Electrification of Transportation: A Path to Decarbonization in Colorado

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1. Background & Summary

The present study aims to access the impact of incorporating electric vehicles (EVs) on the Colorado electricity system. It is hypothesized that electrifying transportation achieves greater greenhouse gas (GHG) emission reductions than entirely decarbonizing the electric sector alone. In addition, decarbonizing through electrifying transportation 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, while the investment period runs from 2018 to 2050.

Two scenarios are modeled to assess the impact of adding EVs to the Colorado electricity grid. A "business as usual" (BAU) counterfactual is defined by a Colorado report from 2014[1]. One modeled scenario simply removes coal power plants and drives decisions economically. The second modeled scenario add EVs to the electricity grid gradually from 2018 to 2050. The scenarios are compared in terms of electricity retail rates, installed capacity, annual generation, GHG emissions, driving costs, and dispatch behavior. 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 resource spatial granularity. Figure 1.2 depicts the WIS:dom® representation of the transmission topology within Colorado. All connections to other states are represented as single zones. Transmission flow is limited between Colorado and other states.

The present study finds that adding Electric Vehicles (EVs) to the Colorado electricity system will assist in reducing GHG emissions, while lowering energy costs for Coloradans. Fuel costs are reduced by nearly $600 per year, while slightly lowering electricity rates. The reduction in GHG emissions equates to more than completely decarbonizing the electricity grid alone. The electrification of transportation becomes essential in helping lower economy-wide emissions in an affordable manner. The addition of EVs provides flexibility within the electricity grid over Colorado, which can enable more variable renewable energy sources.

[1] https://www.colorado.gov/pacific/sites/default/files/AP-COGHGInventory2014Update.pdf

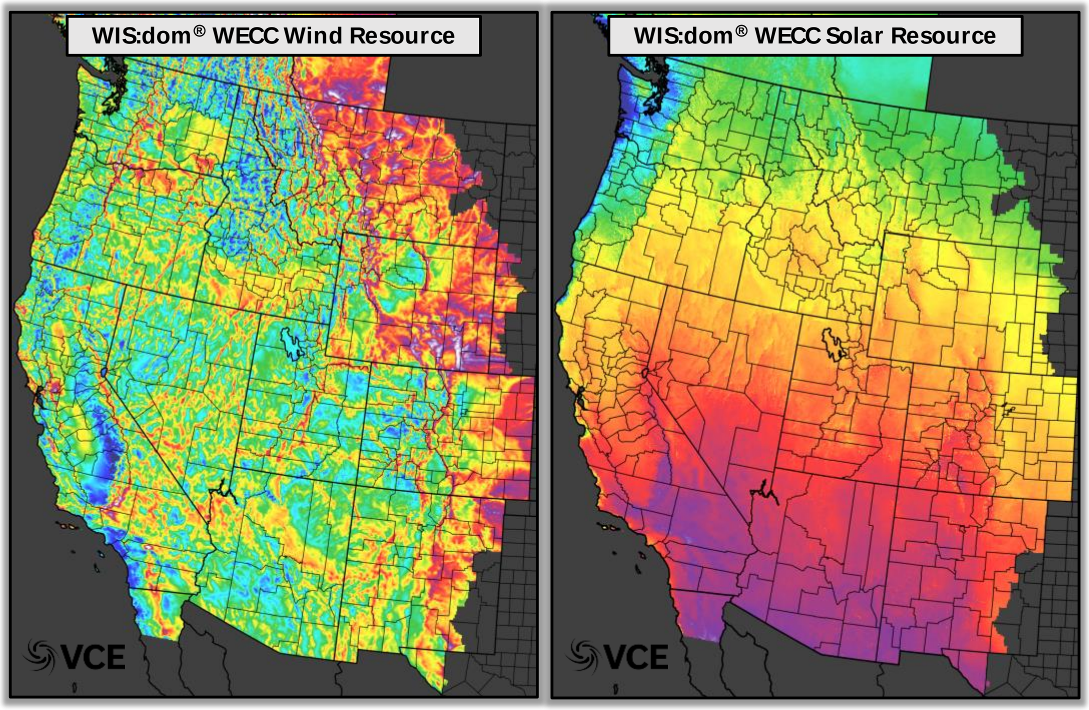


Figure 1.1: The geographic extent of the Western Interconnection showing the wind resource at 80m AGL (left) and solar PV resource (right). The Western Interconnection will be the focus of the present study. Purples and reds define high resource quality, while blacks and blues are for weak resource quality.

