Colorado Electrification & Decarbonization Study

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1. Background & Summary

The present study aims to access the impacts of incorporating electrification of other economic sectors (and hydrogen production) into a carbon constrained electricity system across the state of Colorado. It is hypothesized that electrifying other sectors while decarbonizing the electricity system will enable Colorado to exceed its economy-wide greenhouse gas (GHG) emission reductions targets[1] through 2040. In addition, decarbonizing through electrifying other sectors will result in lower electricity rates for all customers.

The Community Energy Inc. commissioned study models the entire Western electricity grid to be able to determine the interplay between Colorado and its neighboring states. The output time horizon for all scenarios was assumed to be 2040, with investment periods (for the roadmap) of 2018, 2020, 2025, 2030, 2035, 2040.

Three scenarios are modeled to assess the impact of electrifying other sectors while decarbonizing the Colorado electricity grid:

1. The "business as usual" (BAU) counterfactual modeled scenario is executed with the assumption that coal will remain generating on the Colorado electricity grid through 2040. The other sectors are defined using a Colorado GHG inventory report[2].
2. The "retire coal" modeled scenario retires all of the coal power plants in Colorado and drives all other electricity sector decisions economically. The other sectors are defined as in the "BAU counterfactual" scenario.
3. The "Deep Decarbonization" modeled scenario electrifies the other Colorado economic sectors from 2018 to 2040, where the rate of electrification adoption is constrained (upper bound) by the National Renewable Energy Laboratory (NREL) Electricity Futures Study (EFS) "high (moderate advancement)" electrification dataset[3]. The WIS:dom® optimization model selects the amount of adoption that is both economic and conforms to the GHG emission constraints for the electricity sector. The model does not constrain the economy-wide GHG emissions, rather, the study is attempting to establish whether electrification is both economic and effective in GHG emission reductions.

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[1] CO GHG emission reduction targets are outlined in HB19-1261.
[2] https://www.colorado.gov/pacific/sites/default/files/AP-COGHGInventory2014Update.pdf
[3] https://www.nrel.gov/docs/fy18osti/71500.pdf

The three scenarios are compared to each other in terms of electricity retail rates, installed capacity, annual generation, economy-wide and electricity GHG emissions (and other pollutants), heating and transportation costs, dispatch behavior, and job creation. The scenarios were solved for a dispatch of 5-minute intervals using 3-km weather data for an entire calendar year.

Figures 1.1 shows the geographic extent of the WIS:dom® modeling while representing the wind and solar resource spatial granularity. Figure 1.2 depicts the WIS:dom® representation of the nodal transmission topology within Colorado. All connections to other states are represented as single state zones. Transmission flow is limited between Colorado and other states.

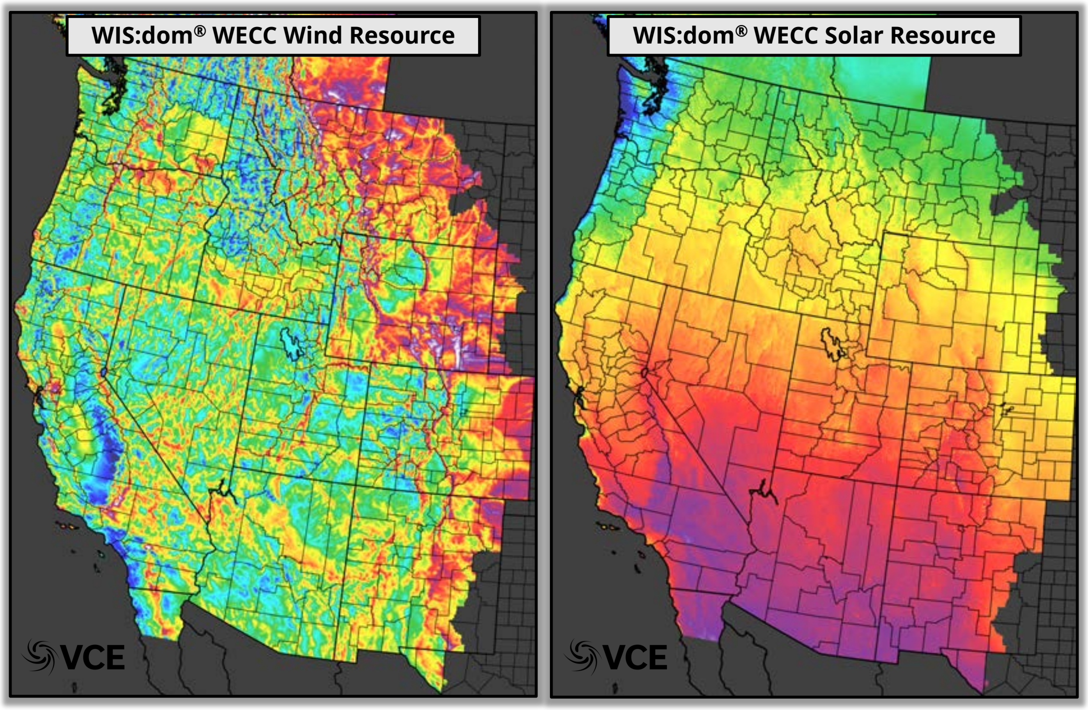

Figure 1.1: The geographic extent of the Western Interconnection showing the wind resource at 80m AGL (left) and solar PV resource (right). The Western Interconnection will be the focus of the present study. Purples and reds define high resource quality, while blacks and blues are for weak resource quality.

The present study finds that electrifying other sectors in Colorado will allow it to meet the HB19-1261 GHG emission targets through 2040, while lowering energy costs for Coloradans. Transportation and space heating fuel costs are reduced by over $600 and by over $500 annually per customer, respectively. The electricity rates are lower than the BAU counterfactual and retire coal scenarios for all investment periods, which implies that customers who do not electrify are not burdened with additional costs.

Retiring coal in a phased manner (as outlined in the next section) creates a net present value (NPV) of $1.5 billion in savings compared with keeping the plants running through 2040 (without electrification). The deep decarbonization scenario creates an NPV of $4.8 billion in savings within the electricity sector, as more wind and solar are added to the grid over more customer units. The coal-fired power plant Nucla is retired in 2019 under all scenarios to match the shuttering of that plant.

