Benefit-Cost Analysis of Transportation Electrification in the Xcel Energy Colorado Service Territory

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Energy+Environmental Economics

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Executive Summary

Study Aims and Methodology

Energy and Environmental Economics, Inc. (E3) modeled the economic and electric grid impacts of plug-in electric vehicle (PEV) adoption in Xcel Energy's Colorado service territory. This work aims to inform Xcel Energy, policymakers, and other stakeholders on the impacts of a pathway for PEV adoption in Xcel Energy's Colorado territory that aligns with the state Electric Vehicle Plan target of 940,000 PEV's by 2030.

E3 employed its EVGrid model to capture key interactions between drivers, vehicles, chargers, utility costs, incentives, and gasoline costs. In this study, we consider the impacts of PEV adoption from 2020 to 2030 and costs and benefits are analyzed from ratepayer, driver, and societal perspectives that are captured through three utility cost tests:

+ Ratepayer Impact Measure (RIM): the costs and benefits to all Xcel Energy Colorado ratepayers – will average utility rates increase or decrease?
+ Participant Cost Test (PCT): the costs and benefits to the vehicle driver or fleet owner – is the total cost of ownership higher or lower for the driver?
+ Societal Cost Test (SCT): the costs and benefits to Colorado State – do EVs provide net benefits for the state as a whole?

Vehicle Types and Scenarios

The study explored how costs and benefits vary under different vehicle types, charging control, charging infrastructure deployment, and utility program scenarios. The base case for each vehicle type studied and the four sensitivity cases are summarized below:

- **Personal Light-Duty Vehicle (LDV) base case:** This case calculates the costs and benefits arising from personal light duty PEV drivers. We simulate 4 different PEV types and assume charging is unmanaged in the base case.
- **Commercial LDV:** This case attempts to model the impacts of PEV adoption for rideshare drivers in Colorado. Charging is also unmanaged in the base case.
- **Transit Buses:** Transit buses are assumed to only charge at their bus depot location where each bus has access to a fast charger. Charge management occurs to minimize electricity bills.
- **School Buses:** School buses are modelled very similarly to transit buses assuming they only charge at their depot location and that charging is managed. School buses do not drive during holidays and only a fraction drive during weekends.
- **Personal LDV managed charging sensitivity:** In this scenario, charging is performed to minimize electricity bills. In addition, for residential charging it is assumed that additional charge management is performed to manage peak loads.
- **Personal LDV high DCFC sensitivity:** This scenario tests the impact of doubling the number of public DCFCs deployed across Xcel Energy Colorado territory. The scenario assumes adoption is increased by 20% relative to the personal LDV base case due to increased consumer awareness and lower range anxiety.

- **Personal LDV socializing charger costs sensitivity:** This sensitivity case assumes that Xcel Energy contributes 50% towards all charging infrastructure costs behind the customer meter.
- **Commercial LDV expensive public charging rate sensitivity:** Under the base scenario we assume commercial LDV drivers pay the utility tariff rate for all public charging (the S-EV tariff). This scenario instead uses the upper end of today's fees for charging in pubic (currently around $0.55/kWh) to understand how this affects the economics of PEV ownership.

Base Case Results

Overall, this study finds that under the base scenarios for all vehicle types *ratepayers stand to benefit by nearly $1.07 billion* in net present value from PEV adoption between 2020 and 2030. *Drivers or fleet owners would benefit by $358 million* in lower total cost of ownership and *Colorado would benefit by $1.51 billion* from avoided gasoline, reduced O&M, emission reductions, and federal and state tax credits. Table 1 summarizes the total Net Present Value (NPV) of all cases. These values represent the total costs and benefits over each vehicles' 12-year lifetime, summed for every vehicle adopted from 2020 to 2030 and discounted using Xcel Energy's weighted average cost of capital.[1]

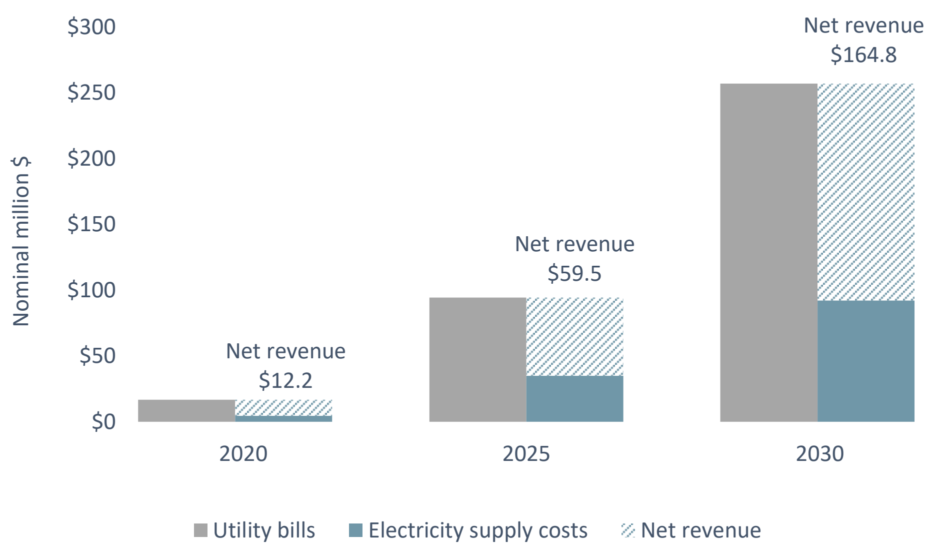
Table 1. Total Net Present Value (NPV) for all vehicles adopted between 2020 – 2030 in ($ Million)

