VIBRANT CLEAN ENERGY

Executive Summary

Why Local Solar For All Costs Less:
A New Roadmap for the Lowest Cost Grid

Prepared By:

Vibrant Clean Energy, LLC

Christopher T M Clack
Aditya Choukulkar
Brianna Coté
Sarah A McKee

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COALITION FOR COMMUNITY SOLAR ACCESS

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1. Executive Summary

The electricity system in the United States (US) is considered to be one the largest machines ever created.[1] With the advent of clean and renewable technologies, a widespread evolution is occurring. The renewable technologies are lower cost than fossil thermal generation on a levelized cost basis,[2] but their variability creates new and unique constraints and opportunities for the electricity system of the next several decades. Superimposed on the changing structure of the electricity system is a damaged climate that will continue to worsen as mankind continues to emit greenhouse gas (GHG) pollution into the atmosphere.[3]

The US electricity system is the second largest in the world (China has the largest). In 2018 it served approximately 150 million customers with over 3,859 terawatt-hours (TWh) of electricity from over 1,190 gigawatts (GW) of generating capacity, routed through 476,000 miles of transmission lines (over 69 kV), 55,000 substations and 6.3 million miles of distribution lines (under 69 kV).[4,5,6] By the end of 2019, there was 86,000 MW of renewable capacity awaiting construction across the US and each year that number continues to grow.[7] The carbon dioxide (CO_2) emissions from electricity generation across the US reached an estimated 1,659 million metric tons (mmT) in 2019, accounting for approximately 32% of the total United States (US) energy-related CO_2 emissions (5,130 mmT).[8]

The present study demonstrates, quantifies and evaluates the potential value that distributed energy resources (DERs) could provide to the electricity system, while considering as many facets of their inclusion into a sophisticated grid modeling tool. The *Weather-Informed energy Systems: for design, operations and markets planning* (WIS:dom®-P) optimization software tool is utilized for the present study. A detailed technical document of the WIS:dom®-P software can be found online.[9] The modeling software is a combined capacity expansion and production cost model that allows for simultaneous 3-kilometer, 5-minute dispatch and power flow along with multi-decade resource selection. It includes detailed representations of fossil generation, variable resources, storage, transmission and DERs. It also contains policies, mandates, and localized data, as well as engineering parameters and constraints of the electricity system and its components. Some novel features include highly granular weather inputs over the whole US, climate change-induced changes to energy infrastructure, land use and siting constraints, dynamic transmission line ratings, electrification and novel fuel production endogenously, and detailed storage dispatch algorithms.

The distribution grid is where the majority of customers connect with the electricity system at large. However, traditional modeling tools ignore its existence almost entirely. Many

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[1] https://www.bloomberg.com/quicktake/u-s-electrical-grid
[2] https://atb.nrel.gov/electricity/2020/index.php?t=in
[3] https://climate.nasa.gov/
[4] https://www.energy.gov/sites/prod/files/2017/01/f34/Electricity%20Distribution%20System%20Baseline%20Report.pdf
[5] https://www.eia.gov/electricity/data/eia860/
[6] https://www.eia.gov/electricity/data/eia923/
[7] https://www.eia.gov/electricity/data/eia860/
[8] https://www.eia.gov/environment/emissions/carbon/
[9] https://vibrantcleanenergy.com/wp-content/uploads/2020/08/WISdomP-Model_Description(August2020).pdf

assume pre-decided buildout rates of distributed solar PV (DPV), energy efficiency (EE), demand-side management (DSM), demand response (DR), and distributed storage (DS). As the electricity system continues to evolve, customers are demanding more local resources. This creates a problem because the providers of electricity (across utility service territories and RTOs) do not possess integrated modeling tools that reveal the opportunities and costs of changing distributed generation and demand as a decision variable. The opportunities could include reduced utility-scale capacity and generation, high-voltage transmission, distribution infrastructure deferments, utility-observed peak load reduction, and increased utility-observed load factors. The costs could be more distribution infrastructure, more high-voltage transmission, increased DER buildout, and utility-scale back-up capacity and generation to cover the DER buildout.

Vibrant Clean Energy, LLC (VCE®) augmented the WIS:dom-P software to improve its representation and computations of the distribution-utility interface. The augmentations enabled a modeling framework that included the distribution grid and DERs that is tractable and akin to traditional utility planning models.

During the entire study, ***fifteen*** nationwide simulations were performed. Numerous intermediate simulations were used to determine the sensitivity of the modeling tool to changes in the augmentation created during the study. The model was initialized and aligned with historical data from 2018 and then the simulations evolved the electricity system across the contiguous United States (CONUS) from 2020 through 2050 in 5-year investment periods. In the present report, we focus on ***four*** main scenarios that answer two main questions:[10]

1. *Can DERs lower costs across the entire electricity system compared with alternatives, while maintaining resource adequacy, reliability and resilience?*
2. *Can DERs provide support and benefits for clean electricity goals across the entire electricity system?*

The four scenarios simulated for the present report were:

Business-As-Usual, Traditional ("BAU"): Allow economics to drive the changes in the electricity system, while including existing policies, mandates, and incentives through 2050. Deploy WIS:dom-P in a manner that mimics traditional models.

Business-As-Usual, Augmented ("BAU-DER"): Allow economics to drive the changes in the electricity system, while including existing policies, mandates, and incentives through 2050. Deploy the augmented version of WIS:dom-P that includes detailed modeling of the distribution-utility (DU) interface.

Clean Electricity, Traditional ("CE"): Enforce a nationwide clean energy standard (CES) that reduces emissions by 95% from 1990 levels by 2050. Deploy WIS:dom-P in a manner that mimics traditional models.

Clean Electricity, Augmented ("CE-DER"): Enforce a nationwide clean energy standard (CES) that reduces emissions by 95% from 1990 levels by 2050. Deploy the augmented

[10] Future reports will present findings from the remaining 11 simulations. One of the simulations electrified and decarbonized the entire CONUS economy. All the remaining 11 simulations enhance or provide additional support for the conclusions detailed in the present report.

version of WIS:dom-P that includes detailed modeling of the distribution-utility (DU) interface.

The augmentation of the WIS:dom-P software to include distribution planning co-optimization results in cumulative system-wide savings of $301 billion by 2050 ("BAU" vs "BAU-DER"), which rises to $473 billion when considering a clean energy standard ("CE" vs "CE-DER"). Interestingly, the "CE-DER" scenario pathway is lower cost than the "BAU" scenario to the tune of $88 billion by 2050. Figure ES-1 shows the cumulative system cost savings through 2050.

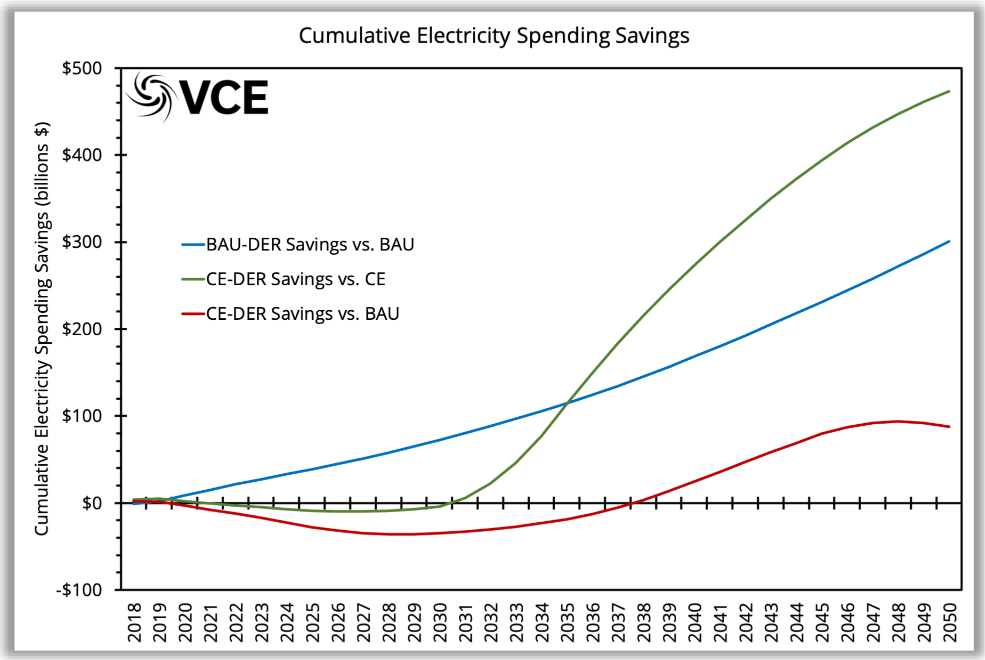


Figure ES-1: The cumulative electricity system due to the augmentation of the WIS:dom®-P software to include distribution planning.

