by a reduction in coal of approximately 111,500 MW; 56,600 MW of natural gas combined cycle; and 72,500 MW of natural gas combustion turbines over the same time period. The tighter electricity interconnection due to transmission[12] expansion accounts for increasing wind capacity by around 2,000 MW; solar PV capacity by 1,000 MW; and electric storage capacity by 5,000 MW, while reducing natural gas combined cycle capacity by 2,800 MW and natural gas combustion turbine capacity by 2,500 MW.

The changes in generation capacity from scenario A1 and A2 occur while the retail cost of electricity is estimated by WIS:dom® to fall by 10.1% and 10.0%, respectively. Thus, two things can be deduced from the cost reductions. First, the difference in costs between scenarios A1 and A2 are very small; and therefore, transmission expansion is a cost-effective way to integrate many more renewables. Second, the adoption of higher renewable penetration levels reduces retail electricity costs. The WIS:dom® optimization model does not include every aspect of the costs to run an electricity system; however, a reduction of 10% is a significant amount that allows me to have confidence that at a minimum the retail rates would be unlikely to increase under the conditions described above.

[12] The difference due to transmission construction is computed by subtracting the change in generation capacity in scenario A2 from scenario A1; since the only change for the two scenarios is the interstate transmission.

The generation share of renewables for the eastern interconnection in scenarios A1 and A2 are 17.2% and 16.9%, respectively. A substantial increase from the 5% observed in 2017[13].

The cost values used for the MN Smarter Grid were taken from the NREL ATB 2017[14], and since then the latest release (NREL ATB 2018) shows the cost of wind and solar PV is on a more aggressive reduction than previously estimated. This will lead to a speed up in the adoption of renewable energy across the United States.

Figure 9 displays a chart from the MN Smarter Grid illustrating the dispatch for the eastern interconnection in a summer month from the WIS:dom® optimization model. It shows the different generation technologies contributing to meet the load each 5-minutes, which considering power flow along the transmission lines. The WIS:dom® optimization model found no difficulties in accommodating the variable renewable energy into the eastern interconnection.

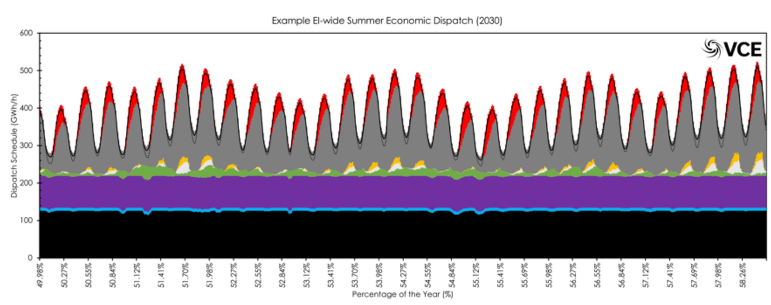

Figure 9: An example dispatch from summer 2030 of the eastern interconnection under the baseline scenario (A1).

[13] The calendar year 2017 was the initialization year for WIS:dom® in the MN Smarter Grid study (Attachment JR-3).
[14] Archived NREL ATB data is available here: https://atb.nrel.gov/electricity/archives.html.

The scenario E1 from the MN Smarter Grid study investigated the ability of the eastern interconnection economy to decarbonize by 80% by 2050. For the purposes of my testimony, I am only interested in the 2030 time period and how the incorporation of larger amounts of renewables impacts the operations of the electricity system, its impacts on costs and the change in the installed capacity.

The scenario E1 increased the capacity beyond the A1 scenario by 49,900 MW for utility-scale solar PV; 33,100 MW for wind; 5,100 MW for distributed solar PV; 3,300 MW for conventional hydroelectricity; and 800 MW for electric storage[15]. The coal-fired power plants were further reduced by another 54,300 MW; natural gas combined cycle by 11,700 MW; and natural gas combustion turbines by 25,700 MW. These changes are in addition to the changes seen in scenario A1 by 2030. This results in the renewable share of electricity being 26.5% of total load, up by 9.3% compared with scenario A1. The increased renewables are accommodated partly by more flexible demands, which combine to reduce the retail rate of electricity by over 19% by 2030, more than 9% lower-cost than the A1 scenario.