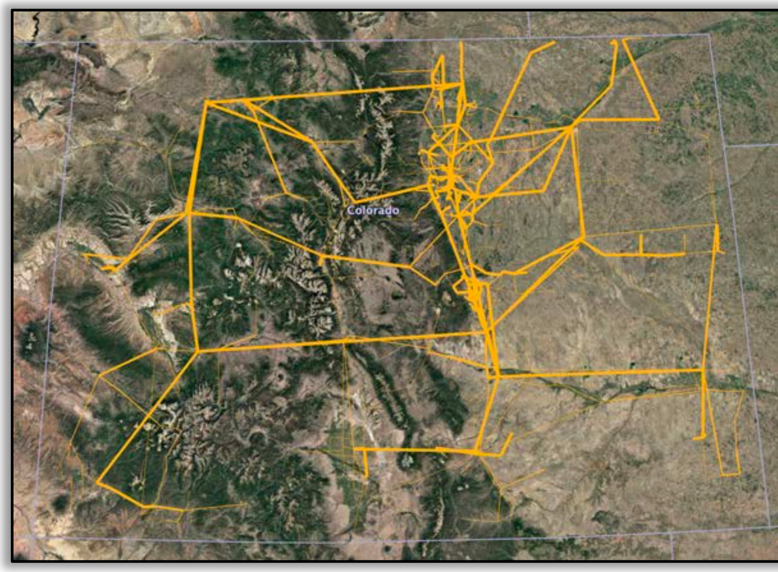

Figure 1.2: The WIS:dom® representation of existing nodal transmission in Colorado.

The reduction in economy-wide GHG emissions are more than 36% by 2025, 56% by 2030 and 69% by 2040 compared with 2005 levels. The reduction in electricity sector GHG emissions are 53% by 2025, 80% by 2030 and 88% by 2040. The simultaneous reduction in GHG emissions is enabled by electrification of other sectors along with low-cost wind and solar electricity generation. The addition of new demands from the other sectors provides new flexibility within the electricity grid over Colorado, which can enable more variable renewable energy sources.

Figure 1.2 displays the 3-km siting for the 2018 and 2040 WECC electricity grid for the Deep Decarbonization scenario. The maps show the increase in renewable energy (and how distributed they are). Only Colorado is modeled with deep electrification, while the other western states continue with BAU counterfactual electricity demand growth. By 2040, all the coal is retired across the WECC electricity grid.

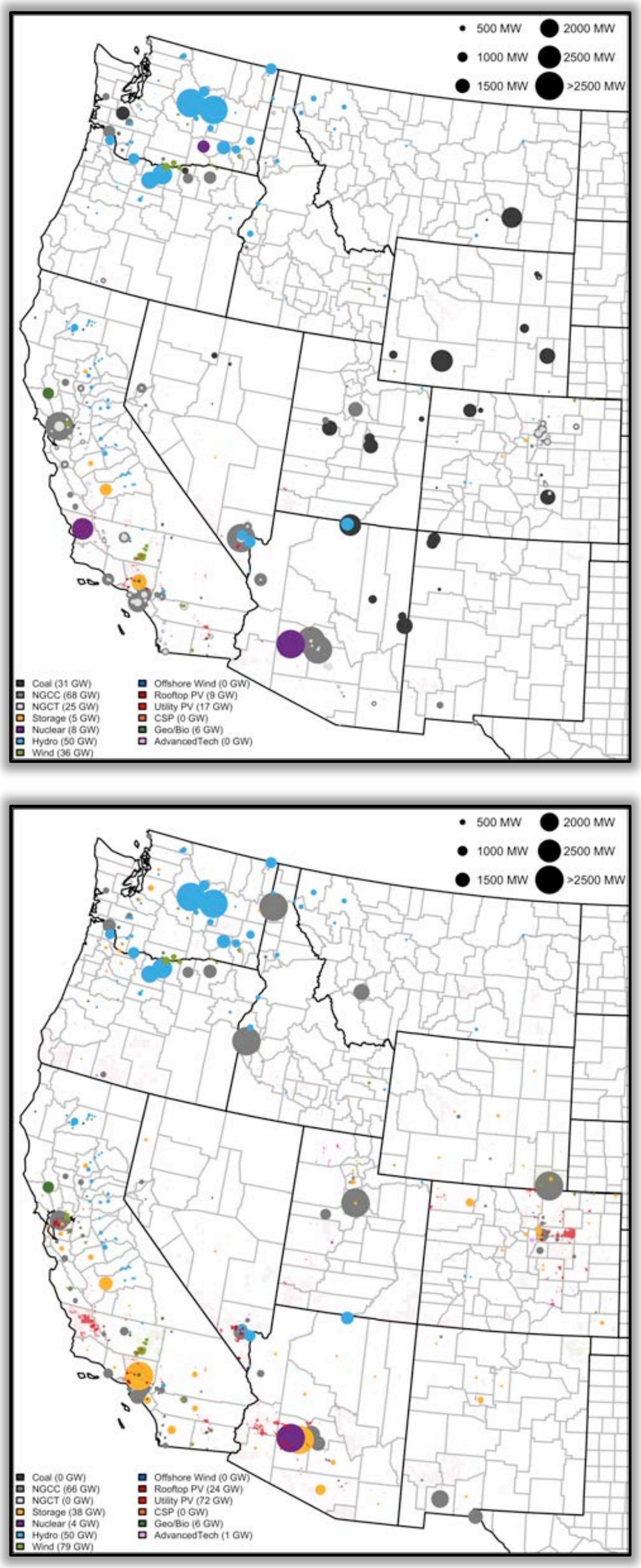

Figure 1.3: The 2018 (top) and 2040 (bottom) installed electricity generation capacities for the deep decarbonization scenario. There is substantial growth in wind, solar and storage. Coal and natural gas combustion turbines are completely retired by 2040.

2. Scenarios

All three modeled scenarios were performed over the entire Western electricity grid for generator siting, transmission expansion, storage capacity additions, demand-side resource deployment, transmission power flow, economic dispatch, and metric tracking. The scenarios were required to meet demand in each county without fail for every 5-minute time interval for a full calendar year for each investment period. The WIS:dom® optimization model additionally must hold planning, load following and contingency reserves for every region.