Case	RIM	PCT	SCT
Personal LDV - base case	$1,018	$326	$1,426
Commercial LDV	$16	$29	$42
School Buses	$7	($27)	($19)
Transit Buses	$27	$30	$59
Sensitivities			
Personal LDV - managed charging	$1,054	$555	$1,533
Personal LDV - high DCFC	$1,193	$577	$1,571
Personal LDV - 50% socialization	$703	$641	$1,426
Com LDV - expensive public charging rates	$16	($41)	$42

[1] Note that the costs and benefit streams that contribute to the NPV values calculated extend out to 2042 since all vehicles adopted in the last year of the study period, 2030, would continue to provide costs and benefits over their full lifetime which is assumed to be 12 years.

The aggregate impact on Xcel Energy's Colorado ratepayers under the base case scenario is summarized in Figure 1, and shows that by 2030 revenue collected from tariffs is over $257 million or an average of $0.12/kWh (in 2030 nominal dollars) which exceeds the total cost to serve PEV charging load at $92 million ($0.04/kWh). Under all vehicle types and every case explored ratepayers benefit substantially from PEV adoption.

Figure 1. Annual utility net revenue from transportation electrification ($ nominal)

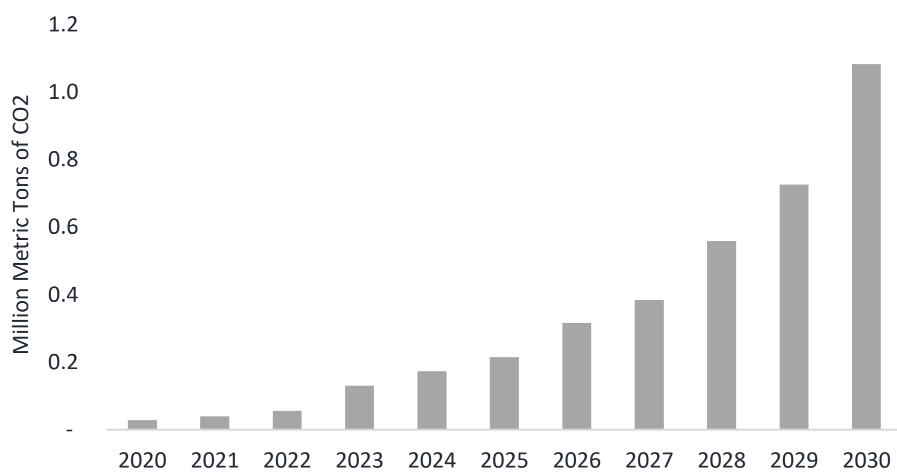


Driver or fleet owner benefits, as reported in the vehicle results sections on a per vehicle basis, show that for nearly all cases PEVs are cheaper in total cost of ownership than ICE vehicles. This is primarily from reduced gasoline or diesel consumption and reduced O&M. Over the vehicle lifetime, these savings outweigh the higher upfront cost of PEVs, the charger installation costs, battery replacements, and charging costs. Drivers also benefit from tax credits at the federal and state level.

The societal benefits to Coloradans in Xcel Energy territory amount to nearly $1.51 billion for all PEVs adopted between 2020 and 2030 over each vehicles' lifetime. The benefits from avoided gasoline and O&M costs (referred to as eVMT savings) and emission savings far exceed the charging infrastructure, electric supply, and incremental vehicle costs in all but the school bus cases. Note that the societal cost benefit results presented in this study do not include other indirect benefits such as the energy security value from lower reliance on fossil fuels and monetized health impacts of reduced criteria pollutants (although emission values are reported).

For all vehicle types and scenarios explored in this study, the CO_2 emissions from electricity generation to meet charging load were lower than the emissions from gasoline or diesel combustion. Total CO_2 emission reduction for all PEVs adopted between 2020 and 2030 sum to 11.7 million metric tons (MMTons) over vehicle lifetimes, with annual CO_2 emission savings peaking in 2030 at 1.1 MMTons /year. Other pollutants were also included in the analysis: emissions from NO_x were found to decrease with PEV adoption by 3,242 metric tons while SO_2 emissions are projected to *increase* by 1,151 metric tons relative to the adoption of new ICE vehicles.