For the clean electricity system cost savings to materialize, a small amount of additional spending occurs in the first decade, however, for "BAU-DER", the savings accrue immediately. By 2035, the "BAU-DER" scenario has saved nearly $115 billion over the "BAU" scenario, while the "CE-DER" scenario has accumulated savings of $114 billion compared with the "CE" scenario. Over the same time period, the "CE-DER" scenario is $19 billion more expensive than the "BAU" scenario, but has reduced cumulative emissions by 5,112 mmT (equivalent to a cost of carbon of ~$3.70 per metric ton). By 2050, the scenario has avoided more than 10,000 mmT compared with "BAU" (as depicted in Fig. ES-2), while saving $88 billion in costs.

If a clean electricity mandate were imposed by 2035, rather than the modeled 2050 (and the US could deploy enough generation), the DERs would bring forward the cost savings observed by 2050 to 2035, since they enable more clean utility-scale variable generation to be deployed efficiently.

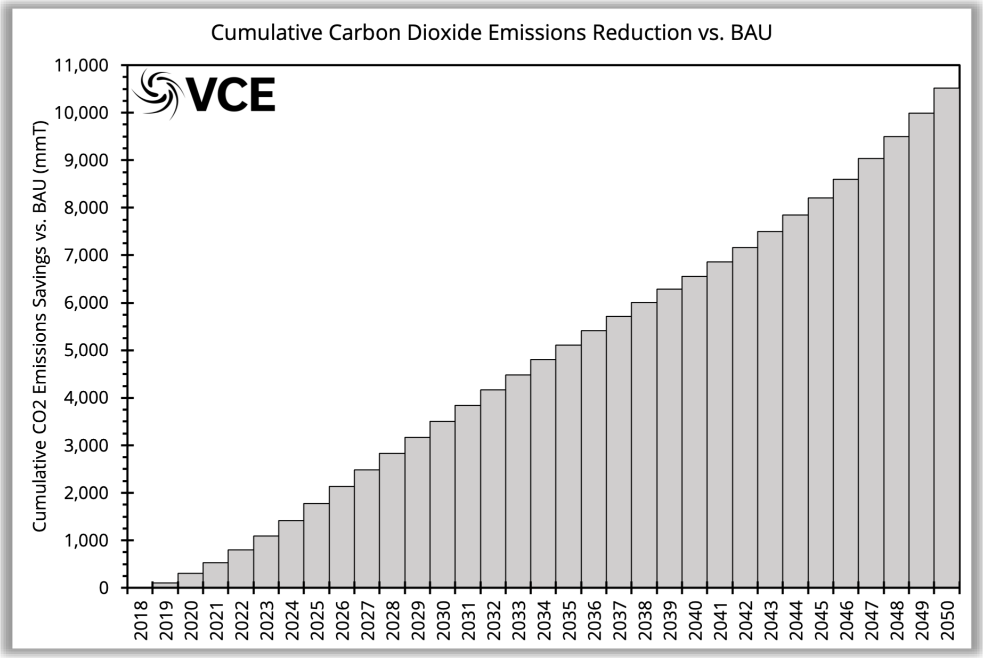


Figure ES-2: The cumulative electricity CO_2 emissions reduction from "CE-DER" compared against "BAU" .

The inclusion of distribution modeling within the WIS:dom-P software drives emergent behavior.[11] The distribution grid seeks to minimize exposure to the utility grid while maximizing its benefits of being connected by minimizing system costs that includes infrastructure connecting the utility and distribution grids. This manifests as increased load factors as experienced by the utility-scale grid, while reduced peak demand. Further, the more local resources can defer some distribution infrastructure costs. The sum of these is net system cost savings, increased jobs, more manageable installation rates, a more reliable and robust system, and more opportunities for private capital investments.

The striking result is that the cost savings come with relatively little change in the macro-scale view of installed capacities and generation stack. This is because a small change in the tails of production and demand can have amplified cost implications throughout the system. Additionally, the distribution cost augmentation facilitates economic tradeoff between more resources, which improves competition and reduces costs further.

[11] Emergent behavior is characterized by properties and behavior that is not dependent on individual components, but rather the complex interactions and relationships between those individual components. Therefore, it cannot be fully predicted by simply observing or evaluating the individual components in isolation.

1.1 Capacity Changes

In all four scenarios, the entire electricity system undergoes substantial evolution in WIS:dom-P from 2020 through 2050. The general trend is a dramatic reduction in coal and natural gas capacity in exchange for increases in wind and solar PV along with DERs and storage. The model did not include deployments of novel technologies, such as natural gas with carbon capture and sequestration (CCS), small modular reactors (SMR), or molten salt reactors (MSR). Figure ES-3 displays the installed capacity across the CONUS electricity system for each investment period and the four scenarios.

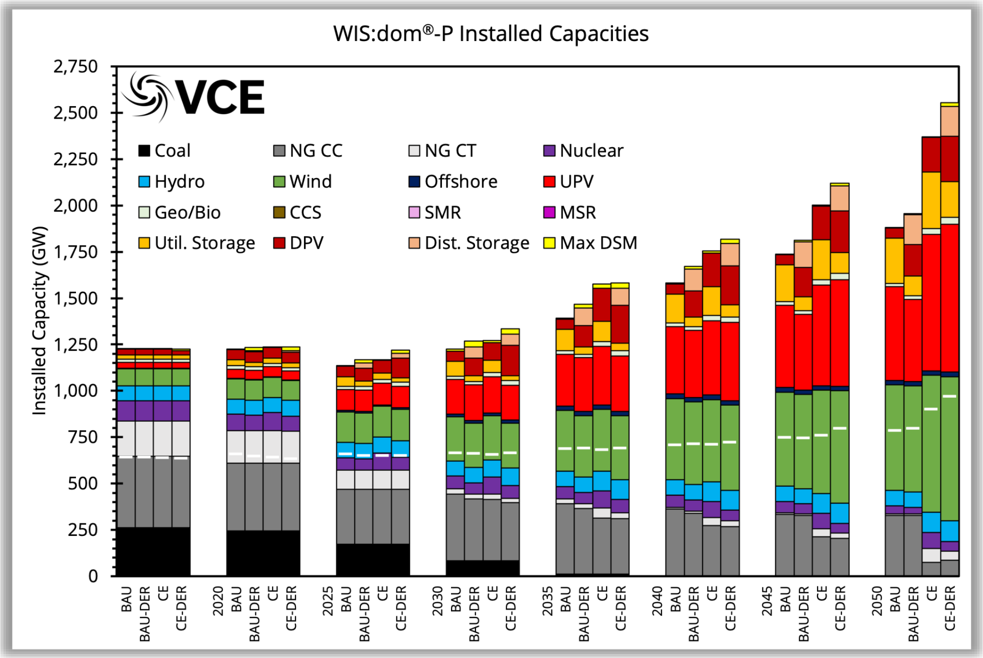


Figure ES-3: The installed capacities over the CONUS. The white bars indicate the peak coincident demand.

The highest buildout of capacity is in the "CE-DER" scenario because it is relying more on DERs and utility-scale wind and solar than the other scenarios. By 2030, the "CE-DER" already has pronounced increases in distributed solar PV and storage (with lower utility-scale counterparts) and deploys much more demand-side management (DSM). The peak demand is similar across all scenarios by 2030. Lower installed capacities of natural gas combined cycle power plants (NGCC) are observed in the clean energy standard scenarios These scenarios deploy more natural gas combustion turbines (NG CT) to assist with capacity requirements (with lower amounts in the "CE-DER" vs the "CE" scenarios).

All scenarios show substantial growth in electricity storage capacity, with significant additional capacity in the clean energy standard scenarios. It should be noted that a shift in storage capacity occurs in the augmented scenarios from utility-scale storage to distributed scale. This is because the model finds more value deploying the storage in the distribution grid than entirely in the utility-scale grid. However, Fig. ES-3 only shows part of the capacity (power). Figure ES-4 shows the electricity storage capacity in terms of energy. The figure shows that under "BAU" 8,200 GWh of storage is deployed between 2020 and 2050 (with only 200 GWh being deployed in the next decade), while in "CE-DER" a further 1,000 GWh is installed (with 400 GWh additional by 2030). For comparison, the Tesla Gigafactory in Nevada produced, at its peak in 2018, an annualized rate of 20 GWh of batteries.[12] Thus, the "BAU" would require almost the entire output of the Gigafactory through 2030 and a sharp increase over the following two decades. The "BAU-DER" and "CE-DER" scenarios require much smoother increases in the deployment requirements of energy storage through 2045 and a steep increase in the final five years of the modeling. Approximately half of the energy storage is deployed in the distribution grid between 2020 and 2050. This shift in deployments facilitates distribution demand profile shaping and shifting that supports the distributed generation and reduces utility-scale system peak demand requirements.