In the scenario E1 from the MN Smarter Grid study (Attachment JR-3), the increased renewables do not cause any additional loss of loads, nor does it increase the requirement for operating reserves. The renewables

[15] The average duration of the electric storage was 30 minutes.

can provide some of the reserves by being down-dispatched or pairing with storage. Further, the WIS:dom® optimization model finds many similar solutions to operating the system with more renewables that are almost the same cost.

Figure 10 displays the same summer dispatch as Fig. 9, but for the scenario E1. Comparing the two figures illustrates the way that WIS:dom® has been able to accommodate much more renewable generation without adversely impacting the other generation on the electricity system.

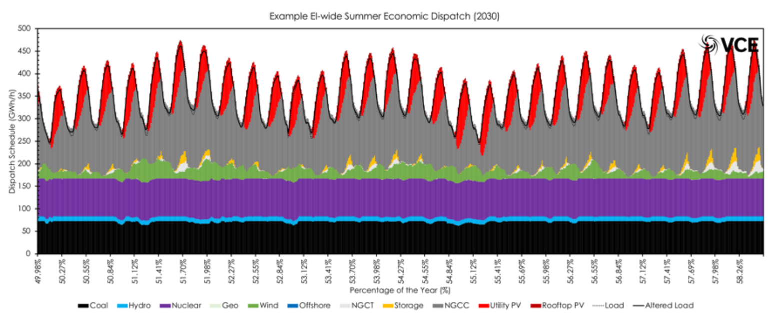

Figure 10: An example dispatch from summer 2030 of the eastern interconnection under the decarbonization scenario (E1).

Q: What does the report show about the possible integration of renewables in Georgia?

A: Each state is different in the eastern interconnection and Georgia has a unique opportunity in its placement between numerous states and possible interstate transmission opportunities. The three (3) scenarios I extracted data from for this testimony show solar PV (both utility-scale and distributed) ranging from 6,200 MW to 17,900 MW by 2030 in Georgia. There is not substantial wind installed within Georgia, but in the neighboring regions some is deployed (along with solar PV) that contributes to the state imports. Electric storage ranges from 6,500 MW to 7,500 MW by 2030 in Georgia, to support the new renewable generation. The nuclear capacity remains unchanged throughout the scenarios. Figure 11 displays the installed capacity mix for Georgia in 2030.

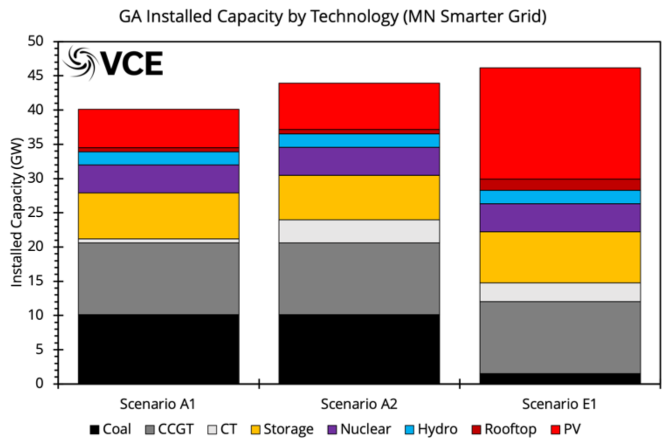

Figure 11: The installed capacity mix for Georgia under three scenarios from the MN Smarter Grid study.

Figure 11 demonstrates that Georgia could accommodate a vast amount of renewable energy and still supply power in a robust manner. The WIS:dom® optimization model dispatched the Georgia electricity system without fail each 5-minute interval for a minimum of three calendar years. Greater regional interconnection assists with reducing the burden on the rest of the generation fleet because renewables are driven by weather, which has a scale larger than the size of Georgia[16].

