Electrification and Decarbonization Pathways for Michigan

Prepared By:

Vibrant Clean Energy, LLC

Christopher T M Clack
Aditya Choukulkar
Brianna Coté
Sarah A McKee

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1 Study Description

Major utilities in the state of Michigan have released their Integrated Resource Plans (IRPs) outlining their projections for meeting demand out to 2050. The Governor of Michigan, in the meantime, signed an Executive Directive for Michigan to become carbon neutral economy-wide by 2050. In the present study, Vibrant Clean Energy, LLC (VCE®) was commissioned by Vote Solar to study the IRPs released by the major utilities in the lower peninsula of Michigan and compare them against scenarios that achieve the Governor's carbon neutrality goal for the state. The modeling in this study was performed through 2050 using WIS:dom®-P, a state-of-the-art model capable of performing detailed capacity expansion and production cost while co-optimizing utility-scale generation, storage, transmission, and distributed energy resources (DERs). The modeled scenarios use the National Renewable Energy Laboratory (NREL) Annual Technology Baseline (ATB) 2020 "advanced" cost projections for installed capital and Operation and Maintenance (O&M) costs. For fuel costs, projections from the Annual Energy Outlook (AEO) 2020 High Oil and Gas supply scenario are used.[1]

The scenarios modeled in the present study are as follows:

(1) **Business-as-usual with major utilities in Michigan following their respective IRPs ("IRP"):** In this scenario, major utilities in Michigan follow their respective IRPs for capacity additions or retirements. The portions of Michigan not covered by the IRPs undergo optimal capacity expansion. The model does not co-optimize the distribution system with the utility-scale generation (as this is not included in the IRPs released by the utilities in Michigan). The model follows all existing RPS and greenhouse gas mandates passed into law. In addition, the model enforces Consumers Energy to reduce its electricity sector emission by 90% as declared by the utility in a recent announcement.[2] WIS:dom-P is constrained to follow the capacity changes in the IRP unless additional capacity is needed for reliability or to meet emission reduction goals or mandates. In this scenario, Michigan does not undergo economy-wide electrification.

(2) **Electrify and decarbonize Michigan in line with the Governor's Executive Directive without distribution co-optimization ("Decarb+nonOptDER"):** In this scenario, Michigan undergoes economy-wide electrification of energy related activities and completely decarbonizes the electricity sector by 2050. In addition, the scenario must meet 30% of demand from renewable electricity by 2025. In this scenario the distribution system is not co-optimized with the utility-scale grid. Natural gas fired power plants with carbon capture and sequestration (CCS) and advanced nuclear power plants [small modular reactors (SMR) and molten salt reactors (MSR)] are allowed to be installed after 2025 and 2035, respectively, if determined cost-optimal by WIS:dom-P.

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[1] https://www.eia.gov/outlooks/aeo/data/browser/#/?id=3-AEO2020&region=1-0&cases=highogs&start=2018&end=2050&f=A&linechart=highogs-d112619a.3-3-AEO2020.1-0~highogs-d112619a.36-3-AEO2020.1-0~highogs-d112619a.37-3-AEO2020.1-0~highogs-d112619a.38-3-AEO2020.1-0~highogs-d112619a.39-3-AEO2020.1-0~highogs-d112619a.40-3-AEO2020.1-0&map=highogs-d112619a.4-3-AEO2020.1-0&sourcekey=0

[2] https://www.usnews.com/news/best-states/michigan/articles/2021-06-23/consumers-energy-plans-to-complete-coal-phaseout-by-2025

(3) **Electrify and decarbonize Michigan in line with the Governor's Executive Directive with distribution co-optimization ("Decarb+optDER"):** This scenario is identical to "Decarb+nonOptDER" scenario with the single exception that the distribution system grids are co-optimized with the utility-scale grid.

The scenarios are initialized and calibrated with 2018 generator, generation, and transmission topology datasets. The model then determines a pathway from 2020 through 2050 with results outputted every 5 years. As part of the optimal capacity expansion, WIS:dom-P must ensure each grid meets reliability constraints through enforcing the planning reserve margins specified by the North American Electric Reliability Corporation (NERC) and having a 7% load following reserve available at all times. Detailed technical documentation describes the mathematics and formulation of the WIS:dom-P software along with input datasets and assumptions.[3]

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

1.1 WIS:dom®-P Model Setup

To investigate the various scenarios, as described in the previous section, WIS:dom-P modeled the state of Michigan (upper and lower peninsula) with its existing generator topology, transmission, and weather inputs obtained from National Oceanic and Atmospheric Administration (NOAA) High Resolution Rapid Refresh (HRRR) model[4] at 3-km horizontal resolution and 5-minute time resolution. The initialized generator dataset is created by aligning the Energy Information Administration Form 860 (EIA-860) dataset[5] with the 3-km HRRR model grid. The existing generator topology in Michigan in 2018 along with existing transmission at 3-km resolution is shown in Figure 1.1.

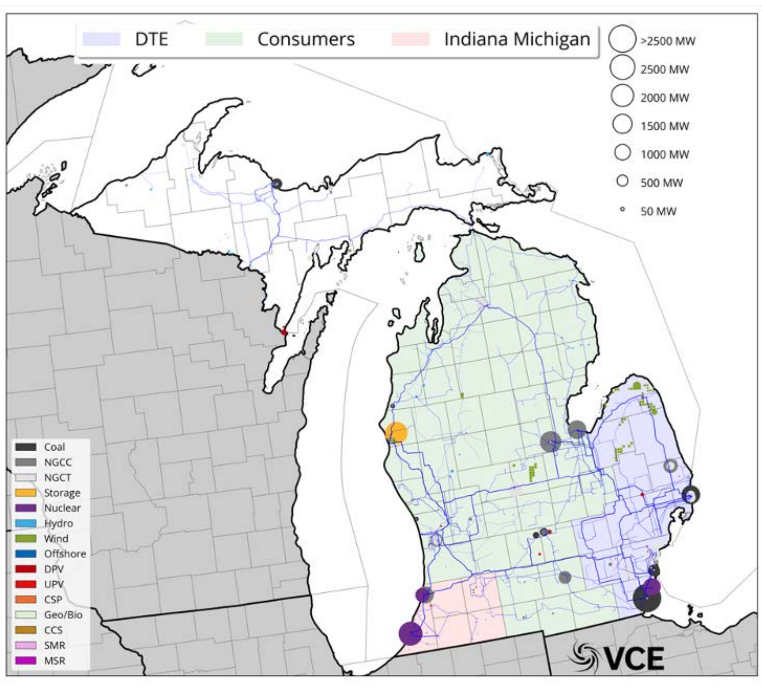

Figure 1.1: WIS:dom-P model domain and existing generators with transmission. The regions shaded show territories of the major Michigan utilities.