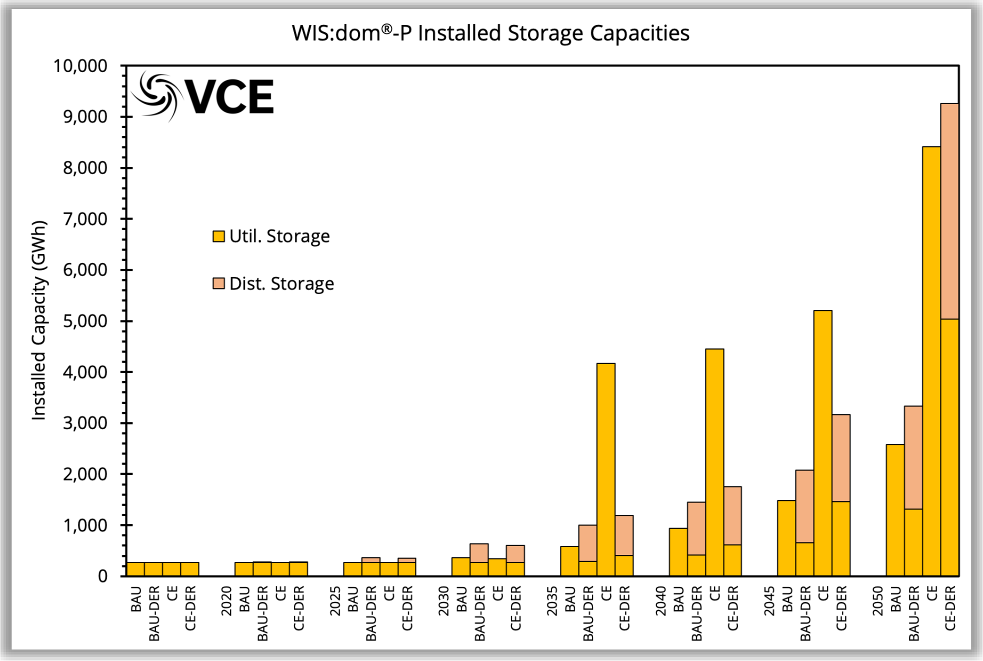


Figure ES-4: The installed capacities over the CONUS for energy storage.

The installed capacity across the CONUS rises by 50% to 100% from 2020 through 2050 in all scenarios. The substantial shift in capacity requires enormous additions and retirements over the next three decades. Figure ES-5 displays the rate of installation and retirement required for each scenario for each investment period. The peak installation rate over all the scenarios was 110 GW per year. For the entire US, the historical peak installation rate is around 55 GW and the typical rate is 10 – 25 GW per year. The rapid increase in installation rate is required to replace higher capacity factor thermal generation with lower-cost, but lower capacity factor variable generation.

More rapid deployments are observed for the "BAU-DER" and "CE-DER" scenarios compared with their traditional counterparts. This is because more utility-scale and distribution-scale variable generation is being constructed. This indicates a more equitable transition of resources because there are more opportunities for competition and siting throughout the whole electricity system, rather than just on the utility-scale.

[12] https://www.tesla.com/gigafactory

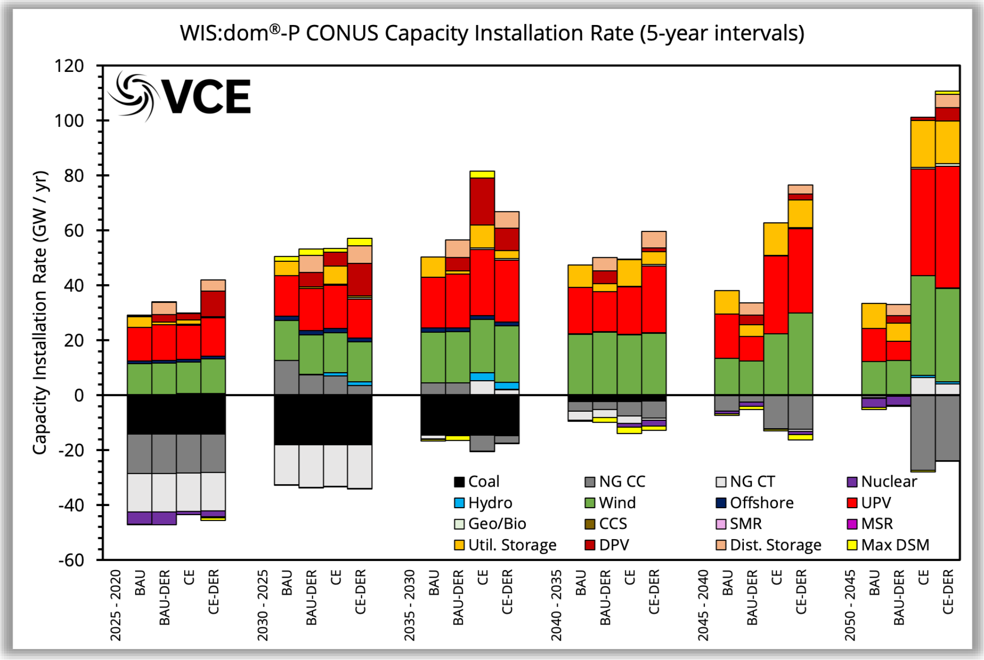


Figure ES-5: The installation and retirement rate over the CONUS.

1.2 Generation Changes

Due to the changing capacity mix generation shifts to lower-emission sources. For the "CE-DER" scenario, the shift is more rapid than the other scenarios, and generally just extends the underlying trend of moving towards VRE and storage. Figure ES-6 displays the generation for each scenario and investment period. It shows that in all scenarios the generation from coal falls to almost zero by 2035. Without the clean energy standard, more natural gas generation replaces the coal retirements. With the clean energy standard, natural gas generation stays about the same as 2018 through 2030 and then rapidly decreases through 2050.

Overall, the addition of distribution modeling results in a shift of generation siting and demand profiles that allows for a more robust system without significant macro-level adjustments to the generation mix. The cost savings come from greater efficiency and more intelligent overall system design.

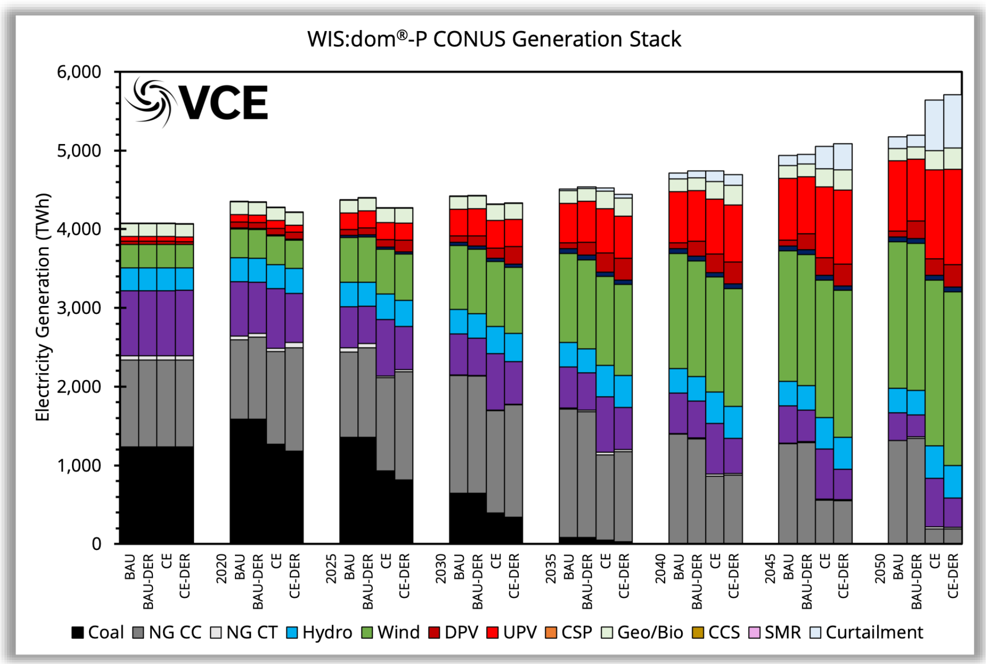


Figure ES-6: The generation breakdown for the CONUS.