All assets (such as storage, other power plants, transmission and demand-side flexibility) that are not constrained to remain at set levels were chosen by WIS:dom® economically. WIS:dom® makes economic choices to build new generation, retire old generation, build transmission lines, construct storage or install demand-side resources. The cost projections used were obtained from the National Renewable Energy Laboratory (NREL) Annual Technology Baseline (ATB) 2019 dataset[4] and Colorado PUC filings. The specific economic data for the Colorado coal-fired power plants were produced by VCE® for a recent study investigating the replacement of coal locally with wind and solar[5]. VCE® combined publicly available datasets for generation and internally produced (reduced form) datasets for transmission. No new interstate transmission was allowed to be built between Colorado and its surrounding states. The importing of electricity is constrained in all modeled scenarios to be no greater than the 2018 levels of importing. For solar PV, it is assumed that new bi-facial solar panels are deployed in Colorado. These are assumed to produce 10% more electricity per unit area and cost 5% more than the standard panels in WIS:dom®.

BAU (counterfactual): The Colorado electricity grid retains all existing coal plants through 2040 with the exception of Nucla, which is retired in 2019. A 2014 GHG inventory report[6] for Colorado was used as a basis for the GHG emissions for all other economic sectors. The rest of the WECC electricity system evolves economically. Finally, the cost of motor gasoline and natural gas for heating was estimated from the EIA AEO 2019. These input data and sources can be found in the accompanying spreadsheets. This scenario is an update on the BAU counterfactual from a previous

[4] https://atb.nrel.gov/electricity/data.html
[5] https://vibrantcleanenergy.com/wp-content/uploads/2019/03/LCOE-Mapping/Coal-Cost-Crossover_Energy-Innovation_VCE_FINAL2.pdf
[6] https://www.colorado.gov/pacific/sites/default/files/AP-COGHGInventory2014Update.pdf

VCE® report on the benefits of retiring coal across Colorado[7]. This scenario will be used to determine the costs savings from retiring coal that can be invested into procuring electrification devices and new wind, solar and storage generation technologies.

Retire Coal Scenario: The Colorado coal plants were assumed to retire on the following schedule (based on results and analysis of the previous Colorado Coal Retirement Study):

2019: Nucla;
2020: Drake & Comanche unit 1;
2025: Craig, Pawnee, & Comanche unit 2;
2030: Nixon & Hayden;
2035: Rawhide & Comanche unit 3.

Every other parameter is identical to the BAU counterfactual scenario. Comparison of this scenario with the BAU counterfactual determines the cost saving enabled by retiring coal early, which can be directed into electrification adoption and/or constructing new wind, solar or storage technologies.

Deep Decarbonization Scenario: This scenario was designed to expand upon the EV grid scenario from a previous VCE® study[8] to incorporate the electrification of other sectors in Colorado. The addition of other sectors (primarily space and water heating) into the mix has two major impacts: additional annual electricity demand and new temporal profiles of the electricity within the state. These additions are cumulative to the new demands encountered with transportation electrification. To model the electrification of other sectors WIS:dom® has the ability to deploy hydrogen production facilities. These purchase electricity and create hydrogen from electrolysis. The model also builds the supporting infrastructure of pipelines and storage. The only state that has this enable is Colorado for the present study.

The electrification was assumed to be bounded by the recently published NREL EFS high with moderate technology advancement end-use dataset[9]. The NREL EFS dataset allows up to 80% of ground-based transportation to be electrified through battery vehicles, hybrid vehicles and fuel cell vehicles by 2040. The remaining 20% was assumed to continue to be internal combustion engines (ICE). The heating is at

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[7] https://www.vibrantcleanenergy.com/wp-content/uploads/2019/01/CO_CoalPlantRetireStudy_FINAL.pdf
8 https://www.vibrantcleanenergy.com/wp-content/uploads/2019/08/CES-CE_VCE.pdf
[9] https://www.nrel.gov/docs/fy18osti/71500.pdf

a slower adoption rate, achieving approximately 60% electrification (including hydrogen production) of space and water heating. Other sectors are also allowed to electrify, such as industry, agriculture, and aviation. These are primarily handled with both electricity conversion and hydrogen production for downstream products; such as ammonia (NH_3) for fertilizer. The electrification of economic sectors results in a decrease in total energy needs by 2040 of more than 10% by 2040 from 2018 levels. Figure 2.1 depicts the energy consumption by sector (in equivalent TWh).

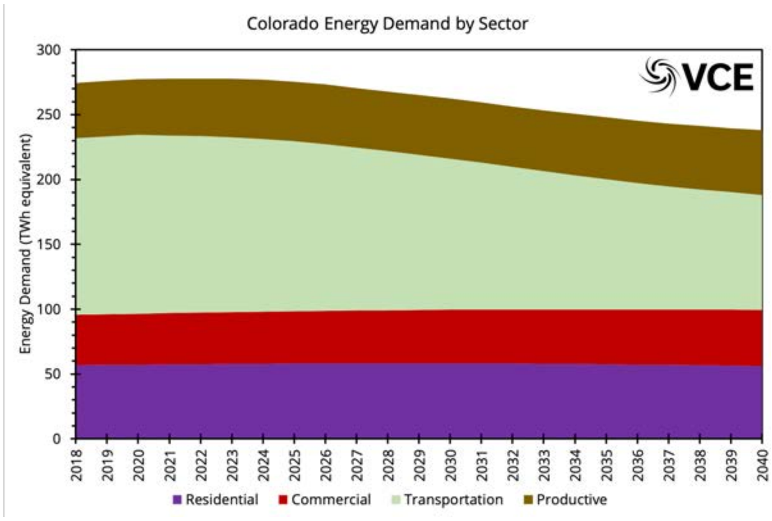

Figure 2.1: The Colorado energy consumption by sector under an electrification future. The energy needs by 2040 are more than 10% lower than 2018 levels.

As with the Colorado Electrified Transportation Study (CES), the new EVs will get their fuel from the electricity grid, this will have a different temporal profile to the traditional electricity demands. In addition, the EVs can have their charging interrupted with minimal disturbance to the owners; providing a new source of flexibility within the electricity system. The WIS:dom® optimization model must ensure that the electricity is within the EV batteries at all times for a standard commute (assumed to be 40-mile round trip).

Figure 2.2 shows the average assumed charging requirements of an EV in Colorado. There are daily and hourly profiles. The WIS:dom® optimization model builds the electricity requirements for each county based on the number of EVs within the county during the investment period. Further, the input profiles are all scaled based upon the weather for that day from the WIS:dom® high resolution weather dataset. Finally, WIS:dom® is provided parameters that allow the charging of the EVs to be interrupted and shifted. It is assumed that all electricity will be restored within 36 hours, and before if the amount of stored electricity is not enough to cover round trip commutes. To shift the EV charging, WIS:dom® must pay the customer $60 / MWh.

