Making Electric Vehicles Work for Utility Customers

A Policy Handbook for Consumer Advocates

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AUTHORS

Pat Knight
Erin Camp, PhD
Divita Bhandari
Jamie Hall
Melissa Whited
Ben Havumaki
Avi Allison
Nina Peluso
Tim Woolf

Synapse Energy Economics, Inc.

485 Massachusetts Avenue, Suite 2
Cambridge, Massachusetts 02139

617.661.3248 | www.synapse-energy.com

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Foreword

Written by Shannon Baker-Branstetter, Consumer Reports; Jenifer Bosco, National Consumer Law Center; Dave Farnsworth, The Regulatory Assistance Project; Dave Kolata, Illinois Citizens Utility Board

About one-third of U.S. households report that lack of affordable access to energy is a major challenge.[1] Energy insecurity is encountered even more frequently among older adults and households of color. As electrification of transportation and heating systems advances, it will be increasingly important to maintain affordable electric service for all consumers, particularly the most vulnerable, and to leverage the opportunity to transition volatile transportation fuel costs toward lower-cost electricity with consumer protections.

While we are still early in the widespread transition to an electrified transportation sector, now is the time for consumer advocates and regulators to ensure that the benefits of EV adoption are maximized and experienced widely and equitably among consumers. The good news is that there are a number of policy tools available to ensure that this happens. *Making Electric Vehicles Work for Utility Customers – A Policy Handbook for Consumer Advocates*, provides a framework to help analyze EV policy options and understand how the benefits of EV adoption could be realized and fairly distributed.

The *Handbook* helps frame the important process of analyzing and understanding the potential opportunities and challenges of EV adoption. For example, EVs reduce pollution, improving air quality and public health, and can lower vehicle ownership costs such as fuel and maintenance, freeing up consumer spending for other household needs and overall purchase power. The *Handbook* notes that if EV charging is carefully optimized as a distributed energy resource, greater EV adoption can create conditions for lower electricity rates and bills over time. However, poorly managed charging can increase costs for both EV owners and other utility customers. Anticipating and addressing these points at the outset helps maximize benefits and avoid costly attempts to correct problems created by uninformed early action.

The *Handbook* encourages consumer advocates to consider several questions, essentially establishing key principles for consumer focused EV policy, and provides case studies based on analytical modeling. Three key questions are:

Will electricity customers' rates and bills increase or decrease, and when?

Under well designed policies, greater electrification can decrease per-kWh costs. Optimized EV charging can use excess capacity on the electric system more efficiently by spreading fixed costs of the existing system over a larger volume of electricity sales and exerting downward pressure on rates. High levels of adoption, in absence of utility and policy planning, however, could require additional power sector investments. The *Handbook* identifies rate design, charging infrastructure investment and planning, and

[1] U.S. DOE. Energy Information Administration (Sept. 19, 2018).

complementary policies that advocates can analyze to seek the best near-term and long-term financial outcomes for consumers.

How will customers' transportation expenditures change?

For many consumer advocates who focus on the electricity sector, a new issue to consider is mobility costs, including the *total cost* of transportation, whether individually owned vehicles, fleets, or public transit. As EVs replace gasoline- and diesel-powered vehicles, total costs for transportation are expected to fall and net consumer expenditures across electricity and transportation will also likely fall, but the distribution of household costs between transportation and electricity expenditures will shift**.** The *Handbook* helps advocates understand the role of total cost of transportation among household energy expenditures, and how to frame the potential changes to total electricity costs when designing effective EV policy.

How will EVs impact air quality and health?

EVs on the grid today are cleaner than an average gasoline-burning vehicle throughout the country, so EVs reduce pollution overall and especially near highways and congested traffic areas. Increased electric demand for EVs will create a need for additional energy. If this additional load is met with improved system efficiency and renewable energy, then emissions will continue to fall. If fossil generation expands, however, consumers located near fossil-fired power plants would experience higher pollution. The *Handbook* lays out these considerations for advocates seeking to lower pollution outcomes for all consumers and those disproportionately impacted by transportation and power sector emissions.

Importantly, the *Handbook* identifies electric utility policies and programs that can help maximize the benefits of transportation electrification and shape the equitable distribution of impacts. These include:

- Sound rate design principles that shift new EV load toward the least-constrained hours, thereby minimizing utility system costs and creating potential to lower customer rates.
- Treating flexible EV charging load as a demand response resource to improve the efficiency of the grid and decrease emissions.
- Siting public charging infrastructure in locations that minimize the need for distribution system upgrades.
- Designing EV rebates or other incentives to benefit low- and moderate-income consumers, including:
    - Creating incentives for lower priced EVs, used EVs, or leases
    - Targeting rebates and fair and affordable financing to the purchasing patterns and needs of lower-income consumers
    - Coordinating non-utility sector transportation electrification policies and programs with utility regulatory agencies and stakeholders

- Directing EV investments toward public transit, mobility services, and targeted charging infrastructure for multi-unit dwellings and low-income areas that the public, including low-income or non-driving customers, could rely on; and

- Electrifying medium- and heavy-duty vehicles to reduce pollution that disproportionately burdens low-income communities and communities of color.

Today the challenge of ensuring energy affordability and access includes the need to understand the costs and benefits of electric transportation. Identifying risks and opportunities associated with EV adoption and related policies will become a core competency for all electric utility consumer advocates. Especially, to the degree that programs are ratepayer-funded, staying abreast of these issues will also be an important role for utility regulators. *Making Electric Vehicles Work for Utility Customers – A Policy Handbook for Consumer Advocates*, provides a useful framework for analyzing EV policy options and ensuring that the benefits of EV adoption are fairly distributed across all consumers.

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EXECUTIVE SUMMARY

Electrification of the transportation sector is imminent, offering promises of lower costs for both electricity consumers and vehicle owners, but the path and speed the transition takes is not predetermined. The costs and benefits of electric vehicle (EV) adoption and the manner in which those costs and benefits are allocated among utility customers can vary substantially, with important implications for equity. The costs to utility customers are largely driven by the timing of EV charging, as well as any utility transportation electrification programs that rely on ratepayer funds. Who experiences the benefits depends, in part, on the design of transportation electrification programs, although many benefits (such as rate reductions and reduced pollutants) will be experienced by all utility customers.

The good news is that there are many tools utility consumer advocates can use to ensure that transportation electrification occurs in a manner that allows all customers, particularly low- and moderate income customers and disadvantaged groups, to share in the benefits while not unfairly bearing the costs. Further, there are many policies that can be adopted to help to maximize benefits for all customers and minimize costs on the utility system. If implemented right, the benefits of EV adoption can outweigh the costs, as shown by the case study analyzed for this report.

This report provides a framework for helping consumer advocates analyze EV policy options (including ratepayer-funded transportation electrification programs) and ensure that the benefits of EV adoption are equitably distributed across customers. The analysis framework is grounded in the three key questions that consumer advocates may wish to ask when considering transportation electrification programs or policies:

1. What are the positive and negative impacts of transportation electrification on electric utility customers (particularly non-EV owners)?
2. What are the broader public interest impacts (positive and negative) of transportation electrification?
3. What actions and policies could be implemented by electric utility regulators to maximize the benefits of EVs for all customers, including non-EV owners, and particularly for disadvantaged groups (e.g., low-income customers and environmental justice communities)?

While EVs have the potential to provide many benefits to customers, ranging from decreased tailpipe emissions and a larger number of electricity sales over which to spread fixed utility costs, appropriate planning and policy is critical. It is important to analyze the potential impacts of EVs and to shape those impacts early on, in order to avoid substantial investments on the grid to accommodate unmanaged charging, and to avoid missed opportunities or inefficiencies in utility transportation electrification programs and customer vehicle adoption decisions. The framework described in this guidebook is designed to better enable decision-makers to determine which policy options best protect customers while maximizing the benefits associated with transportation electrification.

Policies to maximize the benefits of EVs and promote equity

Electric utility policies and programs that can help maximize the benefits of transportation electrification and shape the equitable distribution of impacts (positive or negative) include:

- Implementation of **sound rate design principles** to shift new EV load toward the least-constrained hours, minimizing the costs that are imposed on the utility system and maximizing the positive impact that increased energy sales have on rates and bills.
- Use of **demand response** programs to enable utilities to use EV charging load as a resource to balance supply and demand on the grid to optimize the use of zero-emitting resources or to avoid use of expensive or highly polluting peak resources.
- **Siting public charging infrastructure** in locations that minimize the need for distribution system upgrades.
- **Designing EV rebates or other incentives to benefit low-income customers**, such as through incentives for lower cost EVs, used EVs, or vehicle leases (as opposed to only new car purchases). Other policies for low-income customers could include considering income guidelines to provide larger rebates for those with lower incomes, and providing rebates rather than tax incentives that may be difficult or impossible for low-income consumers to use. If the incentives are provided by a non-utility entity, such as a state agency or a third-party organization, utility transportation electrification programs should be coordinated with other government agencies.
- **Directing EV investments toward services that low and moderate income or non-driving customers may rely on, such as public transit, school buses, mobility services** (e.g., Uber, Lyft), and public charging infrastructure that serves multi-unit dwellings, mobility service drivers, and low and moderate income areas. Transit and mobility focused organizations have not traditionally participated in electric utility dockets but should be encouraged to participate in transportation electrification plans. In particular, closer coordination between consumer advocates and other government agencies (such as departments of transportation or municipal transit agencies) is likely to reap large benefits.
- **Electrification of medium- and heavy-duty vehicles responsible for criteria pollutants and the resulting serious health impacts in disproportionately impacted communities, which are often communities where low-income people or people of color live.** Examples include school buses, yard trucks at ports, delivery trucks in urban areas, or heavy trucking on freeways.

Summary of analytical framework for assessing EV costs and benefits

This guidebook aims to provide consumer advocates with the tools to help assess the costs and benefits of transportation electrification from a broad perspective. Table ES-1 presents an overview of the analysis framework, which includes impacts on electricity rates, as well as broader impacts on customers' transportation expenditures and health. We note that the scope of impacts to be considered may be defined differently across jurisdictions.

This framework can be used to analyze specific transportation electrification investments and rate designs, or it can be used more broadly to help consumer advocates determine the general types of programs and policies that are likely to provide the greatest benefits to customers without shifting costs to non-EV customers. We recommend first conducting a rate impact analysis assuming no ratepayer-funded investments in order to determine the magnitude of potential benefits stemming from EV adoption. The magnitude of the benefits can then be used to set a reasonable cost threshold for ratepayer-funded investments in order to ensure that the costs do not outweigh the benefits over the applicable time horizon.[1]

[1] There may be short-term mismatches between costs and benefits. The time period of the analysis should be long enough to capture costs and benefits associated with investments today. Future costs and benefits can be discounted appropriately to account for equity implications regarding who pays for the costs and who experiences the benefits. This is the same approach taken with traditional utility investments, such as generation resources, when comparing investment options.

Table ES-1. Framework for assessing consumer costs and benefits of increased EV adoption

Impact category	Description	Role
Electric system impacts	Projects the likely electric sector impacts associated with increased EV adoption, including impacts on capacity, generation and dispatch, transmission, distribution, and emissions.	The future electric grid may be substantially different than the electric grid of today, with different operating resources and marginal generators. Careful analysis of likely-to-occur future electric system impacts can yield different answers than reliance on data reflective of the current grid.
Rate and bill impacts	Estimates how electric rates change over time in light of (a) increased electricity sales and (b) increased spending on infrastructure (e.g., generating resources, transmission, distribution, and charging equipment) associated with EVs.	As more EVs are added to the grid, they result in more electricity sales, allowing for the possibility of an electricity rate decrease as fixed utility costs are spread over more kilowatt-hours (kWh). At the same time, costs may be incurred which facilitate this increased electric end-use. Careful analysis can reveal how these two dynamics interact. Policies should ensure that benefits are maximized for all electric customers, including those less likely to purchase an EV in the near-term, and to ensure that electric service remains affordable for all income segments.
Total cost of ownership	Estimates how an EV may save vehicle owners money over time relative to an internal combustion engine vehicle when accounting for fuel, maintenance, and other costs. Relevant for private car ownership and transit buses, school buses, and fleets.	Lower costs of vehicle ownership mean that consumers have more income available to meet other needs or that fleets have lower costs. In addition, lower costs of ownership are expected to increase the adoption rate of EVs, which then impacts electric system costs and electricity rates.
Health and pollution impacts	Estimates the net impact of pollutant emissions (greenhouse gas and public health-impacting) that result from a transition of energy use from the transportation sector to the electric sector.	Electric vehicles reduce tailpipe emissions, helping to abate impacts from greenhouse gases and decreasing the damaging effects that pollutants like nitrogen oxides and sulfur dioxides have on the health of consumers, especially those living in congested transportation areas. This is particularly relevant in situations where EVs may be used to reduce emissions from transit buses, school buses, and large trucks, which disproportionately impact lower-income and communities of color located near industrial and transit sites. Assessment of the net impacts of emissions (including both from tailpipe emissions and electricity sector emission changes) and a monetization of health impacts can help inform a more comprehensive assessment of EV costs and benefits.

Summary of case study findings

In the course of our analysis, we applied the above framework to a case study of several hypothetical EV adoption scenarios in Minnesota. We examined a scenario with business-as-usual (BAU) levels of EV adoption (in line with lower third-party estimates of future vehicle electrification), a "Low" EV adoption case (in line with several third-party estimates of future vehicle electrification), and a "High" EV adoption case (which nears the maximum level of EV adoption that is likely to be possible before 2030).

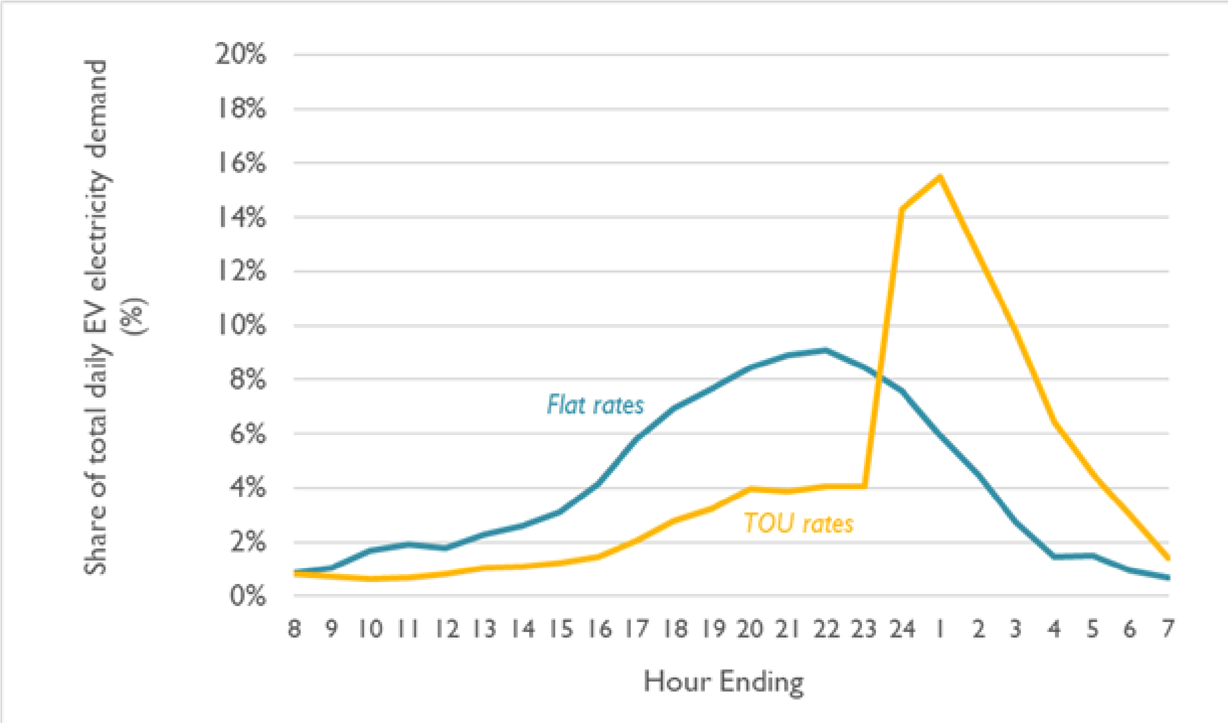
Within these cases, we examined two separate scenarios: one in which EVs follow a charging pattern observed by EV owners in the Midwest today (i.e., "flat" charging), and another in which EV owners respond to a time-of-use (TOU) electricity rate and shift to charging mainly during nighttime hours. Historically, TOU rates have resulted in relatively small shifts in load to off-peak hours, as customers often find it difficult to reschedule household energy use. However, EV load is different because the energy is stored in the vehicle's battery for later use. Most people do not care so much about precisely when their EV is charged, as long as it is ready when it is needed. This is very different from most major residential electricity uses (think of air conditioning) and opens up the possibility of encouraging efficient charging without inconveniencing consumers. Further, many EVs and charging stations have the option to set a time to time charging using the vehicle or charging interface, enabling customers to "set it and forget it." These characteristics lead to high rates of off-peak charging for EV customers facing time-varying rates.

Our team assessed what these levels of EV adoption might mean in terms of electric grid impacts, rate and bill impacts, total cost of ownership, and health and emissions impacts for Minnesota. In our case study, we found:

Increased EV load is projected to have limited impact on electricity demand and the wholesale electricity grid in the near term. Much of the electricity needs can be served by existing system capacity, and additional energy will likely be supplied by low-cost, low- or zero-emitting energy sources.

Our analysis finds that by 2030, even in a high deployment scenario, EVs are unlikely to represent more than a 5 percent increase in wholesale electricity sales relative to a future without EVs. However, EV adoption is unlikely to be linear. Electricity sales are likely to increase very slowly over the next 5+ years, only exceeding 1 percent of sales in 2026. This relatively limited increase in electricity sales is projected to be met first by utilizing current excess capacity on the system, and then by the same types of marginal capacity and marginal generation that would meet increases in load not linked to EV deployment; namely inexpensive renewables and, in some cases, natural gas combined cycle plants. However, rate design matters: the scenarios that feature large quantities of daytime charging result in greater quantities of capacity additions than the scenarios that feature mainly nighttime charging (i.e., the TOU scenarios shown in Figure 1). This demonstrates that time-varying rates can be an important tool in reducing system costs through the optimal use of generation resources.

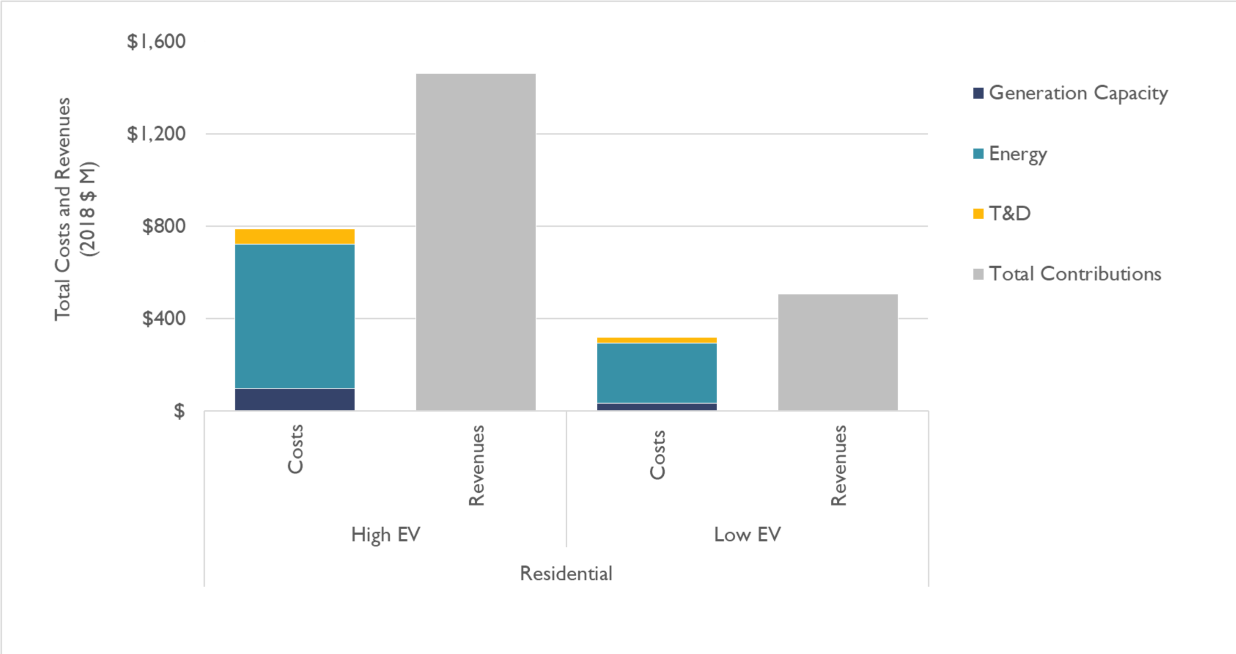
Figure 1. Electric vehicle charging profiles for TOU and flat electricity rates



Increased electricity sales due to EVs are projected to exert downward pressure on electricity rates. Policies and rate designs that align charging with lower cost hours can help to maximize benefits.

In our model, the increase in electricity sales associated with greater EV adoption leads to lower rates than in the base case in nearly every scenario. High EV adoption yields the greatest benefit to residential utility customers, with an average annual electricity savings of $71 in 2030 in the High EV scenario relative to the base case (see Figure 2). In the Low EV Scenario, an average residential utility customer would save about $25 on annual electricity bills in 2030 relative to the base case. These bill impacts are due to EV customers contributing greater revenues than the marginal costs imposed on the system, as shown in the graph below.

Figure 2. Comparison of Cumulative Incremental Costs and Revenues for Residential Customers



To test the robustness of these results, we also conducted a sensitivity with higher marginal transmission and distribution costs. This sensitivity results in smaller rate reductions, but rates were still lower than in the base case, demonstrating that the revenues from EVs more than offsets the incremental costs imposed on the residential class in our case study. This indicates that in practice, EV revenues may more than offset incremental costs.

TOU rates impact electricity rates in several ways: they reduce system costs by encouraging customers to charge EVs during off-peak hours, but may also reduce the revenues the utility collects (relative to the revenues from a flat rate). Another factor that is more difficult to account for is the impact of TOU rates on EV adoption. It is likely that customers will be more willing to adopt EVs if they can charge on off-peak rates that are lower than flat rates. Our sensitivity analysis found that TOU rates have the potential to produce higher or lower rate reductions than flat rates, depending on the design of the TOU rates. Rates structures that require EV customers to pay higher rates will generate greater average rate reductions for all customers, holding all else equal. However, consumer advocates and regulators should also account for any changes in EV adoption that would result from different TOU rate designs.

For commercial and industrial (C&I) customers, the significant variability in charging profiles for high speed charging and for fleets (both light- and heavy-duty) makes assessing costs and benefits more difficult than for residential customers. In our case study, we assumed that the majority of C&I charging occurs during on-peak hours, and we did not assume that TOU rates, demand response programs, or other charging management programs were used to manage C&I charging load. We made this assumption not because C&I customers cannot respond to TOU rates, but rather because we do not currently have robust data indicating the extent to which we can expect load to shift. We also assumed that all charging infrastructure would require line extensions and that those costs would be equal to three years of EV revenues, and that those line extension costs would be recovered from all C&I customers. These assumptions may overstate the costs of integrating many EV charging stations because customers would likely leverage TOU rates and other programs to reduce costs if available, and the modeling assumes the maximum line extension amount that is allowed through line extension credits by Minnesota utilities. If charging stations can be integrated into the grid at lower cost than the maximum line extension credits, then the rate impacts would be improved.

Our modeling results show an overall limited impact on rates for C&I customers: the benefits and costs largely cancel out in the low EV adoption scenario, while the high EV adoption scenarios result in modest rate reductions for C&I customers. If managed charging or TOU rates were implemented, we would expect that the benefits would increase substantially, resulting in clear rate reductions for C&I customers.

Our overall rate impact findings for both residential and C&I customers are:

- EV adoption results in modest rate reductions in nearly all scenarios. These findings are robust even under higher marginal transmission and distribution costs.
- Net benefits to customers can be increased through careful rate design or managed charging, such as through well-calibrated TOU rates.
- To maximize the potential benefits of EVs to utility customers, we recommend that time-varying rates, smart charging programs, and other cost-effective incentives be pursued, as described in Section 3.1.

Despite potentially higher upfront costs, EVs tend to have lower lifetime costs due to reduced fuel and maintenance costs. This results in cost savings for EV owners as well as electrified public transit and mobility services.