By 2050, the change to the generation mix is even more stark when comparing "BAU" and "CE-DER" scenarios daily totals, as plotted in Fig ES-7. It shows the significant growth of utility-scale wind and solar PV as well as distributed PV. There is a much more fluid use of storage as well. The "CE-DER" electricity system is lower-cost than the "BAU" system in 2050; and has accumulated $88 billion in savings since 2018. Thus, the "CE-DER" can be considered to be containing a negative carbon price. This is due to the distribution modeling augmentation. As seen in Fig. ES-6, there is much more curtailment in the "CE-DER" scenario than in the "BAU" scenario, which is an opportunity for new industries to capture low-cost electricity to help support the system further. The $88 billion in cumulative cost savings take into account the increase in curtailment, so the savings could end up higher if novel technologies such as hydrogen electrolysis are utilized.

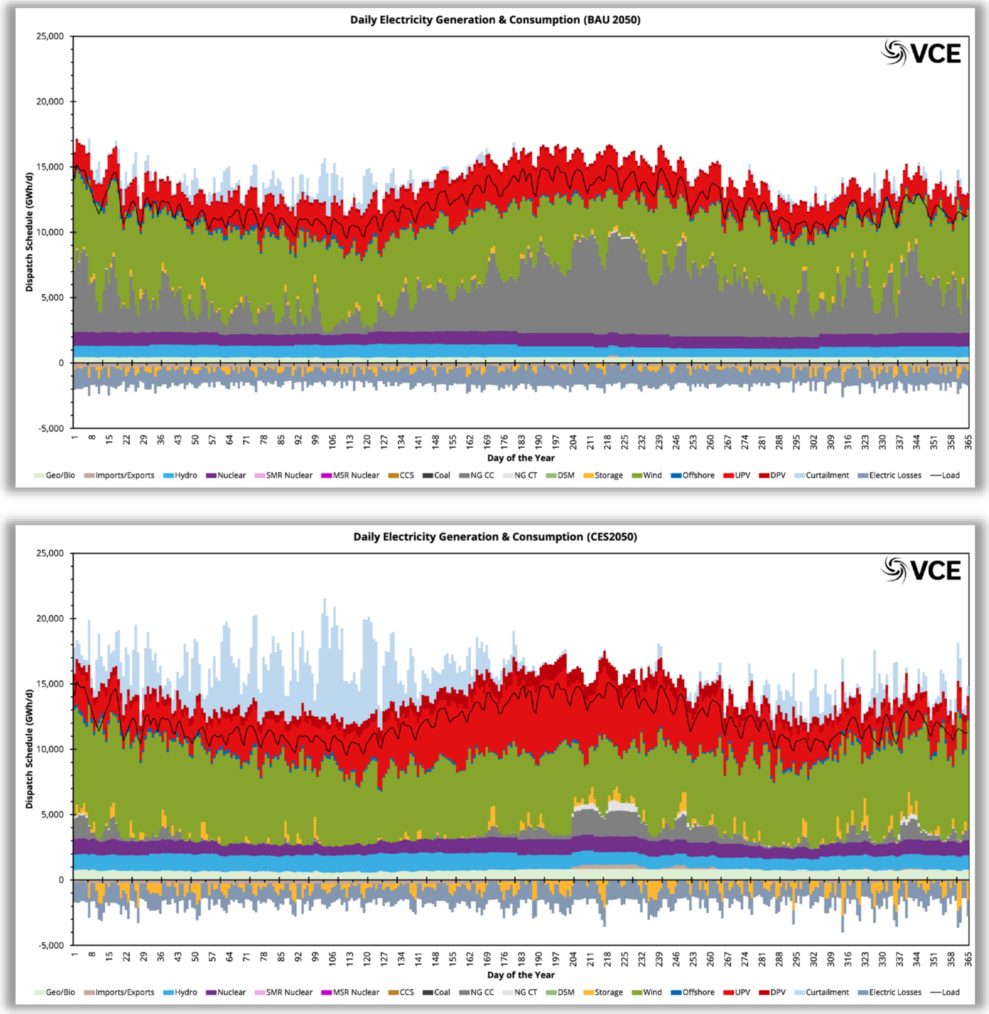
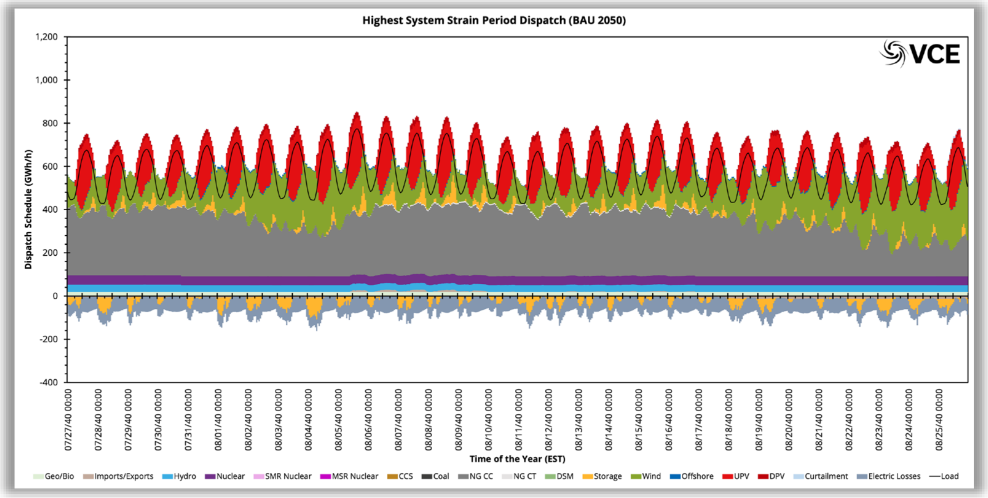


Figure ES-7: The daily generation mix of the CONUS for "BAU" (top) and "CE-DER" (bottom) in 2050.

To deal with the new additional variability of the VRE generation, the WIS:dom-P software must compute reserves and maintain supply and demand for every single time period. The important way this is achieved is that the most difficult times to meet demand are shifted to the lower demand periods where dispatchable generation, transmission, and storage (with residual VREs) can cover the demand much more easily. Figure ES-8 plots the most difficult period for 2050 for the "BAU" and "CE-DER" scenarios. The time period is easily covered by the "CE-DER" scenario with much less natural gas than the "BAU" scenario. In the "CE-DER" scenario, distributed storage, DSM and DR are called upon during these difficult times. This, in combination with both utility- and distributed- scale VRE generation, can reliably cover the coincident peak demands.



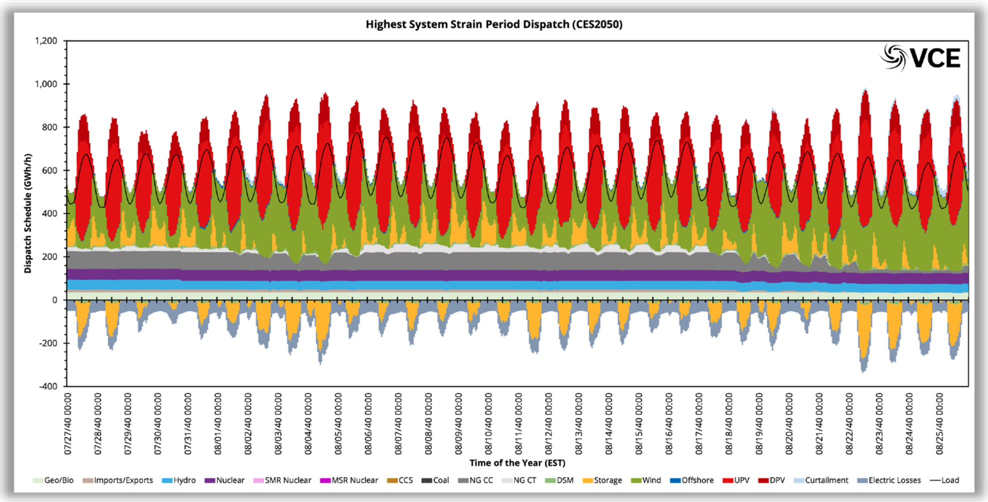


Figure ES-8: The most difficult period to supply demand for the CONUS for in 2050 for the "BAU" (top) and "CE-DER" (bottom) scenario.