[16] This peer-review article (https://www.nature.com/articles/nclimate2921) explains the benefits of wider interconnected grids on renewables and the cost of electricity.

Q: What does the report show about the impact of new renewables on the cost of electricity in Georgia?

A: The retail rate of electricity in Georgia is also altered by the change in the resource mix. The addition of renewables actually reduces the cost of electricity in Georgia more than the average for the whole eastern interconnection. Under scenario A1 the cost of electricity is reduced by 13.1%, under scenario A2 by 11.8% and under scenario E1 by 12.7%. Each of the three scenarios reduce the electricity rate by more than 10%, which equates to over 1¢/kWh saving. The savings that customers receive could boost spending in the economy. Figure 12 shows the retail rate savings.

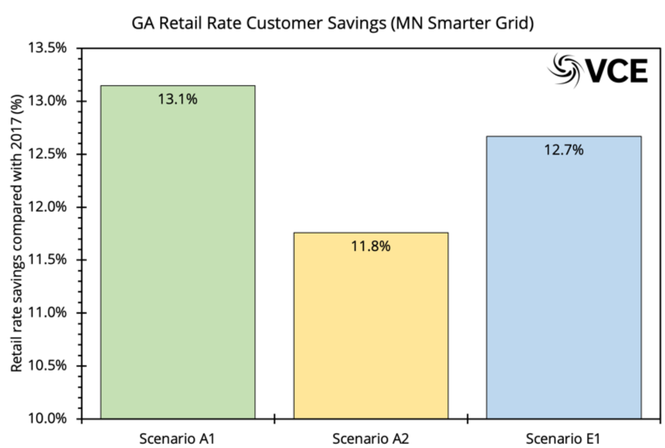

Figure 12: The retail rate savings for Georgia under three scenarios from the MN Smarter Grid study.

Q: What does the report show about the impact of full-time jobs within the Georgia electricity sector?

A: The increase in installed capacity and reduction in electricity rates occurs at the same time as rising employment numbers in the electricity sector. The new renewable generation, along with the accompanying transmission and storage create more jobs within Georgia. By 2030, Georgia could create as many as 83% more full-time jobs in the electricity sector compared with 2017. On the low end, there would be 15% more full time jobs in the electricity sector by 2030. The rise in employment would increase the tax base in Georgia as well as boost the economy. Figure 13 shows the increase in jobs for the three analyzed scenarios from the MN Smarter Grid study (Attachment JR-3).

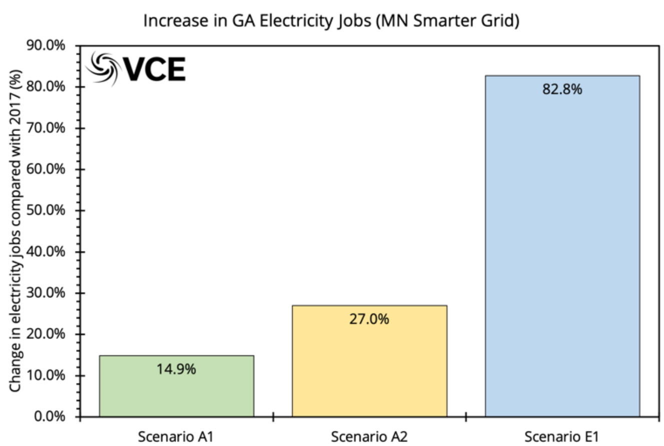

Figure 13: The increase in full time jobs for the electricity sector in Georgia under three scenarios from the MN Smarter Grid study.

Q: What does the report show about the environmental benefits of more renewables in Georgia?