Existing transmission corridors between Michigan and neighboring states are modeled as imports and exports and are constrained to be consistent with limits set by MISO. The energy prices for the imports and exports are provided by a background modeling scenario ("CE-DER") from a previous study.[6] In addition, the transmission capacities between Michigan and neighboring states are assumed to remain constant over the modeling period.

Weather inputs obtained from National Oceanic and Atmospheric Administration (NOAA) High Resolution Rapid Refresh (HRRR) model[7] at 3-km horizontal resolution

[4] https://rapidrefresh.noaa.gov/hrrr/
[5] https://www.eia.gov/electricity/data/eia860/
[6] https://www.vibrantcleanenergy.com/wp-content/uploads/2020/12/WhyDERs_TR_Final.pdf
[7] https://rapidrefresh.noaa.gov/hrrr/

and 5-minute time resolution are used in WIS:dom-P for applications with load, transmission and most noticeably with the dispatch and placement of solar and wind. The average fixed latitude tilt solar capacity factors and 100-m hub-height wind capacity factors calculated from the HRRR model output over the model domain are shown in Fig. 1.2. Michigan's wind resource is highest over the eastern part of the lower peninsula (the "thumb") and western portion of the upper peninsula along with a significantly stronger offshore resource. The solar resource is highest over the over the western part of upper peninsula and central portion of the lower peninsula.

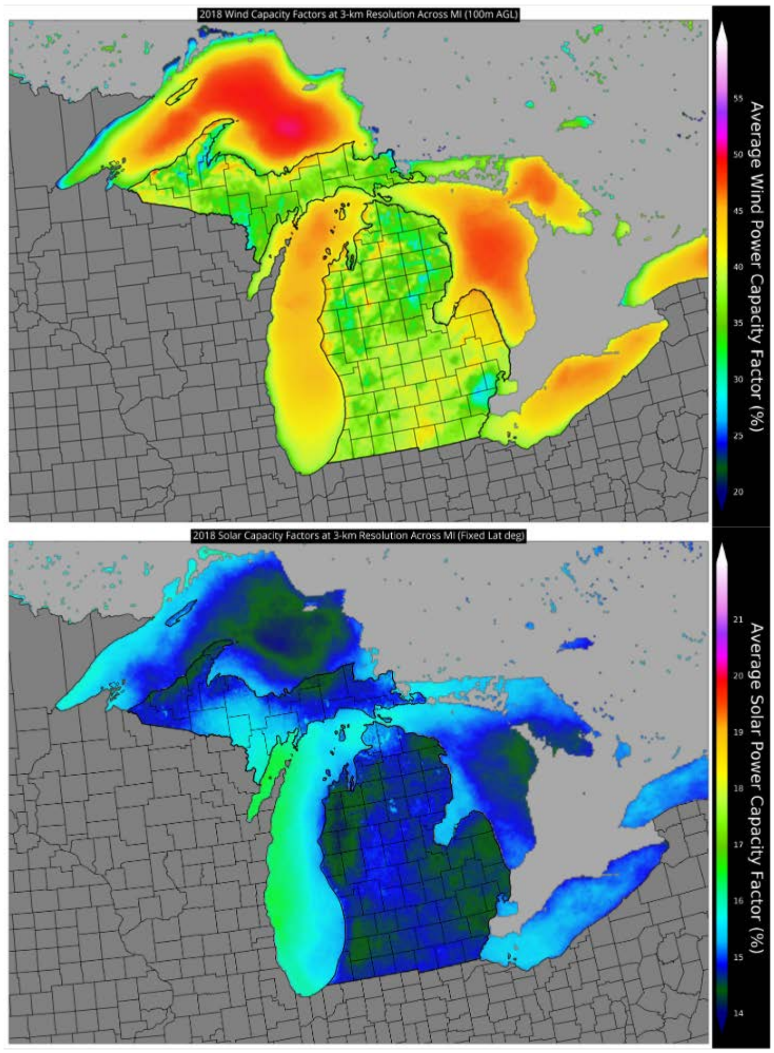

Figure 1.2: Average capacity factors for 100-m hub-height wind (top) and fixed axis latitude tilt solar (bottom) over the state of Michigan calculated from the HRRR model outputs.

2 Modeling Results

2.1 System Costs, Retail Rates & Jobs

In order to study the impact of each scenario on customer bills, the energy burden on customers is calculated for each of the scenarios modeled. The energy burden calculations include customer spending on traditional electricity, space and water heating, transport and industrial operations. The energy burden calculations are combined for residential and commercial customers, while the energy burden for industrial customers is calculated separately. The annual energy burden for an average residential and commercial customer in the "IRP" (top panel) and "Decarb+optDER" (bottom panel) scenario is shown in Fig 2.1.

In the "IRP" scenario, the economy-wide energy related activities are assumed to continue to operate on the current fuel mix and use coal[8], natural gas[9] and oil[10] cost projections from AEO High Oil and Gas Supply scenario. The energy burden in the "IRP" scenario reduces from approximately $4,950 in 2018 to $4,126 in 2030 as a result of reduced retail rates and reduced petroleum prices. After 2030, the energy burden remains almost constant as any reductions in the electricity sector spending (due to reduced retail rates) is offset by increased spending in the heating and transportation sector due to increasing natural gas and petroleum costs.