1.3 Carbon Dioxide Emission Changes

The clean electricity scenarios both reduce emissions equally through the modeling because they are constrained to do so. The "CE-DER" scenario does so through large amounts of utility-scale wind and solar generation coupled with DERs. The "CE" does it almost entirely with utility-scale generation and as such costs much more to achieve. Figure ES-9 displays the annual electricity sector CO_2 emissions.

The "BAU" and "BAU-DER" scenarios increase emissions in the early years as deployment of wind and solar are not fast enough to keep up with natural gas; however, and the model reaches 2030 CO_2 emissions fall rapidly.

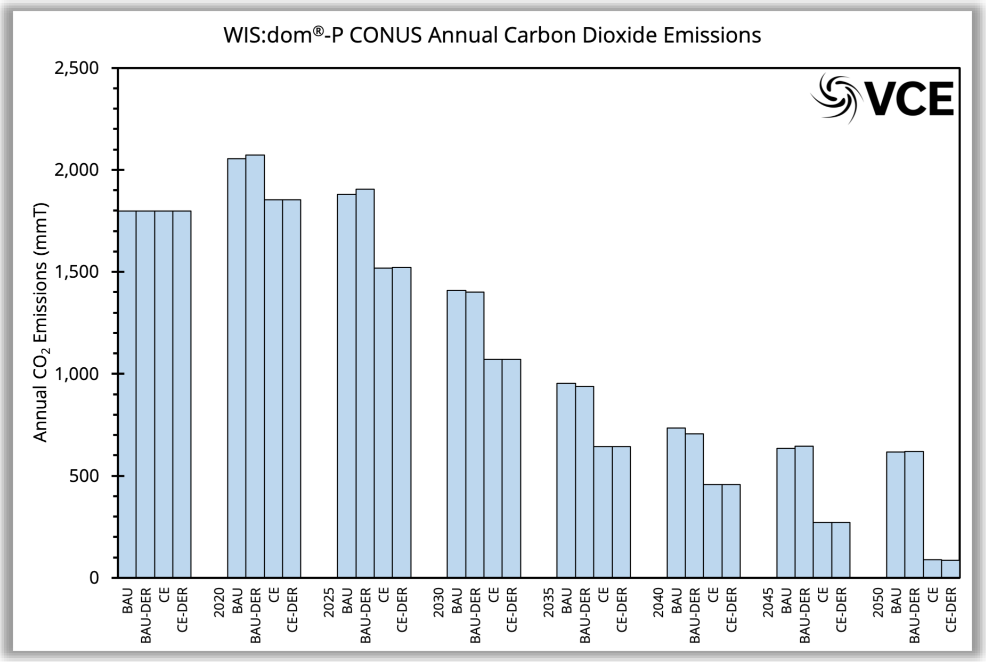


Figure ES-9: The annual CO_2 emissions from electricity production.

Cumulatively, the "CE-DER" scenario reduces emissions by 10 Gt by 2050 compared with the "BAU" scenario and costs $88 billion less in total system costs. In contrast, the "CE" scenario reduces emissions by the same 10 Gt, but costs an additional $385 billion over the "BAU" scenario. The "BAU-DER" scenario emits almost exactly the same amount of carbon dioxide as the "BAU" scenario through 2050 (cumulatively avoids 12 mmT), but costs $301 billion less in total system costs.

The reduction in fossil fuel combustion within the electricity sector for all scenarios dramatically reduces the local pollutants that are damaging to the environment and health; with SO_x, N_2O, $PM_{2.5}$, PM_{10}, VOCs almost entirely eradicated.

1.4 Electricity Price Changes

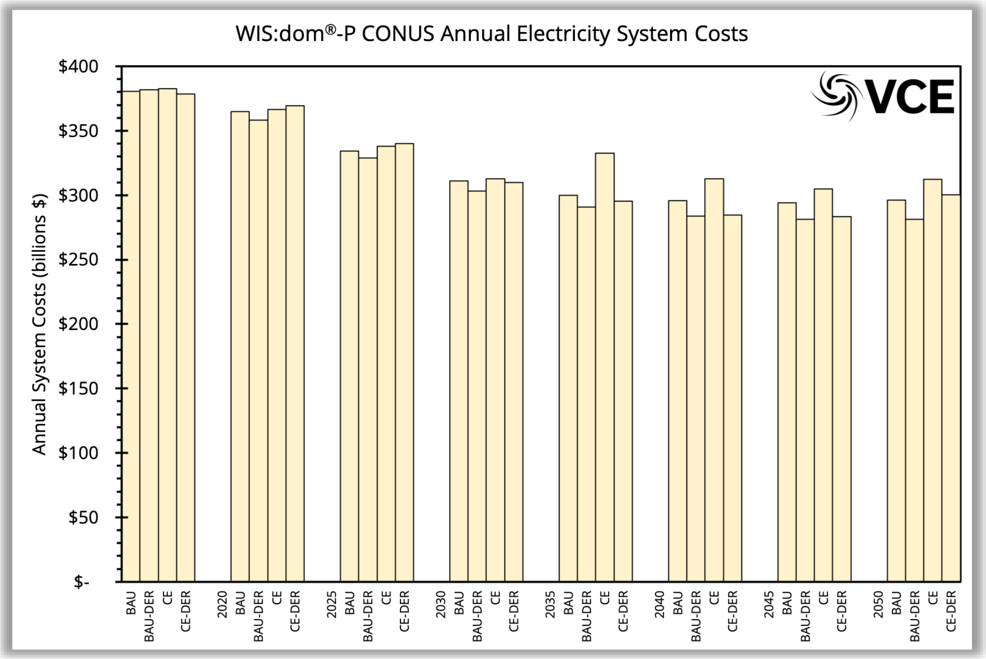
Even though the electricity system is undergoing substantial change in the modeling scenarios, the total system costs are subdued and fall across all scenarios through 2050. This is because low-cost renewables and natural gas help reduce wholesale electricity costs. There are costs to upgrade the distribution infrastructure, but there are also cost savings from deferment of upgrades to the transmission-distribution interface (or connection points) as well as removing unnecessary utility-scale capacity reserved for peaking needs. Since the modeling reduces utility-observed system peaks by around 16% by 2050 (due to the DER coordination) compared with "BAU", a signification fraction of utility-scale peaking and capacity is avoided.

Figure ES-10 shows that both the system costs and the average retail rates drop in each scenario from 2018. Note that the lowest rates by 2050 are for the "BAU-DER" scenario and the highest is for the "CE" scenario. In the earlier years, some addition spending does take place to upgrade the distribution system to accommodate more DERs, but these costs are repaid rapidly and harden the system for other potential changes to demand from either climate change or electrification (or likely both).

It is important to note that in the modeling we used the NREL ATB 2019[13] cost assumptions for generation technologies. The downward trends in all of the output system costs provide reassurance that the costs can remain at or below today's levels given possible uncertainty in price forecasts. The reduction in cost (in general) across the modeling is approximately 30% by 2050. If the NREL price forecasts are 10% too aggressive, then there would still be a 20% reduction in future system costs. Indeed, the additional savings realized by including DER coordination indicates a no-regrets decision in choosing a path that expands their presence on the electricity system.

Finally, a reduced electricity rate could help drive indirect benefits because there will be more disposable income available to customers.

[13] https://atb.nrel.gov/electricity/archives.html



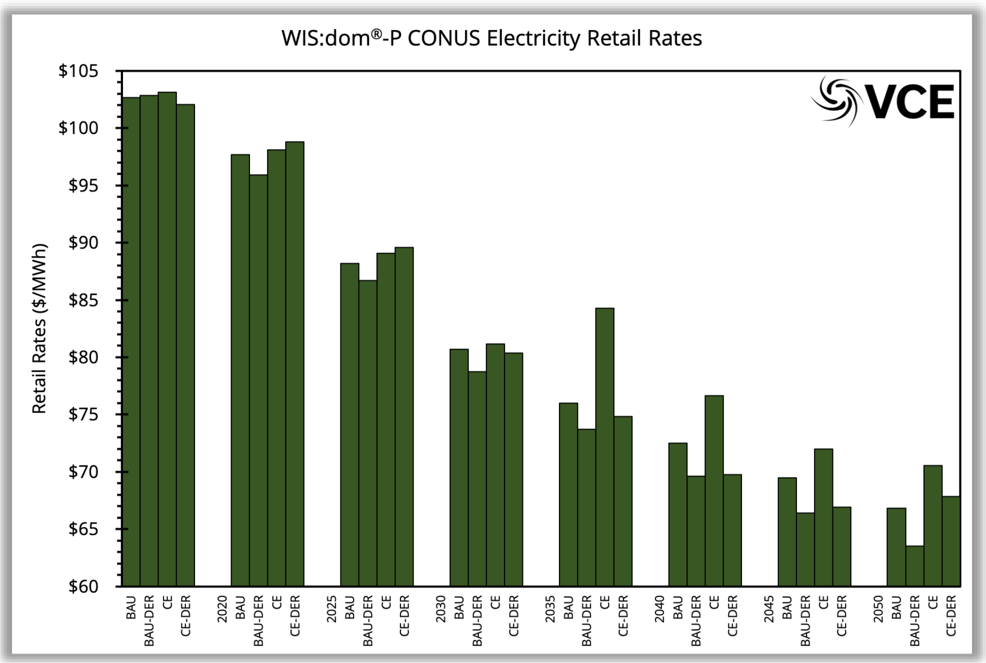


Figure ES-10: The total system costs (left) and average electricity retail rates (right).