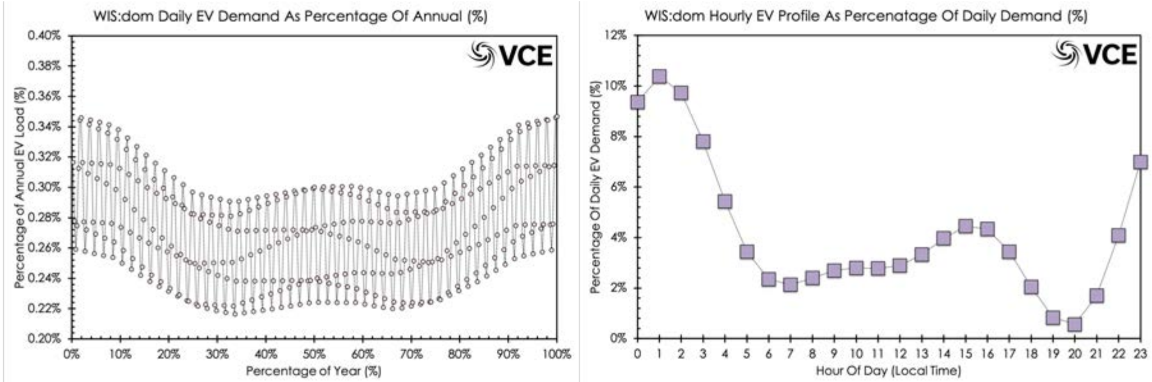

Figure 2.2: The average demand profiles (daily, left; hourly, right) for EVs in Colorado. The WIS:dom® optimization model can shift the charging if it is deemed appropriate.

The EVs are assumed to get more efficient as time progresses, starting at an average of 3.75 miles per kWh in 2018 and rising to 5 miles per kWh by 2040. Simultaneously, it is assumed that ICEs also become more efficient, starting at an average of 28.5 miles per gallon (mpg) in 2018 and rising to 40 mpg by 2040. These assumptions feed into the estimated cost savings of owning an EV in the modeling.

Figure 2.3 shows the average assumed heating requirements for building stock in Colorado. There are daily and hourly profiles. In a manner similar to the EV data, the WIS:dom® optimization model builds the electricity requirements for each county based on the number of buildings (and population) within the county during the investment period. Further, the input profiles are all scaled based upon the weather for that day from the WIS:dom® high resolution weather dataset. This weather data also facilitates computation of the available flexibility. The building stock is estimated with heating losses (and gains) based on ambient temperature. It is assumed that all heating demands will keep temperatures to within ±1ºF of 72ºF within the building stock in the county. If there is too much demand required for heating using air-source heat pumps (ASHP), the model switches to electric back-up and natural gas / hydrogen heating. To shift the heating demand, WIS:dom® must pay the customer $60 / MWh.

There are other devices that are electrified, e.g. natural gas cooktops replaced with induction cooktops. These changes are added to the conventional demand curves based on historical data. For the production of hydrogen, WIS:dom® is supplied a temporal and geographic description of consumption. The model decides where and when to produce the hydrogen, how to store it and transport it to where it is needed. The model must pay for this infrastructure as well as the electricity and purification of water. Figure 2.4 displays an example dispatch of electricity demand for hydrogen production in Colorado.

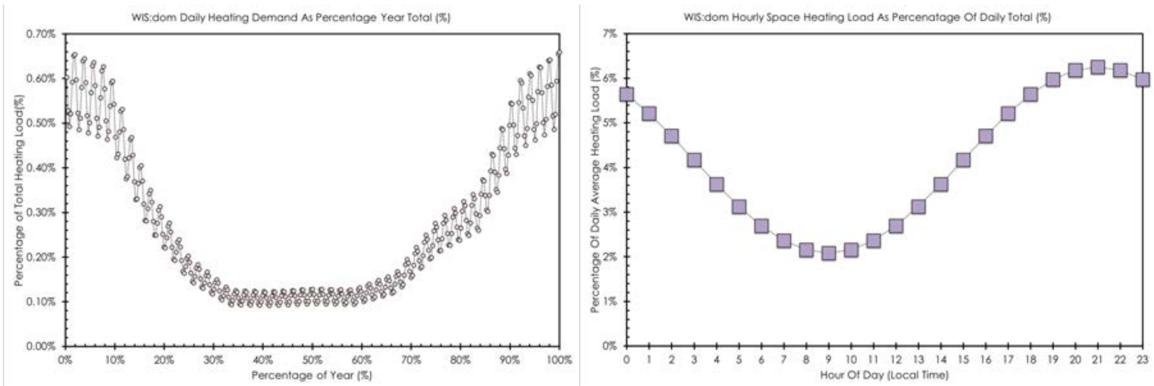

Figure 2.3: The average demand profiles (daily, left; hourly, right) for heating in Colorado. The WIS:dom® optimization model can shift the heating demand if it is deemed available and economic.

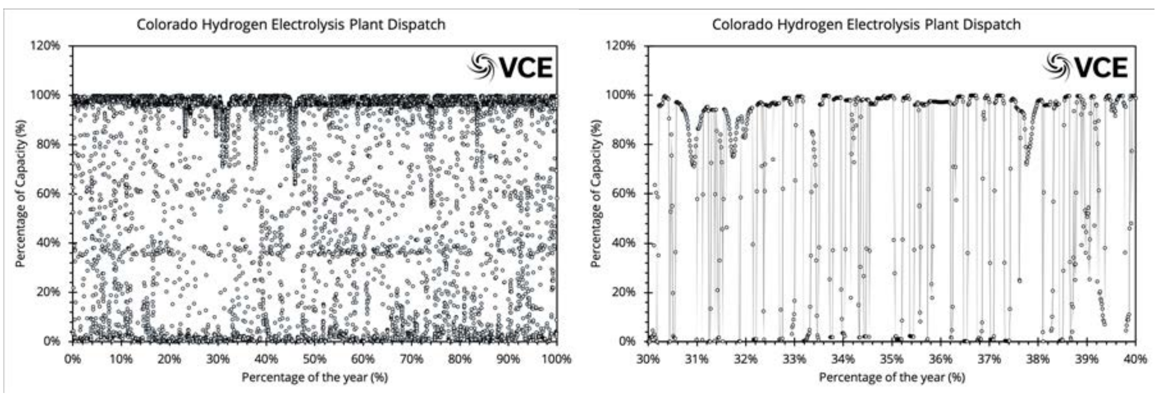

Figure 2.4: The dispatch of H_2 production facilities over Colorado. The left shows the whole year, while the right shows a 10% window. The WIS:dom® model determines how these assets are dispatched. The facility in the plots has a utilization of 70%.