While the overall affordability of transportation options has not historically been a focus of utility consumer advocates, it may be of interest when determining whether investments in transportation electrification are in the public interest. Although the upfront purchase price of some EVs can be higher than the upfront costs of internal combustion engine (ICE) vehicles, our analysis indicates that the reduced fuel and maintenance costs associated with EVs result in cost savings relative to an ICE over the lifetime of a vehicle. We find that this is true across the three vehicle categories in our analysis: car, SUV, and bus. Over a six-year ownership period beginning in 2020, we estimate that electric cars will provide cost savings of approximately $5,000 to $5,500 relative to an equivalent ICE vehicle, while electric SUVs will provide cost savings of approximately $6,200 to $7,200 over their ICE equivalents. Similarly, for an electric bus purchased in 2020, we estimate that the cost savings over a 14-year period would total approximately $57,100 to $78,400 over a standard diesel bus.[3]

[3] We note that these cost savings do not reflect any up-front costs of installing charging infrastructure.

These total cost savings imply that customers are likely to benefit financially from owning or leasing an EV. However, higher upfront costs may continue to be a barrier to EV adoption by lower-income customers, especially until auto manufacturers offer more lower cost models in every state. Well-designed transportation electrification programs can help address such barriers by encouraging greater vehicle offerings throughout the country, reducing upfront purchase costs for low and moderate income customers, improving access to vehicle financing for low and moderate income customers, increasing access to charging infrastructure for low and moderate income populations, and electrifying transit and mobility services relied on by low and moderate income customers.

EVs will substantially reduce greenhouse gases and improve public health due to lower tailpipe emissions and relatively clean sources of additional electricity generation. Communities located near transportation corridors will particularly benefit from the health impacts of transportation electrification.

In 2016, the transportation sector surpassed the electricity sector in terms of carbon dioxide (CO_2) emissions.[4] ICE vehicles also emit other greenhouse gases, smog-forming pollutants, particulate matter, and toxins responsible for poor air quality and adverse public health impacts.[5] Transportation electrification can achieve substantial state-specific greenhouse gas emission reductions, while also improving public health and lowering healthcare costs through reduced tailpipe emissions.

We find that all modeled scenarios result in net overall reductions to CO_2 and net improvements to public health. In scenarios with higher levels of EVs, we observe cumulative CO_2 reductions nearing 25 million metric tons between 2020 and 2030. In addition, scenarios with higher levels of EVs reduce mortality and morbidity and have a monetized health impact as high as $920 million between 2020 and 2030. Importantly, because transportation sector emissions occur at ground level where they are less likely to be dispersed and more likely to have an impact on customers' health, a decrease in tailpipe emissions is likely to produce the most health benefits for the customers who are physically located near where the vehicles are operated. This is particularly relevant in situations where EVs may be used to reduce emissions from transit buses, school buses, and large trucks, which disproportionately impact lower-income and communities of color located near industrial and transit sites.[6]

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[4] United States Energy Information Administration, Monthly Energy Review April 2019, Tables 12.5 and 12.6, https://www.eia.gov/totalenergy/data/monthly/archive/00351904.pdf

[5] United States Environmental Protection Agency, "Smog, Soot, and Other Air Pollution from Transportation," available at https://www.epa.gov/transportation-air-pollution-and-climate-change/smog-soot-and-local-air-pollution#about

[6] Lara P. Clark, Dylan B. Millet, and Julian D. Marshall, "Changes in Transportation-Related Air Pollution Exposures by Race-Ethnicity and Socioeconomic Status: Outdoor Nitrogen Dioxide in the United States in 2000 and 2010," Environmental Health Perspectives 125, no. 9 (14 2017): 097012, https://doi.org/10.1289/EHP959.

1. HOW WILL TRANSPORTATION ELECTRIFICATION IMPACT CUSTOMERS?

Transportation electrification is gaining steam in the United States, propelled by a variety of factors. Many drivers find EVs attractive due to their low maintenance costs, performance attributes, and convenience of "refueling" at home.[7] Some jurisdictions actively promote transportation electrification for the purpose of reducing greenhouse gas emissions, as the transportation sector is largest emitter of greenhouse gases in the United States, or for the purpose of reducing local pollution or dependency on petroleum.[8] Transportation electrification, alongside a transition to renewable sources of electricity, is the most promising approach to decarbonizing the transportation sector and one of the strategies most likely to be employed by policymakers over the coming decade.

As a result, EVs are proliferating. Between 2011 and 2018, manufacturers sold over 1.1 million plug-in EVs nationwide.[9] In 2018, EVs made up over 2 percent of all light-duty vehicle sales—while still a small portion of sales, this is a tripling in market share in just five years.[10]

The rapid adoption of EVs will naturally increase the total electric load on the system, potentially leading to the need for additional investments in electricity generation, transmission, and distribution capacity, especially if not planned for or managed well. This is a key area of concern for consumer advocates, as these investments may impact the electric rates that utility customers pay. In addition to electricity-related costs, advocates are also concerned about any other potential negative impacts on consumers, including low and moderate income and disadvantaged groups. At the same time, EVs have the potential to provide rate benefits, since well-managed EV charging can more efficiently utilize existing system capacity while spreading fixed costs over a higher volume of sales, exerting downward pressure on electricity rates for all customers. In addition, increased deployment of EVs (and associated infrastructure) can potentially improve public health and produce transportation cost savings for consumers when measured over a vehicle's lifetime.

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[7] EV drivers benefit from lower maintenance costs because electric motors have fewer moving parts than a combustion engine and the brakes last longer due to regenerative braking technologies. EV drivers also enjoy quicker acceleration due to the high torque in an electric motor and lack of vibrations from a combustion engine.

[8] U.S. Energy Information Administration. U.S. Energy-Related Carbon Dioxide Emissions, 2017. See https://www.eia.gov/environment/emissions/carbon/

[9] See https://insideevs.com/monthly-plug-in-sales-scorecard/. This statistic includes both plug-in hybrid vehicles, as well as fully electric vehicles.

[10] See data from insideevs.com, as well as data from the United States Federal Reserve at https://fred.stlouisfed.org/graph/?id=TOTALNSA,HTRUCKSNSA,LTOTALNSA,LTRUCKNSA.

This guidebook provides a framework for understanding the range of impacts from transportation electrification and offers recommendations for maximizing benefits to electric utility customers and promoting equitable sharing of costs and benefits.

1.1. The consumer advocate perspective

Public utility consumer advocates are charged with protecting the interests of utility customers. Traditionally, this has largely meant ensuring that utilities provide electricity service that is safe, reliable, and affordable, with electric utility rates and bills as a primary focus. However, the interests of public utility customers may also be defined more broadly to include ensuring equitable achievement of energy policy goals. This guidebook examines the potential impacts of transportation electrification on electric utility customers in general, with particular emphasis on low and moderate income customers and communities who are disadvantaged in some manner.

The costs and benefits associated with transportation electrification will not be evenly distributed unless fair allocation of costs and benefits is prioritized. Low and moderate -income customers and disadvantaged groups may stand to benefit from EVs more in some ways and less in others. For example, the relatively high upfront costs of EVs (and less availability of lower cost EVs) is a formidable barrier for many low-to-moderate income households, which means that they are less likely to benefit from the lower operational and maintenance costs associated with EV ownership in the near-term. On the other hand, even non-EV owners may stand to immediately benefit from EVs as a result of cleaner air from reduced diesel and gasoline emissions, as well as from any downward pressure on electricity rates that results from greater electricity sales.

Transportation electrification policies adopted by utility regulators can encourage the fair allocation of costs and benefits, or not. To ensure equitable outcomes, policymakers should work in consultation with customers who live in disadvantaged communities to ensure that these customers do not disproportionately bear the costs and risks associated with EVs, and that they are able to take advantage of the benefits.[11]

1.2. Key questions to guide EV analyses

When evaluating the potential impacts of EVs, there are several key questions that consumer advocates may wish to ask to ensure that the interests of public utility customers are adequately represented in the decision-making process:

- *Will electricity customers' rates and bills increase or decrease?*
- *How will customers' transportation expenditures change?*

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[11] See section 3.2 for an examination of transportation electrification polices that can impact equity.

- *How will EVs impact air quality and health?*
- *How do these impacts differ for low and moderate income customers and disadvantaged groups? Are costs and benefits being shared fairly?*

To answer these questions, a variety of analyses can be conducted to examine the impacts on electricity rates and bills, the total cost of ownership for electric vehicles, and changes in emissions and related health impacts. Each of these analyses is described in more detail below. In Chapter 4 we provide a detailed case study analysis to demonstrate how these analyses can be undertaken and the potential magnitude of impacts.

Rate and bill impacts

Depending on when they charge, EVs can help to use excess capacity on the electric system more efficiently, thereby spreading the fixed costs of the system over a larger volume of electricity sales and exerting downward pressure on rates. However, adoption of large numbers of EVs may eventually require additional grid investments, particularly if some charging occurs during peak hours. Serving this additional load is therefore apt to impose some additional costs on the grid. For example, generation capacity may need to be added, or existing power plants may be utilized more frequently or over different hours. In some cases, the transmission or distribution systems may need to be expanded or upgraded. Most of these costs will be passed down to ratepayers. The impact on rates depends on whether the revenues from increased electricity sales outweigh the additional costs of expanding the electric system. Thus, to determine if an expanded EV market will increase or decrease electric rates in a region, it is necessary to quantify the revenues from additional electricity sales and the marginal costs to the system from increased EV load.

Some jurisdictions have approved ratepayer-funded programs or investments to facilitate transportation electrification, such as utility investments in EV charging stations. Such programs will also impact rates. We recommend first conducting a rate impact analysis assuming no ratepayer-funded investments in order to determine the potential benefit of EV adoption.[12] The magnitude of the benefits can then be used to set a reasonable cost threshold for ratepayer-funded investments in order to ensure that the costs do not outweigh the benefits over an appropriate time horizon.

Total cost of ownership

The total cost of vehicle ownership includes the costs to purchase, maintain, insure, and fuel a vehicle. This total cost reflects how much customers pay to utilize transportation, whether individually owned vehicles, fleets, or public transit (such as electrified buses). This topic has not traditionally been examined by utility consumer advocates; however, as gasoline- and diesel-powered vehicles are replaced with EVs, the lines between transportation costs and electric utility bills becomes increasingly

[12] In other words, we recommend a rate and bill impact analysis as described in section 2.1.

blurred. As such, the total cost of vehicle ownership is a new area of concern for electric utility customer advocates.

Health and pollution impacts

Health and pollution impacts of transportation have not historically been a focus of utility consumer advocates, except to the extent that emissions reductions from transportation electrification help reduce the costs of utility compliance with environmental mandates. However, the health and pollution impacts of transportation electrification may be of interest when determining whether utility investments in transportation electrification are in the public interest. Transportation electrification will impact local and global emissions in two primary ways. First, as ICE vehicles are replaced with zero-emission EVs, there will be associated reductions in tailpipe emissions leading to fewer health negative impacts. Second, increased electric demand for EVs will create a need for additional energy generation. Depending on the type of energy resources deployed to serve the additional load, emissions from incremental electricity generation may be nonexistent, or could increase. These emissions may include GHG, criteria pollutant, and mercury emissions. Though GHG emissions are most closely linked to climate change, criteria pollutant and mercury emissions cause air and water quality degradation and public health problems.[13] Importantly, these emissions and their impacts occur in different places—reductions in tailpipe emissions occur on roadways, physically adjacent to consumers. As a result, decreased tailpipe emissions may produce improved public health for in-state consumers, or even potentially consumers located in a specific geographic area. In contrast, increases in emissions from power plants may occur only at central (sometimes easily controlled) locations, but may produce health impacts that are spread over a much wider area.

[13] U.S. Environmental Protection Agency, Health and Environmental Effects of Particulate Matter. https://www.epa.gov/pm-pollution/health-and-environmental-effects-particulate-matter-pm

2. MEASURING COSTS AND BENEFITS

Once the categories of relevant costs and benefits of transportation electrification have been identified, the logical next step is to begin quantifying the values for each category of cost or benefit. This quantification can take several forms, including straightforward spreadsheet analysis, more complex production cost or capacity expansion modeling, or many other types of tools. While this quantification is most frequently prepared by electric utilities, it is essential that other stakeholders play a role in order to ensure a more complete assessment of impact categories, as well as a proper inclusion of both costs and benefits.

2.1. Analytical tools and methodologies

Chapter 1 identified three impact categories of particular relevance to consumer advocates when transportation electrification: rate and bill impacts, total costs of ownership, and health and emissions impacts. Underpinning all of these is the impact on the electric system from serving additional EV load. Thus, the analysis should begin with an assessment of impacts on the electric system.

Electric system impacts

Transportation electrification raises important questions for the costs to the electricity grid, including:

- As more electricity is consumed, which generation resources will be deployed?
- Is existing generation capacity adequate? If not, what resources are likely to be added to the grid?
- Is existing transmission and distribution (T&D) capacity adequate?

While it may be most straightforward to simply estimate how today's electricity grid would respond to an increase in demand from EVs, the grid in 5 or 10 years will be different. It is important to begin with an analysis that takes into account likely future changes to the grid in order to develop an accurate baseline. The future electricity system can be modeled using a variety of tools that range from simple and relatively inexpensive, to complex and comprehensive but expensive and time-intensive.[14]

Production cost models

Production cost models are commonly used by utilities to understand the day-by-day or hour-by-hour dynamics of electricity systems. They typically approximate economic dispatch (and often chronological

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[14] Each tool has strengths and weaknesses—one tool may be appropriate for a certain calculation or purpose, but inadequate for another. For additional information on advantages and disadvantages of different electricity modeling approaches, see https://www.energy.gov/sites/prod/files/2016/02/f30/EPSA_Power_Sector_Modeling_FINAL_021816_0.pdf, https://www.epa.gov/sites/production/files/2018-07/documents/epa_slb_multiple_benefits_508.pdf, and http://www.synapse-energy.com/sites/default/files/Guide-to-Clean-Power-Plan-Modeling-Tools.pdf

dispatch) as well as unit commitment, power plant heat rates, fuel prices, environmental constraints, and demand. These models are designed to determine least-cost dispatch of a known set of resources at a very high level of resolution. They frequently provide outputs on hourly wholesale costs, unit-specific generation and dispatch, hourly emissions, and information about congestion and transmission. They are useful for understanding how the grid might respond on an hour-by-hour basis to increased demand from EVs. Examples of these models include EnCompass, PROSYM, PLEXOS, AURORAXMP, GE-MAPS, and Ability.[15]

While these are among the most sophisticated models that are most adept at representing real-world conditions, they are among the most expensive models to run, requiring extensive training and expertise, data and/or license fees, and sufficient time to complete model runs. Because of the required expertise to run these models and their associated cost, these models often lack transparency, making it difficult for consumer advocates or other stakeholders to scrutinize inputs or outputs without assistance from outside experts.

Capacity expansion models

Capacity expansion models are commonly used to understand how the electric system might change over a long period of time. These models can determine least-cost technology type buildout under specified policy and economic constraints, but the models tend to have relatively low temporal or spatial resolution (e.g., grouping units of a particular type together, or by only modeling key hours). These models are useful for forecasting which types of resources may be built in the future as demand for electricity increases as a result of increased vehicle electrification. This is especially important when considering that the electric system of 5 to 10 years from today may be radically different.

Examples of these models include ReEDS, NEMS EMM, and IPM.[16] Some models, like EnCompass, Plexos, Ability, and AURORAXMP, can be run in both a capacity expansion-mode and then in a production cost-mode, allowing the same model to develop a long-term capacity build projection which is then used as a basis for a highly-detailed production cost analysis. Capacity expansion models are commonly applied in developing least-cost resource portfolios for utilities and/or states, including in integrated resource planning (IRP) studies.

Like production cost models, capacity expansion models are invaluable for projecting a rigorous, grounded-in-economics estimate of how the electric system might respond to changes resulting from vehicle electrification. That said, capacity expansion models are also expensive, both in terms of training

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[15] See https://anchor-power.com/encompass-power-planning-software/, https://new.abb.com/enterprise-software/energy-portfolio-management/market-analysis/zonal-analysis, https://energyexemplar.com/products/plexos-simulation-software/, https://energyexemplar.com/products/aurora-electric-modeling-forecasting-software/, https://www.geenergyconsulting.com/practice-area/software-products/maps, and https://new.abb.com/enterprise-software/energy-portfolio-management/commercial-energy-operations/portfolio-optimization.

[16] See https://www.nrel.gov/analysis/reeds/, https://www.eia.gov/outlooks/archive/aeo16/appendixe.php, and https://www.icf.com/technology/ipm.

and data requirements, which present barriers to consumer advocates being able to effectively engage with the model inputs or outputs.

Non-optimization approaches

The last category of electric system analysis spans a wide range of screening tools that may be used for simple simulations or bookkeeping purposes. These tools are typically transparent and user-friendly, which may make them appealing to consumer advocates with limited budget or expertise in this area. These models may employ simplified versions of production-cost or capacity-expansion modeling. They may be limited in geographic or temporal scope, or they may have limited detail on individual unit attributes or operating constraints. These tools may convey useful information on dispatch, prices, or emissions, but perhaps not all three, and perhaps not at a level of resolution that is useful to discern the specific impacts of increased EVs.

Examples of these tools include AVERT (U.S. Environmental Protection Agency), CP3T (Synapse), SUPR (ACEEE), and LEAP (Stockholm Environment Institute).[17]

Rate and bill impacts

Whether transportation electrification will increase or decrease electricity rates depends on whether the revenues associated with increased electricity sales outweigh the increase in cost associated with serving additional load. EV customers typically pay an average electric rate, which may be higher than the cost of serving some small amount of additional load (i.e., the marginal cost). In other words, is the marginal cost imposed by EVs more than or less than the electricity rates paid by EV customers?

In the short run, there is likely to be some excess capacity on the utility's system (both at the generation level as well as on the transmission and distribution system), making the marginal cost of serving additional load quite low. In the long-run, however, the utility may need to expand its capacity to serve EVs (as well as the electrification of other end-uses, such as heating or water heating). These marginal costs of additional electricity supply can be derived from production cost or capacity expansion models. Marginal transmission and distribution costs may be available from utilities' marginal cost of service studies.

A rate impact analysis utilizes the following inputs:

- Current retail rates (including pass-through costs).
- Customer counts, energy consumption, and customer demand without EVs.
- Base utility revenue requirements (including pass-through costs).

[17] See https://www.epa.gov/statelocalenergy/avoided-emissions-and-generation-tool-avert, http://www.synapse-energy.com/tools/clean-power-plan-planning-tool-cp3t, https://aceee.org/research-report/e1601, and https://www.sei.org/projects-and-tools/tools/leap-long-range-energy-alternatives-planning-system/.

- Additional annual electricity sales due to EVs.
- Hourly load curves associated with EV charging load.
- Marginal generation, transmission, and distribution costs associated with serving EV load.

First, the utility's revenue requirements and sales are estimated over the study period assuming only a baseline rate of growth in additional EVs.

Next, for each kilowatt-hour (kWh) of incremental EV load in each year, the utility's revenue requirements are adjusted based on the marginal costs imposed on the utility system (in $/kWh) on an hourly basis. It is important to account for the expected EV charging load profiles when performing this step, as the cost of serving additional EV load during peak hours will be much higher than during off-peak hours.

Finally, the utility's electricity sales are increased in each year to account for additional EV load.

The annual rate impact is calculated by determining new rates from the new revenue requirements and new sales.

The results of the rate impact analysis should include both the long-term change in customer rates as well as the year-to-year impacts. These impacts should be presented in meaningful terms, such as the percent change in rates, as well as the average annual or monthly bill impacts (in dollars) for typical customers in each class.

This calculation can typically be performed in a basic spreadsheet model, as long as adequate data exist for inputs. Such data may come from a variety of sources, including from utility filings, from results of production-cost or capacity-expansion modeling, or from other sources.

Total cost of ownership

A total cost of ownership assessment entails a comparison of the costs of purchasing one type of vehicle (e.g., an EV) versus another (e.g., a comparable ICE vehicle). For a comprehensive assessment, this analysis should evaluate and break out the lifetime costs into the following components:

- Upfront vehicle costs, including any state and federal incentives that are available and considering if and when those incentives end or phase out.
- State-specific sales taxes associated with the vehicle purchase.
- Insurance costs, including how they vary by vehicle age and by manufacturer's suggested retail price.
- Whether (or what share of) customers choose to finance their vehicle purchase, the terms under which they finance, and the ability of those customers to economically finance vehicles. To calculate the average total cost of ownership of a vehicle, it is important to calculate both the financed upfront costs of EVs and ICE vehicles and the unfinanced upfront costs of EVs and ICE vehicles, and to weigh them proportionally by the percent of customers who choose to finance.

- Fuel and electricity spending, calculated from assumptions regarding fuel economy, gasoline prices, electricity prices, and vehicle miles traveled. The electricity rate projections should be based on a rate impact analysis, as well as trends in utility costs. If the EV that is being analyzed is a plug-in hybrid, the analysis must account for both the gasoline and electricity components of its fuel spending.

- Maintenance costs as a function of vehicle miles traveled.

- Resale value, calculated using a resale curve that relates the resale value of a vehicle (as a percentage of the upfront vehicle cost) to its age.

Because many of these factors vary significantly across vehicle types, it is essential that total cost of ownership analyses are calculated for a single vehicle category (e.g., car, SUV, van, or bus) and consistently for each type of vehicle. That is, a total cost of ownership analysis should compare the lifetime costs of an electric SUV and an ICE SUV, but not an electric SUV and an ICE van.

Health and pollution impacts

A proper accounting of pollution and health impacts can help determine the full, societal impact of transportation electrification. Relevant emissions to quantify may include carbon dioxide (CO_2) and other greenhouse gases, as well as nitrogen oxides (NO_X), sulfur dioxide (SO_2), particulate matter (PM), mercury (Hg), volatile organic compounds (VOCs), and other pollutants affecting local communities.

Estimating emissions impacts

Determination of transportation electrification's impacts on emissions includes two components: emission reductions in the transportation sector (as a result of direct-emitting ICEs being replaced by EVs) and emission impacts in the electric sector (which may range from no change to increased emissions depending on which electric resources are generating more electricity).

Changes to transportation emissions can be estimated using simple spreadsheet calculations by estimating the quantity of EVs in each year and estimating what a likely ICE vehicle would have emitted in place of EVs.[18] Calculating electricity emissions that result from EV charging is more complicated: emissions may change over the years as new generating resources are built (as a capacity expansion model could describe), and emissions may change over the course of a day or a year as different resources are available and contributing to the margin (as a production cost model could describe).

Changes in grid emissions are difficult to assess because EVs represent new demand on the grid that may be served by new generating resources, and because EV charging is unlikely to follow current

[18] Other important inputs to this calculation include the emissions content of gasoline or diesel, the vehicle efficiency (which may change as a result of changing consumer preferences or environmental requirements like CAFE), vehicle miles traveled per year, and the lifetime distribution of vehicles. This calculation can be performed with data from U.S. EIA's Annual Energy Outlook, for example (see https://www.eia.gov/outlooks/aeo/supplement/excel/sup_tran.xlsx).

household hourly load profiles. We therefore recommend that consumer advocates avoid using a simple emission rate value that may reflect the average grid emissions rate, and instead seek to estimate the marginal emissions rate that reflects how the system responds to additional electricity demand. Further, the emission rate should not reflect the emission rate of today; rather, it should be based on the expected generation mix in the future.[19] Emissions rates will also vary depending on whether TOU rates or managed/smart charging options help to encourage EV charging that takes advantage of variable renewable power.

By accounting for both emission reductions in the transportation sector and changes to emissions on the electric grid, consumer advocates can perform a full accounting of the emission-related costs and benefits of transportation electrification. By only analyzing one of these components, the net benefits (or net costs) of changes to emissions may be undercounted.

Estimating health impacts

A wide variety of health impact models exist. These range from very complex models (like BenMAP-CE) to simplified models (like COBRA).[20] These models typically take into account the location of emissions (i.e., where pollutants are emitted, both in terms of geography and altitude emitted), pollutant dispersion and atmospheric interactions (i.e., how pollutants move through the atmosphere, and how they interact and change with other), population demographics (i.e., where the pollutants land and who they impact), and health impact monetization (i.e., how health impacts are valued in society in dollar terms). Health impacts may be reported across a wide variety of categories, including impacts to mortality, asthma exacerbation, emergency room admissions, respiratory symptoms, and impacted work productivity.

As with emission impacts, by accounting for health impacts from both the transportation electric sectors, consumer advocates can perform a net assessment (including both costs and benefits) of the health impacts associated with transportation electrification.