1.5 Changes in Employment

The modeled evolution of the US electricity increases jobs. This modeled trend corresponds with historically observed trends as wind and solar generation have been deployed. When DERs are coordinated with the rest of the utility-scale grid, the job numbers accelerate. This is because DERs typically employ more workers than the utility-scale alternative. The coordination with DERs enhances the job growth in wind and solar PV on the utility-scale.

The increase in jobs will provide other benefits that are not modeled or analyzed, such as tax revenues, economic stimulus through higher employment numbers, and supporting jobs (known as induced jobs).

Different states and regions have varying degrees of job creation and reduction. These differences can be homogenized through careful policies and redistribution of savings to help facilitate the transition to a clean energy economy.

The job growth is net of losses that occur due to retirements of legacy generation. The job increases outstrip losses in every state in the for all scenarios, with higher increases in the "DER" scenarios.

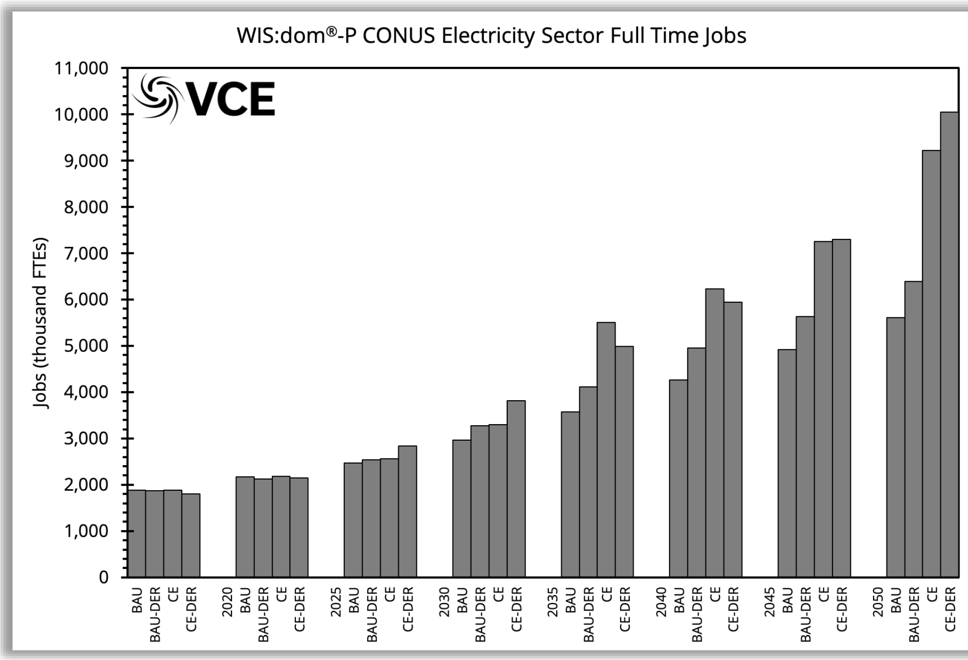


Figure ES-11: The full-time jobs from the electricity sector.

1.6 WIS:dom®-P Augmentation

The WIS:dom-P software was enhanced and augmented during the course of the project. The purpose of the augmentation was to better represent the interface between the utility- and distribution-scale grids. At current computing power, it is not possible to represent every distribution line, home, generator, and feeder across the entire contiguous United States. However, it is possible to parameterize and represent the infrastructure through an interface. This interface can accumulate the costs and associated infrastructure for the distribution grid as new resources are added and the flows change. The modeling sets boundary conditions for full distribution modeling at much higher resolution over much smaller geographic areas.

The interface concept translates to having two different components to the electricity system: a central core that houses the transmission system and utility-scale generation and many satellite bubbles connected to the central core that represent the distribution grids. The WIS:dom-P software is representing the topology at 3-km for generation and transmission (as well as DPV and storage), but the distribution loads are assumed to be singularities at the 69-kV substations, where the costs of the distribution infrastructure is represented with an event horizon. To cross that event horizon in either direction has a cost. For example, if power flows from the distribution grid to the transmission grid (known as back flow), the model assigns a cost for peak power and per unit of energy. The WIS:dom-P software is also simultaneously computing transmission requirements and utility-scale generation. These are all competing with each other as the model seeks a minimum system cost solution to tradeoff all the different costs and values provided by each resource and asset.

A schematic of the process is shown in Fig. ES-12. A detailed technical documentation of WIS:dom-P is available to download on the VCE website.[14] The section of the technical document dedicated to the DU interface is 1.9.2.

The main purpose of introducing a DU interface into WIS:dom-P is to provide information to the optimization to account for: the cost of connecting customers in the distribution grid with the utility grid; the integration costs of distributed resources; the cost of pushing distributed generation to the utility grid; and the value of reducing the power and energy draw from the utility grid into the distribution grid. This new information fundamentally changes the structure of the optimization because it can now recognize that deployments within the distribution grid can reshape the demand observed by the utility grid.

The reshaping of the utility-observed distribution demand provides the following highest value benefits:

1. Ability to remove peaking generation on the utility grid;
2. Increase the utilization of utility grid generation that remains and reduce ramping stress;
3. Reduce burden on transmission system to move electricity at peak demand time periods;

[14] https://vibrantcleanenergy.com/wp-content/uploads/2020/08/WISdomP-Model_Description(August2020).pdf

4. Adjust demand to meet supply variability (rather than supply always adjusting to demand).

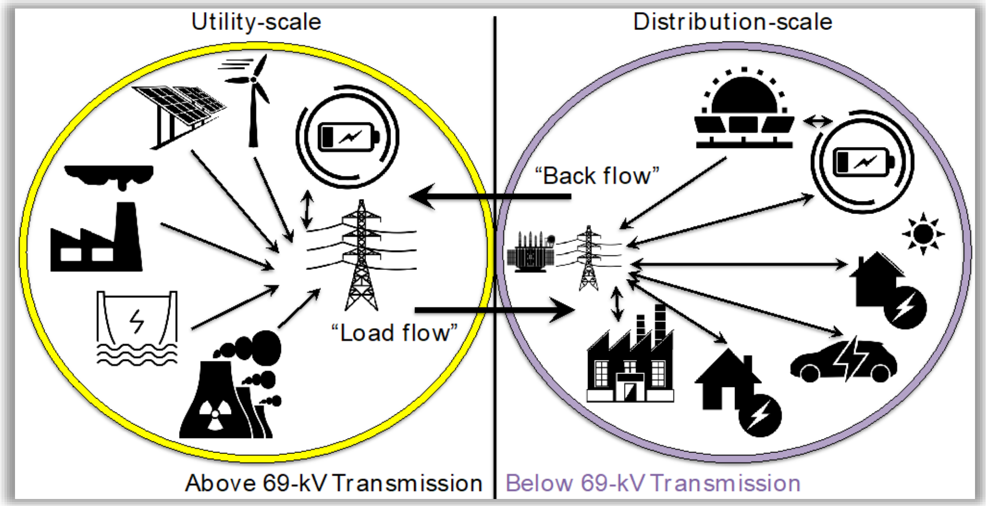
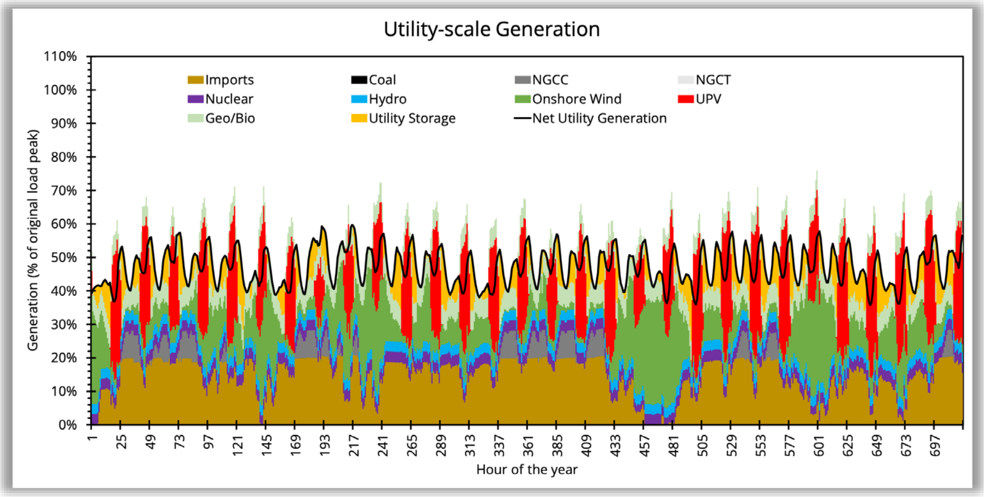