In the "Decarb+optDER" scenario, the energy burden reduces from approximate $4,950 in 2018 to $3,305 in 2030 as a result of the greater reduction in retail rates and electrification of some of the energy related activities, which cost less due to the lower-cost electricity rates and higher energy efficiency. After 2030, the rate of reduction of the energy burden slows down as any savings from electrification of heating and transport are offset by the increase in spending in the traditional electricity sector due to load growth from electrification of cooking and clothes drying as well as from the increasing electricity rates. Cumulatively by 2050, the "Decarb+optDER" scenario results in savings of $24,741 per customer compared to the "IRP" scenario. This cumulative savings translates to an annual savings of $773 per average residential and commercial customer. Therefore, the "Decarb+optDER" scenario achieves the Governor's goals of electrification and decarbonization of economy-wide energy related activities while reducing costs on energy related activities for residential and commercial customers.

[8] https://www.eia.gov/outlooks/aeo/data/browser/#/?id=15-AEO2020&region=0-0&cases=highogs&start=2018&end=2050&f=A&linechart=~highogs-d112619a.37-15-AEO2020&map=&ctype=linechart&sourcekey=0

[9] https://www.eia.gov/outlooks/aeo/data/browser/#/?id=13-AEO2020&region=0-0&cases=highogs&start=2018&end=2050&f=A&linechart=~highogs-d112619a.35-13-AEO2020~highogs-d112619a.36-13-AEO2020&map=&ctype=linechart&sourcekey=0

[10] https://www.eia.gov/outlooks/aeo/data/browser/#/?id=12-AEO2020&region=0-0&cases=highogs&start=2018&end=2050&f=A&linechart=~~highogs-d112619a.12-12-AEO2020~highogs-d112619a.17-12-AEO2020&map=&ctype=linechart&sourcekey=0

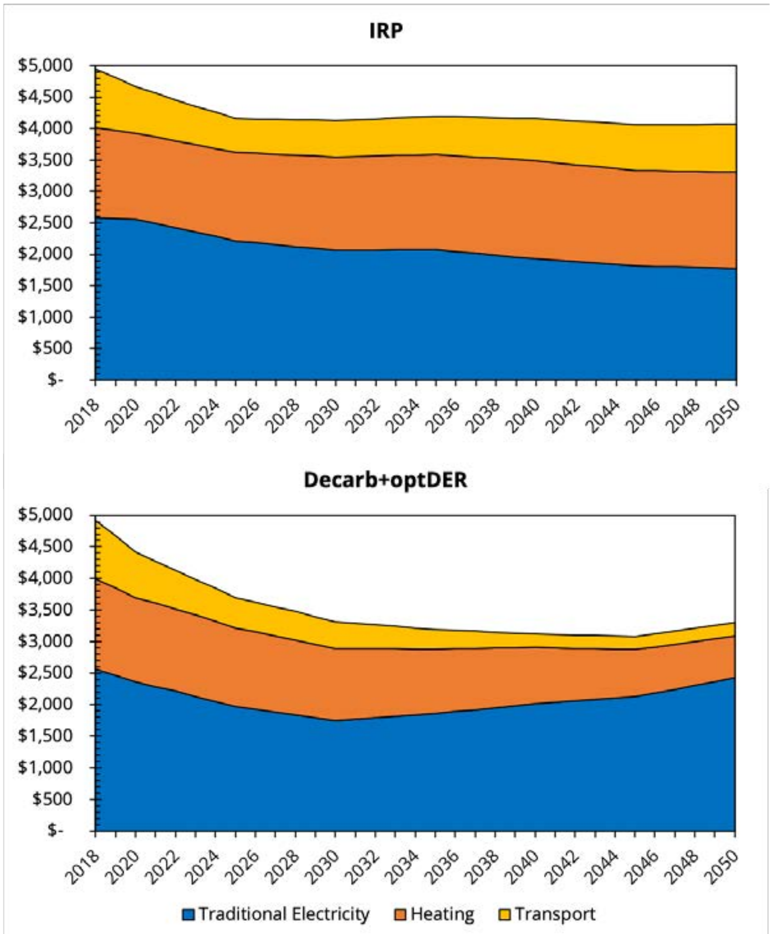

Figure 2.1: Annual spending for an average residential and commercial customer in Michigan in the "IRP" scenario (top panel) and the "Decarb+optDER" scenario (bottom panel).

The "Decarb+optDER" scenario also results in savings for industrial customers who electrify most of their operations with some high heat processes using green hydrogen. As a result of electrification, industrial customers save a cumulative of $2.23 million per customer in the "Decarb+optDER" scenario between 2018 and 2050, which is equivalent to an annual savings of $69,680 per customer. This annual savings is roughly 10% of the average annual operating cost over the modeling period. These savings in industrial energy spending can result in increased profits or be passed on to customers through reduces prices for goods.

The change in total resource costs (which are electricity sector and hydrogen[11] costs) and retail rates in Michigan for the scenarios modeled is shown in Fig. 2.2. In the "IRP" scenario, the total resource costs reduce from approximately $10.7 billion in 2018 to about $7 billion in 2050. The cost reductions come from retirement of expensive coal generation and replacing it with mostly variable renewable energy (VRE) generation along with some imports from other MISO load zones. As a result, the retail rates in

[11] Hydrogen is produced only in the "Decarb+nonOptDER" and "Decarb+optDER" scenarios. No hydrogen is produced in the "IRP" scenario.

the “IRP” scenario also decrease from approximately 11.4 ¢/kWh in 2018 to about 8 ¢/kWh in 2050.

In the two electrification and decarbonization scenarios (“Decarb+nonOptDER” and “Decarb+optDER”), the total resource costs reduce more than the “IRP” scenario until 2030 despite serving additional electricity demand due to electrification. Therefore, the retail rates in the electrification scenarios are substantially lower than the “IRP” scenario bringing significant cost savings to customers. The retail rates in the electrification scenarios drop from 11.4 ¢/kWh in 2018 to approximately 7 ¢/kWh in 2030.