2.2. The role of consumer advocates in analyzing transportation electrification programs

Electric utilities are increasingly proposing ratepayer-funded transportation electrification investments and rate designs. Consumer advocates have a critical role to play in ensuring that such programs benefit customers, particularly low and moderate income customers and disadvantaged groups. Consumer advocates can help to ensure that the analysis properly accounts for all appropriate costs and benefits

[19] To capture detailed emissions impacts, stakeholders may wish to use a production cost model (described in more detail below in chapter 4) or a tool like U.S. EPA's AVERT (https://www.epa.gov/statelocalenergy/avoided-emissions-and-generation-tool-avert), which estimates hourly, regionally specific changes in emissions resulting from changes to demand.

[20] See https://www.epa.gov/benmap and https://www.epa.gov/statelocalenergy/co-benefits-risk-assessment-cobra-health-impacts-screening-and-mapping-tool.

associated with transportation electrification programs, that transportation electrification benefits will reach lower-income customers and members of disadvantaged communities, and that programs are designed with input from customers, particularly those in disadvantaged communities. Further, consumer advocates can help to promote coordination between utility transportation electrification programs and programs funded by other government agencies to ensure that funds are used as efficiently as possible.

It is important to analyze the potential impacts of EVs under different scenarios (e.g., high and low adoption rates, on-peak versus off-peak charging), and to shape the impacts before substantial investments on the grid are needed to accommodate unmanaged charging, and to avoid missed opportunities or inefficiencies in utility transportation electrification programs and customer vehicle adoption decisions. In other words, it is important to implement thoughtful programs and policies early on so that the transportation electrification benefits for all customers can be maximized and costs to the grid minimized (see Chapter 3 for more on this topic).

Stakeholder input

Within the context of regulatory proceedings, utilities are often the first entities to put forth a quantification of transportation electrification costs and benefits (although in some cases these costs and benefits are simply alluded to, rather than quantified). Although utilities may possess the majority of the data and expertise to conduct such analyses, it is important that the analysis (and any utility program design decisions) incorporate perspectives from a wide range of stakeholders. For this reason, consumer advocates may wish to encourage regulators to create a forum for comprehensive, meaningful, and robust input from numerous stakeholders. In addition to state utility consumer advocates, other key stakeholders may include:

- Other representatives of low-income customers and non-EV owners;
- EV owners and charging site hosts;
- Environmental justice communities;
- Social and racial justice organizations;
- Environmental and clean energy advocates;
- Fleet operators and transit authorities;
- C&I customers; and
- Auto manufacturers and vehicle charging service providers.

The input from these stakeholders is important for ensuring that all costs and benefits are appropriately quantified, and that customer groups are not being overlooked. Further, auto manufacturers and charging vendors can help to ensure that utilities propose cost-effective solutions that support competitive and innovative markets. Stakeholders (such as transit agencies) may also have access to more detailed information for articulating their specific needs, which might require different approaches than those established for other customer segments. This information could be used to help quantify costs and benefits, and could include data on vehicle costs, vehicle charging patterns, and technology for transmitting data (e.g., submetering).

There are several forums where the evaluation of transportation electrification may take place. From a regulatory standpoint, the costs and benefits of utility EV investments are often assessed in the course of a rate case. Should this be the venue that consumer advocates are presented with, they may wish to ensure that a comprehensive assessment of costs and benefits is conducted before utility EV investments are approved. However, rate cases are rarely about EVs alone: many other topics may be at issue (such as revenue requirements, cost allocation, rate design, and cost of capital), making it potentially difficult to explore the impacts of EVs specifically. Further, rate cases tend to be contentious, formal proceedings, with little opportunity to incorporate community-level stakeholder processes into the design of transportation electrification programs.

Instead, it may be preferable to discuss transportation electrification within the context of an investigative proceeding, prior to significant utility investments in EV infrastructure. This could include generic proceedings on utility EV initiatives, grid modernization initiatives, or distributed energy resources. It could also take place within a utility's integrated resource planning proceeding. In these types of proceedings, consumer advocates are more likely to have the time and resources needed to dig deeply into the issue of EVs and ensure that the utility and/or the commission is adequately considering all appropriate costs and benefits.

3. What policies can maximize the benefits of EVs and promote equity?

The electrification of the transportation sector is well underway, regardless of actions taken by consumer advocates and utility regulators. However, consumer advocates can play an important role in shaping how this process unfolds, and the extent to which utility customers, including low and moderate income or otherwise disadvantaged customers, are impacted. This chapter outlines two primary approaches that can be employed by consumer advocates to maximize the net benefits from transportation electrification:

1) Optimizing use of the existing grid to minimize costs from EVs on the electric system.
2) Designing transportation electrification programs to promote equitable distribution of the benefits.

The following sections provide examples of policies within each of these two approaches.

3.1. Minimizing costs to the electric system by utilizing excess capacity

Because the electric system is designed to meet the system's single hour of peak demand, a large amount of capacity sits idle most of the year. If transportation electrification results in increased utilization of idle capacity that customers have already paid for, then utility revenues will increase much more than costs, resulting in lower rates for all customers. In contrast, if EVs charge primarily during peak hours, system costs could increase.

Rate design

One of the most powerful tools for managing the timing of EV demand is electric utility rate design. In particular, time-varying rates such as time-of-use (TOU) rates provide price signals that encourage customers to charge during off-peak hours or other hours in which prices are lower. These rates have different prices during on-peak hours and off-peak hours and are meant to align prices more closely with the actual cost to provide electricity during those hours. Data has shown that these rates are very effective in encouraging customers to charge during low-cost times. For example, at Pacific Gas & Electric, 93 percent of charging on the TOU rate for EVs occurs during off-peak or shoulder hours, while at Southern California Edison, 88 percent of charging occurs during the off-peak or shoulder hours.[21] In the data provided by Detroit Edison, 91 percent of charging occurs during the off-peak or shoulder hours.[22] Demand response programs or utility managed charging programs can also be effective at

[21] Synapse Analysis of Joint Utilities Load Research Report, December 2017.

[22] DTE Electric Company, Direct Testimony of Camilo Serna, U-20162, July 6, 2018, p. CS-28

shifting load to off-peak hours, or even to provide grid services that help to integrate renewable resources.

Rate design can also be important for encouraging the adoption of EVs and public charging infrastructure. In addition to reducing costs on the grid, time-varying rates with low off-peak prices can reduce the total cost of vehicle ownership, saving EV customers money and helping to spur additional EV adoption. In contrast, some rate designs such as demand charges can hinder EV adoption.[23]

Demand charges can impose significant costs on charging station vendors and owners of vehicle fleets, resulting in fewer public fast charging stations or reduced fleet electrification. Such consequences may directly impact residents of multi-family housing who rely on public L2 or direct current (DC) fast charging infrastructure, as well as public transit agencies who are seeking to electrify their bus fleets. These concepts are discussed more in section 3.2.

Managing peak demand through smart charging, V2G, and storage

The power consumed by an EV when charging can be significantly higher than typical household appliances. In fact, an EV can double a household's peak demand when charged with a Level 2 charger at approximately 7 kilowatts (kW).[24] Medium- and heavy-duty vehicles are likely to place much higher demand on the system through the use of DC fast chargers.[25] These types of vehicles often charge at a power level of 50 kW, sometimes reaching 350 kW. As technology advances, the power consumed is likely to increase even further. If this charging occurs during circuit or system peaks, costs on the system can increase substantially. To mitigate such costs, utilities can operate smart charging and vehicle-to-grid ("V2G") programs, or deploy energy storage at EV charging locations, as described below:

- Smart charging (also called "managed charging") allows the utility or a third party to shift charging based on grid needs, while also accounting for the vehicle owner's needs. Much like traditional demand response programs, utilities can offer EV owners incentives in exchange for the ability to curtail charging during periods of peak demand (either at the system or circuit level).
- Vehicle-to-grid programs allow vehicles to inject power back into the grid when needed. Such programs can be particularly helpful with providing frequency response and

[23] Demand charges are most commonly used in commercial and industrial rates, but can also be used in residential rates. Such rate designs, particularly when assessed on a non-coincident peak basis, can lead to spikes in bills from EV charging and therefore serve as a strong deterrent to the adoption of EVs. Reducing demand charges or using TOU rates instead can improve EV adoption while still appropriately recovering costs imposed on the grid.

[24] A level 2 charger uses 240 volts (such as a dryer outlet), rather than a 120-volt outlet.

[25] Direct current fast chargers deliver power directly to the vehicle's battery, rather than being first converted to alternating current power. These chargers provide much more power to the vehicle in a short amount of time, allowing customers to "fill up" quickly. DC fast chargers frequently deliver 50 kW of power, but can be as powerful as 350 kW. In the future, we may see even more powerful chargers, particularly for heavy duty vehicles.

integrating variable resources. These programs are currently in their infancy but have the potential to provide substantial benefits to the grid in the future.

- Customer-sited storage can be encouraged as a means for reducing charging station demand, particularly during peak hours. For example, as of April 2019, EVgo had installed 14 battery storage systems at public fast charging locations.[26] Incentives for installing storage at fast charging locations can be explored to determine whether they would be a cost-effective alternative to expanding capacity on the grid.

DC fast charger siting

Available capacity on a utility's distribution system can vary tremendously from circuit to circuit. Siting DC fast charging equipment in less constrained areas of the grid is likely to result in lower distribution system costs for both the charging station provider and for utility customers in general.[27] To reduce costs of building out needed charging infrastructure, utilities should make data regarding system constraints available to charging station developers and include these stakeholders in the planning process so that charging infrastructure is located in areas that optimize the existing assets on the grid.

3.2. Ensuring that all customers benefit from transportation electrification

A key benefit of EVs is that they generally have lower total costs of ownership over the vehicle's lifetime due to lower fuel and maintenance costs. However, these benefits may not be readily available to low and moderate income or otherwise disadvantaged customers. These customers may have different transportation needs and habits that require different policy approaches than those traditionally implemented for other customer segments. These unique needs should be identified through active community engagement and should be considered when designing programs related to transportation electrification. For example, some low and moderate income customers may be more likely to use public transit or ride-hailing services than own vehicles or may have different consumer preferences that factor into the purchase of their vehicles. Other customers may face barriers to transportation access (including geographic barriers), financial barriers (including access to inexpensive vehicle financing), or rules that encumber immigrants or non-English speakers from obtaining a driver's license. Importantly, disadvantaged communities are often disproportionately impacted by local air pollution from transportation corridors.[28] Programs and policies should be designed with these needs in mind.

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[26] EVgo, "EVgo Balances EV Fast Charging With 14 Battery Storage Systems Across 11 EVgo Fast Charging Stations," April 11, 2019, https://www.evgo.com/about/news/evgo-balances-ev-fast-charging-with-14-battery-storage-systems-across-11-evgo-fast-charging-stations/.

[27] Developers of DC fast charging infrastructure are generally required to pay for distribution system upgrades beyond an allowable amount. However, some portion of the distribution system upgrade costs may also be socialized to all ratepayers.

[28] Lara P. Clark, Dylan B. Millet, and Julian D. Marshall, "Changes in Transportation-Related Air Pollution Exposures by Race-Ethnicity and Socioeconomic Status: Outdoor Nitrogen Dioxide in the United States in 2000 and 2010," *Environmental Health Perspectives* 125, no. 9 (14 2017): 097012, https://doi.org/10.1289/EHP959.

EV rebates and incentives

Some utilities offer rebates or other incentives for the purchase of EVs or EV charging equipment. Low- and moderate-income customers have less access to capital and are more likely to purchase a lower-cost new car or a used car. For this reason, rebates offered to customers should be designed to benefit customers who lease EVs (rather than only customers who purchase them), and the incentives should be available for used cars as well as new cars. In addition, low-income customers are less likely to benefit from tax incentives, since these customers are less likely to owe taxes because their income is below the standard deduction or because tax credits offset the taxes they would owe (although leasing vehicles may allow low-income customers to take advantage of EV tax credits, regardless of income level). Thus, up-front rebates can be more beneficial to low-income customers than tax credits. Some states, such as California and Oregon, have developed rebates particularly targeting low-income customers.[29]

Public transit and mobility services

Much of the focus of transportation electrification programs to date has been on light-duty vehicles. However, low and moderate income or otherwise disadvantaged communities are also likely to benefit from programs that electrify public transit and mobility services (such as ride-hailing or car-sharing), depending on the community's particular needs. For example, Lyft reports that 44 percent of rides nation-wide start or end in low-income areas and the median income of riders is 13 percent lower than the national median household income.[30] To determine the optimal investment mix, a community needs assessment should be conducted.[31]

The conversion of public transit buses from diesel to electricity can provide significant local environmental and health benefits to neighborhoods through which buses travel, which are often home to disadvantaged communities, as well as workers who are confronted with diesel exhaust as a matter of their occupations.[32] Utility transportation electrification programs can specifically target these

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[29] National Consumer Law Center (2018). *Principles for Fair and Equitable Investment in Electric Vehicles and Transportation Electrification,* p. 2. See https://cleanvehiclerebate.org/eng and https://www.oregon.gov/deq/aq/programs/Pages/Charge-Ahead-Rebate.aspx for more information on California and Oregon's "Charge Ahead" programs.

[30] Lyft, 2019 Economic Impact Report, available at https://www.lyftimpact.com/stats/national.

[31] See, for example, Portland State University and OPAL. Community-based assessment of Smart Transportation needs in the City of Portland, April 2018, available at http://www.opalpdx.org/wp-content/uploads/2018/05/Community-Assessment-of-Smart-Mobility-OPAL_PSU_Forth-Final.pdf

[32] Racial minorities and low-income households are disproportionately likely to live near a major road in the United States, and more than 140 studies have found higher air pollution exposures for lower-income groups and/or for race-ethnicity minority groups. Clark, L.P., D. B. Millet, and J. D. Marshall (2017). *Changes in transportation-related air pollution exposures by race-ethnicity and socioeconomic status: outdoor nitrogen dioxide in the United States in 2000 and 2010*. Environmental Health Perspectives. See also https://www.osha.gov/SLTC/dieselexhaust/ for information about public health impacts associated with exposure to diesel for construction workers, heavy equipment operators, dockers and longshoremen, truck drivers, farmworkers, and maintenance garage workers .

services through utility make-ready infrastructure investments, transit advisory services,[33] and programs supporting DC fast charging.[34] In addition, closer coordination between consumer advocates, other government agencies (such as departments of transportation or municipal transit agencies), and electric utilities can help to identify potential synergies between transit investments and utility transportation electrification efforts. For example, in 2019 the Federal Transit Administration announced $85 million in grants for low or no emission transit vehicles.[35] Utility transportation electrification programs should be designed to help leverage such sources of external funding, particularly where it will benefit disadvantaged groups. Consumer advocates can help play a leading role in ensuring that such coordination occurs—coordination that utilities should ideally undertake before filing transportation electrification proposals. At a minimum, consumer advocates can highlight the need for coordination with other government agencies prior to regulatory approval of utility EV investments.

Electrification of medium- and heavy-duty vehicles

Electrifying medium- and heavy-duty trucks warrants attention. For example, disadvantaged communities located along freeways or near ports often shoulder a disproportionate amount air pollution burden. Electrifying school buses, heavy trucks, yard trucks in ports, and other large vehicles, or providing charging infrastructure to facilitate electrification, can substantially reduce criteria pollutants in these areas. Pilot projects in California have been designed specifically with these goals in mind.[36]

EV charging options for renters and multi-unit dwellings

Renters and residents of multi-unit dwellings often lack dedicated parking spots or the ability to modify parking areas to install charging ports. Lack of access to charging infrastructure presents a key barrier to EV adoption for these households. To remedy this, additional charging stations will need to be installed to provide access to customers in these market segments.

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[33] See, for example, National Grid's Fleet Advisory Services offered in Rhode Island through its Electric Transportation and Charging Programs: https://www.nationalgridus.com/RI-Business/Energy-Saving-Programs/Electric-Vehicle-Charging-Station-Program; and Portland General Electric's proposal to construct and maintain charging equipment investments (including distribution system upgrades) for public transit operators, who desire such services: Portland Gas and Electric, UM 1811 Transportation Electrification Compliance Filing, February 15, 2019, https://edocs.puc.state.or.us/efdocs/HAD/um1811had151943.pdf.

[34] For example, temporary relief from demand charges can help to support DC fast charging while the market is still relatively undeveloped. While the electrical demand (kW) at these stations is very high, energy use (kWh) tends to be low due to the limited number of EVs on the road today. This means that the demand charges tend to dominate the electricity bills for these stations, undermining the business case for these stations. To address this problem, some utilities have temporarily reduced or eliminated demand charges for customers on EV rates, opting instead to price electricity using TOU rates.

[35] Federal Transit Administration, "Low or No Emission Low-No Program FY 2019 Notice of Funding," Opportunity ID FTA-2019-001-TPM-LowNo, Grant Program Low or No Emission Vehicle Program – 5339(c). Available at: https://www.transit.dot.gov/funding/applying/notices-funding/low-or-no-emission-low-no-program-fy-2019-notice-funding

[36] For a description of many of the projects that California has undertaken, see: https://www.arb.ca.gov/msprog/lct/project-a.htm

Currently, the competitive market is successfully deploying charging stations in many areas where there is demand. However, these charging stations are located where they are most easily and profitably installed, not necessarily where they are most needed to address equity concerns. Thus, it is important that utility investments in charging infrastructure, when proposed, be directed to fill these market gaps and provide access to all customers. In essence, even if there isn't a business case for installing these chargers, there may be a public interest case for ensuring that all customers have access to this service (i.e., in line with historical deployment of electricity distribution infrastructure or telephone infrastructure).

3.3. Equity in rate impacts

If done well, transportation electrification will result in electricity rate reductions for all customers. A rate and bill analysis will help determine whether the additional load from EVs will drive rates down, or whether this effect will be outweighed by higher electric system costs. See section 4.2 for the results of a case study on rate and bill impacts.

Electric utility programs to electrify the transportation sector can influence customer rate impacts in four important ways:

1. The programs can increase EV adoption (which can increase the benefits to customers through exerting downward pressure on rates);
2. Utility programs can increase costs to utility customers (primarily through socialized program costs);
3. Utility programs can influence who benefits and who pays for transportation electrification investments; and
4. Utility programs can influence the time periods in which EV customers charge through time-varying rates or other incentives to charge off-peak, thereby impacting the costs to the grid.

All of these factors should be weighed when evaluating utility programs, as well as the potential health benefits and cost of ownership benefits associated with EV adoption.

To the extent that utility transportation electrification programs are cost-effective and result in greater rate reductions than would otherwise have occurred, these programs will benefit customers overall. In some cases, programs that increase rates but result in significant additional benefits (such as improvements in health) may also be deemed to be in the public interest.

However, there is often substantial uncertainty regarding the benefits of utility EV investments. This uncertainty may include the timing of the benefits as well as the extent to which utility investments or programs drive incremental EV adoption, and thus whether the cost of the program will in fact be outweighed by the benefits from additional electricity sales. This uncertainty does not mean that utility investments in transportation electrification should not be undertaken. Rather, it points to the need to ensure that utility investments to support transportation electrification are implemented carefully, and that additional effort is taken to ensure that investments are directed to the areas where they can improve equity and have the greatest benefit. The following principles can help consumer advocates evaluate utility transportation electrification programs:

- Utility proposals should be reviewed carefully to ensure that utility involvement does not crowd out the competitive service providers, and that utility investments are not redundant with those of competitive service providers. Where possible, utility programs should be designed to support innovation and competitive service providers, such as through the provision of information and advisory services regarding locations on the grid where charging infrastructure would be least costly.

- To the extent that it is available, funding from other sources should be used first in order to prevent such costs from being passed on to utility customers through higher rates.[37] However, there are likely to be cases where utility investment is beneficial. As discussed above, one of the most promising roles for utility transportation electrification expenditures is in underserved markets, such as low-income and multi-unit dwellings. Public utilities can play a major role in promoting the equitable distribution of EV benefits through installing chargers that are accessible to low and moderate income customers, or through providing targeted subsidies or incentives to encourage the market to provide charging stations in underserved areas. Utilities can also play a key role in providing make-ready infrastructure to attract EV charging infrastructure development in areas that would otherwise be too expensive for the market to serve.[38]

- Where rate reductions due to transportation electrification investments are less certain, extra steps can be taken to shield low income customers and other disadvantaged communities from potential rate increases. For example, low-income discounts can be provided so that low-income customers do not shoulder excess costs related to utility EV infrastructure investments.[39] Another option is to make utility cost recovery of investments contingent upon realization of actual benefits to ratepayers.[40]

[37] Philip Jones et al., "The Future of Transportation Electrification: Utility, Industry, and Consumer Perspectives," Future Electric Utility Regulation (Lawrence Berkeley National Laboratory, August 2018), 94, http://eta-publications.lbl.gov/sites/default/files/feur_10_transportation_electrification_final_20180813.pdf.

[38] *Ibid.*

[39] National Consumer Law Center (2018), p.3.

[40] Philip Jones et al., p. 94.

4. Case Study: Quantifying Consumer Costs and Benefits from Transportation Electrification Policies

This chapter summarizes the approach and results of a case study intended to quantify the impacts of increased transportation electrification on a U.S. state. Minnesota was selected for this case study because it has not yet been the subject of a detailed study of the impacts of transportation electrification. In addition, Minnesota exhibits a number of features that make it closely resemble a "typical" state (in terms of electricity generation, electricity consumption, and retail bills). An analysis was conducted for each impact category, including electric system impacts, rate and bill impacts, cost of vehicle ownership, and emissions and health impacts. Though the case study is only for Minnesota, many of the results are applicable to other areas of the country. Following the results, we discuss the transferability of results to other states or jurisdictions in the United States.

To dissect the impacts of different potential futures with transportation electrification, Synapse performed the analyses described above for five scenarios:

1. A Business-As-Usual scenario (BAU) with limited deployment of EVs;
2. A scenario with EV penetration higher than in the BAU, but still at a relatively **low** level;
3. A scenario with **low** penetration of EVs and **TOU** charging[41];
4. A scenario with **high** penetration of EVs; and
5. A scenario with **high** penetration of EVs and **TOU** charging.

Because the primary goal of this case study is to understand the impacts of each of the four EV scenarios relative to what would happen in a future with no policies supporting EV adoption (BAU scenario), the results for each EV scenario are typically presented as deltas from the BAU scenario.

For an illustration of how electric light-duty vehicle (LDV) sales and stock are assumed to increase in each scenario, see Figure 3 (which shows the percentage of new cars sold each year that are EVs) and Figure 4 (which shows the total number of EVs on the road in any given year, as a share of total LDVs).[42] The BAU scenario modeled here is in line U.S. EIA's trajectory of EV adoption in AEO 2019. The "Low"

[41] For the purposes of this study, TOU charging refers to a charging profile where the majority of EV charging occurs in the hours between midnight and 6AM. In all other scenarios, we assume that the majority of charging occurs between 4PM and 2AM (i.e., consistent with customers charging their cars when they arrive home from work or school).