Figure ES-12: A schematic picture of the DU interface within the WIS:dom-P modeling platform.

The generation stack changes due to the DU interface can be seen for an example region in Figs ES-13 through ES-16. Figures ES-13 and ES-15 display traditional optimization framework dispatch, while Figs ES-14 and ES-16 show augmented optimization framework dispatch. The solid black lines denote the demand. These plots demonstrate how the DERs are reshaping the demand observed by the utility grid to dampen the volatile oscillatory behavior (peaks and troughs), while simultaneously capitalizing on low-cost utility-scale wind and solar when supply is high. It can also be seen that the DERs are *charging* at times of lower demand, which increases the utilization of the distribution infrastructure, increases the efficiency of utility-scale generation and transmission, and enables demand peak reduction at a later time.

Figure ES-17 displays the same data as in Figs ES-14 through ES-16, but for an entire calendar year. It is organized as a demand duration curve. The blue and red denote the change to the demand due to the DU interface augmented framework. The blue shows utility-observed demand reduction, while the red shows the increase. The grey denotes the unchanged portion of the demand duration curve. For the example region, the peak demand is reduced by over 30%, while the lowest period is increased by just under 10%. This illustrates the smoothing of utility-observed demand. The demand is reduced for approximately 80% of a calendar year, so the augmentation is more than merely a peak-shaving exercise.

Figure ES-17 captures the most important consequence of the DU interface: demand can be reshaped to meet supply in a manner that provides value for the entire electricity system.



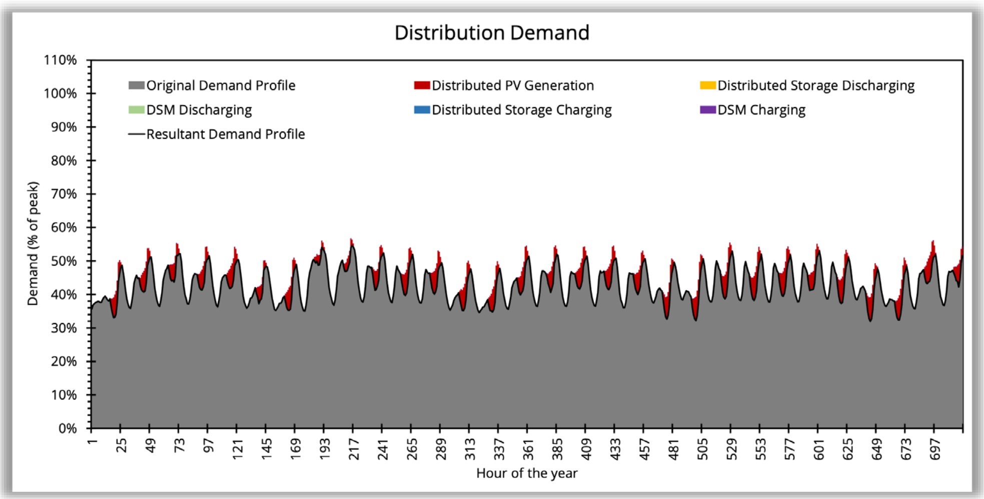


Figure ES-13: A winter example region dispatch of utility- (top) and distribution- (bottom) grid generation under a traditional optimization framework.

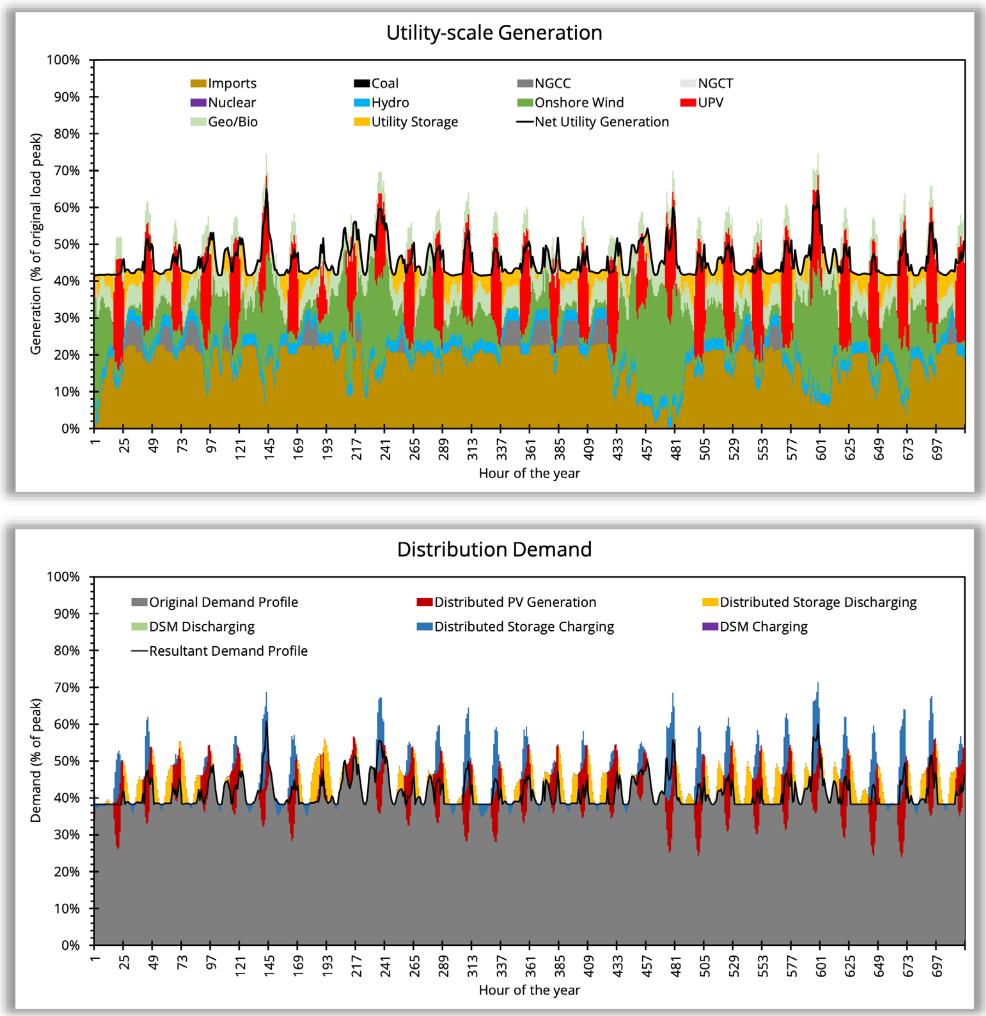
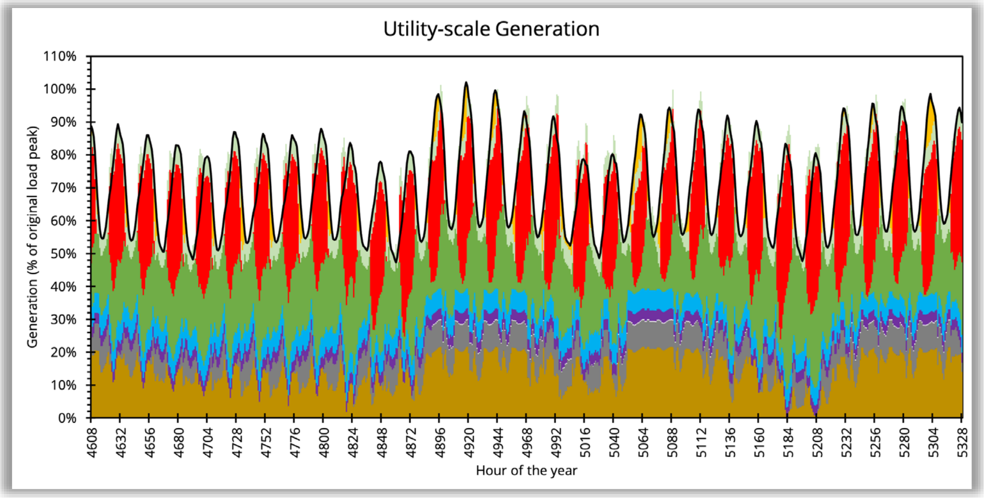


Figure ES-14: A winter example region dispatch of utility- (top) and distribution- (bottom) grid generation under an augmented optimization framework.