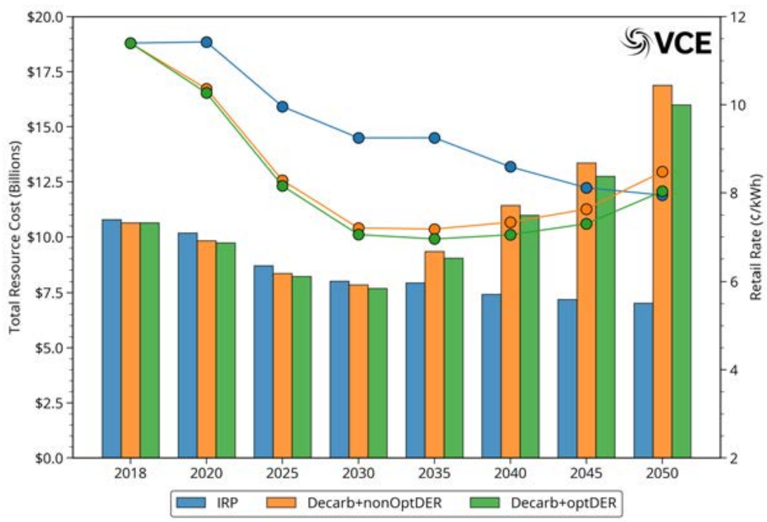

Figure 2.2: Total system cost (bars) and retail rates (solid lines) in Michigan for the scenarios modeled.

After 2030, the rate of electrification accelerates brings in significant new demand into the electricity sector, and the electrification scenarios experience greater investment in the electricity sector to build clean generation to meet the Governor’s goal of electrifying and decarbonizing the economy. As a result, by 2050, the annual system cost in the “Decarb+nonOptDER” scenario is $16.8 billion, while in the “Decarb+optDER” scenario it is $15.9 billion due to savings from the distribution system co-optimization. These systems costs are however spread over a much larger load which results from electrification of energy related activities in the rest of the economy. The retail rates also start to increase slowly after 2030 as a result of the additional investments in the electricity sector and decarbonizing the economy. By 2050, the retail rates in the “Decarb+nonOptDER” scenario are slightly higher than the “IRP” scenario at 8.4 ¢/kWh, while the retail rates in the “Decarb+optDER” scenario are almost the same as the “IRP” scenario at 8 ¢/kWh. Therefore, in the “Decarb+optDER” scenario, Michigan can electrify and decarbonize its economy without causing increases in rates for customers compared to the “IRP” scenario. It is to be noted that the maximum import and exports from Michigan are held constant at 2018 levels. Therefore, it may be possible to reduce costs and thus retail rates further if the transmission capacity were allowed to grow beyond 2018 levels with the rest of MISO and possibly PJM.

The contributions to the cost per kWh of electricity delivered broken out by sectors in the scenarios modeled is shown in Fig. 2.3. In 2018, almost half the cost of electricity is due to fossil fuel generators, with coal being the largest contributor to cost of energy. In the "IRP" scenario, as the coal is gradually retired, the cost of energy reduces as the VRE generation provides energy at much lower cost.

In the electrification scenarios ("Decarb+nonOptDER" and "Decarb+optDER"), the cost of energy reduces faster than the "IRP" scenarios because the fossil fuel generation is retired at a faster rate and the cost of energy is distributed over a larger demand. The cost of energy in the electrification scenarios stays below the costs in the "IRP" scenario until 2045. After 2045, as Michigan decarbonizes the electricity sector completely, the cost of energy in the electrification scenarios increases slightly compared to the "IRP" scenario. The cost of energy increase in the electrification scenarios could be tied to limiting the amount of imports and exports out of Michigan to 2018 levels and allowing the expansion of transmission to other load zones in MISO could help Michigan achieve decarbonization at a lower cost. Compared with the "Decarb+nonOptDER" scenario, the "Decarb+optDER" scenario has lower cost of energy throughout the modeling period. The co-optimization of the distribution system ensures that the distribution system costs in the "Decarb+optDER" scenario remain lower as a result of deferring distribution system capital investment.

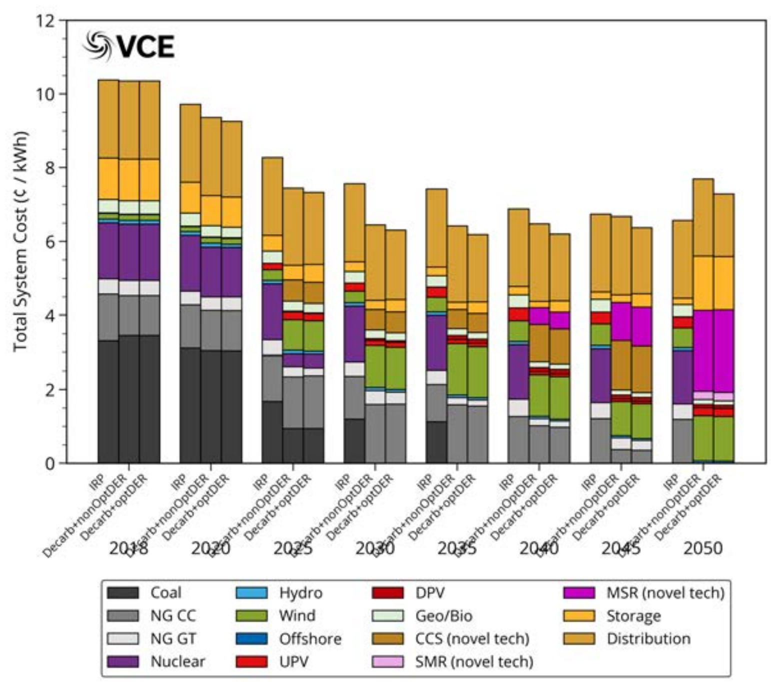

Figure 2.3: Contribution to total system cost per kWh load from each energy system sector for the scenarios modeled.