[42] Each scenario also includes some amount of electrification of medium- and heavy-duty vehicles. These trajectories are not depicted here for purposes of simplicity. Note that these trajectories have been revised since the input memo—new research by Synapse now suggests a vehicle lifetime much longer than was previously assumed. As a result, we have reduced the 2030 stock target such that the sales trajectory is in line with moderate and advanced EV projections developed by other organizations, including BNEF, DNV GL, and EPS.

scenario reaches 40 percent EV sales by 2030, which is similar to the business-as-usual forecasts of Bloomberg NEF (BNEF), DNV GL, and Energy Innovation's Energy Policy Simulator (EPS).[43] Finally, the "High" scenario represents a very fast transformation to EVs, featuring substantially higher EV sales adoption than most forecasters project today. Note that there is a significant lag between the penetration of EV *sales* and the penetration of EV *stock*, because of the long turn-over rate of LDVs. Based on data aggregated by the Alliance of Automobile Manufacturers, we assume that about 80 percent of cars last more than 10 years and about 20 percent of cars last more than 20 years.[44]

Figure 3. Light-duty EV sales (vehicles sold each year)

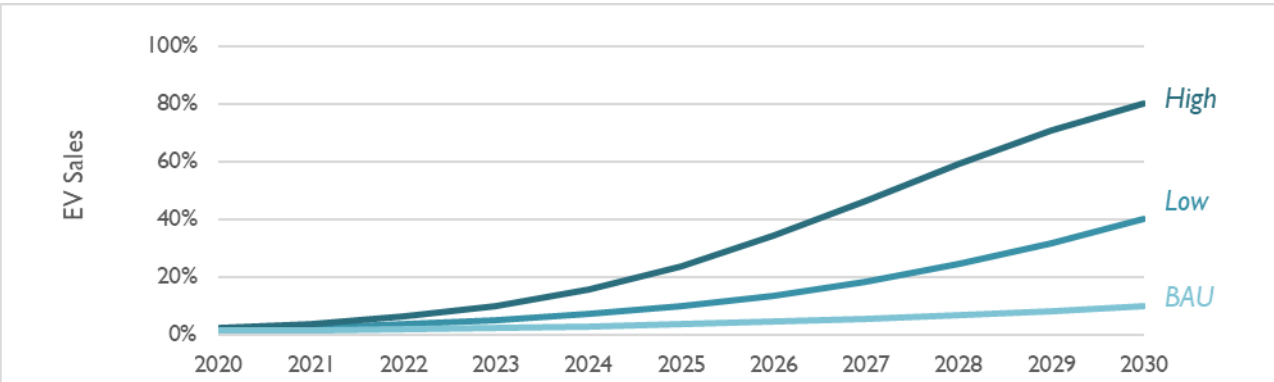
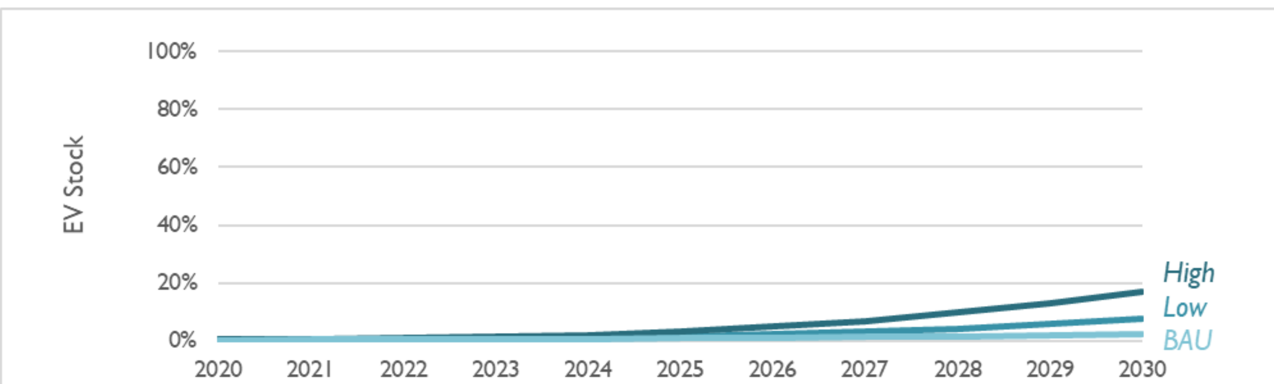


Figure 4. Light-duty EV stock (vehicles on the road)



Total electricity sales are assumed to be the same in the non-TOU and TOU scenarios (i.e., the High Scenario load growth from EVs is assumed to be equivalent to the High-TOU Scenario load growth from EVs), although the hourly load profiles are different.

43 See https://eto.dnvgl.com/2018, https://about.bnef.com/electric-vehicle-outlook/, and https://us.energypolicy.solutions/.

44 Polk, R. L. National Vehicle Population Profile, 1975-2009 (state-level average vehicle age data from Alliance of Automobile Manufacturers).

4.1. Impacts on the electric system

As EVs are added to the electric system and electricity consumption increases, electric generation will also increase. In addition, depending on the existing capacity of the electric system to produce and deliver electricity, and the times of the day that increased levels of EVs require electricity for charging, the electric system may also require an increase in generating capacity and transmission and distribution system expansion.

Modeling approach

In this case study, we utilized several models to project the likely impact of increased levels of EVs on the MISO electricity system.[45] This analysis included developing projections of EV electricity consumption using Synapse's EV-REDI model. To assess the impact that the different scenarios of EVs will have on the future electric grid, Synapse used EnCompass, a production-cost and capacity-expansion model of the electricity sector. This model calculates changes to annual energy prices, capacity prices, generation, and capacity as a result of increased load on the system from EVs for the entire MISO system. See Appendix B for more information on EV-REDI, EnCompass, and various modeling assumptions.

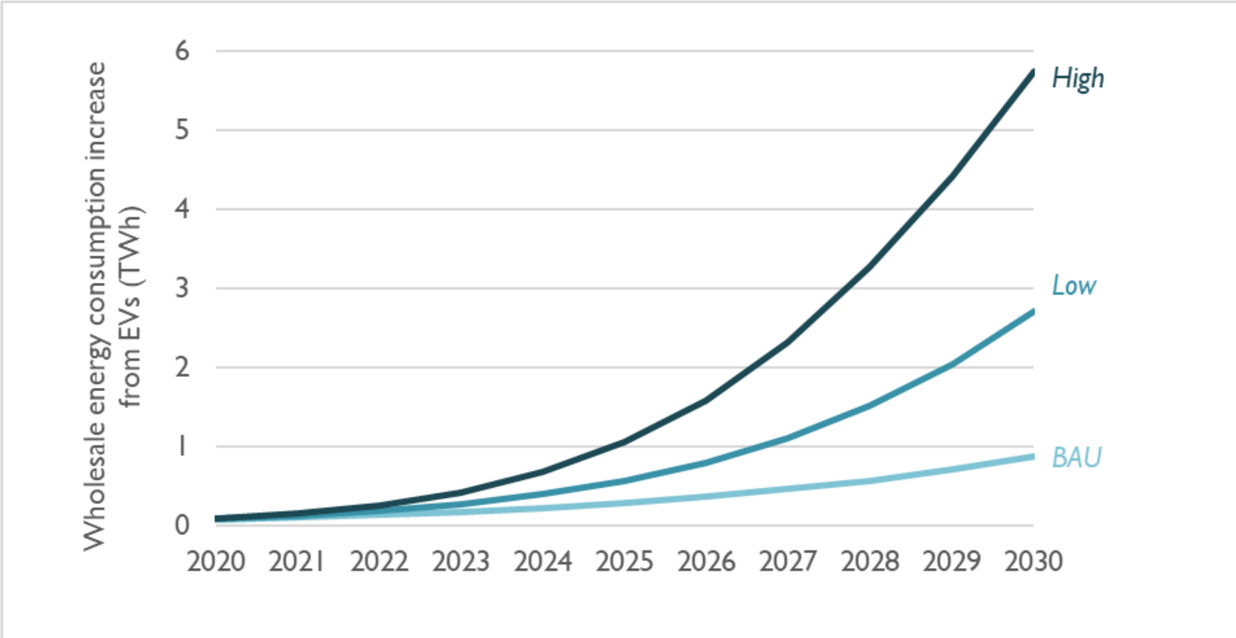
Figure 5 displays the annual impacts on wholesale electricity consumption modeled in each scenario. In the BAU case, we model an increase in 2030 wholesale sales of 0.9 terawatt-hours (TWh), while the Low EV case is roughly three times that value, and the High EV case more than six times that value at 5.7 TWh.

Minnesota is located in an electric load zone with all of North Dakota and parts of Wisconsin and Montana. For the purposes of this analysis, we refer to this load zone as the "Minnesota region." Compared to the scope of the Minnesota region modeled in this project, the High EV scenario in 2030 represents at most a 4.7 percent increase in energy consumption—for the MISO region, this is an increase in load of 0.6 percent.[46] Figure 6 shows the magnitude of EV impact on electricity sales within the modeled region of which Minnesota is a constituent state.

[45] MISO is the independent system operator that manages system reliability and electricity markets for the midwestern United States, including Minnesota.

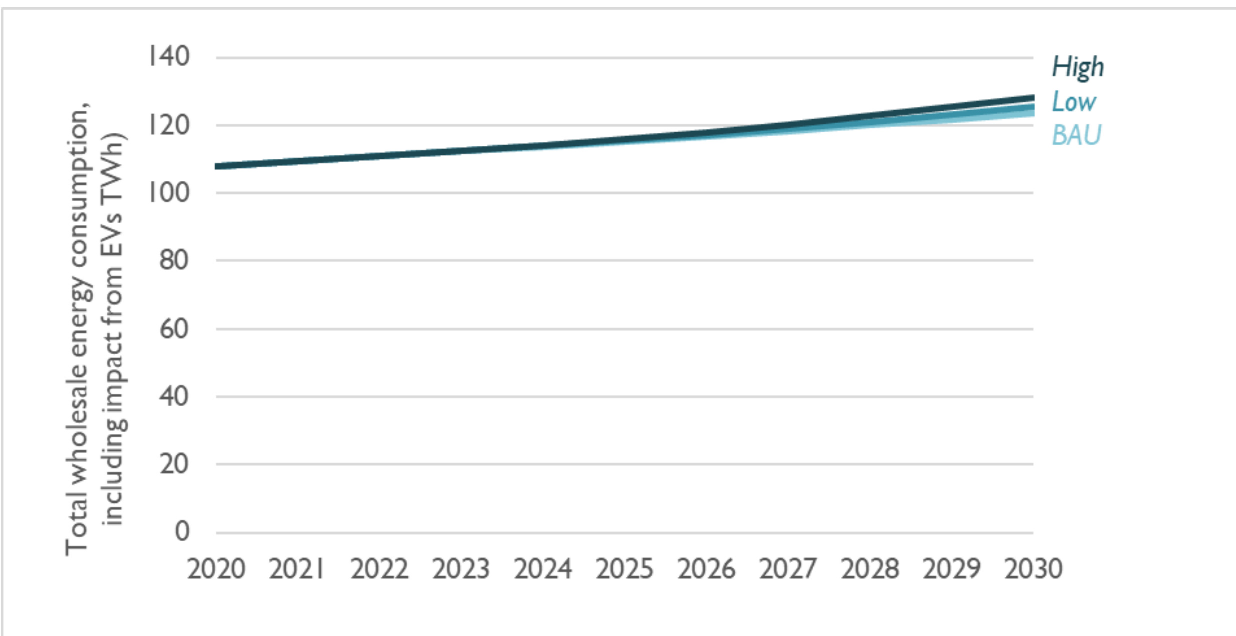
[46] In this analysis, we model regions that align with MISO's load reserve zones (LRZs), which means that Minnesota is modeled as part of a joint region containing both North Dakota and Minnesota. See Appendix B for more information about modeling topology.

Figure 5. Change in wholesale energy consumption due to electric vehicles



Note: This figure includes sales impacts from both LDVs and other vehicle types.

Figure 6. Total wholesale energy consumption for modeled Minnesota region, inclusive of electric vehicle impacts



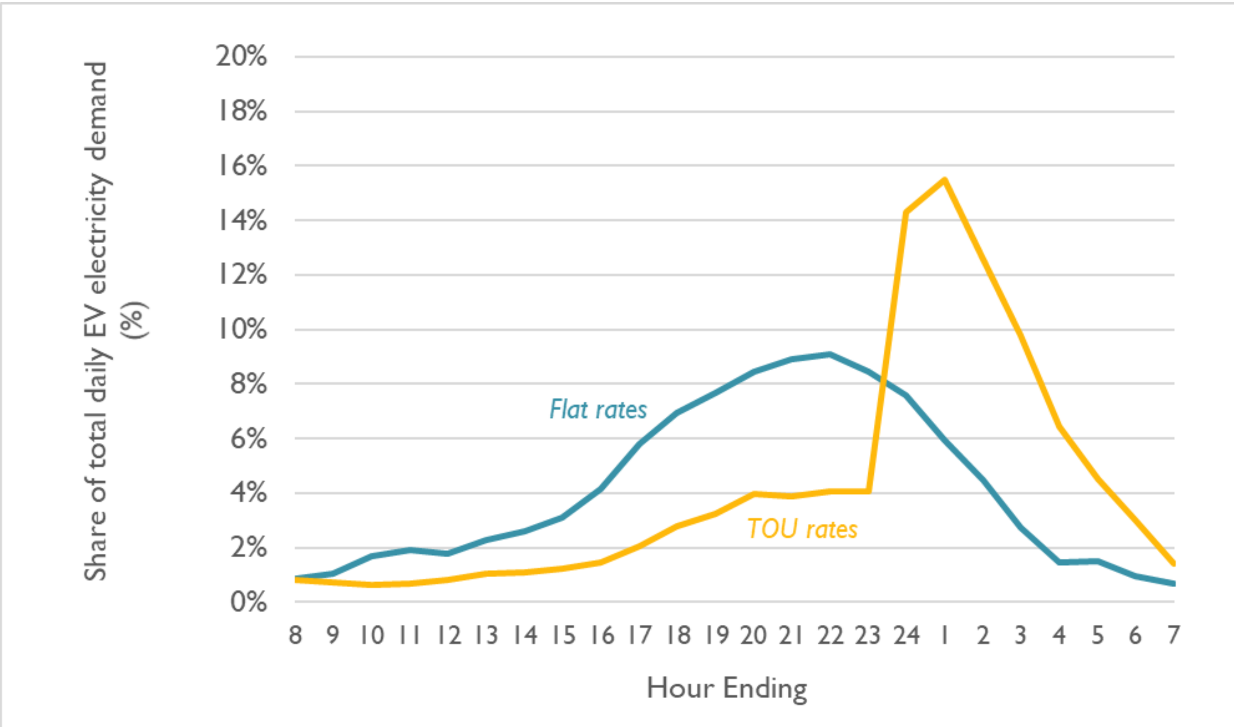
Note: This figure includes sales impacts from both LDVs and other vehicle types.

EV charging profiles

EV customers on flat and time-varying rates have differing charging patterns, with research showing that those on time-varying rates shift more of their usage to off-peak hours. The timing of EV charging can have significant implications for costs imposed by EV drivers on the system.

We used the charging profiles from Detroit Edison's EV charging pilot to represent the expected charging profiles for EV customers.[47] These charging profiles are shown in Figure 7.

Figure 7. Electric vehicle charging profiles for TOU and flat electricity rates



Source: Adapted from DTE Electric Company, Direct Testimony of Camilo Serna, U-20162, July 6, 2018
Note: In DTE's analysis, 9AM until 11PM were assumed to be "on peak" hours.

For non-light duty vehicles (e.g., buses, heavy-duty vehicles, and medium-duty vehicles), Synapse assumed a charging profile in line with the "flat rates" profile shown in Figure 7 for all scenarios.[48]

Capacity builds and retirements

In the BAU case, solar dominates the buildout of new capacity through 2030, with 62.8 gigawatts (GW) of new utility-scale and distributed solar built in MISO between 2020 and 2030 (see Table 1). This is

[47] DTE Electric Company, Direct Testimony of Camilo Serna, U-20162, July 6, 2018, p. CS-28

[48] In reality, charging profiles for fleet and heavy-duty vehicles are highly dependent on how these vehicles are used. For example, a charging profile for electric school buses is likely very different from the charging profiles for parcel delivery electric vehicles or long-haul trucks. Further, these loads may be less sensitive to TOU pricing, as their business depends on the vehicle operating when needed, with little flexibility in scheduling.

primarily because the cost to build solar in the later model years is cheaper than all other resources, rather than for reasons of compliance with state-specific renewable requirements (such as Minnesota's renewable portfolio standard).[49] The BAU case also produces limited buildout of natural gas combined cycle units (8.5 GW between 2020 and 2030).[50] In the BAU case, we observe substantial retirements of older gas steam plants and coal plants during this same time period (23.6 GW between 2020 and 2030). In the Minnesota region (modeled as a combined region containing both Minnesota and North Dakota, referred to here as MN-ND), we observe directionally similar results for each resource type.

Table 1. Capacity additions and retirements in the BAU case, 2020 to 2030, compared to total 2030 capacity (GW)

	Solar	Wind	NGCC	Coal and gas steam	Nuclear	Other	Total Change	2030 total capacity
MISO	66.8	0.6	8.5	-23.6	-1.8	-0.1	50.4	237.1
MN-ND Region	3.7	0.4	0.7	-3.4	0.0	-0.1	1.4	25.5

Note: "Solar" includes both utility-scale and distributed solar. "Other" includes hydro, biomass, landfill gas, and other miscellaneous resources.

Because the EV scenarios represent at most a 4.7 percent increase in electricity consumption for the MN-ND region (and a 0.6 percent increase in load for MISO as a whole), they have minimal impacts on capacity builds on a relative basis, even in the scenarios with high levels of EV adoption. In 2030, the four EV scenarios feature capacity changes (relative to the BAU) varying between 0.3 and 2.5 GW in the MN-ND region. In most cases, this includes 0.5-2 GW of natural gas combined cycle capacity, as well as 0.2 to 0.4 GW of solar capacity (see Table 2).[51]

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[49] Note that our modeling assesses two 24-hour periods for a representative weekend and weekday, for each month and year of the analysis period. As a result, this analysis takes into account system reliability requirements (i.e., such as ramping, or the ability of the system to meet electricity demand during nighttime periods).

[50] While not selected by the model in any scenarios analyzed here, it is possible that less expensive battery storage could supplant increased capacity builds from natural gas resources, producing a scenario entirely lacking in incremental fossil capacity.

[51] Note that values for 2030 do not always yield directionally consistent results—for example, while the high EV cases produce greater capacity additions than the low EV cases, we observe more capacity added in the High EV Flat case than in the High EV TOU case. The reverse is true in the Low EV cases. This is most likely due to the relatively minor changes to load associated with EVs causing resource additions and retirements to be advanced—or deferred—by a year.

Table 2. 2030 capacity additions and retirements in each EV case, compared to 2030 BAU capacity (GW)

	Solar	Wind	NGCC	Coal and gas steam	Nuclear	Other	Total Change	2030 total capacity
Low EV Flat	0.3	0.0	0.0	0.0	0.0	0.0	0.3	25.8
Low EV TOU	0.2	0.0	0.7	0.0	0.0	0.0	0.9	26.4
High EV Flat	0.4	0.0	2.1	0.0	0.0	0.0	2.5	28.0
High EV TOU	0.3	0.0	0.7	0.0	0.0	0.0	1.0	26.6

Note: "Solar" includes both utility-scale and distributed solar. "Other" includes hydro, biomass, landfill gas, and other miscellaneous resources.

Generation changes

For the BAU case, on a MISO-wide basis, changes in generation are largely in line with changes to capacity (see Table 3). We observe an 2020-2030 increase in solar generation of 125.8 TWh, and an increase in generation from natural gas combined cycle units of 19.6 TWh. At the same time, we observe a decrease in generation from coal and gas steam units of about 54 TWh, and a reduction in generation from nuclear units of about 13 TWh.[52]

Table 3. Changes in generation and imports in the BAU case, 2020 to 2030 (TWh)

	Solar	Wind	NGCC	Coal and gas steam	Nuclear	Other	Total Change	2030 total energy
MISO	125.8	4.0	19.6	-53.8	-12.7	81.0	163.9	788.6
MN-ND Region	7.0	2.0	2.9	-7.8	-0.5	12.4	16.1	123.4

Note: "Solar" includes both utility-scale and distributed solar. "Other" includes hydro, biomass, landfill gas, net imports, and other miscellaneous resources.

Table 4 displays the changes in generation in each EV case. In all cases, incremental generation matches incremental wholesale load from EVs. Resource-specific and case-specific results closely resemble the trends observed in Table 2, with most incremental generation coming from solar and natural gas combined cycle (NGCC) plants. In the High EV cases, we also observe a small increase in older coal and gas steam generation, relative to the BAU case.[53]

[52] In most cases, by 2030, increased levels of EVs yield increases in natural gas or coal generation ranging from 1 to 5 TWh. In certain scenarios, we observe a minor decrease in solar generation consistent with the trends observed for capacity. However, even at their peak (i.e., in the Low TOU EV case in 2030), these decreases represent less than 0.2 percent of regional annual demand for electricity.

[53] Note that in the High EV Flat case, a substantially higher amount of electricity is produced by NGCCs (relative to the other cases) and less from net imports (grouped in the "Other" category). This artifact is a result of a swap between two very similar NGCC power plants, one located in the MN-ND region and another in a nearby MISO load zone.

Table 4. 2030 generation changes in each EV case, compared to 2030 BAU generation (TWh)

	Solar	Wind	NGCC	Coal and gas steam	Nuclear	Other	Total Change	2030 total capacity
Low EV Flat	0.5	0.0	0.4	0.1	0.0	0.7	1.8	125.3
Low EV TOU	0.3	0.0	4.1	0.1	0.0	-2.7	1.8	125.3
High EV Flat	0.7	0.0	11.6	0.2	0.0	-7.7	4.9	128.3
High EV TOU	0.6	0.0	4.5	0.2	0.0	-0.5	4.9	128.3

Note: "Solar" includes both utility-scale and distributed solar. "Other" includes hydro, biomass, landfill gas, net imports, and other miscellaneous resources.

We note that because adoption of EVs is likely to be non-linear, and because vehicle lifetimes are long, substantial increases in load (e.g., greater than 5 percent) could occur from vehicle electrification, although probably not before 2030. In addition, our analysis models a vehicle electrification within a single state—our findings could be different were we to model substantial vehicle electrification across the entire region; although costs to customers in Minnesota would likely remain relatively consistent (see the following section).

4.2. Rate and bill impacts

One of the most important concerns for consumer advocates is the impact that widespread electric vehicle adoption could have on electric rates and customer bills.

Modeling approach

To determine the rate and bill impacts to non-EV owners, Synapse developed a rate and bill impact model for Minnesota. The model estimates the total costs to the utility for generation, transmission, and distribution, as described in more detail in Appendix B.[54] To estimate average electricity rates for each class, we used the simplifying assumption that total costs are equal to the utility's revenue requirement in each year, and then divided the revenue requirement by the total load on the system to yield the new electric rate.[55]

New EV load means greater electricity sales, which should push down average rates as long as the marginal costs of serving additional load are lower than the average embedded costs. In other words, as

[54] Synapse based its central estimates of the T&D system costs associated with incremental EV load on marginal cost and avoided costs studies conducted by Minnesota's largest utilities.

[55] For all scenarios, we first subtracted the expected revenue from the scenario incremental EV load from the total scenario revenue requirement, and then divided the remaining revenue requirement by the remaining load to derive the effective average volumetric rate – an approach that is akin to assuming an annual "true-up" in rates, such as through a revenue decoupling mechanism. In reality, this true-up would likely be one year delayed. Note that the remaining load used to derive the effective average volumetric rate includes some residual EV load – the same quantity as in the base case. Since this analysis focuses on the impact of incremental electrification above what would be otherwise be expected without any interventions, removing this residual EV load from the denominator would be inconsistent with the aim of the analysis.

long as there is available capacity on the system, or system upgrades can be undertaken relatively inexpensively, the costs to serve additional load from EVs will be less than the electricity rates that EV customers pay. This difference is referred to as the "contribution to margin."

However, EVs may also increase demand during peak hours, requiring more expensive generation units to run more, or requiring capacity investments at the generation, transmission, and distribution level, potentially driving up costs for electricity consumers. The magnitude of these costs is dependent on two factors: (1) the extent to which EV load increases peak energy consumption, and (2) local system conditions, particularly the availability of excess capacity and the cost to add additional capacity.

The degree to which EV load increases peak demand is determined by the charging profiles of new EV load. Implementation of time-varying rates and demand response programs can help reduce on-peak charging load. To test the extent to which rate design could mitigate cost increases, we modeled two separate charging patterns for residential customers: one with TOU rates and one with flat rates (see section 4.1, above, for more information on the charging patterns assumed). In the TOU scenarios, the majority of charging takes place during off-peak hours, while the non-TOU scenario provides no incentive for off-peak charging, resulting in the majority of charging load occurring during the early evening on-peak hours. We did not model TOU rates for commercial and industrial (C&I) customers, as we assumed that these medium- and heavy-duty vehicles would be less responsive to TOU rates due to operational requirements, such as the need to deliver packages during business hours.[56] We also assumed that the public charging stations on a C&I rate would not charge their customers based on a time-differentiated rate[57] or that these customers would be less sensitive to a time-differentiated rate due to the need to fuel-up en route to their final destination. Therefore, EV load for charging stations on C&I rates was assumed to occur primarily during on-peak hours.

The different charging patterns for light-duty EV load under the TOU and flat rate scenarios result in different energy costs and produce different T&D marginal costs. EV load also imposes greater generation capacity costs on the system under the flat rate scenarios than under corresponding TOU cases.[58] For example, under the High EV TOU scenario, we estimated that in 2030, EV residential customers would impose 10 percent lower costs on the system than under the High EV flat rate scenario.

The second key determinant of costs that EVs impose on the system is related to the local conditions. In particular, the availability of excess capacity on the system and the cost to add additional capacity can

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[56] Note that while C&I scenarios all assume a flat rate structure, results are sensitive to the assumed rate structure for light-duty vehicles under the residential tariff. Assuming a TOU structure for new light-duty EV load increases ratepayer benefits resulting from new C&I EV load.

[57] Very few public charging stations currently charge EV drivers a price that varies by time of day. Instead, customers typically pay by the minute.

[58] Increased costs for transmission and distribution upgrades were based on utilities' marginal cost estimates and were socialized across the entire rate class in both the residential and C&I scenarios. Note that these marginal rates are understood to apply even for small changes in load, such as those associated with a single EV.

vary from jurisdiction to jurisdiction. For example, in dense urban areas, the cost to add additional distribution and transmission capacity might be very high due to transmission congestion and the high cost of land. In other areas, total energy load may be falling, leading to large quantities of underutilized capacity. For this reason, we conducted a sensitivity in which we used much higher marginal T&D costs from California, rather than the relatively low marginal T&D costs from Minnesota utilities.