Figure 2. Annual avoided CO_2 emissions from all vehicle types



Sensitivity Case Results

Additional key findings from sensitivity cases include:

+ The managed charging sensitivity demonstrates the large benefits that could be obtained from managed charging to minimize utility bills, which increases drivers' bill savings by 70% and ratepayer benefits by a total of $36 million.
+ Doubling DCFC deployment in Colorado could increase ratepayer benefits by $175 million *if* PEV adoption is increased by 20%, however PEV adoption impacts of DCFC deployment remain highly uncertain.
+ Ratepayers would still benefit by an NPV of $703 million if Xcel Energy paid for 50% of residential charging infrastructure costs behind the meter and driver net benefits would nearly double. This does not include any increase in adoption from reducing upfront costs for drivers.

+ Rideshare electrification could *cost* the average rideshare driver a total of $34,048 over the vehicle's lifetime if the cost of charging in public remains the same as it is today. If rideshare drivers were to pay for public charging at Xcel Energy's commercial tariff (S-EV) rate or if access to charging at home were increased, particularly at multi-unit dwellings, this could reduce lifetime costs by up to $77,000 per vehicle which would make PEV adoption a substantial net *benefit* for rideshare drivers.[2]

[2] Average values per vehicle are calculated by taking the final NPV result for all vehicles adopted between 2020 – 2030 and dividing it by the total number of vehicles adopted during this period.

1 Study Aims

Colorado is one of the leading states advancing transportation electrification in the US and has enacted various regulations, laws, and incentives in recent years. The first Colorado Electric Vehicle Plan published in 2018 set the goal of reaching 940,000 EVs on the road by 2030 and in August 2019 Colorado became the eleventh state in the US to adopt ZEV standards. This study evaluates the costs and benefits of PEV adoption aligned with this target in Xcel Energy's Colorado territory (U.S. Department of Energy, 2020; Colorado Energy Office, 2020). Specifically, this study aims to support Xcel Energy, policymakers, and other stakeholders in understanding:

+ the costs and benefits of plug-in electric vehicle (PEV) adoption, from a ratepayer, driver, and broader societal perspective,
+ the potential value of systems or programs that manage the timing of PEV charging,
+ potential carbon dioxide reductions from electrified transportation, and
+ potential impacts of electric vehicles on utility planning, specifically electricity consumption and planning loads.

2 Methodology

2.1 Cost-Benefit Overview

To perform a Benefit Cost Analysis (BCA) of transportation electrification in Xcel Energy's Colorado service territory, E3 compared the costs and benefits accrued over the lifetime of each PEV adopted against an equivalent Internal Combustion Engine (ICE) vehicle. Whether a particular value stream is a cost or a benefit depends on the perspective taken. E3 performed BCAs from the perspective of EV owners (drivers), other utility customers, and Colorado as a whole. Each perspective offers distinct insights that help describe the overall impact of EV adoption in Xcel Energy's Colorado territory and inform development of policy and programs. The three perspectives are as follows:

+ Ratepayer Impact Measure (RIM): the costs and benefits to all Xcel Energy Colorado ratepayers – will average utility rates increase or decrease?
+ Participant Cost Test (PCT): the costs and benefits to the vehicle driver or fleet owner in the case of buses – is the total cost of ownership higher or lower for the driver?
+ Societal Cost Test (SCT): the costs and benefits to Colorado State – do EVs provide net benefits for the state?

Table 2 provides and overview of the various costs and benefits analyzed under each perspective:

Table 2. Cost and benefits associated with each cost test perspective

Cost/Benefit Component	PCT	SCT	RIM
Incremental EV cost	Cost	Cost	
Federal & State EV tax credit	Benefit		
EV O&M savings	Benefit	Benefit	
Fuel savings	Benefit	Benefit	
Electricity Supply Costs for EV charging		Cost	Cost
Charging infrastructure cost	Cost	Cost	
Electricity Bill for EV charging	Cost		Benefit
Emission savings		Benefit	

2.2 Modelling methodology

E3's EVGrid model performs BCAs from each of the perspectives described above and uses various input streams that are described in detail in the Inputs and Assumptions section. The model calculates the net present value of EV adoption relative to gasoline vehicles across a region of interest. Accurate forecasting of electricity supply costs and electricity bills depends strongly on the hourly load shape from PEV charging. Charging load shapes in turn vary substantially across the driver population and depend on several factors such as vehicle type, charging access, cost of charging and many others.

To model charging behavior E3 has developed a bottom-up modelling approach that simulates driving and charging of thousands of PEV drivers. Driving behavior is captured using travel survey data and converted to 15-minute driving patterns though a Markov-Chain Monte Carlo method. The driving population is characterized by drivers' access to charging and the type of EV they drive. For personal Light-Duty Vehicle (LDV) cases there are 4 PEV types and 6 charging access types, resulting in 24 combinations or customer types. Potential charging locations are categorized into residential, workplace, and public areas and drivers choose where and when to charge by minimizing their charging cost through linear optimization subject to various constraints. This generates a normalized load shape for each customer type which are then scaled by portion drivers representing that customer type. The final load shape therefore captures the diversity of driving behavior, charging access, and PEV adoption across the driving population.