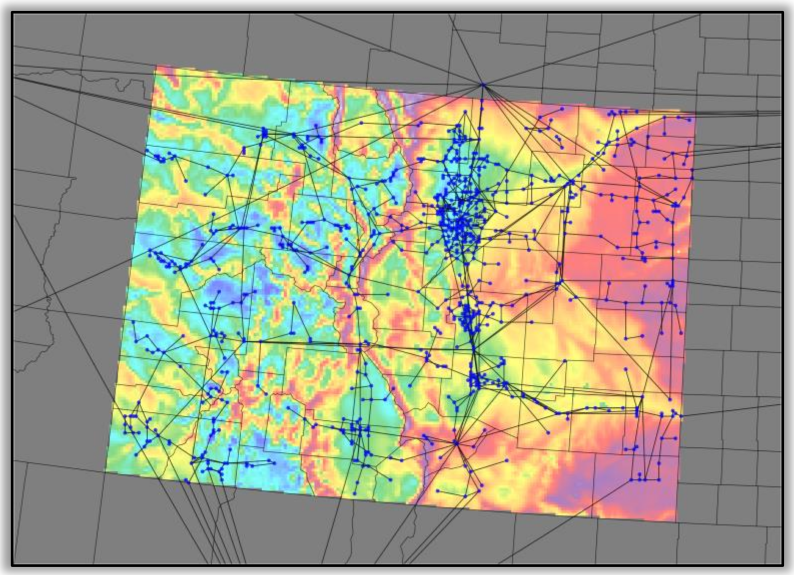


Figure 1.2: The WIS:dom® representation of existing transmission in Colorado with the wind capacity factor map (80 m AGL) represented in the background.

2. Scenarios

Both 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.

BAU (counterfactual): A previous Colorado report[1] was used as a basis for the GHG emissions, while retail rate costs were derived from historical values continuing at a flat rate (in real terms). Finally, the cost of motor gasoline was estimated from the EIA AEO 2019. These input data and sources can be found in the accompanying spreadsheets.

Cleaner Grid Scenario: The Colorado coal plants were assumed to retire on the following schedule (based on results and analysis of a previous study[2]):

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

All other assets (such as storage, other power plants, transmission and demand-side flexibility) 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) 2018 dataset and Colorado PUC filings. 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.

EV Grid Scenario: This scenario was designed to expand upon the cleaner grid scenario to incorporate the electrification of transportation in Colorado. The addition of EVs into the mix has two main impacts: additional annual electricity demand and new temporal profiles of the electricity within the state. The electrification was assumed to be achieved through a rapid stock turnover of light-, medium-, and heavy-duty vehicles (LDV, MDV &

[2] https://www.vibrantcleanenergy.com/wp-content/uploads/2019/01/CO_CoalPlantRetireStudy_FINAL.pdf

HDV). The modeling assumed that 100% of the LDV would be electrified by 2050, while 80% of MDV and HDV would be electrified by 2050. The remaining 20% was assumed to continue to be internal combustion engines (ICE).

The transition rate of the vehicle fleets on the roads in Colorado is depicted in Fig. 2.1. The transition is assumed to be aggressive to denote an upper bound on the electricity requirements that the Colorado electricity grid would have to handle by 2040.

The new EVs that get their fuel from the electricity grid 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).