A: The greenhouse gas (GHG) emissions from Georgia are slightly increasing in the two baseline scenarios (A1 and A2), but are dramatically reduced in the decarbonization scenario (E1). Although not the focus of my testimony, I shall note that the reduction in GHG emissions occurs in scenario E1 under the backdrop of reduced electricity rates and rising full-time employment in the electricity sector. The reduction in GHG emissions is similarly matched by the reduction in local pollution that can be harmful to health. In particular, the closure of the coal-fired power plants in the scenario E1 remove almost all the particulate matter (PM) at 2.5 and 10 microns. These pollutants are known to cause damaging health impacts[17]. In addition, the reduction of the thermal generation (coal and natural gas) also diminishes the strain on water resources within the state. Figure 14 illustrates the change in GHG emissions for the three scenarios evaluated from the MN Smarter Grid study.

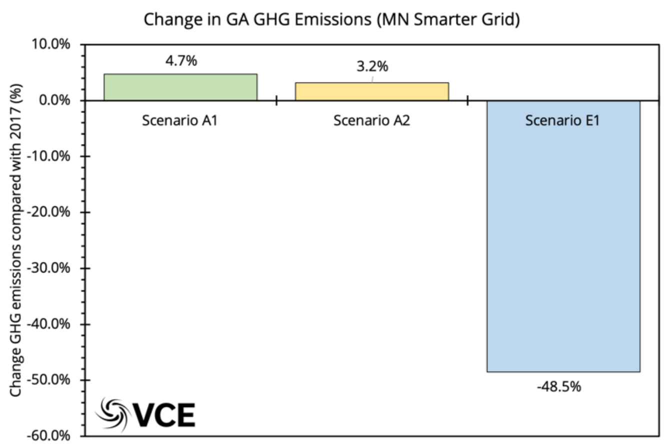

Figure 14: The change in GHG emissions for the electricity sector in Georgia under three scenarios from the MN Smarter Grid study.

Q: What are your recommendations?

A: The MN Smarter Grid study (Attachment JR-3) shows that, under detailed modeling, the state of Georgia can accommodate substantial quantities of renewables and storage. The study used fine granular weather data (3-km and 5-minutely) to estimate the generation from the wind and solar PV generators to mimic conditions the electricity grid will

[17] See a detailed review from the National Institute of Health here: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3550231/

encounter. There is a limit to the number of renewables that an electricity grid can integrate without significant operational changes; however, the MN Smarter Grid study did not reach those levels for Georgia under any of its scenarios by 2030. Thus, I can recommend that, based upon the MN Smarter Grid study, Georgia could feasibly include up to 18,000 MW of renewable generation capacity over the next decade as well as 7,500 MW of electric storage.

The MN Smarter Grid study did not install any wind power generation in Georgia. This was due to the cost curves that were used from the NREL ATB 2017. Since that time the cost of wind has decreased significantly and there are opportunities for Georgia to procure onshore and offshore wind from within its borders (by using higher hub heights) or purchase wind generation from neighboring states. A blend of wind and solar PV generation is typically more appropriate for grid integration because of the anti-correlation nature of the two technologies: the wind is typically more powerful at night and in the colder seasons, while solar PV produces more power in the middle of the day and in the hotter seasons.

In conclusion, Georgia could be ambitious in its goals of high renewable generation numbers without fear of integration issues because of its older, slower generators that can be retired and replaced at a lower-cost by more flexible, modular renewables and storage.

VI. Description of WIS:dom® Optimization Model

Q: Please describe the WIS:dom® model.

A: WIS:dom® (Weather-Informed energy Systems: for design, operations and markets) is a state-of-the-art energy model that co-optimizes capacity expansion (generation, transmission, and storage) and dispatch requirements (production cost, power flow, reserves, ramping, and reliability). WIS:dom® utilizes high-resolution (spatially and temporally) weather data to determine resource potential over vast spatial-temporal horizons. The WIS:dom® optimization model contains weather datasets for variable renewable energy (VRE) [3-km, 5-minute gridded data[18]], transmission lines and power flow, investment time periods, retirements, pollutant tracking, hourly (or 5-minutely) dispatch, reserve requirements, emission constraints, employment and revenue output/input, and economic inputs/outputs. The WIS:dom® model will plan the system in customizable investment time periods [1-, 2-, 5-, 10-year] out to a desired time horizon; typically, 2050.