In addition, charging sessions can then be further managed to minimize peak loads or demand charges at each location through a heuristic cost minimizing method. This modelling framework enables PEV charging load shapes to be generated under various scenarios for Vehicle-Grid Integration (VGI), charging infrastructure deployment, and adoption scenarios. PEV charging load shapes output from EVGrid's load shape module have been benchmarked and calibrated using real OEM charging session data.

2.3 Modelling Scenarios

This study calculates the lifetime costs and benefits for every PEV adopted between 2020 – 2030. Personal LDV, Commercial LDV (rideshare drivers), transit bus, and school bus vehicle types were modelled encompassing a majority of future PEV adoption in Xcel Energy's Colorado territory. There were also sensitivities conducted for the LDV cases, which E3 expects will make up 99% of

PEV adoption and 95% of forecasted PEV charging load by 2030. Each case is described below:

- **Personal LDV base case:** This case calculates the costs and benefits arising from personal light duty PEV drivers. We simulate four different PEV types and assume charging is unmanaged or uncontrolled. Drivers are still sensitive to the average cost of charging in each location and choose where to charge based on this cost, but when they arrive at a location that they plan to charge in they immediately plug-in and the vehicle is charged at the maximum rate until the battery is full or the vehicle leaves the charging premises.
- **Commercial LDV:** This case attempts to model rideshare drivers in Colorado. These drivers own their vehicle, some have access to charging at home, but most rely on public charging infrastructure. Charging is unmanaged in this case.
- **Transit Buses:** Transit buses are modelled as only charging at their bus depot location where each bus has access to a fast charger. It is assumed electric transit buses are only assigned shorter routes where daily mileage is less than the vehicle range. Charge management minimizes demand and energy charges.
- **School Buses:** Similar to transit buses, school buses are assumed to only charge at their depot location. School buses do not drive during holidays and only a fraction drive during weekends. Charing is also assumed to be managed.

A number of sensitivities were explored for the LDV cases to evaluate different electrification scenarios:

- **Personal LDV managed charging:** In this scenario, charging is performed to minimize the driver's cost of charging. Charging is managed on a 15-minute basis to minimize energy and demand charges. In addition, for residential charging it is assumed that additional charge management is performed by Xcel Energy to mitigate the impact of rebound peaks when the off-peak TOU period begins. This is performed by a combination of cascading charging start times over a 45-minute interval and peak 'flattening' where charging is further staggered throughout the period the vehicle is parked.

+ **Personal LDV high DCFC:** This scenario tests the impact of doubling the number of public DCFCs deployed across Xcel Energy's Colorado territory. The scenario assumes adoption is increased by 20% relative to the personal LDV case to account for the indirect network effects of reducing range anxiety and increasing consumer awareness from having a denser DCFC network.
+ **Personal LDV socializing charger costs:** Here it is assumed that Xcel Energy contributes 50% towards all charging infrastructure costs behind the customer meter. This case is a simple reallocation of costs. No impact on adoption or charging shape and no additional utility rate base or return on equity is assumed.
+ **Commercial LDV expensive public charging rates:** Under the base scenario we assume commercial LDV drivers pay the utility tariff rate for all public charging (the S-EV tariff). This scenario instead uses the upper end of today's fees for charging in pubic (currently around $0.55/kWh) to understand how this affects the economics of PEV ownership.

3 Inputs and Assumptions

3.1 Driving and Charging Behavior

To simulate PEV driving and charging behavior the team utilized thousands of vehicle trips from detailed trip datasets. For the personal LDV case, trip data was extracted from the 2017 National Household Travel Survey (NHTS) (Federal Highway Administration, 2017), for commercial LDV case the Chicago Taxi trip database (City of Chicago, 2020) was used, and for both bus cases the NREL Fleet DNA database (NREL, 2019) was used. Each dataset was cleaned, filtered for the specific vehicle of interest, and where possible filtered for Colorado trips only. The origin and destination locations were categorized and the mileage was adjusted slightly to align with Colorado specific annual VMT sources as shown in Table 3.