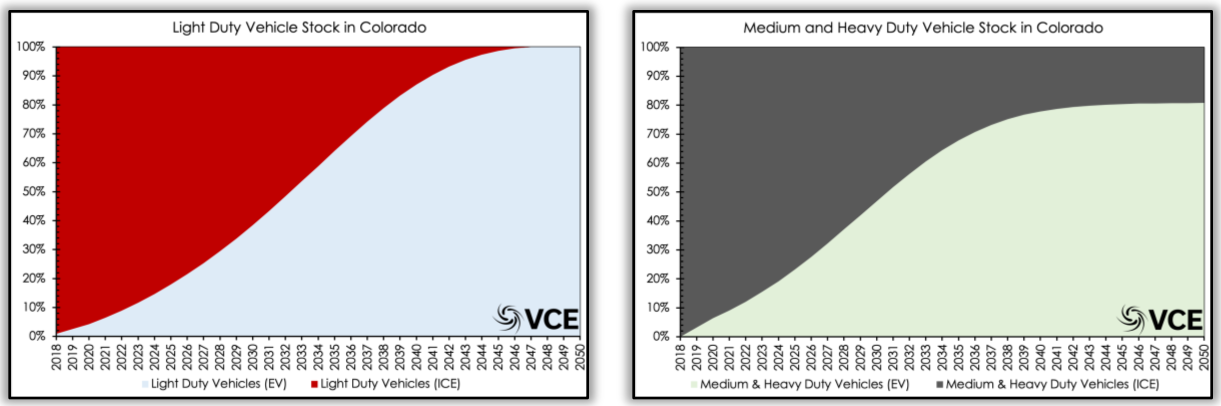
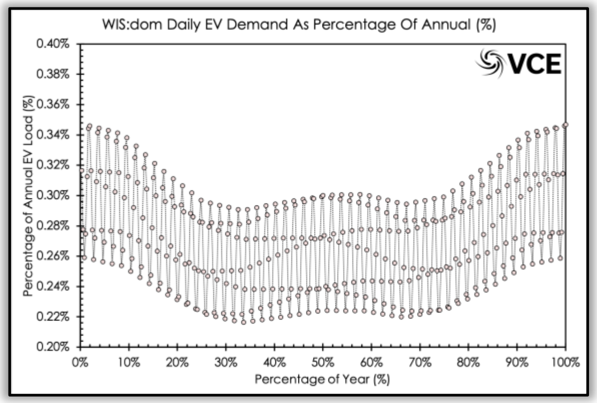


Figure 2.1: Increases in electric vehicles in Colorado. It is assumed that by 2040 87% of LDV are electrified and 78% of MDV and HDV are electrified.

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 WIS:dom®'s 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.



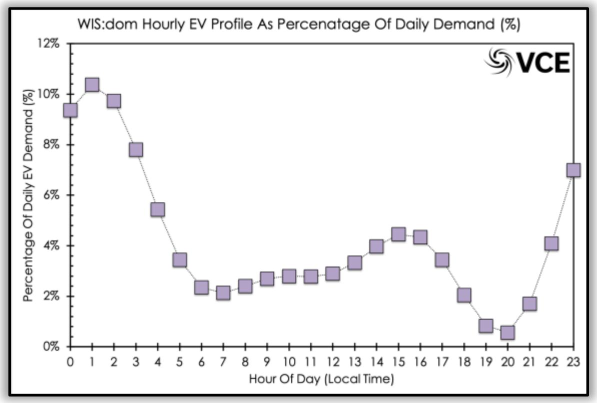


Figure 2.2: The average demand profiles (daily, left; hourly, right) for EVs in Colorado. The WIS:dom® optimization model can shift the charging if it is deemed appropriate.

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.

3. Results

CO_2 Emissions: CO_2 emissions for all 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 both the Cleaner and EV Grid scenarios, the WIS:dom® model outputs the annual CO_2 emissions for the electric sector at each investment period. Residential, industrial, commercial and transportation CO_2 emissions in the Cleaner grid scenario were taken from the Colorado Department of Public Health and Environment report. For the EV Grid scenario, the reduction in CO_2 emissions from the transportation sector due to electrification was computed by removing the estimated emissions from LDV, MDV and HDV ICEs vehicles that were transitioned to EVs. This is because the fuel for the EVs is not within the electricity sector and WIS:dom® tracks those emissions endogenously. The emissions in the residential, commercial and industrial sectors are assumed the same as in the Cleaner Grid scenario.

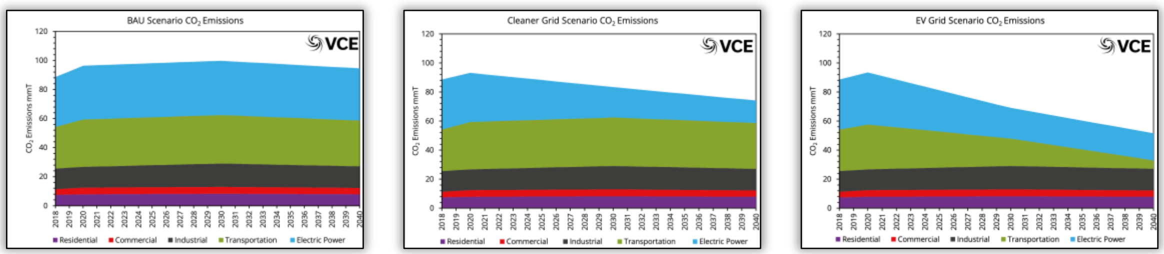


Figure 3.1: CO_2 emissions for Colorado from the residential, commercial, industrial, transportation and electric sectors for each of the scenarios from 2018 to 2040.