In addition to the general T&D costs imposed on the system, we recognized that many high-power or multi-port charging stations would require line extensions and other local distribution system upgrades. Such costs are often partly borne by the customer and partly socialized among existing utility customers. For example, Xcel Minnesota currently provides a line extension credit equal to approximately three times the anticipated annual revenue resulting from the additional service.[59] Consistent with Minnesota utilities' practice, we assumed that additional distribution costs (beyond those associated with the marginal cost estimates mentioned above) equal to three years of revenue for each new C&I customer would be imposed on the entire customer class. This estimate may overstate the costs that would be borne by other customers, as this is the maximum that would be imposed on non-EV customers, and some charging stations may require very little additional infrastructure.[60] Therefore, we also ran a sensitivity in which the EV customers were assumed to pay for all of the additional line extension costs, with none of those costs being socialized to other customers.

On the other side of the ledger, we also accounted for the fact that EV customers will contribute different amounts of revenue based on their respective rates. EV customers impose marginal costs on the system, but they typically pay electricity rates that are based on average system costs. These average costs can be calculated as the average across the year, or for TOU rates, they are calculated as the average within a certain time period (such as during the on-peak or off-peak windows). When the marginal costs associated with serving EV load are less than the average cost of electricity, it results in EV drivers contributing more in revenues than the costs they are imposing on the system. This is what exerts downward pressure on rates.

Customers on TOU rates who charge primarily off-peak will generally pay less than customers on a flat rate. Thus, the TOU scenarios result in lower costs imposed on the system, but also lower revenues. It is

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[59] Minnesota Electric Rate Book – MPUC No. 2, Section 6, Sheet No. 26, effective February 1, 2017. The line extension credit is set to 3.5 times "the anticipated annual revenue, excluding the portion of the revenue representing fuel cost recovery from the sale of additional service to result there from…". We estimate that this is close to 3 times the average revenue including fuel costs. Similarly, Minnesota Power requires the customer to pay for line extension costs in excess of three times the customer's guaranteed annual revenues. *See:* Minnesota Power, Electric Rate Book – Volume I, Section VI, Page No. 4.2, Revision 15, effective June 18, 2018.

[60] We note that effective rate design may mitigate against the imposition of new system costs by C&I EV load, especially as medium and heavy-duty electric vehicle range improves. While this analysis assumes that C&I EV load is likely to exhibit an inelastic demand for energy, and thus unlikely to be influenced in its charging behavior by time-differentiated rates, increasing vehicle range may strengthen the role for price signals to shift C&I charging to less-constrained times. An example of time-differentiated rates for C&I customers is seen in California, where, effective in 2019, Southern California Edison offers three TOU rates for EVs in its industrial tariff, differentiated by customer peak load. TOU-EV-9, for the highest demand EV charging customers – with loads exceeding 500 kW – imposes elevated rates only between 4 pm – 9 pm. See Southern California Edison "Schedule TOU-EV-9."

unclear whether the contribution to margin will be greatest for TOU customers or for customers on a flat rate, and the result can change based on the specific design of the TOU rate. We therefore conducted a sensitivity with a somewhat lower peak to off-peak price ratio (which has a higher off-peak rate).

Results

Table 5 summarizes the estimated average annual impacts on electric rates for the residential and C&I classes for the study period 2019 - 2030. In nearly all scenarios, EV adoption results in lower rates than in the BAU scenario. The rate reduction is relatively modest when averaged across the study period, but by 2030 these rate impacts are much larger. The 2030 rate reduction relative to the BAU ranges from 4 and 6 percent for the High EV scenarios and 2 and 4 percent for the Low EV scenarios.

Table 5. Average rate impacts 2019-2030, relative to BAU

		Low EV	Low EV & TOU	High EV	High EV & TOU
Residential	*2018 $/kWh*	($0.001)	($0.001)	($0.002)	($0.002)
	%	-0.5%	-0.4%	-1.7%	-1.1%
C&I	*2018 $/kWh*	$0.000	$0.000	$0.000	-$0.001
	%	0.1%	-0.3%	-0.1%	-0.5%

Sensitivity results

We also evaluated three sensitivities. We tested the impacts of higher TOU rates for EV load; higher, marginal T&D system costs; and no credits for C&I distribution system upgrades to accommodate charging stations.

Alternative TOU rate sensitivity

We evaluated an alternative TOU rate for the residential models as a sensitivity. In the initial TOU scenarios we used a TOU rate with an off-peak price of $0.07/kWh and an on-peak price of $0.35/kWh. In the alternative TOU sensitivity, we used a rate structure with a lower peak to off-peak price ratio of $0.10/kWh for off-peak energy and $0.34/kWh for on-peak energy. (These alternative rates were designed to be revenue neutral based on a typical residential load shape.)

Because residential EV customers are expected to charge primarily off peak on TOU rates, increasing the off-peak rate results in even greater rate reductions for the residential class. Under the alternative TOU scenario, the average annual rate reduction is -0.7% in the Low EV TOU scenario and -1.8% in the High TOU EV scenario, reltaive to the BAU. This results in the alternative TOU sensitivities providing greater rate reductions than under flat rates or the initial TOU rates. However, we did not examine whether higher off-peak electricity rates would dampen customers' willingness to adopt EVs. This should be considered when making any rate modifications.

Figure 8. Alternative TOU rates sensitivity

	Low EV	Low EV & TOU	Sensitivity: Low EV & Alt TOU	High EV	High EV & TOU	Sensitivity: High EV & Alt TOU
Residential	-0.5%	-0.4%	-0.7%	-1.7%	-1.1%	-1.8%

Higher T&D cost sensitivity

The cost of upgrading the transmission and distribution system to accommodate additional EV load can vary substantially from jurisdiction to jurisdiction. We therefore conducted a senstivity analysis using the time-differentiated marginal T&D costs of Pacific Gas and Electric (PG&E) in California rather than the original ones that were derived from utilities in Minnesota. PG&E's marginal T&D costs are much higher than those reported by the Minnesota utilities, and thus the use of these marginal costs increases the costs imposed by EVs.

As expected, increasing the marginal T&D costs to the levels of PG&E (while keeping the rates paid by EV customers at Minnesota levels) increases the cost associated with integrating EVs. The table below contrasts the rate impacts using Minnesota T&D costs to the rate impacts using PG&E's T&D costs. The results show that the residential class still experiences rate reductions, while the C&I class experiences limited rate increases.

Table 6. Alternative T&D sensitivity, average rate impact 2019-2030

		Low EV	Low EV & TOU	High EV	High EV & TOU
Residential	*MN T&D Costs*	-0.5%	-0.4%	-1.7%	-1.1%
	PG&E T&D Costs	-0.1%	-0.1%	-0.7%	-0.2%
C&I	*MN T&D Costs*	0.1%	-0.3%	-0.1%	-0.5%
	PG&E T&D Costs	0.3%	-0.1%	0.4%	0.0%

No line extension credit sensitivity

Finally, we conducted a sensitivity specific to the C&I scenarios, to examine the impact of our assumption that new EVs would impose integration costs equal to three years of revenue due to the utilities' policies of granting line extension credits to new customers. If the costs of integrating new EV charging equipment is less than three years of revenue, or if utility policy changes such that a greater share of the costs are borne by the customer adding the charging equipment, then we would expect the cost impact on C&I customers to be much less.

In this sensitivity, we assume that line extension credits are not provided to new EV customers. We also assume a flat rate structure for residential EV load. Not surprisingly, our modeling shows that the upward pressure on rates associated with incremental C&I load is slightly reduced when socialization of T&D costs is largely removed from the equation. In the sensitivity, annual rate impacts average between -0.1 percent and -0.5 percent relative to the BAU for the C&I rate class. However, we did not examine whether not providing line extension credits would reduce customers' willingness to adopt EVs. This effect should be examined when considering line extension credit policies.

Table 7. Sensitivity analysis of line extension costs, average rate impact 2019-2030

		Low EV	High EV
C&I	*Integration Costs Equal to Three Years of Revenue*	0.1%	-0.1%
	Sensitivity: No Integration Costs Imposed on Class	-0.1%	-0.5%

Contribution to margin

Over the study period, the cumulative contribution to margin (i.e., the revenues provided by EV customers in excess of costs) across customer classes is positive in all scenarios, and greatest in the scenarios with High EV adoption (see Table 8). This suggests that increased adoption of EVs will have a beneficial impact on rates. The cumulative contribution to margin over the study period ranges from $158 million in the Low EV Flat Rates scenario to $852 million in the scenario with high EV adoption and alternative TOU rates. (The alternative TOU rates represent the TOU rates tested in the sensitivity analysis, with slightly higher off-peak prices.)

Table 8. Sensitivity analysis of contribution to margin, average 2019-2030

	Low EV Flat Rates	Low EV TOU Rates	Low EV Alt. TOU Rates	High EV Flat Rates	High EV TOU Rates	High EV Alt. TOU Rates
Residential	$189 million	$178 million	$269 million	$674 million	$448 million	$703 million
C&I	-$31 million	$87 million	$87 million	$29 million	$149 million	$149 million
TOTAL	**$158 million**	**$265 million**	**$356 million**	**$703 million**	**$597 million**	**$852 million**

Rate impacts by year

The rate impacts and contribution to margin are not felt evenly across the study period – they are primarily related to high levels of EV penetration in the latter years. The modeled rates for each scenario over the entire study period are shown in Figure 9 and Figure 10, below. Note that Figure 10 assumes a flat rate structure for residential EV load.

Figure 9. Residential rates 2019-2030

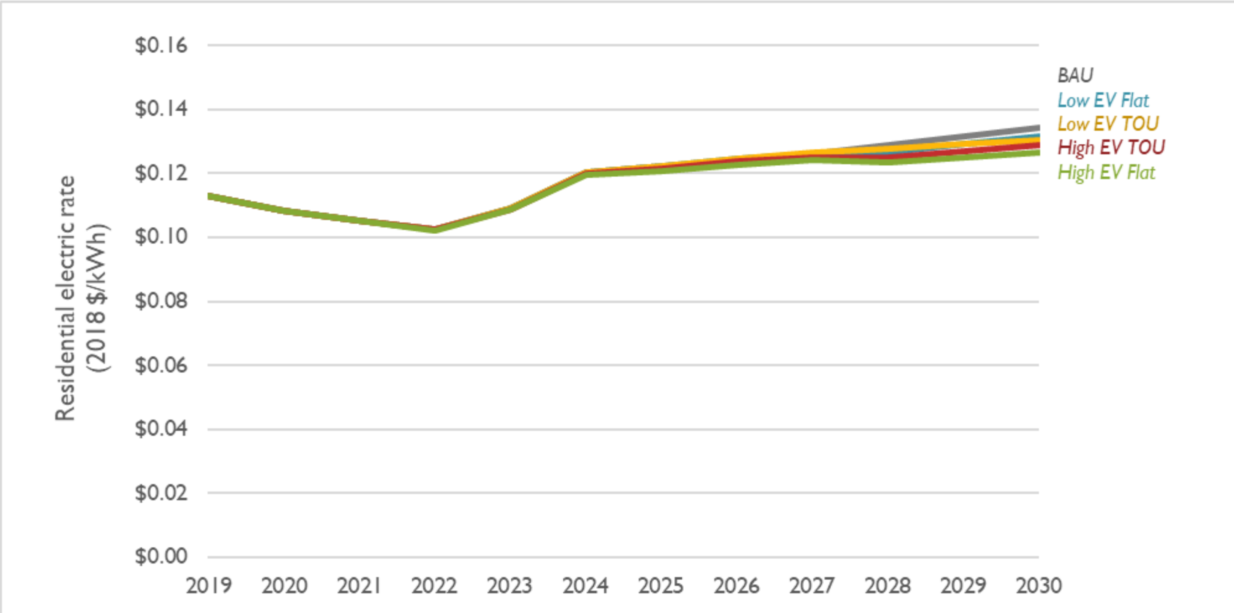
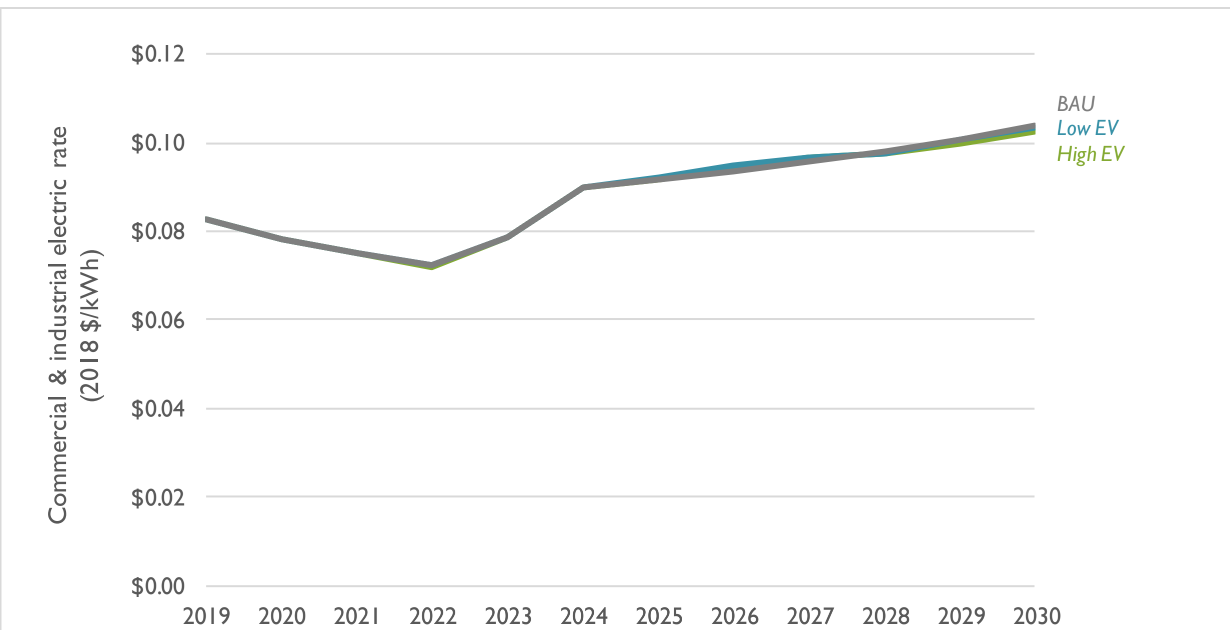


Figure 10. C&I rates 2019-2030



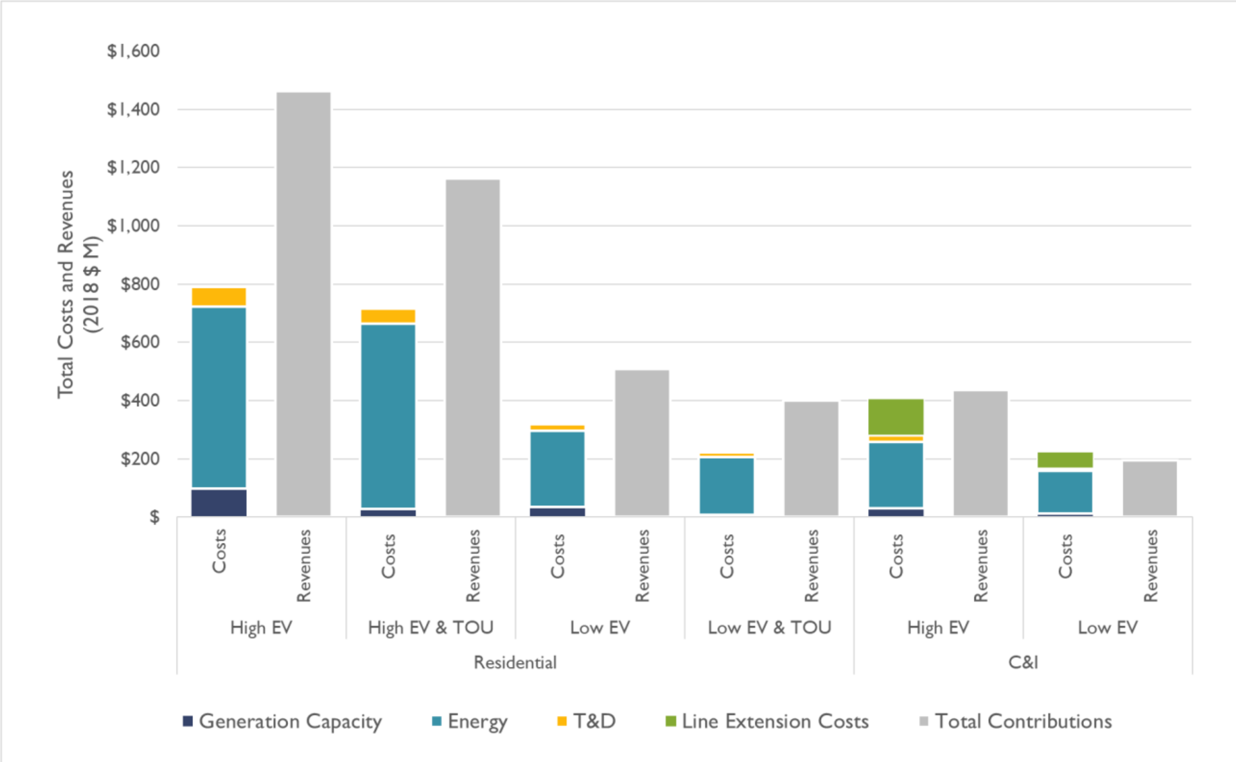
Discussion of rate impact results

There are several key factors influencing these results:

1) The positive contributions to margin indicate that EV customers are generally paying rates that are greater than the marginal costs that they impose on the system. This is particularly true in the scenario that tests alternative TOU rates.
2) The impacts on C&I rates are influenced by the assumption that EV charging in this category will mostly occur on-peak using high-power fast charging infrastructure, which results in higher marginal costs imposed on the system. Time-varying rates, smart charging programs, incentives for behind-the-meter storage, or other utility programs could mitigate these costs, as described in Section 3.1. Consumer advocates can play an important role in ensuring such programs are implemented to reduce peak demand.
3) C&I rate results also reflect the assumption that line extension costs equal to three years of EV revenues are being imposed on all C&I customers. These costs are particularly high in the latter years when large quantities of EVs (and associated charging stations) are being added to the system.
4) Total costs are lower in the TOU scenarios relative to the flat rate scenarios, since EVs are charging less during on-peak hours under TOU rates. However, revenues contributed by EVs are also lower in the TOU scenarios, due to low off-peak rates. In the Low EV scenarios, the TOU rate yields the greatest benefits, while in the High EV scenarios, the flat rate provides greater benefits. The fact that there is not a linear relationship between costs and revenues is related to fluctuations in energy market prices from year to year and the fact that capacity additions are lumpy. We do not expect that this outcome would necessarily continue to hold in later years or in other jurisdictions. However, it does highlight the need to periodically recalibrate TOU rates to ensure that they are reflective of actual costs.
5) The modeled costs do not include any utility program costs, such as utility EV incentives, installation of charging stations, or make-ready infrastructure beyond the cost of general system upgrades (such as substation expansion or feeder reconductoring) and the line extension credits extended to EV customers. Any utility EV programs would increase the costs of integrating EV load. However, utility EV programs could potentially also increase the rate of EV adoption, thereby increasing revenue from EVs. The benefits and costs of such programs should be weighed carefully to ensure that the costs do not outweigh the potential benefits. In this case study, the results show that there is some room to implement utility EV programs in the residential sector without increasing rates above the BAU.

Figure 11 illustrates the modeled costs that EVs could impose on the generation, transmission, and distribution systems in each of the scenarios, compared with the expected revenues that this new load could provide. These values represent cumulative totals over the period of 2019 through 2030. As shown in the figure, the majority of costs are related to energy and generation capacity. In all residential scenarios and the High EV C&I scenario, the revenues from EV load outweigh the additional costs on the system during the study period. In the Low EV C&I scenario, costs exceed revenues during the study period. Note that C&I scenarios assume a flat rate structure for residential EV load.

Figure 11. Total costs and contributions of incremental EV load, 2019-2030



To help put the above rate impacts into context, we also calculated annual bill impacts for utility customers who do not own an EV.[61] Similar to the rate impacts above, all four residential scenarios yield reduced annual electric bills for non-EV utility customers, relative to the BAU.[62] The High EV Scenario yields the greatest benefit to residential utility customers, with an average annual electricity savings of $71 in 2030. In the Low EV Scenario, an average residential utility customer would save about $25 on annual electricity bills in 2030.

We do not provide average bill impacts for C&I customers due to the great variation C&I rate structures, customer load, and corresponding bills. There simply is no "average" commercial or industrial customer and thus no clear average bill impact to report. Nonetheless, bill impacts may generally be expected to

[61] Benefits to residential EV owners across the scenarios follow a pattern similar as those accruing to residential customers without EVs. EV owners do worst in the Low Scenario and best in both TOU scenarios, which by construction feature the same rates for EV owners.

[62] To estimate the average bill impact for residential customers without EVs, we divided the total load not associated with incremental EV energy consumption by the total number of customers without EVs, and then multiplied by the effective average volumetric rate for each scenario.

track the rate impacts provided previously. Relative to the BAU, C&I customers should expect to see modest increases in rates in most cases.

4.3. Total cost of ownership analysis

The total cost of ownership model developed by Synapse compares the lifetime costs of an ICE vehicle to those of an EV, considering upfront costs and incentives, insurance costs, fuel and/or electricity costs, and O&M costs. For fuel costs, the model incorporates projected increases in gasoline and diesel prices and projected electricity rates from the rate and bill impact analysis (described above).

For this analysis, Synapse calculated the total cost of ownership for a standard car, an SUV, and a transit bus—both in internal combustion engine and battery electric vehicle form—for a total of six vehicle types.[63] In other words, our analysis does not compare specific models of vehicles against one another; instead, we assess total cost of ownership within specific vehicle classes.

Table 9 compares the total cost of ownership for these vehicles, assuming that ownership begins in 2020. It presents the difference between the total cost of ownership of an EV and the total cost of ownership of an equivalent ICE. Table 10 provides the same data, assuming that ownership begins in 2030. We find that across all scenarios, the total cost of ownership of a 2020 EV car, EV SUV, and EV bus and a 2030 EV car, EV SUV, and EV bus is less than the total cost of ownership of their ICE counterparts.

While the upfront costs of EVs are generally higher than the upfront costs of ICEs, the O&M and fuel costs associated with EVs are consistently lower than those associated with ICE vehicles (see Appendix C for a detailed comparison of vehicle cost components). This, combined with higher resale values and the EV tax credit, makes it such that electric cars and SUVs have a lower total cost of ownership than ICE cars and SUVs in both 2020 and 2030.[64] See Figure 12 and Figure 13 below for more detail on the impact of the EV tax credit.

Importantly, the upfront cost of EVs is one of the main drivers in determining the breakeven point of cost-of-ownership. As battery technology rapidly improves leading to cost declines, EVs may prove to be even more favorable than their equivalent ICE vehicles than estimated in this analysis. Another important component is the availability of charging infrastructure and the cost of installing additional infrastructure. This is particularly the case for heavy-duty vehicles, such as buses, which require high-capacity chargers and may impose large distribution system upgrade costs on customers.

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[63] For detailed assumptions on the selected ICE and battery electric vehicle types, see Appendix B: Modeling Assumptions.

[64] For more detailed versions of these tables, including the total cost of ownership values of EVs and ICE vehicles, see Appendix C: Total cost of ownership, detailed results.

Table 9. Difference between the total cost of ownership for EVs vs. ICE vehicles, 2020 (2018 dollars)

	BAU	Low EV	Low EV & TOU	High EV	High EV & TOU
Car	-$5,500	-$5,000	-$5,500	-$5,000	-$5,500
SUV	-$7,200	-$6,200	-$7,200	-$6,200	-$7,200
Bus	-$78,400	-$57,100	-$77,900	-$57,200	-$78,400

Table 10. Difference between the total cost of ownership for EVs vs. ICE vehicles, 2030 (2018 dollars)

	BAU	Low EV	Low EV & TOU	High EV	High EV & TOU
Car	-$3,700	-$3,100	-$3,600	-$3,100	-$3,700
SUV	-$7,000	-$5,900	-$7,000	-$6,000	-$7,000
Bus	-$139,300	-$114,500	-$137,600	-$116,900	-$139,300

Figure 12, Figure 13, and Figure 14 demonstrate how the savings associated with an EV change over time for the three different vehicle types. These figures show the difference between the total cost of ownership of an EV and the total cost of ownership of an ICE vehicle under the High EV Flat Rates scenario.[65] For cars and trucks, the total cost of ownership of an EV is increasingly less than the total cost of ownership of an ICE through 2023.[66] In 2024, we assume the federal EV tax credit begins to phase out, but we find that the total cost of ownership for a 2024 EV car or SUV remains less than the total cost of ownership of a 2024 ICE car or SUV.[67] In 2025, we assume the federal EV tax credit has been fully phased out, but the total cost of ownership of EV cars and SUVs remains lower than the total cost of ownership of ICE cars and SUVs. After 2025, the total cost of ownership of an EV is again increasingly declining compared to the total cost of ownership of an ICE. Electric buses have a total cost of ownership that is consistently lower than the total cost of ownership of their ICE equivalents (as seen in Figure 14).