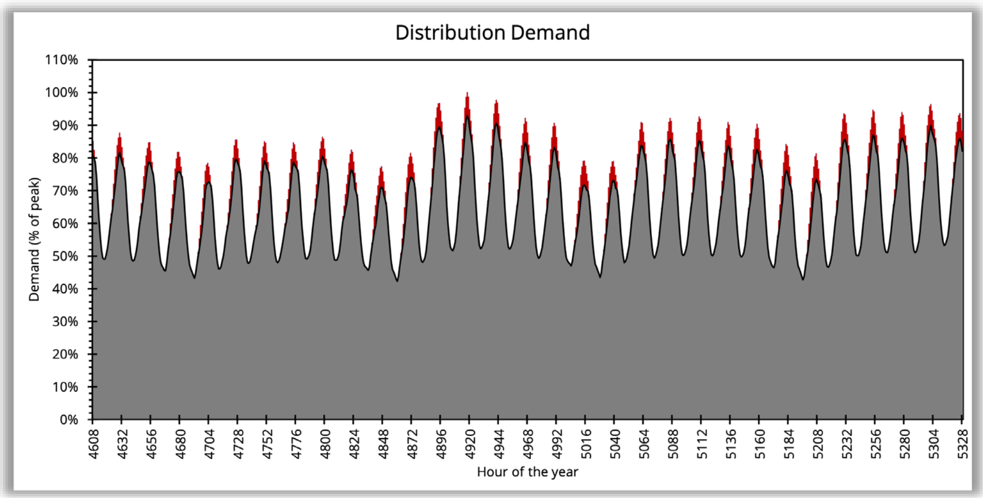
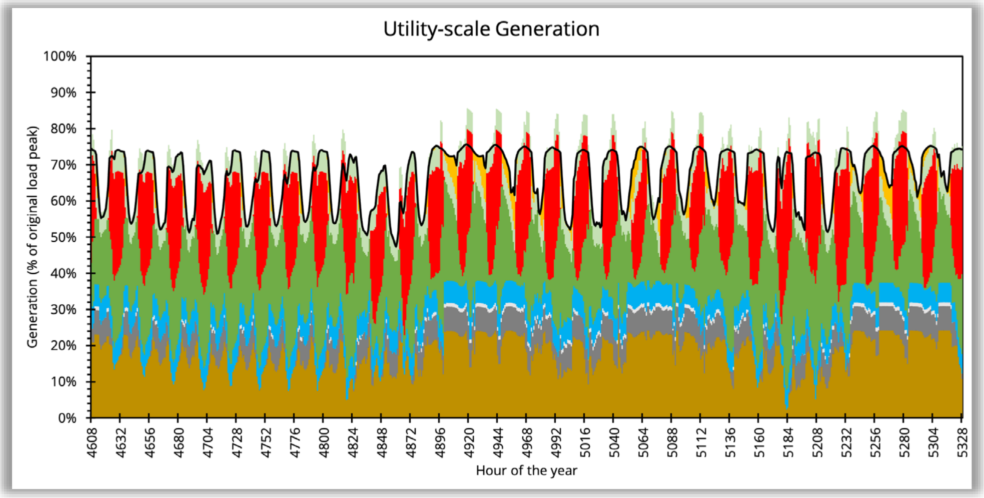


Figure ES-15: A summer example region dispatch of utility- (top) and distribution- (bottom) grid generation under a traditional optimization framework.



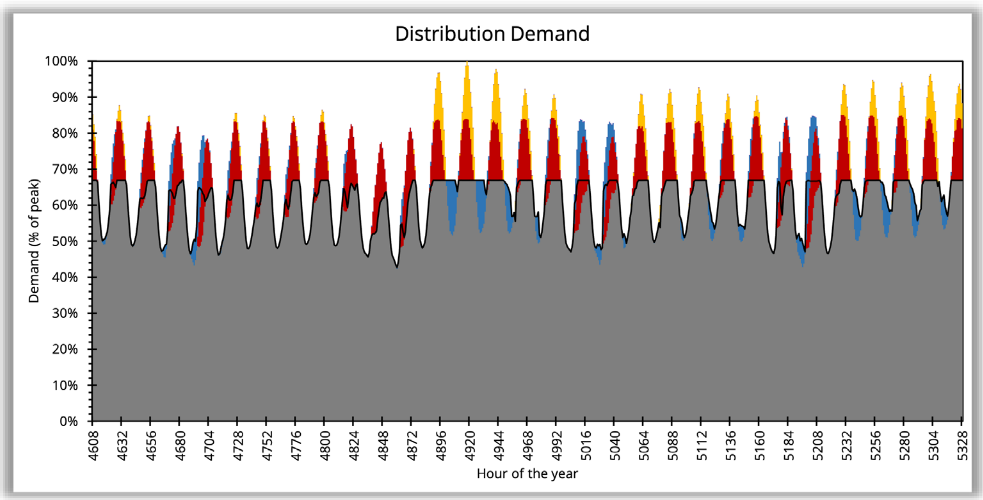


Figure ES-16: A summer example region dispatch of utility- (top) and distribution- (bottom) grid generation under an augmented optimization framework.

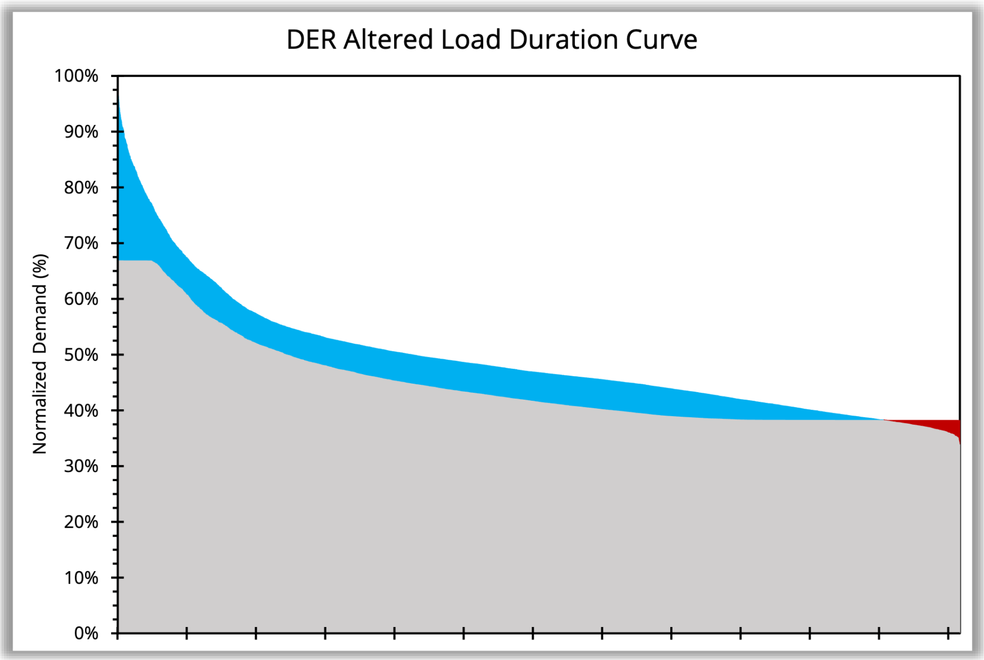


Figure ES-17: A demand duration curve for an example region that shows the reduction in demand (blue) for the majority of the year. The red shows an increase in demand.

VCE

Vibrant Clean Energy, LLC
6610 Gunpark Drive
Suite 200
Boulder CO 80301
(720) 287 1150

Vibrantcleanenergy.com
@VibrantCE