As can be seen in Fig. 3.1, the BAU scenario has CO_2 emissions remaining relatively steady from 2018 to 2040, with no substantial reduction in any of the sectors. A reduction of 55% in CO_2 emissions is shown within the electricity sector in the Cleaner Grid scenario. The total CO_2 emissions for Colorado drop by 16% by 2040 from 2018. This is due to retirement of the coal-fired power plants and building new wind, solar, storage and natural gas. In the EV Grid scenario, a 46% decrease in CO_2 emissions within the electric sector is seen. However, the total CO_2 emissions for Colorado drop by 42% by 2040 from 2018 levels. This is due to the dramatic 80% reduction in emissions from the transportation sector. The fall in CO_2 emissions is greater than completely decarbonizing the electricity sector. Thus, by electrifying transportation, retiring coal and allowing economic expansion of the electricity sector an annual reduction of 37 million metric tons of carbon dioxide being emitted is achieved. This is equivalent to fully decarbonizing the entire electricity sector in Colorado.

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 is far more efficient than many internal combustion engines producing power for vehicles. In total, the EV Grid scenario would stop 561 million metric tons of CO_2 being released into the atmosphere in Colorado by 2040 compared with BAU (approximately twice as much as the Cleaner Grid scenario) as shown in Fig. 3.2.

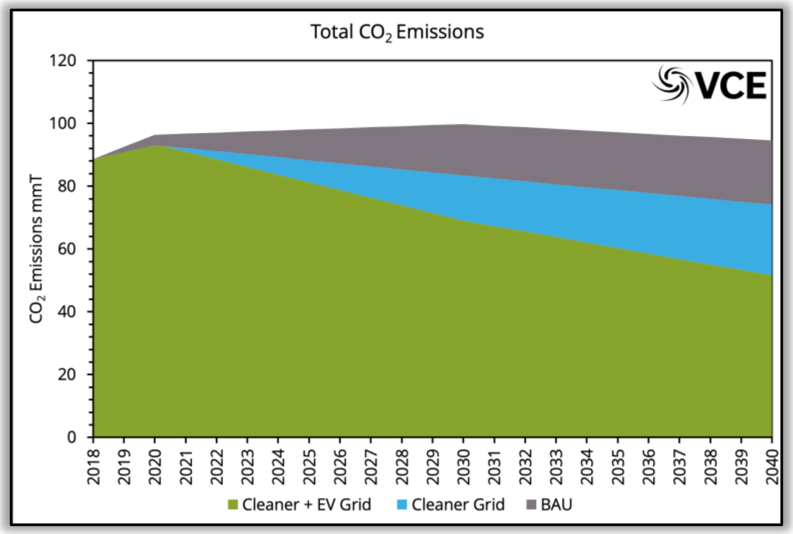


Figure 3.2: Total annual carbon dioxide emissions for Colorado under each scenario. The green shows the emissions for the EV Grid scenario, the blue shows the additional emissions under the Cleaner Grid scenario and the grey shows the further increased emissions under BAU.

Cost of transportation: There is a substantial cost saving to exploited for customers if the transportation sector in Colorado moves away from ICEs and towards EVs. 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. For the EV Grid scenario, the costs were calculated twice, once using the residential cost of electricity and a second time using a separate transportation rate (based on historical differences in those rates). 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.