[65] For versions of these figures with data series for each scenario (BAU, Low EV Flat Rates, High EV Flat Rates, Low EV TOU Rates, and High EV TOU Rates), see Appendix B: Modeling Assumptions.

[66] Changes to federal tax credit policies or in-state incentives have the potential to further improve the cost-of-ownership.

[67] We use EV sales by manufacturer data from EV Adoption to calculate the average expected final year of the tax credit across manufacturers. See: https://evadoption.com/ev-sales/federal-ev-tax-credit-phase-out-tracker-by-automaker/.

Figure 12. Total cost of ownership of EVs less total cost of ownership of ICEs over time for cars

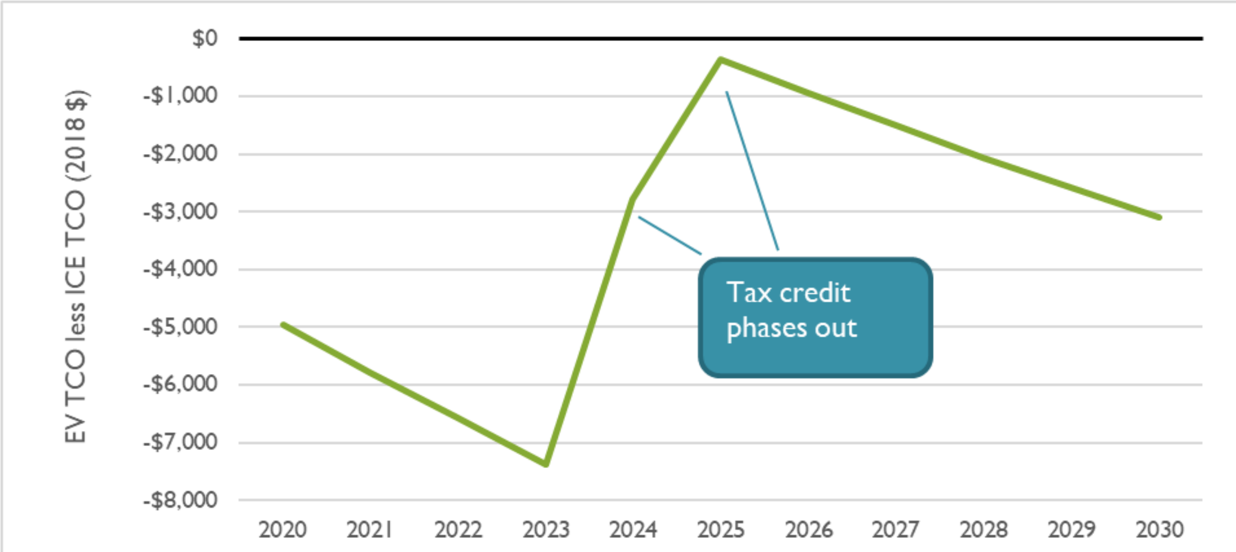


Figure 13. Total cost of ownership of EVs less total cost of ownership of ICEs ownership over time for SUVs

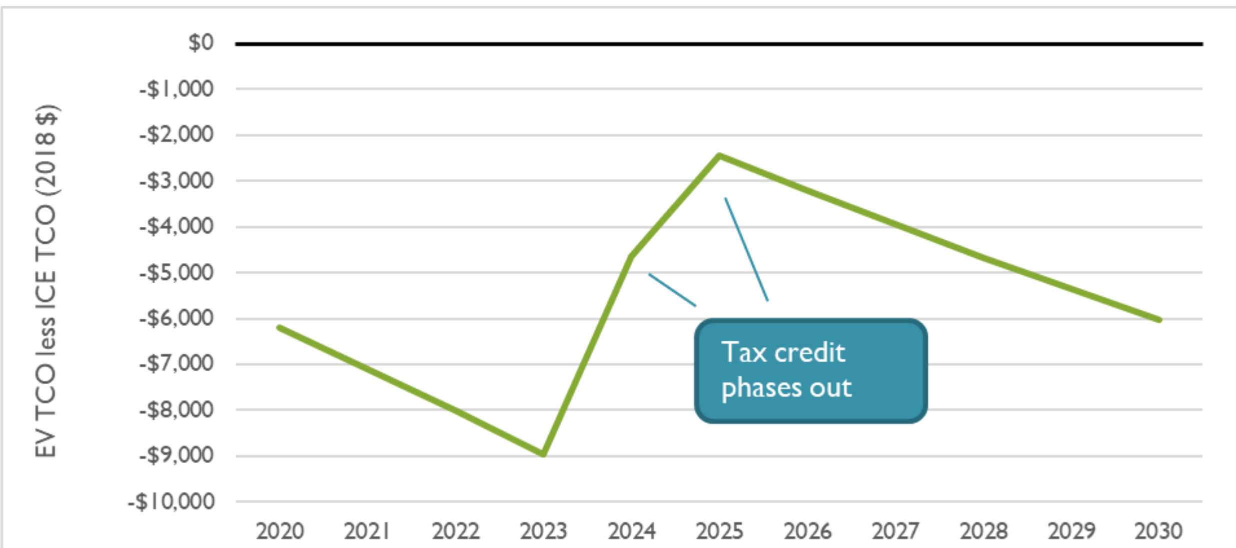
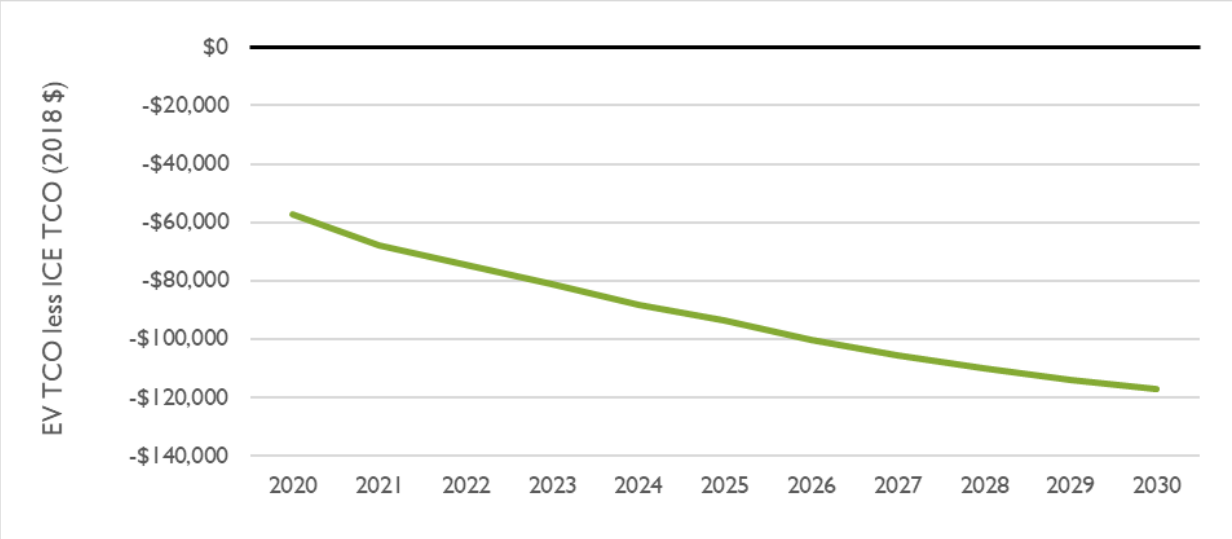
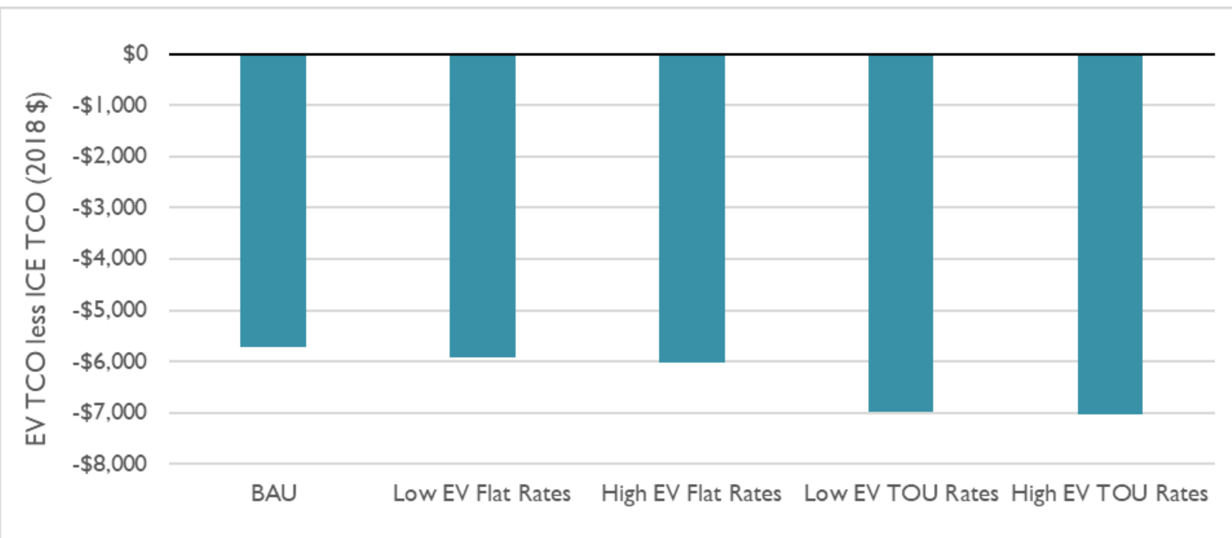


Figure 14. Total cost of ownership of EVs less total cost of ownership of ICEs over time for buses



In all years, TOU rates provide the lowest electricity rates for EV charging (when assuming that the majority of this charging occurs off-peak). Thus, TOU rates result in the lowest cost of ownership for an EV. Greater EV adoption also results in rate decreases relative to the BAU for all customers, which in turn further lowers the cost of ownership for an EV relative to the BAU scenario. This is represented in Figure 15, which shows the deltas across each of the five scenarios for SUVs in 2030.

Figure 15. Total cost of ownership of SUVs less total cost of ownership of ICEs in 2030 for SUVs



4.4. Health and pollution impacts

As customers switch from vehicles powered by gasoline to vehicles powered by electricity, they reduce tailpipe emissions of greenhouse gases and other pollutants. However, transportation electrification may increase emissions of greenhouse gases and other pollutants from the electricity grid if the marginal resources are powered by fossil fuel. Reductions in greenhouse gases are desired to meet state goals related to climate change mitigation, whereas net reductions in criteria pollutants can improve public health and help ensure that a state or region is in attainment with the U.S. Environmental Protection Agency's Clean Air Act.[68] The EnCompass model calculates changes in electric-sector greenhouse gases (CO_2 and NO_x), and SO_2 emissions. Synapse's EV-REDI model calculates the tailpipe emissions reductions associated with the increased penetration of EVs, allowing us to estimate how total emissions change.[69] Calculated tailpipe emissions include CO_2, NO_X, SO_2, particulate matter ($PM_{2.5}$), and volatile organic compounds (VOCs).

Figure 16 shows the changes in CO_2 emissions over 2020-2030 for each of the EV cases relative to the BAU across the entire MISO region. In most cases, the bulk of the CO_2 emissions reductions in all four scenarios is due to a reduction in tailpipe emissions, rather than generation changes in the power sector. The one exception is the High Flat case, where emission reductions in the electric sector are slightly larger than emission reductions in the transportation sector, largely as a result of the addition of newer, lower-emitting gas plants in this case that displace older, higher-emitting plants. In most cases, despite higher overall levels of load, emissions in the power sector are frequently lower than in the BAU due to increased levels of solar and shifts from coal to more flexible gas generation. The one exception to this is the Low TOU case, which features slightly higher emissions as a result of the load increase being enough to cause higher-emitting plants to run, but not so high as to cause new, cleaner plants to come online. Generally, we find that higher levels of EVs produce more net emission reductions relative to lower levels of EVs. At the same time, we find that the particular TOU profile modeled in this analysis results in fewer emission reductions as a result of causing more load to occur in nighttime hours when lower-emitting resources (like solar) are not operational.

[68] According to U.S. EPA, in recent years, all areas of Minnesota have been in compliance with Clean Air Act requirements related to NO_X, SO_2, and $PM_{2.5}$ (see https://www3.epa.gov/airquality/greenbook/anayo_mn.html). Nevertheless, reductions in criteria pollutant emissions still lead to improved air quality, public health, and avoided health costs.

[69] See Appendix B for more information on model methodology and assumptions.

Figure 16. Changes in CO_2 emissions relative to BAU case

Figure 17 and Figure 18 display the analogous changes in economy-wide emissions of NO_X and SO_2. In contrast to CO_2, reductions of NO_X and SO_2 primarily come from the electric sector, rather than the transportation sector. This is a result of newer vehicles emitting far less NO_X and SO_2 than older vehicles; as a result, future EV purchases offset relatively small quantities of these criteria pollutants. As a result of older vehicles coming off the road, transportation-sector NO_X emissions are projected to decline by 71 percent between 2020 and 2030 in the BAU case, while transportation-sector SO_2 emissions are projected to decline by 12 percent between 2020 and 2030 in the BAU case.[70]

[70] Note that the EV-REDI model also estimates changes in $PM_{2.5}$ and VOCs from the transportation sector. These emission changes largely the direction of SO_2 emission shown in Figure 18.

Figure 17. Changes in NO_X emissions relative to BAU case

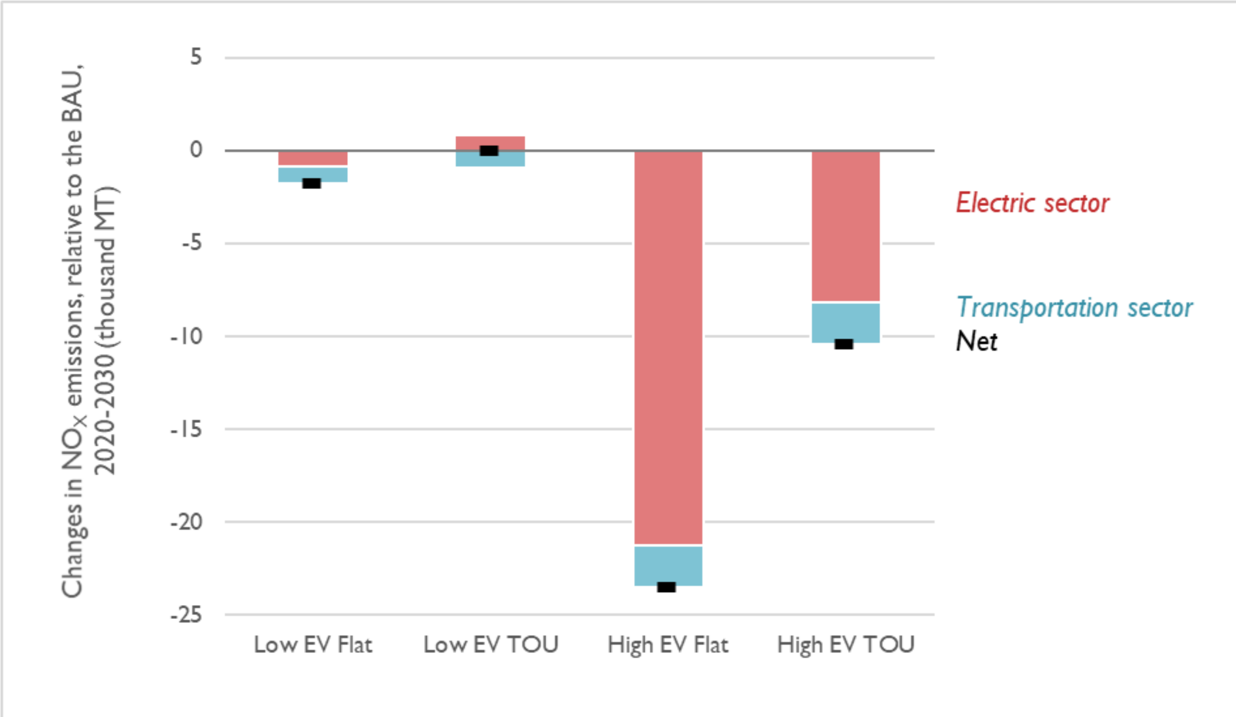
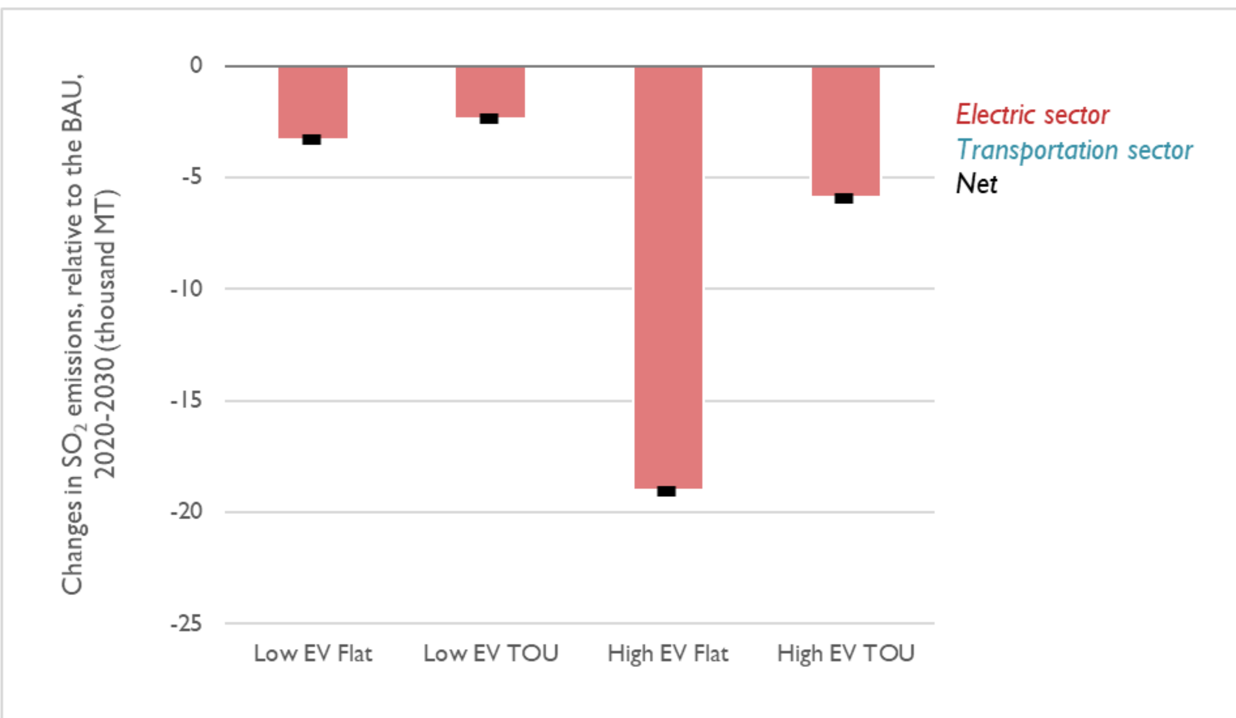


Figure 18. Changes in SO_2 emissions relative to BAU case



Note: Transportation-sector SO_2 emission reductions of are two orders of magnitude smaller than analogous emission reductions in the electric sector.

These emission reductions have important quantifiable impacts on the health of residents in Minnesota and nearby midwestern states.[71] Synapse utilized EPA's COBRA model to estimate changes to future mortality and morbidity impacts based on the emissions changes in each scenario, relative to the BAU. The COBRA modeling examines changes in criteria pollutant emissions in the transportation sector and power sector, estimates air dispersion and demographic data, and returns values in terms of incidence rates of health impacts as well as direct medical and societal costs associated with these health impacts.[72]

Note that while some changes in emissions are occurring in Minnesota (e.g., as Minnesota customers switch from ICE vehicles to EVs), the health impacts of the emissions changes are likely to affect surrounding states as well (given the dispersive behavior of air pollution). Conversely, some of the increased electricity load from EVs in Minnesota may be met by increased emitting generation in nearby states, which could produce health impacts for residents in Minnesota.

Table 11 highlights the changes in mortality, avoided work loss days, and monetized health impacts relative to the BAU scenario for the Low and High EV Flat scenarios. Depending on the case, the total monetized impacts range from as low as $278 million in the Low EV (flat rates) case to as high as $920 million in the High EV (flat rates) case.

Table 11. Health impacts and avoided health costs of each EV scenario relative to the BAU, 2020 through 2030

	Avoided Deaths	Avoided Work Loss Days	Monetized Health Impact (2018 $M)
Low EV Flat	20	8,600	$178
High EV Flat	90	44,000	$920

Note: Values shown for the flat rate cases only due to computational limitations. Monetized health impacts reflect changes in NO_X, SO_2, $PM_{2.5}$, and VOCs.

4.5. Summary of results and discussion of policy implications

The results of our case study indicate that EVs are likely to have the following impacts on customers:

- EVs increase electricity consumption by less than 5 percent in all scenarios, leading to minimal impact on the wholesale electricity grid in the near term. Much of the electricity to serve EVs can be provided by existing system capacity, and additional energy will likely be supplied by low-cost, low- or zero-emitting energy sources.
- Increased electricity sales due to EVs exert downward pressure on electricity rates in nearly every scenario we modeled. High EV adoption yields the greatest benefit to residential utility customers, with an average annual electricity savings of $71 in 2030 in the High EV scenario relative to the base case. Under High EV adoption, the cumulative

[71] Note that our analysis does not account for the health impacts (monetized or otherwise) associated with mercury or the social cost of carbon.

[72] See Appendix B for more information on model methodology and assumptions.

contribution to margin ranges from $597 million to $852 million, depending on the rates that EV customers pay. These results are robust even under higher T&D costs.

- TOU rates have the potential to produce greater rate reductions than flat rates. Because we did not assume TOU rates, demand response programs, or other charging management programs to manage C&I charging load, the benefits and costs of EVs in the C&I sector largely cancel out.

- Despite their higher upfront costs, EVs have lower lifetime costs due to reduced fuel and maintenance costs.

- EVs will substantially reduce greenhouse gases and improve public health due to lower tailpipe emissions and relatively clean sources of additional electricity generation.

These impacts can be further shaped through policies and programs that work to maximize the benefits of EVs and enhance equity. In particular:

- Policies and rate designs that align charging with lower cost hours can help to maximize benefits. For example, if demand response programs or other incentives to charge off-peak were provided to C&I customers, we would expect the benefits to all customers to increase substantially.

- Higher upfront costs may continue to be a barrier to EV adoption by lower-income customers. Programs and policies can be designed to ensure that low and moderate income customers also benefit from the lower lifetime costs of EVs. For example, electrifying public transit and mobility services (such as Lyft and Uber) can help low and moderate income customers benefit from transportation electrification. In addition, programs designed to reduce upfront purchase costs and increasing access to charging infrastructure for low and moderate income populations can help these customers take advantage of EVs.

- To ensure that lower income customers, renters, and residents of multi-unit dwellings have access to EVs, utility investments in charging infrastructure can be directed to fill market gaps in these sectors.

- Because transportation sector emissions occur at ground level where they are less likely to be dispersed and more likely to have an impact on customers' health, a decrease in tailpipe emissions is likely to produce the most health benefits for the customers who are physically located near where the vehicles are operated. Communities located near transportation corridors will particularly benefit from the health impacts of transportation electrification. Increasing electrification of heavy-duty vehicles (large trucks, buses) and machinery (forklifts, construction vehicles) will help amplify these benefits.

4.6. Applicability to other states

Though this case study was performed only for Minnesota, many of the results are applicable to other states or jurisdictions in the United States. For each of the potential impact areas, we discuss the ways that these results may or may not be transferrable to other locales.