Q: What geographic scales does WIS:dom® solver over?

A: WIS:dom® has been designed to work at all geographic scales up to an entire continent, while including a wide range of technologies that are more appropriate for a broad array of studies/analyses. The WIS:dom® model initializes by dividing the US into three main regions: Eastern

[18] https://www.youtube.com/watch?v=OFPapVWCWk0

Interconnect, Western Interconnect, and ERCOT. Offshore wind is also considered as an additional layer, along with regions external to the interconnects that exchange power with the continental USA. The WIS:dom® description of the electricity grid is then further divided down into the Independent System Operator (ISO) / Regional Transmission Organizations (RTO). The ISO/RTO regions are then further subdivided; depending upon the use profile. For example, WIS:dom® was used for a storage study within MISO footprint (**here**[19] and **here**[20]). The MISO footprint was subdivided into the LRZs (10 of them) and superimposed upon that was the Minnesota footprint. The way this is done in WIS:dom® is by a nesting of the regions: EI→MISO→LRZs→MN. This allows the model to simultaneously consider changes outside the region/grid of interest, while focusing on planning within a specific footprint (at high fidelity).

Q: What data does the WIS:dom® model initialize with?

A: WIS:dom® incorporates existing generation, existing short-term queue, existing transmission, proposed transmission (if required), retirement dates (enforced or economic), set pathways, emission targets, RPSs, incentives (PTC, ITC, ZECs, RECs), EV projections, DSM/DR projections, and other aspects warranted. The model initialization also includes the natural gas infrastructure that defines constraints on the supply and demand for that fuel source. Each of the externally provided data can be

[19] https://www.vibrantcleanenergy.com/wp-content/uploads/2017/07/Modernizing_Minnesotas_Grid_LR.pdf
[20] https://www.vibrantcleanenergy.com/wp-content/uploads/2017/07/MN_PUC_July11th_2017_VCE-LR.pdf

analyzed against a least-cost, least-regrets pathway; that is one where the WIS:dom® optimization calculates the optimal pathway without certain constraints. The WIS:dom® optimization model comes with all the default data pre-loaded. The default data is sufficient to run the model to do resource planning. However, there is the ability to add proprietary / confidential information to the WIS:dom® model. All input datasets are customizable. Therefore, if a different set of capital costs, or fuel costs are desired they can exchange that data easily without reconfiguring the model. The weather/power data is also customizable, as is the domain of interest.

The default data includes: hourly (and 5-minutely) power data for VREs, hourly (and 5-minutely) load data with assumed growth rates, existing generators, existing transmission, siting constrained regions for generators, economic inputs for generators/transmission, job inputs, tax revenue inputs, emission constraints, cost of carbon, generator specific variables (heat rates, marginal costs, capacity, minimum operation, retirement dates, etc.).

Q: What are some of the unique features of WIS:dom®?

A: WIS:dom® has the unique ability to solve over vast geographic scales at high spatial and temporal granularity (3-km, 5-minutely) for several years chronologically, while performing resource planning over decades. The confluence of these temporal and geographic scales enables WIS:dom® to determine and analyze the impacts of VREs, transmission, storage, and conventional generation at both dispatch and annual levels for a more robust planning scenario. Further, the effect of distributed generation can be analyzed with the distributed generation module, which includes distributed solar PV, behind-the-meter storage, Electric Vehicles, demand-side management, and sector electrification.

Q: Can WIS:dom® track pollution and economic indicators?

A: The WIS:dom® optimization model is a leader when it comes to tracking emissions from electricity generation. The model has been designed from the beginning to compute the emissions of various pollutants (more can be added) to investigate / constrain the systems' behaviors with changing policy. The tracking is typically done on a county level basis, aggregated from the individual plants. However, it is relatively simple to track each generator asset instead of zonally. The purpose of zonal is computational efficiency. Further, each pollution type is separated by technology in WIS:dom®.