The total full-time equivalent electricity sector jobs in the scenarios modeled is shown in Fig. 2.4. The total full-time equivalent jobs in the electricity sector in the "IRP" scenario increase from about 45,000 in 2018 to 90,000 in 2050 driven largely by jobs supported by the solar industry. In the electrification scenarios, the job growth over the investment periods is higher than the "IRP" scenario due to the larger VRE deployment. By 2045, the electrification scenarios see 150,000 and 159,000 jobs in the "Decarb+nonOptDER" and "Decarb+optDER" scenarios, respectively. The largest job growth is observed in the distributed solar sector. Between 2045 and 2050, the electrification scenarios deploy large amounts of solar and storage in order to meet the 100% decarbonization goal. As a result, these scenarios see a large increase in workforce in the electricity sector to support this increase in generation deployment. By 2050, the storage industry supports the largest number of jobs in the electrification scenarios, followed by the solar industry. The "Decarb+optDER" scenario see slightly less jobs created in the distribution sector due to the distribution co-optimization deferring investments in the distribution grid.

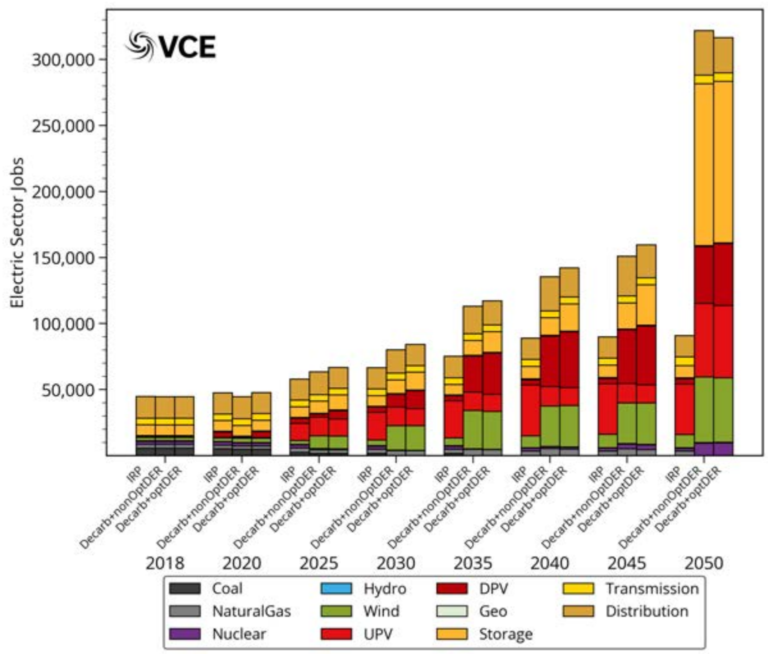

Figure 2.4: Direct full-time equivalent jobs created in the electricity sector by industry for the scenarios modeled.

2.2 Changes to Installed Capacity & Generation

The changes to installed capacity and generation mix in Michigan for the three scenarios modeled are shown in Fig. 2.5. The “IRP” scenario is the slowest to retire coal generation keeping it online until 2040. The retired coal generation in the “IRP” scenario is replaced with some new natural gas combined cycle (NGCC) generation and VRE generation with solar being the dominant addition. WIS:dom-P models both utility scale photvoltaic (UPV) and distributed photovoltaic (DPV). The distributed solar (DPV) includes both rooftop solar and community solar installations. In the electrification scenarios, the capacity turnover takes on very similar paths. Coal is completely retired by 2030 along with some older natural gas generation. Wind makes up a significant portion of new VRE generation added due to the better wind resource available in Michigan along with wind generation’s better correlation with electrification load, especially in winter. The electrification scenarios deploy carbon capture and sequestration (CCS), molten salt reactors (MSR) and small modular reactors (SMR) to provide dense clean dispatchable generation. All CCS in the electrification scenarios is retired by 2050 as they are not 100% emission free.

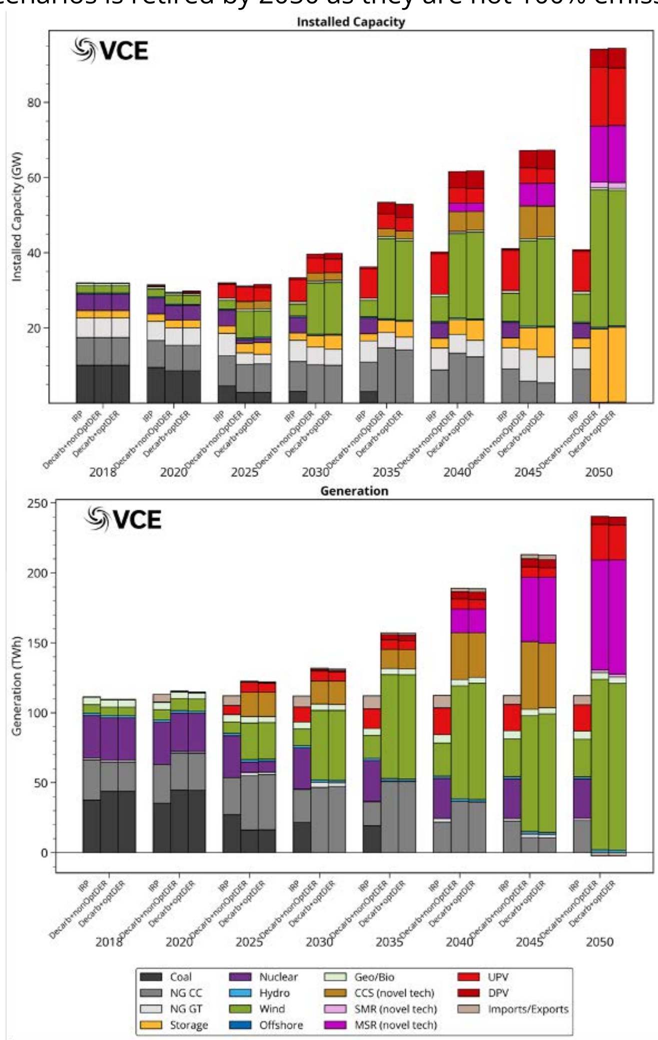

Figure 2.5: WIS:dom-P installed capacities (top) and generation (bottom) for the scenarios.