Impacts on the electricity grid

First, the makeup of the existing electric generating fleet in a region is a main driver of how incremental demand from EVs may impact wholesale energy prices, customer bills, or emissions of criteria pollutants. The degree to which these impacts differ from a BAU case without incremental EV demand will depend on the attributes of the current generating fleet, including their operational availability, age, heat rates, and other operational characteristics. For example, a relatively new fleet with lower maintenance costs or more flexible capability could produce different results for wholesale prices in a future with more EVs, compared to a fleet primarily composed of older, more expensive, and less flexible units.[73]

A state's plan for new electric generating resources also plays a role in terms of how increased EVs may impact utility customers. Increased load growth from EVs could result in an increased buildout of the new generating resources. Depending on the resource alternatives that are available (both from an economic and geographic perspective) to meet the higher load growth, the wholesale energy and capacity prices associated with this resource may differ significantly across states. The expected resource buildout often depends on the lowest-cost available resource. In some states, the cost of building a solar or wind unit may be higher or lower than in the case of Minnesota, or the cost of building new natural gas plants may be cheaper or more expensive. Nationwide, wind and utility solar resources are frequently the same price or less expensive than a comparable natural gas combined cycle plant, on an all-in levelized basis, even when removing the effects of renewable subsidies.[74]

In addition, the exact buildout of resources may be dependent on when the peak demand of the system occurs and the existing resource availability within the state to meet that peak demand. Minnesota is a summer peaking state, but a winter peaking state could see a different electric resource buildout than modeled in this case study, which may produce different energy and capacity prices.[75] Certain states may be required to meet minimum reserve margins within their territories, which could further impact the expected resource build out to meet the demand requirements. Even absent increases in demand requirements, some states may observe an increased buildout of new, low-cost renewables, as new resources are able to displace existing conventional generation based on marginal economics alone.

Furthermore, if a state has an RPS requirement, it is likely to build out more renewables, regardless of whether there exists a demand from a grid operation perspective, or whether the renewables are less expensive than current generation. In addition, RPS targets may include carve outs and can possibly be met through interstate sales. Within Minnesota, RPS targets can be met by sales from adjacent states within MISO, which may impact wholesale energy and capacity prices even if renewable resources are

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[73] This generally holds true both for vertically integrated jurisdictions as well as wholesale markets.

[74] See https://www.lazard.com/media/450784/lazards-levelized-cost-of-energy-version-120-vfinal.pdf and https://energyinnovation.org/wp-content/uploads/2019/03/Coal-Cost-Crossover_Energy-Innovation_VCE_FINAL.pdf, for example.

[75] According to 2017 data from EIA's Form 861 (see https://www.eia.gov/electricity/data/eia861/), 39 states are summer peaking, while only 12 are winter peaking. Winter peaking states are most frequently states which both have relatively low summer air conditioning load and relatively high quantities of electric resistance heating.

not built in the state in question. Conversely, the Minnesota RPS has specific solar carve-outs, which effectively target small facilities (less than 40 kW) and facilities that are located in-state. Other state incentives may further encourage increased adoption of renewables, or storage facilities, and produce analogous changes in resource buildout and resulting changes to wholesale energy and capacity prices.

In summary, because peak-coincident EV load growth can be managed through TOU rates and other mechanisms, it is feasible for new EV load to take either advantage of existing, underutilized resources, operate in concert with new, low-emitting resources, or both.

Rate and bill impacts

The degree to which the rate and bill impact results are transferrable to other states depends on the marginal generation and T&D costs for that state, and more specifically, for the locations within the state that are expected to experience the greatest rates of EV growth. For example, if another state has higher T&D costs than Minnesota, the resulting costs of serving EV load will be higher, thereby reducing the downward impact on rates. T&D costs are very location dependent. In areas where the distribution system is highly constrained (such as dense urban areas), the cost of additional EV load may be high. In rural areas with plenty of excess capacity and little load growth, the marginal T&D cost from EVs will likely be minimal.

The degree to which customers in other states will experience an increase in rates as a result of utility investment in EV infrastructure depends primarily on the relationship between average system costs and marginal costs of EVs in the state. If the marginal costs of adding EVs to the system in another state are greater than the average system costs, then a non-EV customer would experience a rate increase resulting from utility investment in EV chargers.

Total cost of ownership analysis

The degree to which total cost of vehicle ownership results are transferrable to other states depends on the (1) electricity, diesel, and gasoline prices in those states; (2) whether those states have EV incentives (e.g., rebates on purchase price or discounts on insurance) and in what year those incentives end or EV registration fees that effectively raise the cost of EVs; and (3) the relative insurance costs and sales tax rates in other states.

According to EIA data, Minnesota's electricity rates are similar to the national average (i.e., 2 percent lower than the national average between 2013 and 2017).[76] Similarly, the price of gasoline in Minnesota is also quite similar to the national average (i.e., also 2 percent lower than the national average between 2013 and 2017).[77] Our case study analysis finds that for ICE cars and SUVs, fuel costs typically represent 14 percent of total cost of ownership over a six-year period, while for EV cars and SUVs, electricity costs typically represent between 7 and 12 percent of the total cost of ownership. While non-fuel costs may

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[76] Based on data available at https://www.eia.gov/electricity/data/state/

[77] Based on data available at https://www.eia.gov/state/seds/seds-data-fuel.php?sid=US

represent the majority of the cost difference between ICE vehicles and EVs, in states with higher-than-average electricity costs but lower-than-average gasoline costs, potential EV customers may find that the delta between the total cost of ownership of EVs versus ICE vehicles is smaller than observed for Minnesota. On the other hand, in states with lower-than-average electricity costs, but higher-than-average gasoline costs, potential EV customers may find that they would save even more money by choosing an EV rather than an ICE vehicle than demonstrated here. EVs also help to reduce dependence on purchases of gasoline, the price of which can be volatile. Spending less on fuel is particularly important for low-income customers, who routinely spend a larger share of their income on transportation expenditures, relative to wealthier households.[78]

The upfront purchase price of an EV is a key factor in the total cost of ownership analysis, and rebates on EV purchases can bring down the upfront price of EVs. Minnesota does not offer rebates on EV purchases, and therefore customers in states that do offer rebates would likely save more money by choosing an EV rather than an ICE vehicle than demonstrated in this analysis.[79] Similarly, customers in states that offer incentives on home chargers and/or electric rates for EVs would find that they save more money by choosing an EV rather than an ICE vehicle than demonstrated here.

Insurance costs and sales tax are tied to the upfront purchase price of vehicles. Because the upfront price of EVs remain and are projected to remain higher than their ICE equivalents in the near term,[80] the insurance costs and sales taxes associated with EVs are higher than those for ICE vehicles. Therefore, customers in states with lower insurance costs or sales tax rates would likely save more money by buying an EV than demonstrated in this analysis, while customers in states with higher insurance costs or sales tax rates would save less money by buying an EV.

Health and pollution impacts

The degree to which the health and emissions impact results are transferrable to other states is strongly linked to the composition of marginal generation and capacity (see the results described above in section 4.2). In the many states that have falling prices of renewables or have RPS policies, the marginal capacity and generation that may accompany a growth in EV-related electricity growth may not lead to any increase in the use of fossil fuel-fired generation, resulting in zero incremental emissions of CO_2 and criteria pollutants. Depending on the makeup of the marginal generation associated with increased electricity demand from EVs, these increased emissions may be more than offset by emission decreases from reduced gasoline consumption (i.e., “tailpipe emissions”). In addition, in other states where an RPS

[78] See https://www.pewtrusts.org/~/media/assets/2016/03/household_expenditures_and_income.pdf

[79] Minnesota does charge a $75 annual fee for non-hybrid electric vehicles. Annual fees and registration fees act as the opposite of a rebate in that they increase the upfront or ongoing costs of EV ownership. Although we did not model these annual fees in our analysis, we can assume that customers in states that do not charge annual fees or registration fees would save more money by choosing an EV rather than an ICE vehicle, holding all else constant.

[80] According to the International Council on Clean Transportation (ICCT), a BEV150 car will achieve cost parity in 2024 while BEV150 crossovers and SUVs will achieve cost parity in 2025. See: https://www.theicct.org/sites/default/files/publications/EV_cost_2020_2030_20190401.pdf.

or decreased renewable costs produce a pronounced buildout of emissions-free electric capacity, customers may observe a marked decrease in criteria pollutant emissions, as well as an increase in associated health benefits.

Two important considerations in assessing emissions-related health impacts associated with EV deployment are emissions location and geographic dispersion. Tailpipe emissions occur at ground level, where they are less likely to be dispersed and more likely to have an impact on customers' health. Correspondingly, a decrease in tailpipe emissions (e.g., through substantial deployment of EVs) is likely to produce the most health benefits for the customers who are physically located near where the cars are driven. This is particularly relevant in situations where EVs may be used to reduce emissions from transit buses, school buses, and large trucks, which disproportionately impact lower-income and communities of color located near industrial and transit sites.

However, this same movement may not necessarily be true for emissions produced by the electric grid. Emission increases from increased fossil fuel-fired generation (as a result of increased EV deployment) may occur in states other than the state deploying higher levels of EVs. In addition, these emissions are produced from power plant stacks which range from 500 to 1,000 feet in height; as a result, these emissions may be dispersed over a wide geographic area. Depending on the location of power plants, and atmospheric dispersion, the resulting grid-associated health impacts from increasing EV deployment may affect customers far from the site of EV deployment.

5. CONCLUSIONS

Transportation electrification impacts include impacts on electricity rates, as well as broader impacts on customers' transportation costs and health. While increased deployment of EVs may provide many benefits—decreased tailpipe emissions and a larger number of electricity sales over which to spread fixed utility costs—appropriate planning and policy is critical to minimize increased electricity rates or bills for customers who do not own an EV.

To evaluate the potential impacts of EVs, a variety of analyses can be conducted to examine the impacts on electricity rates and bills, the total cost of ownership for electric vehicles, and changes in emissions and related health impacts. Chapter 2 of this guidebook describes how these analyses can be conducted, while Chapter 4 applies these analyses to a case study of Minnesota.

In the course of our case study of Minnesota, we found:

- The incremental impact of EV load on the wholesale electricity grid is likely to be limited in the near term. That limited increased load will likely be supplied by low-cost, low- or zero-emitting energy sources. However, rate structure matters in influencing which resources will be utilized. Consumer advocates may wish to examine how to apply time-of-use rates optimally to produce lower system costs.

- The increase in electricity sales associated with greater EV adoption leads to lower rates than in the base case in nearly every scenario we modeled. However, the benefits to C&I customers are nearly offset by the costs of EVs. This result is in part driven by our assumption that C&I load would primarily occur during peak hours in the absence of smart charging programs or other programs to manage peak demand. We recommend that policies to minimize peak demand be explored, such as smart charging, incentives for storage, or other utility programs targeted at C&I customers and high-powered charging installations.

- EVs provide savings over the lifetime of the vehicle from reduced monthly fuel costs and annual maintenance costs, despite higher upfront costs. However, higher upfront costs may continue to be a barrier to EV adoption by lower-income customers, especially until auto manufacturers offer more lower cost models in every state. Well-designed transportation electrification programs can help address such barriers by encouraging greater vehicle offerings throughout the country, reducing upfront purchase costs for low income customers, and increasing access to charging infrastructure for low and moderate income customers.

- Because the additional electricity needed for EVs is likely to have low emission rates CO_2 and criteria pollutants, EVs will substantially reduce greenhouse gases and improve public health for customers.

Although the electrification of the transportation sector is likely inevitable, the path it takes is not predetermined. The manner in which costs and benefits are allocated among utility customers can vary substantially, with important implications for equity. Utility consumer advocates play a critical role in helping to ensure that transportation electrification occurs in a manner that allows all customers, particularly low and moderate income and disadvantaged groups, to share in the benefits while not unfairly bearing the costs.

Electric utility programs that can help maximize the benefits of transportation electrification and shape the equitable distribution of impacts include:

- Implementation of sound rate design principles to shift new EV load toward the least-constrained hours, minimizing the costs that are imposed on the utility system and maximizing the positive impact that increased energy sales have on rates and bills.
- Use of demand response programs to enable utilities to use EV charging load as a resource to balance supply and demand on the grid to optimize the use of zero-emitting resources or to avoid use of expensive or highly polluting peak resources.
- Siting public charging infrastructure in locations that minimize the need for distribution system upgrades.
- Designing EV rebates or other incentives to benefit low-income customers, such as through incentives for lower cost EVs, used EVs, or vehicle leases (as opposed to only new car purchases), considering income guidelines to provide larger rebates for those with lower incomes, and providing rebates rather than tax incentives that may be difficult or impossible for low-income consumers to use. If the incentives are provided by a non-utility entity, it may be appropriate to coordinate utility transportation electrification programs with other government agencies.
- Directing EV investments toward services that low and moderate income or non-driving customers may rely on, such as public transit, school buses, mobility services (e.g., Uber, Lyft), and public charging infrastructure that serves multi-unit dwellings, mobility service drivers, and low-income areas. These entities have not traditionally participated in electric utility dockets but should be encouraged to participate in transportation electrification plans. In particular, closer coordination between consumer advocates and other government agencies (such as departments of transportation or municipal transit agencies) is likely to reap large benefits.
- Electrification of medium- and heavy-duty vehicles responsible for criteria pollutants and the resulting serious health impacts in disproportionately impacted communities. Examples include school buses, yard trucks at ports, delivery trucks in urban areas, or heavy trucking on freeways.

Appendix A. Study caveats

Limitations, caveats, and areas of uncertainty

Any modeling exercise is limited by the inability to perfectly predict future electric system costs and customer behavior. This study is no different. Numerous simplifications and assumptions were used to conduct the modeling for this study. To the extent that these simplifications and assumptions differ from future circumstances, the results of our study can be expected to be inaccurate. Below we describe some of the key limitations, caveats, and areas of uncertainty for the various models that we used to develop the results of our study.

Electric system modeling

Our analysis explored five scenarios in electric system modeling: business-as-usual future, a low EV future, a low EV future with TOU rates, a high EV future, and a high EV future with TOU rates. Additional findings could potentially be gleaned from modifications to these scenarios that assess different levels of EV adoption or different charging patterns. In addition, additional sensitivities to underlying electric system modeling assumptions, such as demand projections (absent EVs), fuel prices, or cost projections for renewables and battery storage, could produce different results than those modeled here.

Rate and bill impacts

For rate and bill impacts, we studied light-duty vehicle and heavy-duty vehicle electrification effects separately, assuming that all LDV impacts would accrue to the residential class and HDV impacts would accrue to the C&I class. This separation is a simplification that does not account for spillover impacts. For example, LDVs may charge at C&I tariffed charging installations, particularly DC fast chargers. Nevertheless, we believe it is reasonable to assume that the majority of LDV load will be served under the residential tariff, and the majority of HDV load is likely to be served under the C&I tariff. To the extent that this is not the case, the rate impacts would likely be reduced for the residential class and increased for the C&I class.

Our rate and bill impacts are also highly dependent on the assumed charging load profiles for EV customers. We assume that TOU rates will cause residential customers to charge primarily off-peak, based on the experience of other jurisdictions. However, this assumes that all incremental residential EV customers will be enrolled on the rate. The magnitude of load shifting is also dependent on the design of the TOU rates (such as the peak to off-peak price ratio). If the TOU rate is optional, or if the peak to off-peak price differentials are very mild, the load shifting is likely to differ.

For C&I customers, the modeled rate impacts assume that system upgrade costs attributable to a specific customer will be shared by all C&I customers, up to the value of three years' of expected revenue from the specific customer, based on the policy of Xcel. If instead these costs were not socialized, the upward pressure on rates would be reduced.

Finally, the rate and bill impacts are dependent on the accuracy of the marginal cost estimates. We used the simplifying assumption that generation capacity costs would increase linearly year-to-year from the most recent MISO capacity auction results to the cost of new entry (CONE) for a new peaker plant. In reality, the generation capacity costs are likely to fluctuate from year-to-year and may be lower or higher than those assumed in our model.

Total cost of ownership analysis

The total cost of ownership analysis relies on projections for future prices of EVs. As with any new technology, the actual prices are likely to deviate significantly from projections, and therefore the future upfront costs associated with EVs is a significant area of uncertainty.

Potential next steps

The adoption of EVs is still in its early stages, and thus this analysis should be refined in the future to include more up-to-date information about vehicle costs (particularly HDVs), T&D system upgrade costs, and electricity market changes. Further, the analysis could be expanded to explore additional EV options. In particular, the cost of ownership analysis could analyze PHEVs relative to ICEs or BEVs. It could also include sensitivities on:

- State and federal policies and incentives related to EVs;
- Upfront costs of EVs; and
- EV charger and charger installation costs.

Finally, the analysis could be expanded to explore other types of vehicles, such as freight vehicles and school buses.

Appendix B. Modeling Assumptions

This appendix provides additional documentation about the modeling methodology applied in our case study, as well as more detail on modeling assumptions.

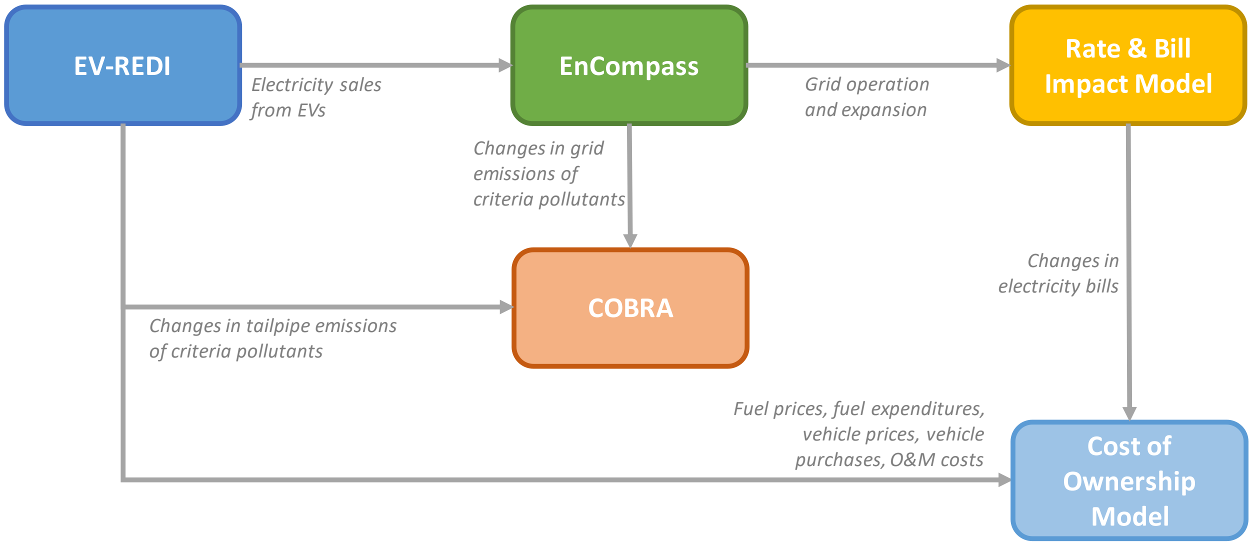
Description of models

This analysis employed the use of the following models for our case study analysis:

- **EnCompass:** Used in our assessment of electric grid impacts through capacity expansion and production cost modeling.
- **EV-REDI:** Used to analyze of EV sales and stock; impact of EVs in terms of retail electricity demand impacts and tailpipe emissions.
- **COBRA:** Used to assess the health impacts of emission changes in the transportation and electricity sectors.

In addition, our analysis leveraged the use of two custom-built spreadsheet models to analyze rate and bill impacts and cost of ownership of EVs versus ICE vehicles. Figure 19 depicts the purpose of each of these models, along with information on what information was passed from model-to-model to ensure comprehensive, consistent analysis.

Figure 19. Case study modeling schematic



EV-REDI uses detailed, state-specific data to calculate the impacts of various EV adoption trajectories. Other impacts calculated include electricity consumption, GHG and criteria pollutant emissions, and avoided fuel consumption.

EnCompass is a production-cost and capacity-expansion model of the electric sector. It uses inputs (including demand, resource costs, and regulatory requirements) to estimate hourly impacts on the electricity system, including changes in generation, emissions, and capacity.

Synapse developed a custom-built Rate & Bill Impact Model to analyze rate and bill impacts. This model takes into account changes in electricity sales, varying types of charger cost allocation, changes in the cost of energy and capacity, and impacts on the distribution grid.

COBRA is a health impacts screening and mapping tool. COBRA uses county-level inputs on changes in criteria pollutants to estimate impacts on public health. Impacts include morbidity and monetized health effects.

Synapse developed a custom-built Cost of Ownership Model to assess the lifetime costs of EVs and conventional vehicles. This model calculates upfront cost, fuel and electricity costs, maintenance costs, and other cost categories.

EnCompass

Developed by Anchor Power Solutions, EnCompass is a single, fully integrated power system platform that allows for utility-scale generation planning and operations analysis. EnCompass is an optimization model that covers all facets of power system planning, including the following:

- Short-term scheduling, including detailed unit commitment and economic dispatch
- Mid-term energy budgeting analysis, including maintenance scheduling and risk analysis
- Long-term integrated resource planning, including capital project optimization and environmental compliance
- Market price forecasting for energy, ancillary services, capacity, and environmental programs

EnCompass provides unit-specific, detailed forecasts of the composition, operations, and costs of the regional generation fleet given the assumptions described in this document and detail contained within the EnCompass National Database, created by Horizons Energy. Horizons Energy benchmarked its comprehensive dataset across the 21 NERC Assessment Areas and it incorporates market rules and transmission constructs across 76 distinct zonal pricing points. Synapse uses EnCompass to optimize the generation mix in MISO and to estimate the costs of a changing energy system over time, under a variety of EV scenarios. In this analysis, we have modeled the entire MISO region, split up into MISO's load reserve zones (LRZs).

More information on EnCompass and the Horizons dataset is available at www.anchor-power.com.

EV-REDI

Synapse's EV-REDI (Electric Vehicle Regional Emissions and Demand Impacts) is a tool for modeling multiple impacts of transportation electrification for specific states and provinces. With EVs on the rise, there will be enormous opportunities for making transportation more sustainable and modernizing the electric grid. But in order to realize this potential, it will be necessary to plan ahead. More and more, states, cities, utilities, and regional authorities are seriously considering the impacts of futures in which electric vehicles play an increasingly important role in the transportation sector. Synapse's EV-REDI model can help meet the need to quantify the impacts of increased EV penetration on electricity sales, greenhouse gases and criteria pollutant emissions, and avoided gasoline consumption for all 50 U.S. states, Washington D.C., and ten Canadian provinces. EV-REDI accounts for:

- State- and province-specific trends in LDV stocks, sales, and driving patterns
- Vehicle ownership lifetime
- Vehicle miles travelled (VMT)
- Changing efficiencies of both EVs and conventional vehicles
- Changing trends in vehicle preferences
- Distinctions between driving patterns of PHEVs and purely battery-powered EVs

More information on EV-REDI can be found at http://www.synapse-energy.com/tools/electric-vehicle-regional-emissions-and-demand-impacts-tool-ev-redi.

COBRA

U.S. Environmental Protection Agency's CO–Benefits Risk Assessment (COBRA) model is a free screening tool designed to help state and local governments:

- Explore how changes in air pollution from clean energy policies and programs, including vehicle electrification, can affect human health at the county, state, regional, or national levels.
- Estimate the economic value of the health benefits associated with policies to compare against program costs.

- Display incidence rates and monetized values quantifying air quality, human health, and health-related economic benefits from reductions in emissions of particulate matter ($PM_{2.5}$), sulfur dioxide (SO_2), nitrogen oxides (NO_X), ammonia (NH_3), and volatile organic compounds (VOCs) that result from policies such as vehicle electrification.

COBRA contains detailed emission estimates of $PM_{2.5}$, SO_2, NO_X, NH_3, and VOCs for the year 2017 as developed by EPA. Users then specify emission increases or decreases relative to this baseline estimate. Emission changes can be entered at the county, state, or national levels, and can be entered for different types of emitting sources (including the transportation sector and electric sector). COBRA then applies these emission changes within a reduced form air quality model, the Source-Receptor (S–R) Matrix, to estimate the effects of emission changes on ambient PM. Using an approach to estimating avoided health impacts and monetized benefits consistent with EPA best practices, COBRA then translates the ambient PM changes into human health effects and monetizes them.

More information on COBRA is available at https://www.epa.gov/statelocalenergy/co-benefits-risk-assessment-cobra-health-impacts-screening-and-mapping-tool.

Total cost of ownership analysis

Upfront vehicle costs and fuel economy

Data for ICE cars are taken from the U.S. Energy Information Administration's Annual Energy Outlook 2019 based on the "midsize car" category. Data for EVs are taken from NREL's Electrification Futures Study (EFS) based on the "light duty car" category.[81] The prices of EVs are rapidly declining, and therefore we scale the EV upfront prices as provided in the EFS dataset to the current average price of a 200-mile range EV car per InsideEVs' All-Electric Car Comparison table.[82] We use EFS for EV fuel economy data and EV price data. We use the "Moderate Advancement" scenario data (other options include Slow and Rapid Advancement). For both ICE cars and ICE SUVs, we assume vehicle efficiencies (miles-per-gallon) in line with current CAFE standards remaining in effect, rather than being rolled back or extended.