3. Results

CO_2 Emissions: CO_2 emissions for all other sectors in the BAU were taken from the "Colorado Greenhouse Gas Inventory – 2014 Update" released by the Colorado Department of Public Health and Environment. The report states a projection of CO_2 emissions to 2030 for each of the sectors. To calculate a projection for 2040, an average of the CO_2 emissions from 2018 to 2030 was used as a conservative estimate.

For all modeled scenarios, the WIS:dom® model outputs the annual CO_2 emissions for the electric sector at each investment period. For the deep decarbonization modeled scenario, WIS:dom® outputs the economy-wide CO_2 emissions, which are being tracked endogenously. The emissions in the residential, commercial and industrial sectors are assumed the same in both the BAU counterfactual and the retire coal scenarios.

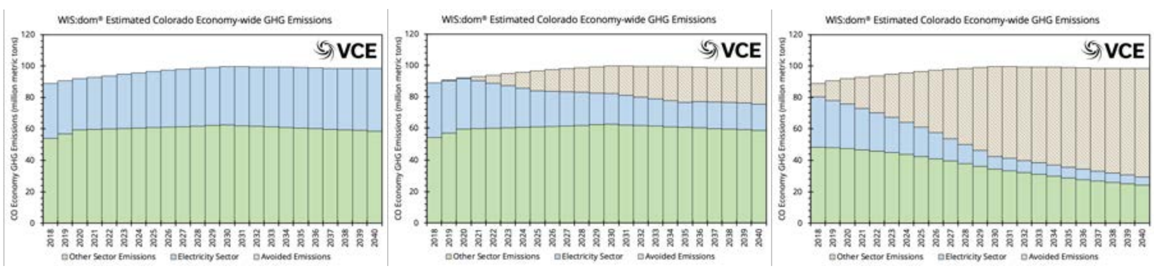

Figure 3.1: CO_2 emissions for Colorado from the electricity and other sectors for each of the scenarios from 2018 to 2040. The panels also show the avoided emissions through decarbonization and electrification.

As can be seen in Fig. 3.1, the BAU scenario has CO_2 emissions remaining relatively steady from 2018 to 2040, with no reduction. A reduction of 12%, 14% and 22% in CO_2 emissions is shown across the economy in the retire coal scenario for 2025, 2030 and 2040, respectively, from 2005 levels. The total CO_2 emissions for the electricity sector drop by 60% by 2040 from 2005 levels. This is entirely due to retirement of the coal-fired power plants and building new wind, solar, storage and natural gas. In the deep decarbonization scenario, a 90% decrease in CO_2 emissions within the electric sector is seen by 2040 (53% by 2025 and 80% by 2030). Moreover, the total CO_2 emissions for Colorado economy-wide drop by 36%, 56% and 69% by 2025, 2030 and 2040, respectively, from 2005 levels. This is due to the electrification of other sectors while carbon constraining the electricity system. The fall in CO_2 emissions is greater than those required by HB19-1261 and puts Colorado on a path to zero emissions by 2050. Thus, by electrifying other sectors and decarbonizing the electricity system an annual reduction of 69 million metric tons of carbon dioxide being emitted is achieved by 2040. Cumulatively, the emissions avoided by 2040 (from 2018) is one billion metric tons.

The electrification brings new demand to the electricity sector, which has been stagnant (in terms of demand) for a decade. This unlocks investment possibilities and a more flexible demand profile that can accommodate more variable generation. Further, the electricity system (and producing hydrogen) is far more efficient than many internal combustion engines producing power for vehicles and burning natural gas to heat water and spaces. The emissions intensity of electricity reduces by half from the BAU to the retire coal scenario (by 2040) and is reduce by a factor of four from the retire coal to the deep decarbonization. This is depicted in Figure 3.2.

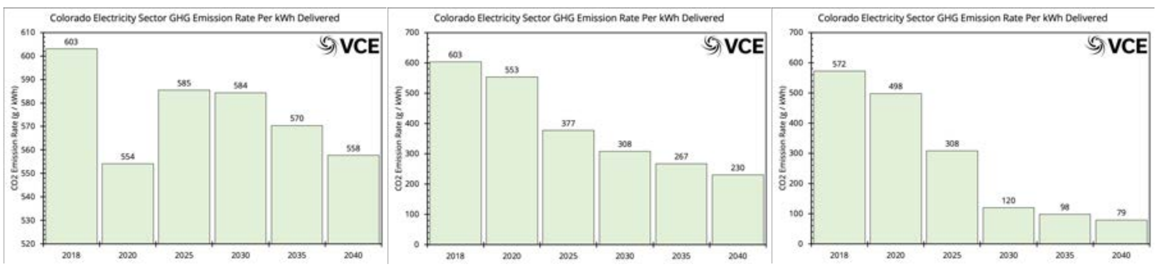

Figure 3.2: CO_2 emissions intensity of electricity for Colorado from 2018 to 2040 for the three scenarios. BAU is the left panel, retire coal is the middle panel and deep decarbonization is the right panel.

Cost of transportation and heating: There is a substantial cost saving to be exploited for customers if the transportation and heating sectors in Colorado move away from burning fossil fuels towards electrification via EVs, ASHPs and hydrogen fuel cells. The total cost of transportation was calculated using projected motor gasoline prices to 2040 from the Energy Information Administration (EIA) Annual Energy Outlook (AEO) 2019 along with the total estimated gasoline consumption in Colorado. The total cost of heating was computed using the flat natural gas rates through 2040 along with total consumption of natural gas for heating in Colorado.

For the deep decarbonization scenario, the costs for transportation and heating were computed using the electricity purchases required, the hydrogen bought and the remaining building stock still using natural gas.