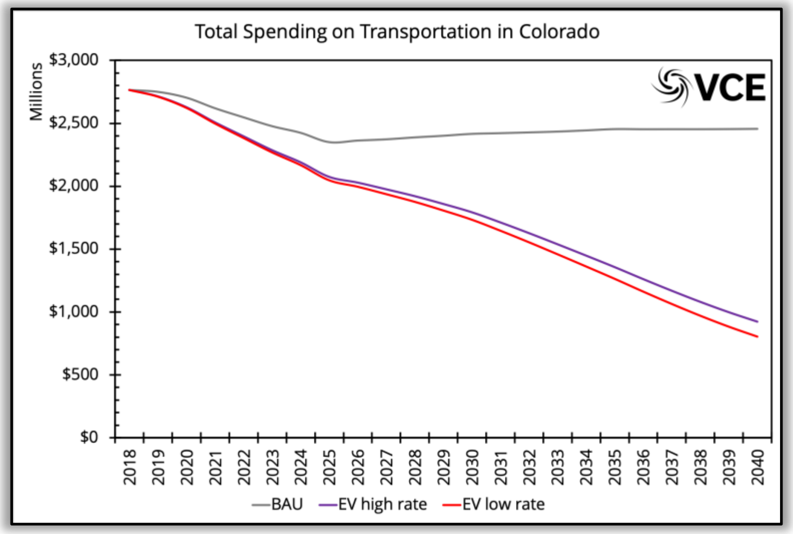


Figure 3.3: The total annual cost of transportation in Colorado in the BAU scenario compared with the EV Grid scenario with a high and low rate of electricity.

Figure 3.3 shows the significant cost savings that electrifying the transportation sector could provide. The EV high rate uses the residential rate of electricity and the EV low rate uses the transport rate. The total savings between 2018 and 2040 are estimated to be $16 billion (real 2017$), which equates to a saving of almost $700 million per year.

The slope in Fig. 3.3 hides the immediate savings that could be gained by switching from an ICE to an EV in Colorado, since the majority of the savings comes from using electricity rather than gasoline, which is more efficient in powering transport. Thus, in Fig. 3.4, we show the average saving for a Coloradan to switch from an ICE to an EV between 2018 and 2040. It shows that $590 could be saved annually for switching at residential electricity rates. If a special rate (transportation rate) was adopted in Colorado for charging EVs the savings could increase to $645 per year.

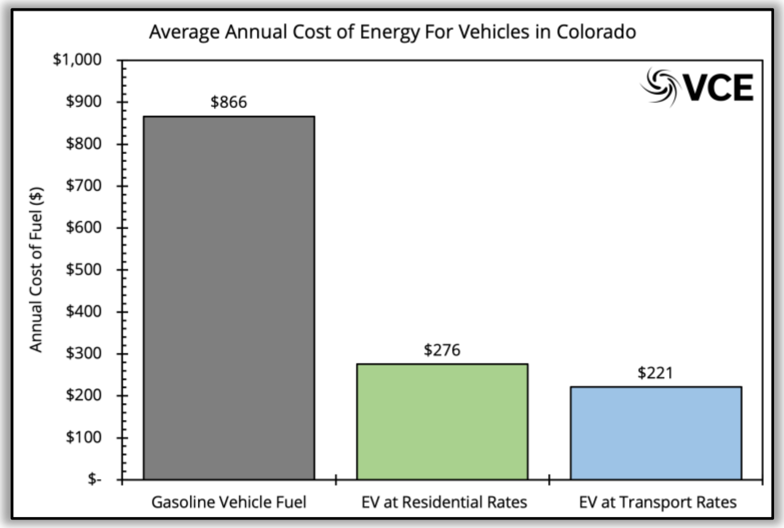


Figure 3.4: The difference between the average annual cost of fuel between gasoline vehicles, EVs at residential rates and EVs at transport rates.

Electricity Generation Capacity: The adoption of the EVs in Colorado increases the requirement for electricity capacity. However, the breakdown is somewhat similar to the Cleaner Grid scenario, namely, wind, solar, storage and natural gas. The generation capacity is shown in Fig. 3.5. The amount of storage deployed by WIS:dom® in Colorado is approximately 1,550 MW (with 3.5 hours) in the Cleaner Grid scenario and 1,650 MW (with 3.1 hours) in the EV Grid scenario by 2040. The increase in generation capacity increases employment in Colorado's electricity sector by approximately 68% by 2040.