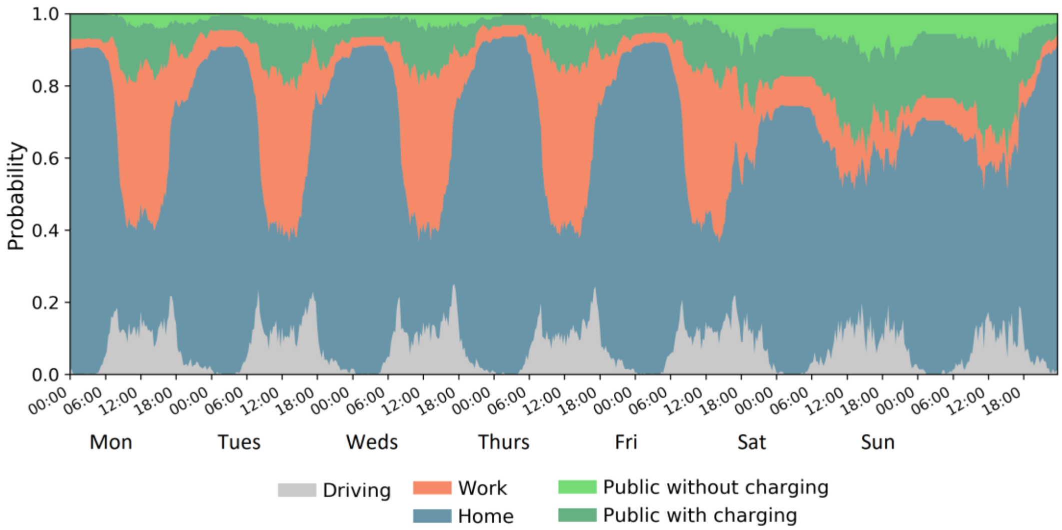
Table 3. Annual VMT for each vehicle class

PEV category	Annual VMT
Personal LDVs	12,861[3]
Commercial LDVs	58,689[4]
Transit buses	42,500[5]
School buses	12,792[6]

[3] Colorado personal LDV mileage from the National Transportation Statistics 2017 (Bureau of Transportation Statistics, 2018)
[4] Taken from the Chicago Taxi trip database (City of Chicago, 2020) and mileage adjusted for Colorado taxi deadhead hours and trip lengths using Colorado specific rideshare data (Henao, 2017)
[5] Colorado specific transit VMT from (Federal Transit Administration, 2019)
[6] Taken from (U.S. Department of Energy, 2020; NREL, 2019)

A random sample of trips is then drawn from the dataset covering 500 driver days to construct driving profiles through a Markov-Chain Monte Carlo approach. An example weekly driving pattern for a group of drivers is shown in Figure 3.

Figure 3. A weekly driving profile generated for personal LDV drivers using 2017 NHTS data and the Markov Chain methodology



Drivers who had travel days that could not be completed using the EV and charging access options assigned to them were deemed to have 'unserved driving energy' and were dropped from the sample to generate the final aggregated charging loads. This implies that drivers with driving patterns where they cannot complete their travel day with the EV and charging access they were assigned would not purchase this EV type and would not therefore contribute to the final load. A minimum dwell time of 15 mins was set for charging, if the driver was parked at a destination for less time than this time, no charging was assumed to occur.

Due to the computational intensity of simulating driving and charging behavior only a winter and summer week in 2025 was simulated, the resulting load shapes were scaled based on PEV adoption and interpolated for adoption forecast between 2020 – 2030.

3.2 EV Adoption

EV adoption assumptions in this analysis are based on forecasts by Xcel Energy's EV strategy team for Colorado territory. Personal LDVs are expected to grow cumulatively to 451,342 vehicles in Xcel Energy's territory in 2030, capturing a market share of 17% as visualized in Table 4Table 4. The total market for LDVs is expected to grow 1.1% per year, following assumptions by the FHWA on growth of VMT in the US (FHWA, 2019). In the high DCFC case, E3 estimates a slightly higher adoption curve of EVs assuming driver's range anxiety declines with more fast charging possibilities. Conservative assumptions in literature describe how a 100% increase in DCFC stock results in 20% increase in EV adoption (Li, et al., 2016).

Commercial LDV population was extrapolated based on employment statistics of drivers and chauffeurs in Colorado and adjusted for an update that included ride-hailing drivers (U.S. Bureau of Labor Statistics, 2018). The team estimated 2,740 commercial LDVs in 2020 in Xcel Energy's Colorado territory and 3,288 in 2030. EVs are forecasted to grow from 204 vehicles in 2020, following the announcement by Lyft to introduce 200 electric vehicles in 2020, to 1,644 vehicles in 2030 (Paul & Chuang, 2019). Based on a "clean mile" target proposed to SB 1014 in California (Anon., 2018), the team assumes the share of electric taxis would grow to 50% in 2030 in Colorado.

For buses, we follow the growth rate of Xcel Energy's EV forecast assumptions for Heavy Duty Vehicles. This results in a gradual increase toward 520 electric transit buses in 2030 in Xcel Energy territory, corresponding to a market share of around 68%. For school buses, we assume 575 electric buses on the road in 2030, corresponding to a market share of around 24%.

Table 4. Overview of EV adoption per vehicle category

PEV category	Total Vehicles*	2020 PEV	2025 PEV	2030 PEV
Personal LDVs	2.68 million	30,450	169,211	451,342
Personal LDVs – high DCFC	2.68 million	36,540	203,065	541,611
Commercial LDVs	3,288	205	863	1,644
Transit buses	760	22	70	520
School buses	2,389	25	77	575

*Total Vehicles in Xcel Energy's Colorado territory in 2020 (PEV + ICE)

3.2.1 CHARGING ACCESS

To model charging behavior the driving population is segmented by where they have access to charging and by PEV type. For personal LDV cases six charging access types are used, while for commercial LDV cases only 3 are assumed. For bus cases, it is assumed that charging access is limited to the bus depot, so no split is required.