The efficiency of the EVs were assumed to increase with time from an average of 3.75 miles per kWh in 2018 to 5 miles per kWh in 2040. The cost of gasoline is taken from the EIA AEO 2019 projections. The average number of miles assumed to be driven by each vehicle was 10,000 miles. The cost per vehicle was then multiplied by the number of vehicles to compute the total cost of transportation in Colorado for each scenario. These calculations take into account the changing numbers of ICEs and EVs on the roads in Colorado.

The efficiency of ASHPs were assumed to stay constant through 2040. The cost of natural gas was also assumed to be constant. These assumptions were taken because of the high production potential in Colorado and the cold winters, which can stress ASHPs (it is assumed improvements simply allow ASHPs to be used more than backup methods over time). The cost per household and business was then multiplied by the number of households and businesses to compute the total cost of heating in Colorado for each scenario. These calculations take into account the changing numbers of heat pumps and furnaces in Colorado.

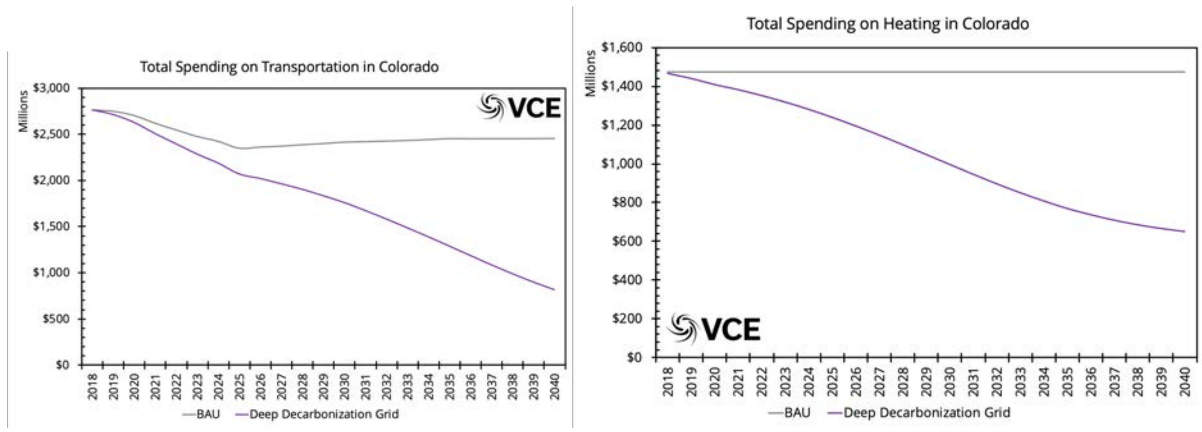

Figure 3.3: The total annual cost of transportation (left) and heating (right) in Colorado in the BAU scenario compared with the deep decarbonization scenario.

Figure 3.3 shows the significant cost savings that electrifying the transportation and heating sectors could provide. The total savings between 2018 and 2040 for transportation are estimated to be $15.6 billion (real 2017$), which equates to a saving of almost $680 million per year. The total savings between 2018 and 2040 for heating are estimated to be $9.7 billion, which amounts to an annualized saving of $424 million. Therefore, the combined savings are $25.3 billion by 2040, at an annual average amount of approximately $1 billion. More savings are accrued later in time as more Coloradans adopt the technologies. These savings are in addition to the $4.8 billion saved by retiring the coal-fired power plants, of which $1.5 billion (NPV savings for the retire coal scenario) was invested in WIS:dom® to help with adoption of electrification and building of wind, solar and storage.

The slope in Fig. 3.3 hides the immediate savings that could be gained by switching from an ICE to an EV and a furnace to an ASHP in Colorado, since the majority of the transportation savings comes from using electricity rather than gasoline, which is more efficient in powering transport. The savings in the heating comes from using a heat engine rather than combustion to heat properties and water. Thus, in Fig. 3.4, we show the average saving for a Coloradan to switch from an ICE to an EV and a furnace to an ASHP between 2018 and 2040. It shows that $610 could be saved annually for switching to an EV and $530 could be saved by switching from a natural gas furnace to an ASHP (with backup heating from either electricity or natural gas).

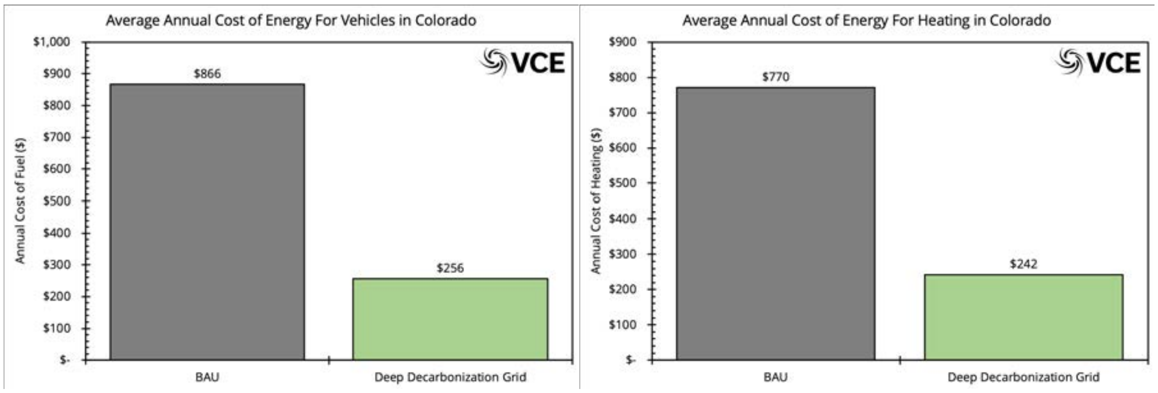

Figure 3.4: The annualized cost of transportation (left) and heating (right) for the BAU and decarbonization scenarios.

Electricity Generation Capacity: The electrification of other sectors in Colorado increases the requirement for electricity capacity. The retire coal scenario increased dependency on natural gas (while increasing wind and solar). The deep decarbonization scenario decreases gas capacity by 2040 and substantially increase wind and solar (along with storage). The generation capacity of all three scenarios is shown in Fig. 3.5. The amount of storage deployed by WIS:dom® in Colorado is approximately 1,100 MW (with 8 hours) in the retire coal scenario and 7,400 MW (with 8 hours) in the deep decarbonization scenario by 2040. The increase in generation capacity increases employment in Colorado's electricity sector by approximately 65% by 2040 in the retire coal scenario and nearly doubles employment in the deep decarbonization scenario by 2040. The electrification unlocks the potential of the low-cost renewables and large solar deployments pair with storage to provide firming capacity.