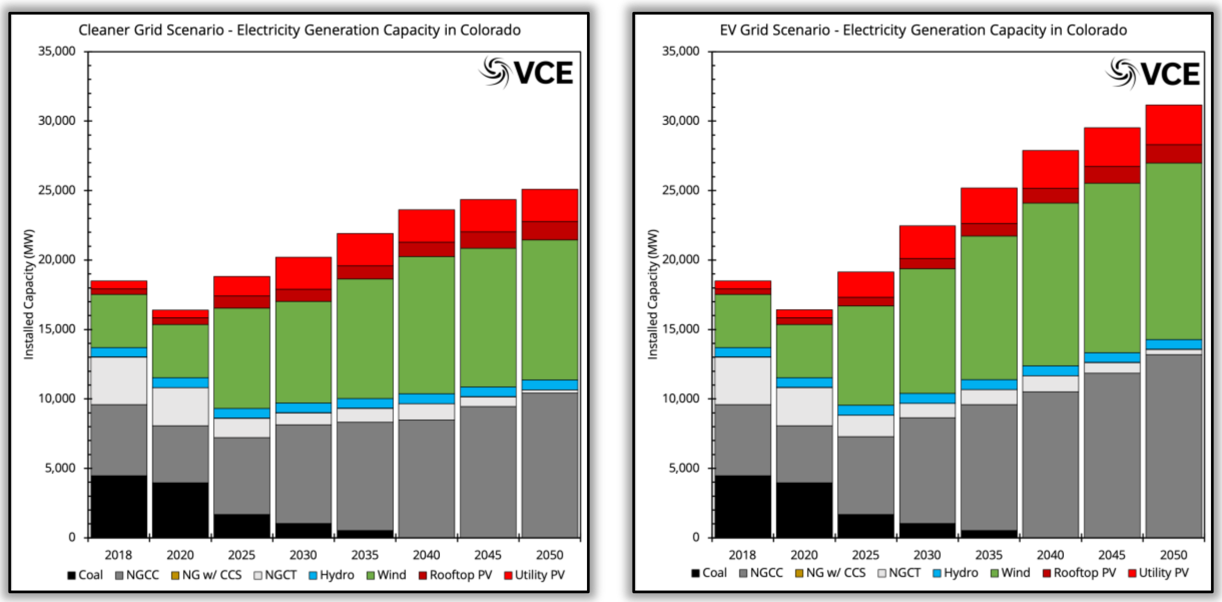


Figure 3.5: Total installed generation capacity in Colorado for the Cleaner and EV Grid Scenarios.

Colorado Generation: Since EVs require electricity, and the reason the generation capacity increases, the annual demand increases. There is assumed some load growth in Colorado in the Cleaner Grid scenario because of population migration into the state and the projections for the economy; however, for the EV grid even more demand is expected. This increase is about 20% higher than the Cleaner Grid demand by 2040. Figure 3.6 shows the electricity generation by fuel type over time under the Cleaner and EV Grid scenarios.

The increase in demand from the Cleaner Grid to the EV grid scenario is primarily covered by wind and solar, with some additional generation from natural gas. The natural gas and the electric storage that is deployed help manage the electricity system. The EV charging 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.