Data for ICE SUVs are taken from AEO 2019 (fuel economy data taken from Table 52 and ICE price data taken from Table 53) based on the "large crossover car" category, while data for EV SUVs are taken from NREL's Electrification Futures Study (EFS) based on the "light duty trucks" category. In this report, we present results for a 200-mile range electric SUV. As with EV cars, we scale the upfront price of EV SUVs using the current average price of a 200-mile range EV SUV per InsideEVs' All-Electric Car Comparison table.

[81] Note that data on electric vehicle costs and costs projections is changing rapidly. This analysis used the best available data at the time of our primary analysis, which took place in early 2019.

[82] See https://insideevs.com/compare-plug-ins/ for more information.

For ICE buses, we use fuel economy data from AEO 2019's Table 50: Freight Transportation Energy Use. Data for ICE buses are taken from the California Air Resources Board's Innovative Clean Transit cost data (2017) based on the "diesel" category, and data for EV buses are taken from the same CARB source based on the "battery electric (324kWh) (depot charge)" category.

Fuel and O&M costs

Data on gasoline and diesel prices are derived from AEO 2019 projections. We rely on electricity rates derived in our Rate and Bill Impacts analysis. We use car and SUV maintenance costs ($/mile) from ICCT's 2019 *Update on electric vehicle costs in the United States through 2030*.[83]

Additional assumptions

Additional assumptions in the cost of ownership analysis include:

- The average person owns a car or SUV for six years, and the average transit agency owns a bus for 14 years.[84]
- 70 percent of vehicle purchases are financed over an average loan term of 68 months at a rate of 4.25 percent.[85]
- The average home charger costs $1,053.[86] We do not include the costs of heavy-duty chargers while evaluating buses as the funding and financing for these chargers can vary considerably across transit agencies.
- Vehicle owners sell their vehicle at the end of the ownership period using resale values derived from a curve based on Table II-36 in the Safer Affordable Fuel-Efficient (SAFE) Vehicles Rule for Model Years 2021-2026 Passenger Cars and Light Trucks. This curve describes the relationship between the share of value remaining (as a percentage of the vehicle's retail price and vehicle age.
- Cars and SUVs follow vehicle miles traveled schedules (by vehicle age) from the Federal Highway Administration's 2017 National Household Travel Survey, and buses follow

[83] See: https://www.theicct.org/sites/default/files/publications/EV_cost_2020_2030_20190401.pdf.

[84] The average length of a new car loan is 69.5 months (https://www.edmunds.com/industry/press/rising-interest-rates-vehicle-prices-can-cost-car-shoppers-thousands-more-to-finance-new-vehicles-in-2018-according-to-edmunds.html) which we use as a proxy for ownership period. The 14-year ownership period assumption for transit buses comes from the California Air Resources Board's Innovative Clean Transit cost data (2017).

[85] These assumptions are consistent with NHTSA and EPA's The Safer Affordable Fuel-Efficient (SAFE) Vehicles Rule for Model Years 2021-2026 Passenger Cars and Light Trucks and its accompanying Preliminary Regulatory Impact Analysis at the following links: https://www.govinfo.gov/content/pkg/FR-2018-08-24/pdf/2018-16820.pdf and https://www.nhtsa.gov/sites/nhtsa.dot.gov/files/documents/ld-cafe-co2-nhtsa-2127-al76-epa-pria-180823.pdf.

[86] See page 12: https://mjbradley.com/sites/default/files/NE_PEV_CB_Analysis_Methodology.pdf.

vehicle miles traveled schedules from AEO 2019's Table 50: Freight Transportation Energy Use (using the medium size class).

- The federal EV tax credit ($7,500 in 2018) begins phasing out in 2024 and is fully phased out by 2025.[87]

Rate and bill impact analysis

In the residential rate and bill impact model, each EV is taken to correspond to a single residential customer (whose energy consumption is equal to that of the average non-EV owner plus the incremental energy associated with the EV). In the C&I model, the customer is the owner of charging infrastructure. Each C&I customer is assumed to own five ports; in practice this cluster might represent a truck stop charging station, a bus depot, or various other alternative configurations that may materialize under conditions of heavy-duty fleet electrification.

We model both *high* and *low* scenarios for LDV and HDV electrification over the period 2019-2030, along with a *base case* in which the current growth trend in LDV and HDV electrification is carried forward to 2030. These growth trends, and associated energy demands, are generated using Synapse's in-house EV-REDI model. For the LDV scenarios, we consider both flat rate and TOU rate alternatives, whereas we assume C&I load is subject to flat rates only. These rate variations are important in the residential case since they are assumed to influence the load shape of LDV charging, shifting EV energy consumption to off-peak, lower-cost hours. We do not evaluate TOU rates for HDVs, assuming that C&I vehicle demand for electricity is price inelastic. These EVs are likely to be highly schedule-bound and probably idiosyncratic in their charging patterns.

However, the results of the C&I scenarios are sensitive to whether flat or TOU rates are assumed for the residential class. Implicit in the C&I modeling is the assumption of concurrent electrification in the light-duty sector; the assumed load shape for this new residential class EV load influences overall energy costs, which in turn affects C&I scenario costs.

Primary modeling assumptions

In our analyses, we are interested in the rate and bill impact of just the EV load in the low and high scenarios that is incremental to the load in the BAU case. In the early model years, there is little difference between the scenarios and the BAU case, but this gap grows rapidly toward the terminal model period. To isolate the impact of this incremental EV load, we hold other system features constant – both between the models, and over time.

We derive our BAU case residential and C&I load forecasts using actual 2017 figures, and then escalate these values at the rate of the forecast for MISO load zone LRZ1 (which is almost entirely represented by

[87] This is based on the average year when manufacturers are expected to reach 200,000 sales (at which point the credit begins phasing out for each manufacturer) using data from EVAdoption. See: https://evadoption.com/ev-sales/federal-ev-tax-credit-phase-out-tracker-by-automaker/.

Minnesota). We assume that average non-EV customer load is constant across the model period, and between the scenarios, for each class.

Incremental EV costs

For each year, class revenue requirements are calculated using the following formulas, shown in Equation 1 and

.

Equation 1. Revenue requirement calculation (base case)

$$Revenue\ requirement =$$
$$total\ energy_{\ T} \times base\ case\ energy\ rate_{T}$$
$$+\ total\ energy_{\ 2019} \times\ base\ case\ capacity\ rate_{\ 2019}$$
$$+\ total\ incremental\ peak\ demand\ with\ respect\ to\ 2019_{T} \times\ capacity\ rate_{T}$$
$$+\ total\ energy_{T} \times\ embedded\ T\&D\ rate_{2017}$$

Equation 2. Revenue requirement calculation (scenarios)

$$Revenue\ requirement =$$
$$total\ energy_{\ T} \times scenario\ energy\ rate_{T}$$
$$+\ total\ base\ case\ capacity\ costs_{T}$$
$$+\ total\ incremental\ peak\ demand\ with\ respect\ to\ base\ case_{\ T} \times\ capacity\ rate_{T}$$
$$+\ total\ base\ case\ T\&D\ costs$$
$$+\ total\ incremental\ energy\ with\ respect\ to\ base\ case_{\ T} \times\ marginal\ T\&D\ rate$$
$$+\ total\ base\ case\ T\&D\ costs$$
$$+\ line\ extension\ costs\ (only\ in\ C\&I\ scenarios)$$

Notes on values:

- Subscripts indicate the year of the specific term, with T indicating that values change with each model year; where terms are not subscripted, values are not year-specific.
- All values are provided in 2018 dollars, assuming a 2 percent rate of inflation.
- The energy rates (dollars per-MWh) are output from the EnCompass model.
- The Base Case capacity rate (dollars per-MWh) is output from the EnCompass model; it is applied to just the portion of energy in both the base case and the scenarios equal to 2019 base case energy to assess embedded capacity costs.
- The year-variable capacity rate (dollars per-MW-year, subscripted with T) is based on the most recent capacity auction results for MISO Load Zone 1 and is escalated linearly to the most recent estimate of the CONE (Cost of New Entrant) for MISO Load Zone 1 over the study period.

- The embedded T&D rate (dollars per MWh) is separately calculated for the residential and C&I classes using 2017 Xcel revenue requirements, estimated energy and capacity rates, and total energy sales.
- The marginal T&D rate (dollars per-MWh is a load- and seasonally-weighted statewide estimate based on the published study of Otter Tail Power and other publicly-available data.
- Line extension costs in the C&I scenario reflect additional local system upgrades required by increased demand from new EV load. As discussed in section 4.2, for each new incremental EV customer in a given scenario-year, this value is equal to the expected annual revenues from this customer multiplied by three. Expected annual revenues from these incremental customers are assessed by dividing incremental revenues from EV load by the number of incremental C&I EV customers, as presented below, and then multiplying the result by 3.

Equation 3. Line extension costs

$$Line\ extension\ cost\ per\ new\ C\&I\ EV\ customer =$$

$$\frac{incremental\ revenues\ from\ EV\ load_T}{incremental\ EV\ customers\ _T} \times 3$$

- We assume that line extension costs are depreciated over a 20-year period; for a given year, revenue requirements associated with line extension costs are determined by adding the depreciation expense and the return on rate base, which is the remaining non-depreciated portion of total investment in line extensions multiplying by Xcel's weighted average cost of capital (WACC) of 7.09 percent.[88]

Incremental EV contributions

New system costs associated with incremental EV load may be offset by revenues from retail sales. For all scenarios, we subtract expected revenues from incremental EV load from total scenario revenue requirements, then divide the result by total energy, less energy associated with incremental EV load to derive an *average effective rate*. While this rate is not perfectly reflective of actual rates paid by customers, it serves as a reasonable approximation and as an effective indicator of the overall system impacts of incremental EV load. Comparing scenario rates with BAU case rates for a single year provides a view of the estimated rate impacts of incremental EV load for the specified year.

Revenues from incremental EV load are calculated as follows:

[88] Northern States Power Company. "Avoided Transmission and Distribution Cost Study." 2017. Pg. 8.

- In the residential time-of-use scenarios, we assume a fixed TOU rate, and then adjust this rate each year with a true-up mechanism in proportion to the change in the average effective rate.

- The residential flat rate scenarios, we assume that scenario EV load pays the previous year's average effective rate.

- In the C&I model, we assume that owners of EV charging infrastructure are demand-metered on the general service tariff at primary voltage. Tariff charges are taken from Xcel's current schedule and are assumed to hold through the study period. We assume that these C&I customers are at the primary, rather than secondary tier, due to the heavy draw of DC fast chargers, which may require up to 400 kW of power and are expected to become increasingly mainstream with heavy duty fleet electrification.

Rate true-up

To capture the effect of regulation on utility revenue requirements, we include an annual true-up in all models to calibrate the rates the rates that applied to EV load with overall changes in average class rates.

Equation 4. EV rate true-up mechanism

$$EvRate_T = EvRate_{T-1} \times \left(\frac{ClassRate_{T-1} - ClassRate_{T-2}}{ClassRate_{T-2}}\right)$$

Other modeling assumptions

- Supply rates and the embedded capacity rate are calculated as a single, weighted dollars-per-MWh figure, based on the Encompass modeling results.

- For each scenario-year, the reported supply rate is an average of the Encompass results for that year and the results for the previous year.

- Embedded T&D and marginal T&D costs are assumed to remain constant in real terms over the study period.

- All base case energy is subject to embedded, not marginal, T&D costs.

- Systemwide peak EV load, a critical value in the C&I model which assumes demand-metering of C&I charging customers, is based upon the EV load research of DTE; for each charging customer, peak load is assumed to be at least 200 kW.

- Seasonal variation in EV energy consumption driven by worse wintertime efficiency is reflected in the marginal T&D costs, but not in the TOU rates or the monthly systemwide peak demand figures.

APPENDIX C. TOTAL COST OF OWNERSHIP, DETAILED RESULTS

Table 12. Total cost of ownership for EVs vs. ICE vehicles, 2020. All values are expressed in 2018 dollars.

	BAU	Low EV	Low EV & TOU	High EV	High EV & TOU
EV Car	$22,600	$23,100	$22,600	$23,100	$22,600
ICE Car	$28,100	$28,100	$28,100	$28,100	$28,100
Car - Delta	***-$5,500***	***-$5,000***	***-$5,500***	***-$5,000***	***-$5,500***
EV SUV	$29,800	$30,800	$29,800	$30,800	$29,800
ICE SUV	$37,000	$37,000	$37,000	$37,000	$37,000
SUV - Delta	***-$7,200***	***-$6,200***	***-$7,200***	***-$6,200***	***-$7,200***
EV Bus	$908,000	$929,400	$908,500	$929,200	$908,000
ICE Bus	$986,400	$986,400	$986,400	$986,400	$986,400
Bus - Delta	***-$78,400***	***-$57,100***	***-$77,900***	***-$57,200***	***-$78,400***

Note: Results are presented for a 200-mile battery electric vehicle as the "EV Car" and "EV SUV."

Table 13. Total cost of ownership for EVs vs. ICE vehicles, 2030. All values are expressed in 2018 dollars.

	BAU	Low EV	Low EV & TOU	High EV	High EV & TOU
EV Car	$25,900	$26,500	$26,000	$26,500	$25,900
ICE Car	$29,600	$29,600	$29,600	$29,600	$29,600
Car - Delta	***-$3,700***	***-$3,100***	***-$3,600***	***-$3,100***	***-$3,700***
EV SUV	$31,400	$32,500	$31,400	$32,400	$31,400
ICE SUV	$38,400	$38,400	$38,400	$38,400	$38,400
SUV - Delta	***-$7,000***	***-$5,900***	***-$7,000***	***-$6,000***	***-$7,000***
EV Bus	$973,900	$998,700	$975,600	$996,200	$973,900
ICE Bus	$1,113,200	$1,113,200	$1,113,200	$1,113,200	$1,113,200
Bus - Delta	***-$139,300***	***-$114,500***	***-$137,600***	***-$116,900***	***-$139,300***

Note: Results are presented for a 200-mile battery electric vehicle as the "EV Car" and "EV SUV."

Figure 20. Total cost of ownership of EVs less total cost of ownership of ICEs over time for cars (all scenarios)

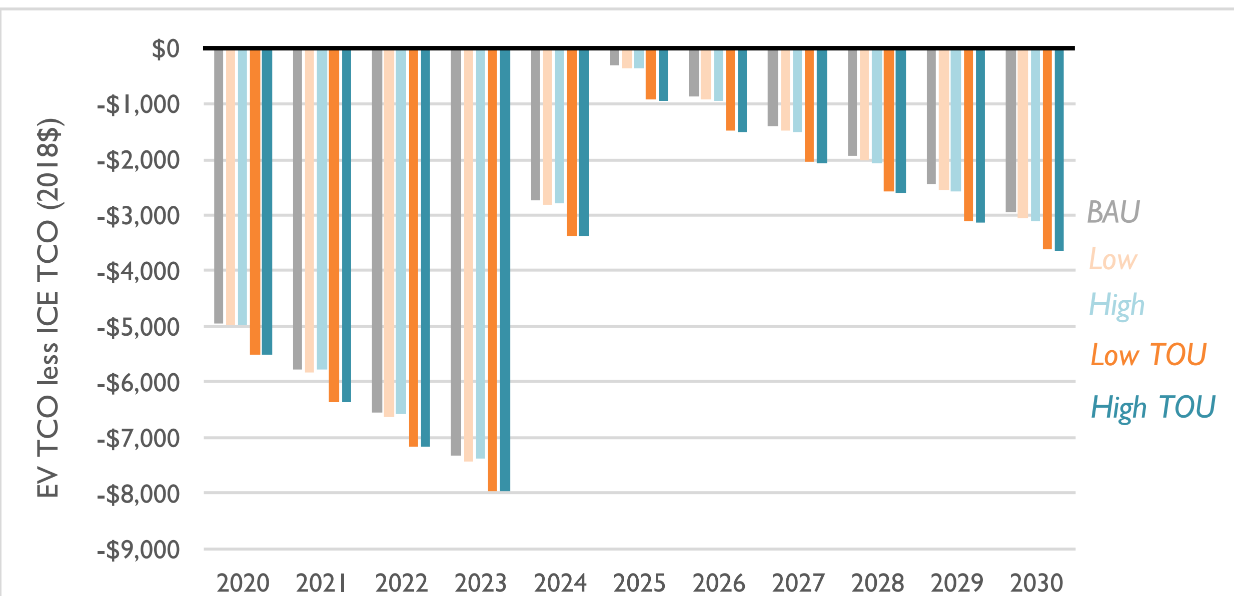


Figure 21. Total cost of ownership of EVs less total cost of ownership of ICEs over time for SUVs (all scenarios)

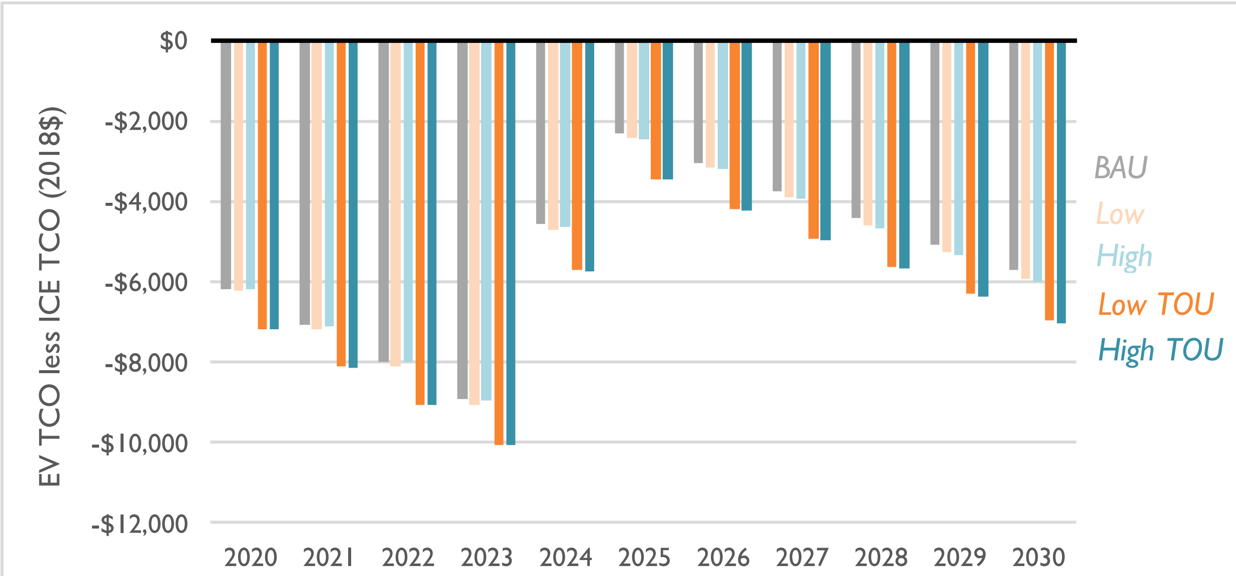


Figure 22. Total cost of ownership of EVs less total cost of ownership of ICEs over time for buses (all scenarios)

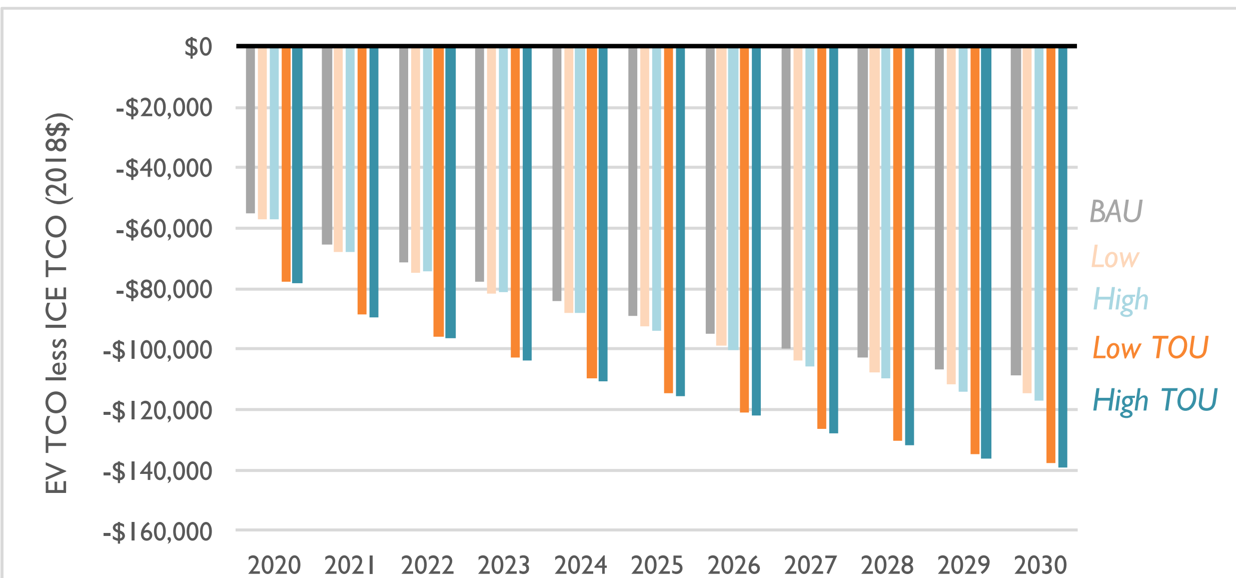


Table 14. Comparison of EV and ICE cost components, 2020 (BAU).

Cost Component	Car – EV	Car – ICE	SUV – EV	SUV – ICE	Bus – EV	Bus – ICE
Capital	$17,100	$18,100	$21,700	$22,800	$725,600	$477,400
O&M	$3,900	$5,900	$5,300	$8,900	$122,300	$348,100
Fuel	$1,600	$4,100	$2,800	$5,300	$60,100	$161,000
Total	***$22,600***	***$28,100***	***$29,800***	***$37,000***	***$908,000***	***$986,400***

Note: The capital component includes upfront vehicle costs (including sales taxes), charging costs, and resale value. The O&M component includes insurance costs and maintenance costs. All values expressed in 2018 dollars

Table 15. Comparison of EV and ICE cost components, 2020 (Low EV).

Cost Component	Car – EV	Car – ICE	SUV – EV	SUV – ICE	Bus – EV	Bus – ICE
Capital	$17,100	$18,100	$21,700	$22,800	$725,600	$477,400
O&M	$3,900	$5,900	$5,300	$8,900	$122,300	$348,100
Fuel	$2,100	$4,100	$3,800	$5,300	$81,500	$161,000
Total	***$23,100***	***$28,100***	***$30,800***	***$37,000***	***$929,400***	***$986,400***

Note: See notes on Table 14 for more information.

Table 16. Comparison of EV and ICE cost components, 2020 (Low EV & TOU).

Cost Component	Car – EV	Car – ICE	SUV – EV	SUV – ICE	Bus – EV	Bus – ICE
Capital	$17,100	$18,100	$21,700	$22,800	$725,600	$477,400
O&M	$3,900	$5,900	$5,300	$8,900	$122,300	$348,100
Fuel	$1,600	$4,100	$2,800	$5,300	$60,600	$161,000
Total	***$22,600***	***$28,100***	***$29,800***	***$37,000***	***$908,500***	***$986,400***

Note: See notes on Table 14 for more information.

Table 17. Comparison of EV and ICE cost components, 2020 (High EV).

Cost Component	Car – EV	Car – ICE	SUV – EV	SUV – ICE	Bus – EV	Bus – ICE
Capital	$17,100	$18,100	$21,700	$22,800	$725,600	$477,400
O&M	$3,900	$5,900	$5,300	$8,900	$122,300	$348,100
Fuel	$2,100	$4,100	$3,800	$5,300	$81,300	$161,000
Total	***$23,100***	***$28,100***	***$30,800***	***$37,000***	***$929,200***	***$986,400***

Note: See notes on Table 14 for more information.

Table 18. Comparison of EV and ICE cost components, 2020 (High EV & TOU).

Cost Component	Car – EV	Car – ICE	SUV – EV	SUV – ICE	Bus – EV	Bus – ICE
Capital	$17,100	$18,100	$21,700	$22,800	$725,600	$477,400
O&M	$3,900	$5,900	$5,300	$8,900	$122,300	$348,100
Fuel	$1,600	$4,100	$2,800	$5,300	$60,100	$161,000
Total	***$22,600***	***$28,100***	***$29,800***	***$37,000***	***$908,000***	***$986,400***

Note: See notes on Table 14 for more information.