Q: What is the purpose of the WIS:dom® model?

A: The WIS:dom® model has been built to be able to service numerous requests of it. From policy and regulation compliance, to reliable transmission power flow, to economic dispatch and resource planning. To facilitate that WIS:dom® is, typically, a customized solution for the client. The client describes the solutions they want to look at, and a branch of the WIS:dom® optimization model is created on their behalf.

Q: What is included in the resource siting constraints for WIS:dom®?

A: Wind and solar have a base GIS data layer for forbidden development sites; Conventional generation is limited to current or specified sites; Grid tied storage can be sited in utility or Behind the Meter; Distributed Energy Resources can only be sited in urban areas; Able to model the entire US, but typically reduced to interconnect; Spatial constraints are applied within the gridded data to ensure no double use.

Q: How is transmission expansion constrained in WIS:dom®?

A: Transmission upgrades can be limited by the user/client; Transmission and storage can be considered together as similar style assets; Explicit lines of interest can be included to determine the benefit/disadvantage of the lines; Multiple optional expansion can be offered to the model and it will determine the least-cost built out, while simultaneously considering the generation and load at dispatch intervals; Hurdle rates are applied to transmission crossing boundaries of utilities, states, ISOs and RTOs.

Q: How does WIS:dom® consider spatial and temporal variability of renewables?

A: A minimum of 3 years of hourly weather data is used over the entire electricity grid; A single "depiction" year is optimized against at 3-km, 5-minute dispatch; The hourly data also include forecasts (2-hr, 6-hr), to assess the impact of forecast error [for dispatch in WIS:dom®]; Capacity credit evaluation based upon various penetrations and weather variability; Renewables can contribute to reserves by being down-dispatched.

Q: What distributed resources and other considerations are there in WIS:dom®?

A: Electric vehicle adoption; Sector electrification and load shape changes; Residential/Commercial storage; Rooftop solar PV; Demand response/management; Role of charging/discharging vehicles on grid; Planning and following reserve requirements in a changing resource mix.

Q: How does WIS:dom® take into account the fuel supply mix for natural gas?

A: Reduced form natural gas pipelines between the States; Inter-investment period elasticity for the natural gas market prices; Intra-annual cost curves for natural gas based on supply and demand over previous investment period and the elasticity; Natural gas storage and pipeline expansion co-optimized with the electricity sector.

Q: What are the main technologies available in WIS:dom®?

A: The technologies available in WIS:dom® are:

1. Conventional Generation
    a. Coal-fired power plants,
    b. Natural gas combined cycle,
    c. Natural gas combustion turbines,
    d. Hydroelectricity,
    e. Nuclear power plants,
    f. Geothermal power plants,
    g. Biomass power plants;
2. Solar Photovoltaics
    a. Fixed axis,
    b. 1-axis tracking,
    c. 2-axis tracking,
    d. Distributed solar PV;
3. Grid tied energy storage
    a. Li-Ion,
    b. Flow batteries;
4. Wind Turbines
    a. 80 m hub height,
    b. 100 m hub height,
    c. Other [120-160 m] hub heights,
    d. Turbine designs,
    e. Rotor diameter;

5. Electric Vehicles
    a. Charging/discharging behavior,
    b. Amount and location of EVs,
    c. V2G, G2V, etc.;
6. Distributed Energy Resources
    a. Storage,
    b. Heat pumps,
    c. Other demand management;
7. Large scale demand management.
8. Novel Technologies
    a. Hydrogen production for seasonal storage;
    b. Small Modular Reactors (SMR);
    c. Molten Salt Reactors (MSR);
    d. Carbon Capture and Sequestration (CCS);
    e. Ammonia production for seasonal storage;
    f. Synthetic fuels for circular energy economy.

Q: Does this conclude your testimony?

A: Yes, this concludes my testimony.