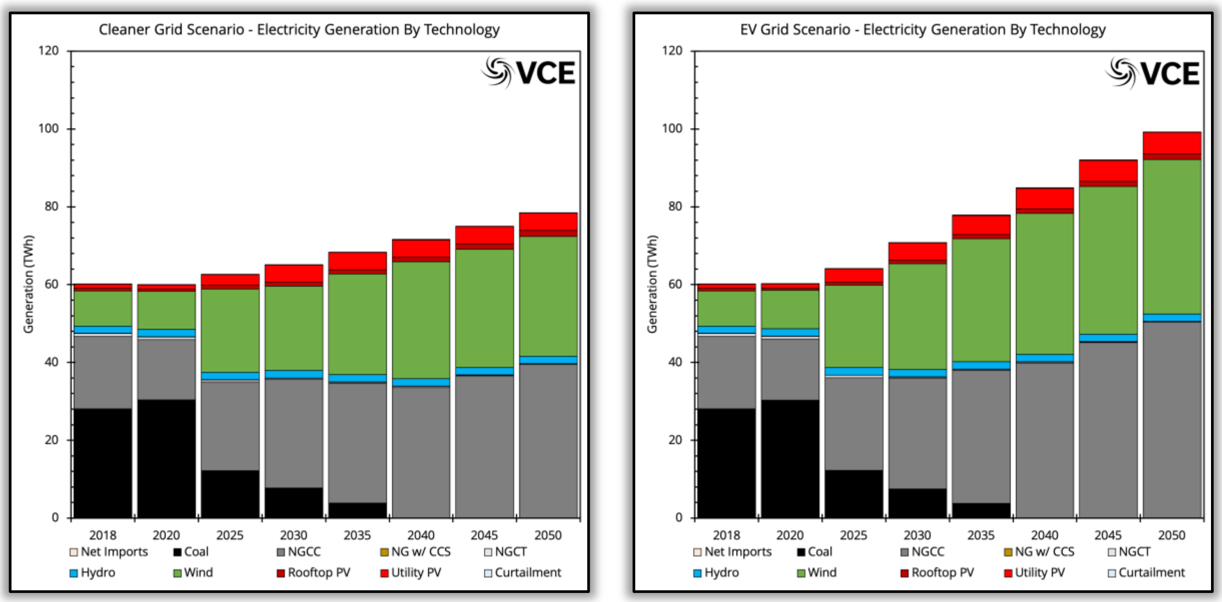


Figure 3.6: The annual generation by technology for Colorado for the Cleaner Grid (left) and EV Grid (right) scenarios.

Colorado Dispatch: Both the Cleaner Grid and EV Grid 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. For the EV Grid scenario, much more demand-side flexibility is available and this accommodates even more variable renewables. The electrification of transportation 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 April.