The VRE generation deployed in the "IRP" scenario is higher than that proposed in the IRPs of the major utilities in Michigan. The larger deployment in mainly to satisfy the 90% decarbonization by 2040 goal of Consumers Energy utility. In order to meet its 90% decarbonization goal, Consumers Energy utility needs to deploy about 1,400 MW of additional wind generation, 1,300 MW of additional utility-scale solar and 236 MW of additional storage over that proposed in its IRP. Furthermore, Consumers Energy depends on imports of clean generation from DTE which deploys an additional 3,000 MW of wind and 487 MW of utility-scale solar to export clean energy to Consumers Energy. Therefore, the IRP proposed by Consumers Energy through 2034 falls well short of reaching its own 90% decarbonization goal by 2040.

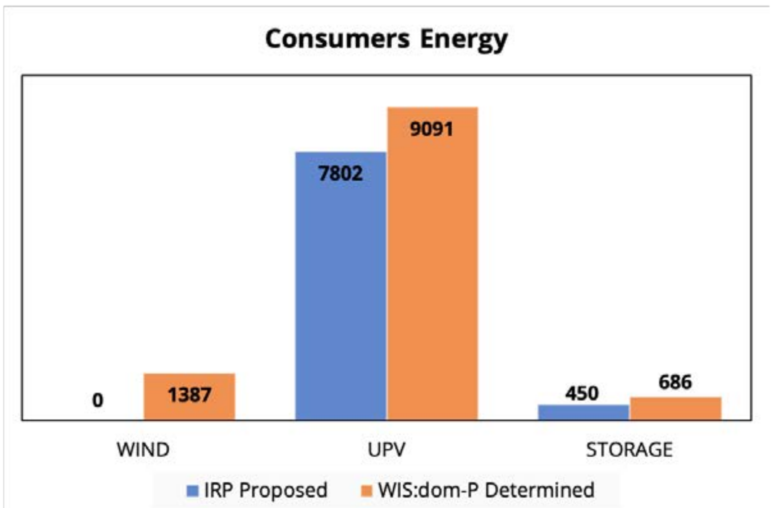

Figure 2.6: Additional VRE deployed by WIS:dom-P to ensure Consumers Energy meets it 90% decarbonization by 2040 goal.

The storage power and energy capacities installed over the investment periods in the scenarios modeled is shown in Fig. 2.7. In the "IRP" scenario, very little new storage is added until 2040 at which point about 700 MW of storage is added to the grid. In comparison, the electrification scenarios add significantly more storage over the investment periods along with a large deployment of storage between 2045 and 2050 to meet the 100% decarbonization goal. By 2045, the "Decarb+nonOptDER" scenario deploys 5,800 MW of storage to the grid to effectively utilize the installed VRE generation. The average storage duration in 2045 in the "Decarb+nonOptDER" scenario is 7.5 hours to help cover lulls in the VRE generation. The "Decarb+optDER" scenario, on the other hand, has a total of approximately 8,000 MW of storage deployed by 2045, out of which 2,000 MW is on the utility grid and the rest is on the distribution grid with an average duration of 7.5 hours.

Between 2045 and 2050, the electrification scenarios deploy large amounts of storage to the grid with the total storage installed reaching about 19,500 MW in both the electrification scenarios. In the "Decarb+optDER" scenario, 8,300 MW of the total storage is on the distribution grid. The average duration of the storage installed is approximately 24 hours. The long storage duration is specifically aimed at meeting load during the long lulls in wind generation that occur over the course of the year.

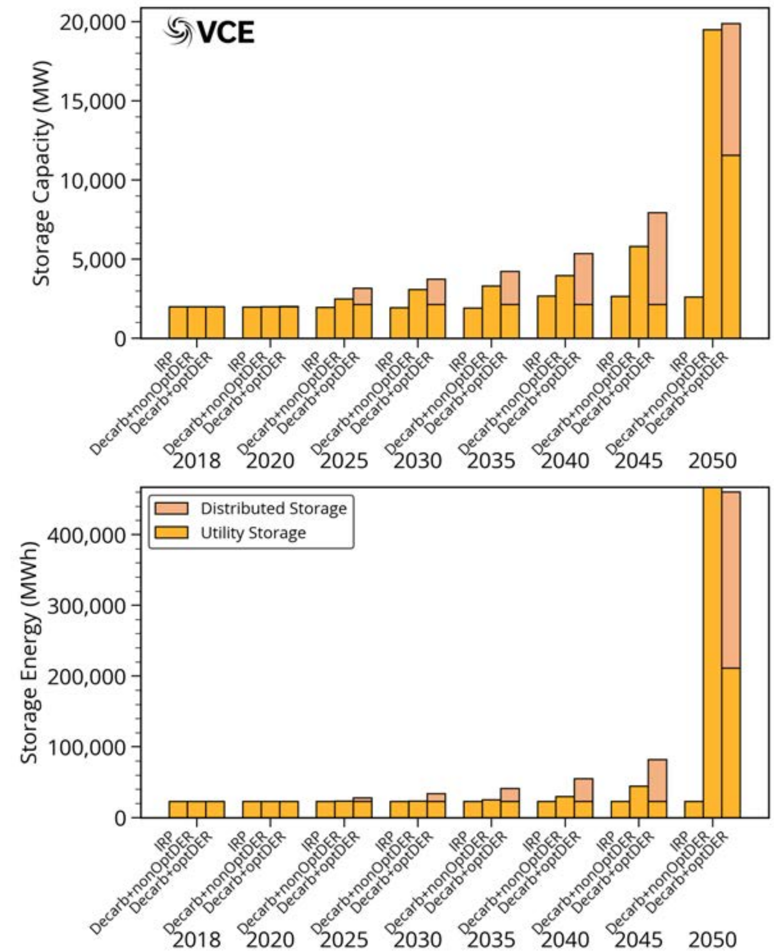

Figure 2.7: Utility storage and distributed storage installed in each investment period for the "Optimized DER" scenario.