For personal LDVs the team used information on population and housing type from the American Community Survey (ACS) to estimate the number of households by type, the percentage of each household type that own a car, and the percentage of car owners that drive to work (U.S. Census Bureau, 2016). The team then used a report from University of California, Davis to estimate the availability of home charging at each type of housing and the percentage of vehicles that would charge at home, at work, and on public chargers (Nicholas & Tal, 2017).

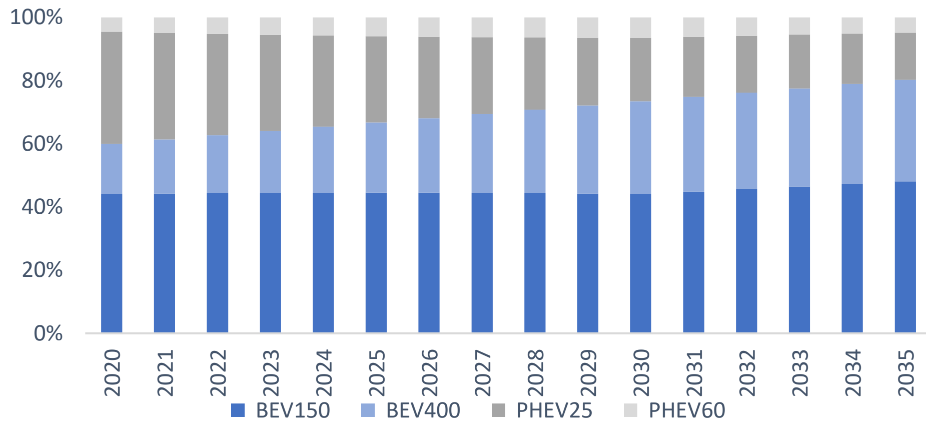
For commercial LDVs, due to limited data availability, the team halved the percentage of drivers with access to home charging for personal LDVs and assigned the rest of the population to having access to public charging only. In this study, 42% of commercial LDV drivers would have access to home charging and 58% would charge on public chargers only. This is consistent with the findings that around 24% of Colorado residents and 44% of residents of Denver live in multi-family housing (Svitak, et al., 2017) and most TNC drivers do not have home charging (Colorado PUC, 2019).

3.2.2 PEV TYPES

The driving population was also segmented by the type of PEV driven, for LDV cases four PEV types were used distinguishing long- and short-range BEVs and PHEVs. Transit bus cases had only 1 BEV for each case. The split between BEV and PHEVs is based on the Bloomberg New Energy Finance EV outlook (BNEF, 2019) while the split between long and short range PEV types were used to ensure the average BEV and PHEV range was aligned with forecasts from NREL (Kontou, et al., 2018).

Figure 4. shows how the vehicle mix used in this study gradually changes towards 2030, assuming a growing role for battery electric vehicles as the market matures.

Figure 4. Cumulative) change in vehicle mix - 2020 -2035



3.3 Vehicle and charger parameters

This study includes an analysis of four driver types: personal LDVs, commercial LDVs, school buses and transit buses. The team assumed that both personal and commercial LDVs adopt the same vehicles types in the same proportions over the modelling period. As described in section 3.2.2 for LDVs four vehicle types were modelled, for which vehicle and charger parameters are shown in Table 5. Note that as described in section 3.1, only charging profiles for 2025 were simulated. The normalized charging profiles for each of the four LDV types were scaled using their relative proportion by year over the modelling period to represent growth in average BEV and PHEV ranges over time. Therefore, the range of BEVs and PHEVs selected represent the lower and upper end of potential vehicle ranges that may be on the market by 2030.

LDVs are expected to have an efficiency of 0.35 kWh/miles based on the weighted average of the LDV market in Colorado. An efficiency de-rate of 10% was applied for colder temperature driving during the winter period from a US Department of Energy source adjusted for the vehicle mix in Colorado (U.S. Department of Energy, 2020; Auto Alliance, 2020).

Table 5. Vehicle and charger parameters of LDVs

Vehicle type	Electric range (miles)	Battery size (kWh)	Max DC charging power (kW)	Max AC charging power (kW)
BEV – long range	400	140	20	105
BEV – short range	150	52.5	20	50
PHEV – long range	60	21	3.6	n/a
PHEV – short range	25	8.75	3.6	n/a

Different parameters were used for transit and school buses based on the vehicle duty cycle. Transit buses require large daily mileage with few in-between charging stops, whereas school buses have lower daily mileage and distinct driving peaks in mornings and late afternoons, leaving room for mid-day charging. The vehicle and charger parameters of both vehicle types are summarized in Table 6. Both bus types are assumed to only use 80% of their total battery capacity to preserve battery life and provide emergency backup. The vehicle efficiencies of both vehicle types are derived from (Eudy & Jeffers, 2018) and (VEIC, 2020).