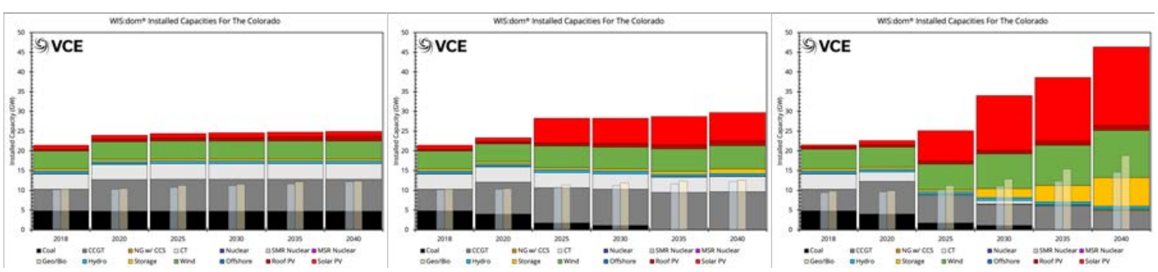

Figure 3.5: Total installed capacity in Colorado for the BAU (left), Retire Coal (middle), and Deep Decarbonization scenarios.

Colorado Generation: Since EVs and ASHPs require electricity, and the reason the generation capacity increases, the annual demand increases. There is some assumed load growth in Colorado in the BAU counterfactual and retire coal scenarios because of population migration into the state and the projections for the economy; however, for the deep decarbonization scenario even more demand is expected. This increase is about 25% higher than the BAU and retire coal demands by 2040. Figure 3.6 shows the electricity generation share by fuel type over time under the three modeled scenarios.

The increase in demand from the retire coal to the deep decarbonization scenario is entirely covered by wind and solar. In fact, the amount of natural gas also decreases because of the carbon constraint and access to low-cost renewables due to the new flexible demands that have come online. The natural gas and the electric storage that is deployed help manage the electricity system. The EV charging and ASHP shifting also plays a role in enabling more wind and solar. The increase in demand unlocks the potential for more remote resources and cost sharing the transmission buildout required within Colorado.

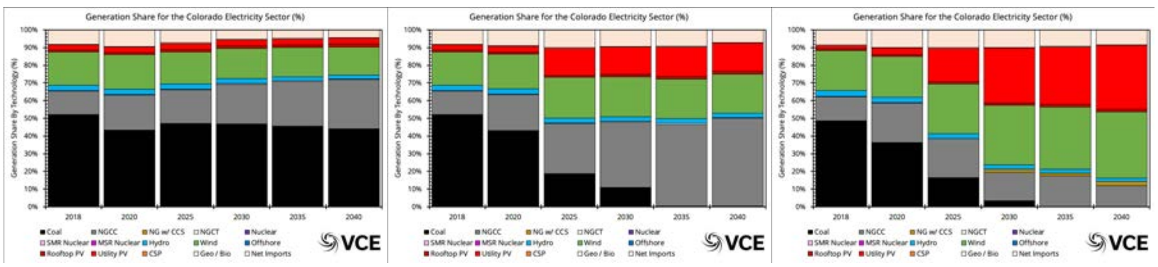

Figure 3.6: The annual generation by technology for Colorado for the BAU (left), Retire Coal (middle), and Deep Decarbonization (right) scenarios.

Colorado Dispatch: Both the retire coal and deep decarbonization scenarios fundamentally change the way electricity is generated and transmitted in Colorado. The economics in Colorado result in much more wind, solar, storage and natural gas than exists today in the retire coal scenario; while the deep decarbonization reduces reliance on natural gas and increases it on wind, solar and storage (along with flexible demand). For the deep decarbonization scenario, much more demand-side flexibility is available and this accommodates even more variable renewables. The electrification of transportation and heating reduces emissions more efficiently than fully decarbonizing the electricity sector alone. However, the dispatch of the new system will present challenges and opportunities. Figure 3.7 displays a section of the 2018 and 2040 5-minute dispatch of Colorado. Both scenarios are shown for 2040. The month shown is for January.