Although the wind resource is significantly better in Michigan compared with the solar resource, the electrification scenarios add substantially more solar generation on the grid compared with the "IRP" scenario. The "IRP" scenario installs about 11,000 MW of solar by 2040. About 1,800 MW of this is additional solar added by WIS:dom-P over the values prescribed by the IRPs in order to ensure Consumers Energy meets its 90% decarbonization goal.

The electrification scenarios install more wind generation over solar until 2045 due to the better wind resource in Michigan. After 2045, the electrification scenarios install about 12,000 MW of solar to help meet the 100% decarbonization goal. The "Decarb+optDER" scenario installs slightly more distributed solar compared with the "Decarb+nonOptDER" scenario as the distribution co-optimization uses the distributed solar along with the distributed storage to defer distribution system upgrades and save costs.

2.3 CO_2 Emissions & Pollutants

The percentage reductions in economy-wide carbon dioxide (CO_2) emissions from 2005 levels for energy related activities is shown in Fig. 2.8. The "IRP" scenario reduces the economy-wide emissions by 25% from 2005 levels by 2025 and, thus, falls short of the Governor's goal of 28% reduction by 2025. By 2050, the annual economy-wide emissions reduce by 38% from 2005 level in the "IRP" scenario as a result of retirement of coal generation and replacing it with VRE generation. The additional VRE installations by WIS:dom-P over the IRP proposed values help the "IRP" scenario reach the 38% reduction by 2050. The electrification scenarios, by contrast, reduce annual economy-wide emissions by 37% by 2025, exceeding the Governor's goal. This reduction in annual emissions is possible through a combination of electrification and decarbonization of the electricity sector. By 2050, the electrification scenarios reduce annual economy-wide emissions by almost 97% from 2005 levels as the economy-wide energy related activities are electrified and the electricity sector is 100% decarbonized.

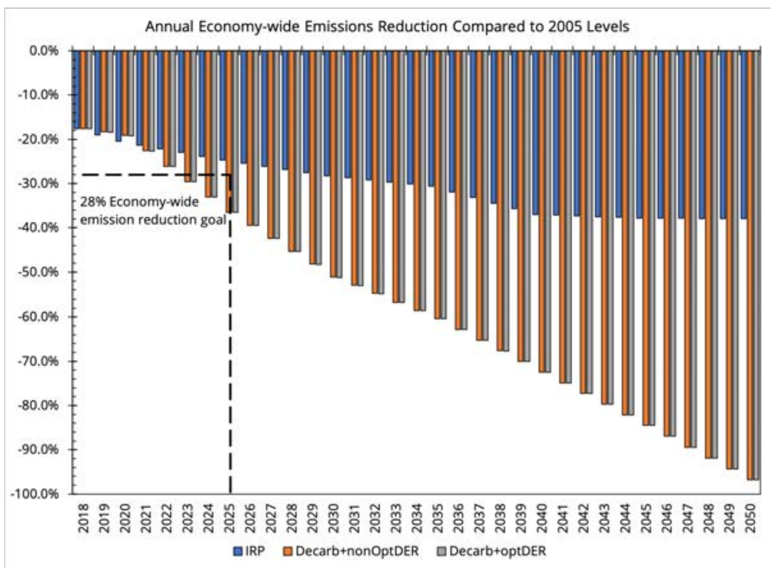

Figure 2.8: Percentage reduction in economy-wide energy related carbon emissions from 2005 levels. The black dashed line indicates the Governor's emission reduction goal of 28% by 2025.

Figure 2.9 shows the cumulative economy-wide CO_2 emissions from the three scenarios modeled. The "IRP" scenario, which does not electrify economy-wide energy related activities, has the highest cumulative CO_2 emissions of 4,374 million metric tons (mmT) by 2050. The "Decarb+nonOptDER" and the "Decarb+optDER" scenarios, which have similar emission reduction profiles, cumulatively emit 2,650 mmT of carbon dioxide by 2050. Therefore, electrification and decarbonization of the electricity sector can cumulatively reduce Michigan CO_2 emissions by 1,724 mmT by 2050, which is more than 10 times the economy-wide emissions in 2018. A majority of these emission savings (1,650 mmT) come from electrification of economy-wide energy related activities. Therefore, electrificatinon is a key element for effective decarbonization.

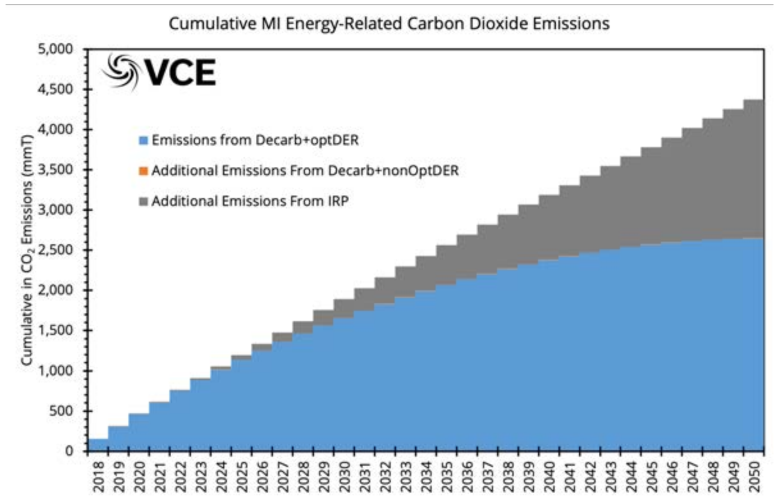

Figure 2.9: Cumulative economy-wide carbon dioxide emissions for the three scenarios modeled.