Table 6. Vehicle and charger parameters of buses

Vehicle type	Effective electric range (miles)	Battery size (kWh)	Max charging power (kW)	Vehicle efficiency (kWh/miles)
Transit buses	170	625	50	2.84
School buses	90	200	20	1.81

3.4 Utility tariffs and charging costs

Residential locations were assigned Xcel Energy's Modified Residential TOU rate[7] (effective January 1, 2021) and Xcel Energy S-EV rate was applied to workplace, public, and bus depot locations. The team also assumed 25% of EV drivers have access to free charging at workplace. It was assumed that all EV chargers were separately metered and therefore building loads were not included when calculating demand charges for the S-EV rate. Since the intention is to measure the impact of EV charging on utility bills versus a counterfactual where an ICE vehicle is owned, all metering charges and fixed charges were not included in the bill calculation for simplicity. Tariffs energy and demand charges are assumed to grow at the inflation rate of 2%/year.

For personal and commercial vehicles, the rates paid by the drivers are distinguished from the electricity bills paid by charging station site hosts for public locations, see Table 7. Commercial charging prices for L2 and DCFC chargers were selected from a publicly available source[8] to reflect the charging costs EV drivers pay at public locations, which are often much higher than the S-EV rate paid by charging station site hosts or owners. This difference will reflect again on the cost

[7] See Steven Wishart's testimony in December 2019 (Public Utility Commission of Colorado , 2019)
[8] Blink member charging fees for Colorado taken from (Blink, 2020)

of charging to drivers in the Participant Cost Test (PCT) and the utility revenue for ratepayers in the Ratepayer Impact Measure (RIM).

Table 7. Charging fees paid by EV drivers versus charging site hosts or owners

	Home	Workplace	Public	Bus Depot
Drivers	Modified RE-TOU	75% S-EV 25% free	Blink L2 or Blink DCFC	S-EV
Charging Site Hosts	-	S-EV	S-EV	S-EV

Table 8. Rate information

	Critical Peak	Peak	Shoulder	Off-peak	Peak Period Definition
Modified RE-TOU	-	0.18	0.13	0.09	Peak: Summer weekdays 3pm-7pm Shoulder: Summer weekdays 11am – 3pm & 7pm-10pm
S-EV (Winter)	-	0.12	-	0.06	Peak: weekdays 12pm – 9pm Critical peak pricing is added to one day in a week in summer from 3pm – 6pm
S-EV (Summer)	1.67	0.18	-	0.09	
Blink L2	-	0.44	0.44	0.44	-
Blink DCFC	-	0.54	0.54	0.54	-

The rates above were used to simulate PEV charging in EVGrid by minimizing the driver's electric bill. For commercial LDV rideshare drivers (such Lyft or Uber) time spent charging during shifts hours could reduce revenue potential from fares. The team therefore added an opportunity cost for charging during shift hours to reflect the cost of time that could have been spent earning income. This results in faster charging being heavily favored by commercial drivers when on shift due to the shorter charging sessions. Note these costs were only applied during the driving and charging simulations to create charging load shapes and were not applied to the bill calculation used in the cost benefit analysis.

Opportunity cost ($/kWh)[9] = expected earning of a driver / charger power

Table 9. Commercial LDV Opportunity Costs ($/kWh)

Location	Initial Rate	Opportunity Cost	Final Rate
Residential	0.09 - 0.18	0	0.06 – 0.18
Public L2	0.44	2.37	2.82
Public DCFC	0.54	0.31	0.85

3.5 Incremental Vehicle Costs

On average, electric vehicles are currently more expensive in purchase price than their ICE counterparts, mostly as a result of battery costs. E3 used the base assumptions on the purchase price for both electric and ICE LDVs in the US from recent projections by the ICCT (ICCT, 2019). These were specified for vehicle mix and battery packages as used in this analysis, resulting in average incremental vehicles costs of an EV over an ICE vehicle of $8,920 in 2020. As battery costs are

[9] Expected earnings for a driver in Colorado is around $15.69/hr (Henao, 2017)
L2: $15.69/6.6kW = 2.37
DCFC: $15.69/50 kW = 0.31

forecasted to decline towards 2030, incremental vehicle costs are reduced to $1,721 in 2030.[10]

As the annual mileage for commercial rideshare LDVs is very high, E3 estimated battery replacement costs on top of incremental vehicle costs. Assuming a lifespan of a battery pack of around 150,000 miles, E3 estimates commercial LDV's to require battery replacements every 3 years, while an ICE vehicle is replaced after 6 years. Battery replacement costs are calculated using battery costs projections by ICCT combined with labor costs specific to Colorado.