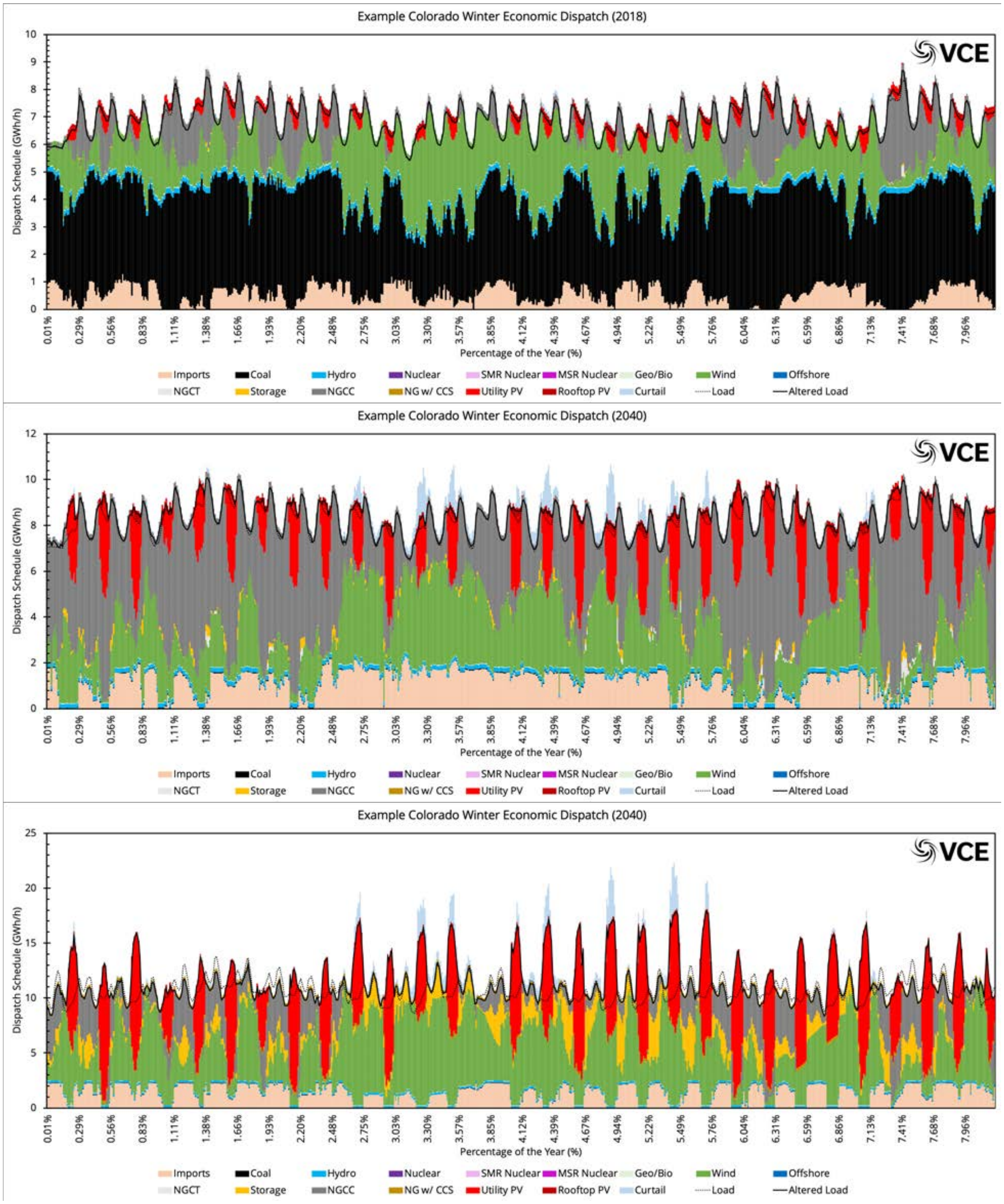

Figure 3.7: The dispatch of the Colorado electricity system for 2018 (top), 2040 in the retire coal scenario (center) and deep decarbonization scenario (bottom). In 2040, the dispatch swings between 100% variable generation to almost 0% regularly. This is due to Colorado being small compared with the scale of weather systems. It can be seen that much less gas is dispatched in the deep decarbonization scenario, as well as imports being reduced.

Electricity Retail Rates: The change in the electricity supply can also impact the cost of electricity for customers. Moreover, it is important to determine if adding EVs and ASHPs increases the bills of customers who have not purchased an EV to unlock the fuel savings. Figure 3.8 shows the rate for the BAU counterfactual, retire coal and the deep decarbonization scenarios.

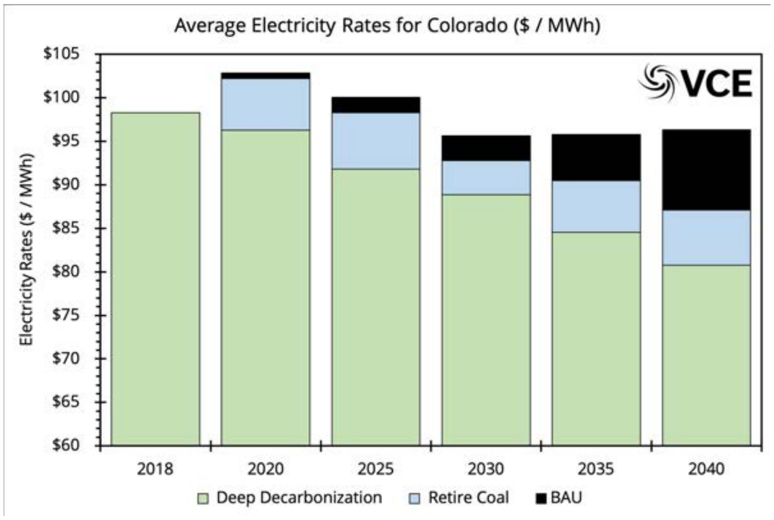

Figure 3.8: The average retail rates for the BAU counterfactual, retire coal and deep decarbonization scenarios. Both the BAU and retire coal are more expensive than the deep decarbonization scenario. The rates for the deep decarbonization are 20% lower than 2018 and 10% lower than the retire coal scenario by 2040.

It can be seen in Fig. 3.8 that the retail rates for the deep decarbonization scenario are much lower than the retire coal scenario through 2040. The reduction in rates benefits all Colorado customers. The decrease is tied to new demands coming online from electrification that enables lower-cost renewables to be integrated more seamlessly. The retail rates suggest that the cost of electricity would be improved for all by the adoption of EVs and ASHPs in Colorado along with the retirement of the coal-fired power plants. This is predicated on EVs and ASHPs being installed with flexibility associated with them, which WIS:dom® does through demand shifting, so the vehicles and heat pumps can be used at low rate / high production time intervals.

For an average residential customer, the lower rates in the deep decarbonization scenario would save them an average of $100 annually (16% reduction) compared with the BAU counterfactual between 2018 and 2040. If they purchased and used an EV, their savings would climb to $700 (35% reduction) annually. With the addition of an ASHP for water and space heating the savings would reach $1,230 (78% reduction) annually. This incentivizes electrifying because the higher the adoption the greater the savings for all customers.

4. Conclusions

The state of Colorado can substantially overachieve the GHG emission reduction required by HB19-1261 through 2040 by electrifying other sectors and carbon constraining the electricity system. The retirement of the coal-fired power plants along with new wind, solar, natural gas and storage saves Coloradans $1.4 billion by 2040. If this is paired with electrification and higher emission targets for the electricity sector, Coloradans can invest in wind, solar and storage while reducing their dependency on oil and gas. The costs used in the modeling for new technologies were conservative and cost savings could be even higher.

The electrification of transportation and heating (along with other sectors) along with a carbon constrained and efficient electricity system results in CO_2 emission reductions of over one billion metric tons by 2040. In addition, it would save Colorado residents $25 billion by 2040 in fuel costs. The average fuel saving per vehicle by switching to an EV would be $610 per year and the saving per household for heating would be $530 per year.

The total economy-wide emissions reduction for the deep decarbonization scenario by 2040 is 70% below 2005 levels. The pathway takes the emission reductions well below those stipulated in HB19-1261. These emission reductions come with increased jobs in the electricity sector, renewed economic activity with new generation and transmission being constructed, lower rates for customers and massively reduced local air pollution from transportation and electricity generation.