In addition to reducing CO_2 emissions, the modeled scenarios also reduce emissions of criteria air pollutants emitted by fossil fuel generation. The air pollutants tracked by WIS:dom-P emitted by the electricity sector are shown in Fig. 2.10. In the "IRP" scenario, the SO_2, PM_{10}, and $PM_{2.5}$ emissions reduce steadily from 2018 to 2035 as coal generation is retired and then sharply reduce to zero by 2040 as all coal generation gets retired. In the electrification scenarios, all coal generation is retired by 2030 and hence the SO_2, PM_{10}, and $PM_{2.5}$ emissions see rapid declines to zero by 2030. In the "IRP" scenario, some NO_x, CH_4 and VOC emissions remain due to presence of natural gas generation on the grid, while in the decarbonization scenarios these emissions are reduced to zero by 2050 as a result of the decarbonization goal. Hence the electrification scenarios not only reduce greenhouse gas emissions, but also eliminate emissions of criteria air pollutants, which will result in better health outcomes for local populations.

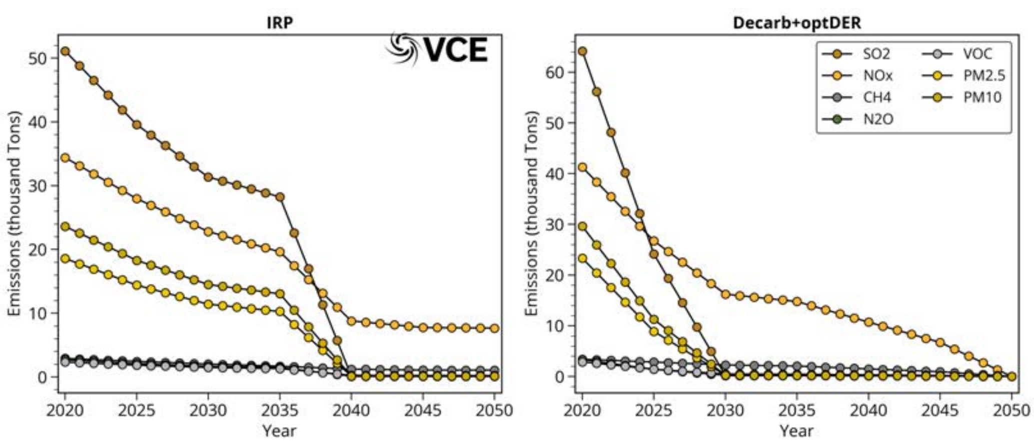

Figure 2.10: Emissions of criteria air pollutants from the electricity sector in the "IRP" scenario (left) and the "Decarb+optDER" scenario (right).

2.4 Siting of Generators (3-km)

WIS:dom-P uses weather datasets spanning multiple years at 3-km spatial resolution and 5-minute temporal intervals over the contiguous United States. WIS:dom-P performs an optimal siting of generators on the 3-km HRRR model grid. The WIS:dom-P installed capacity layout at 3-km resolution along with the transmission paths above 115 kV in 2050 for the "IRP" scenario is shown in Figure 2.11 (left panel), while the installed capacities for the "Decarb+optDER" scenario is shown in Figure 2.11 (right panel). The greater VRE deployment in the "Decarb+optDER" scenario is apparent along with deployment of dense clean dispatchable generation in the location of retired fossil fuel generation.

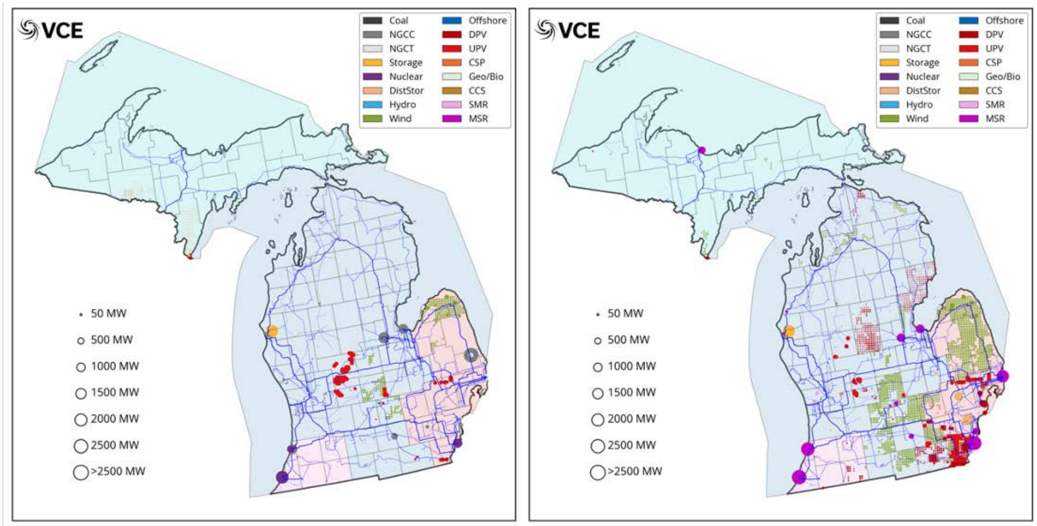

Figure 2.11: Installed generation layout in 2050 in the "IRP" scenario (left) and "Decarb+optDER" scenario (right) at 3-km resolution along with transmission paths above 115 kV.

As seen from Fig. 2.11 (left panel), the "IRP" scenario installs almost all the wind in DTE territory, and most of the solar deployed in Consumers territory. The VRE generation is more widely distributed in the "Decarb+optDER" scenario. The DTE region still installs most of the wind generation, with substantial wind installed in the Consumers regions as well. Most of the utility-scale solar is installed in the DTE region, while the Consumers region is dominated by distributed solar. The locations of retired fossil fuel generators are used to build MSRs and SMRs.

When making the siting decisions, the model takes into account several criteria to determine the optimal siting for generators. In addition to accounting for expected generation and distance from the load (for transmission considerations), the model ensures that generation is not sited in unsuitable locations. The model also ensures that the technical potential of each grid 3-km grid cell is not exceeded. The technical potential for the various VRE technologies in each grid cell is determined according to factors such as population, land cover, terrain slope, and others. In addition, each technology is limited by a maximum packing density to ensure that generators do not hamper performance of other generators in the grid cell, such as through wakes for wind turbines and excessive shading for solar panels. More information about these criteria and the WIS:dom-P model can be found in the technical documentation.[12]

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