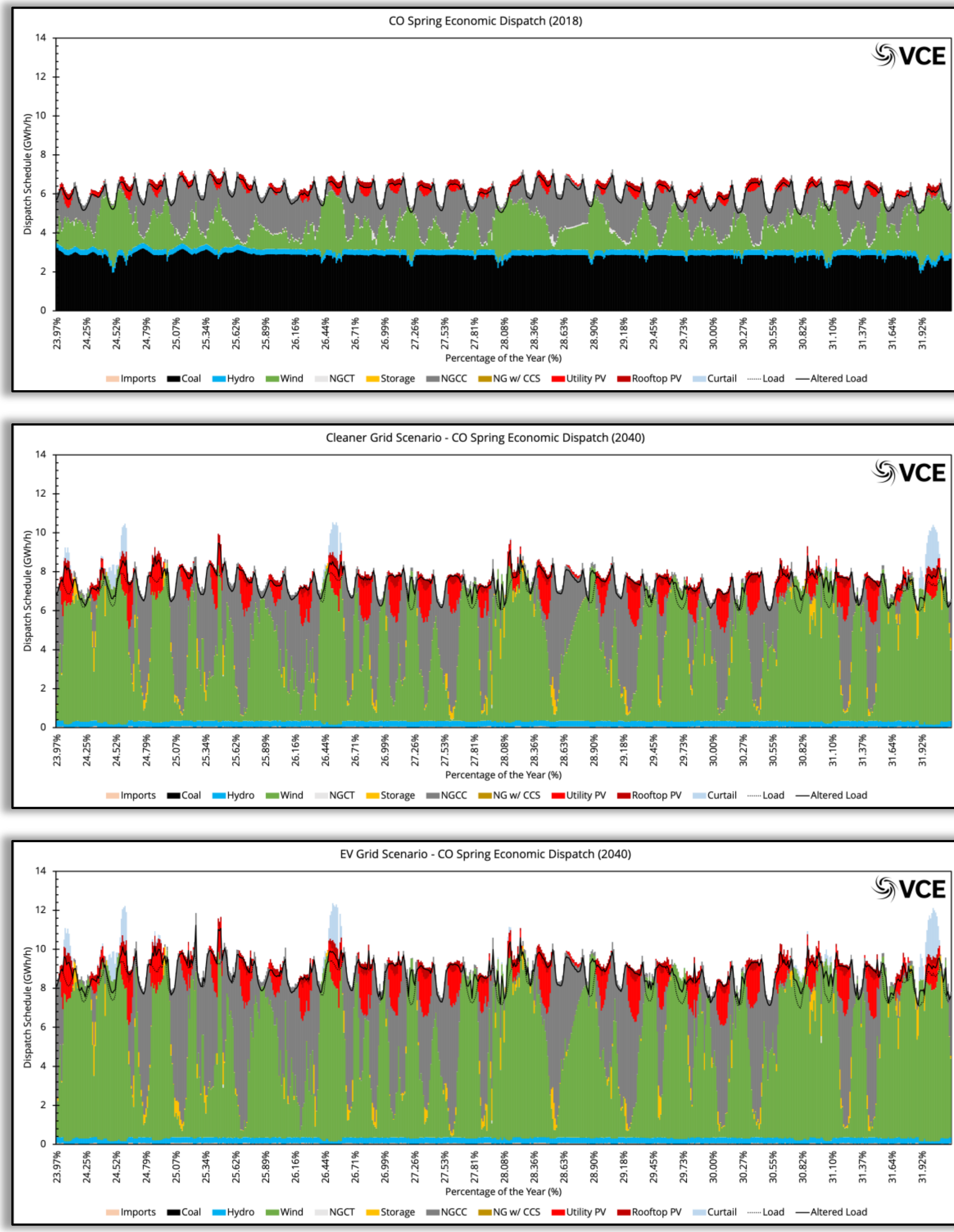


Figure 3.7: The dispatch of the Colorado electricity system for 2018 (top), 2040 in the Cleaner Grid scenario (center) and EV Grid scenario (bottom). In 2040, the dispatch swings between 100% variable generation to almost 0% regularly. This is due to Colorado being small compared with the scale of weather systems.

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

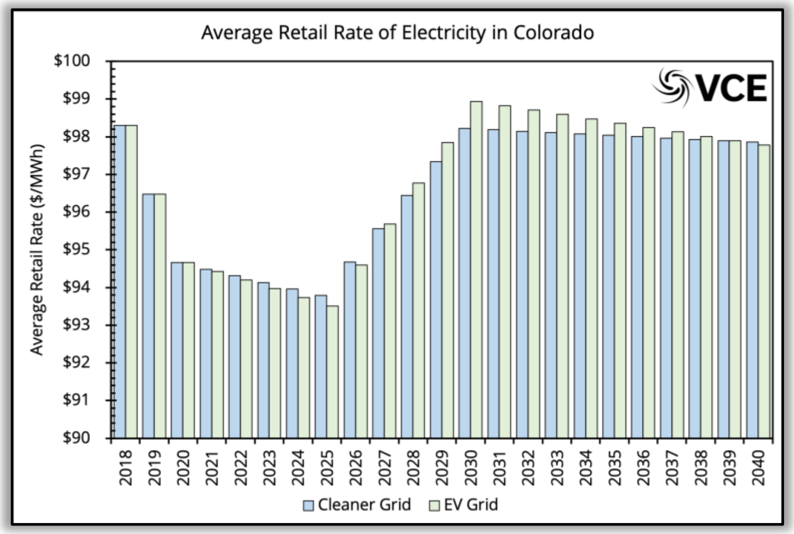


Figure 3.8: The average retail rates for the Cleaner and EV Grid scenarios. Both scenarios follow similar trajectories. In fact, the retail rates remain within 0.7% of each other from 2018 to 2040.

It can be seen in Fig. 3.8 that the retail rates for the EV Grid scenario are slightly lower than the Cleaner Grid scenario until 2026 at which point, they become slightly larger, and then decline again to become lower by 2040. The difference in estimated rates is a maximum of 0.7%. The retail rates suggest that the cost of electricity would be minimally impacted by the adoption of EVs in Colorado. This is predicated on EVs being charged in an efficient manner, which WIS:dom® does through demand shifting, so the vehicles can be charged at low rate / high production time intervals. This is predominantly at night in this case for Colorado to take advantage of the abundant wind power.

4. Conclusions

The state of Colorado can achieve the same GHG emission reduction as completely decarbonizing the electricity sector by electrifying transportation. No limit on emissions nor carbon tax was used in the current modeling. The retirement of the coal-fired power plants along with new wind, solar, natural gas and storage allowed electrification of transportation to provide benefits for all electricity customers in Colorado. The costs used in the modeling for new technologies were conservative and cost savings could be even higher.

The electrification of transportation along with an efficient electricity system results in CO_2 emission reductions of over half a billion metric tons by 2040. In addition, it would save Colorado residents $16 billion by 2040 in fuel costs. The immediate fuel saving per vehicle by switching to an EV would be $590 per year.

The total emissions reduction for the EV Grid scenario by 2040 is 42% below 2018 levels (45% lower than 2005 levels) and while it is not enough to entirely tackle climate change it does support the premise that electrification provides a cost-effective pathway to much higher emission reduction potential than concentrating solely on the electricity sector.