For transit buses, E3 used incremental vehicle costs based on Bloomberg's report on electric buses in cities, corrected for the battery pack size for transit buses used in this analysis (BNEF, 2018). Transit buses are also expected to need battery replacements because of high annual mileage. E3 estimated battery replacements of transit buses at every 4 years, compared to ICE replacements of 12 years. This brings the total incremental vehicle costs for transit buses at $237,595 in 2020, declining to $126,014 in 2030 as a result of declining battery costs.

The relative gap between electric school bus costs and their diesel counterparts is larger than for transit buses. In 2020, incremental vehicle costs are fairly similar to transit buses at $213,614. These costs are based on an analysis of manufacturing data of the Vermont Energy Investment Corporation (VEIC, 2020) and research by the University of Delaware (Noel & McCormack, 2014). As shown in Table 10, the decline in incremental costs is slower for this vehicle group since

[10] In nominal dollars - based on battery costs projections by ICCT (2019)

battery costs take up a much smaller portion of total partly due to lower battery replacement needs.

Table 10. Incremental vehicle costs per vehicle category (Nominal $)

PEV category	2020	2030
Personal LDVs	8,920	1,721
Commercial LDVs	15,047	2,381
Transit buses	237,595	126,014
School buses	213,614	219,295

3.5.1 TAX CREDITS

To reduce the impact of upfront incremental vehicle costs, all EV drivers in Colorado benefit from both federal and state tax credits. Federal tax credits amount up to $7,500 per BEV purchased, phasing out when at least 200,000 vehicles have been sold by each manufacturer in the U.S which E3 assumed would occur by 2023 (Internal Revenue Services, 2020). In addition, Coloradans benefit from the Innovative Motor Vehicle and Truck Credits which reduce upfront vehicle costs by $4,000 per LDV and $16,000 per HDV if purchased in 2020, dropping to $2,000 per LDV and $16,000 per HDV by 2026 (CDOR, 2020).

3.6 Avoided Electric Vehicle Miles Travelled (eVMT)

Avoided electric Vehicle Miles Travelled (eVMT) costs in our analysis are based on two factors: avoided fuel costs and avoided operation and maintenance (O&M) costs. For avoided fuel costs, we calculate the amount of fuel an ICE vehicle would have used under the same circumstances over the lifetime of the vehicle, multiplied by the costs of fuel in each year. The average annual fuel consumption avoided per EV per year is assumed to decrease over time according to the relative improvement in ICE vehicle fuel efficiency projected by NREL in their Light-Duty Vehicle Attribute Projections prepared for the California Energy Commission (Kontou, et al., 2018). The assumed fuel efficiencies per vehicle category are shown in Table 11.

Table 11. Fuel economy assumptions

Year	LDVs (miles/gallon gasoline)	Buses (miles/gallon diesel)
2020	31.5	7.3
2025	35.6	7.7
2030	36.9	8.1

Gasoline and diesel forecasted prices are derived from the EIA Annual Energy Outlook 2020 and include an inflation rate of 2%/year to convert them to nominal dollars. Table 12 shows the projected fuel costs for both gasoline and diesel for several end years (U.S. Energy Information Administration, 2020).

Table 12. Fuel price forecast (Nominal $)

Year	Gasoline (nom $/gallon)	Diesel (nom $/gallon)
2020	2.65	3.00
2025	2.83	3.37
2030	3.29	3.91
2035	3.89	4.54
2040	4.49	5.18

Note that these gasoline prices are based on the EIA's latest long-term price forecasts which were published in January 2020 and therefore do not include recent price impacts of the 2019 novel coronavirus disease (COVID-19). While it is uncertain what the long term price impacts are, the EIA's current Short-Term Energy Outlook shows the price impacts are expected be largest in the second quarter of 2020 and then dissipate over the following 18 months (U.S. Energy Information Administration, 2020). Given that much of the avoided gasoline in this study occurs beyond 2025 based on PEV adoption forecasts, this should not have a substantial impact on the analysis.

To calculate annual O&M savings, E3 multiplied annual mileage of different vehicle categories by an estimation of the per mile difference between maintenance costs for ICE and electric vehicles. To inform these estimates for LDVs, E3 used data provided by the International Council on Clean Transportation, estimating conventional vehicle maintenance costs for LDVs at $0.061 per mile versus $0.026 per mile for their electric counterparts (ICCT, 2019).

For buses, E3 assumed maintenance costs of conventional diesel school and transit buses at a relatively conservative estimate of $1.00 per mile following the Bus Lifecycle Cost Model developed by the US Department of Transportation (US DOT Volpe Center, 2019). Electric bus maintenance costs are considered significantly less expensive due to the relatively simple drive system compared to diesel buses. Although exact numbers are still uncertain with relatively few electric buses on the road, the University of Delaware research on electric school buses estimated the cost to maintain an electric school bus at $0.20 per mile (Noel & McCormack, 2014). For transit buses, E3 used a recent study on lessons learned from electric buses currently on the road, which states maintenance costs of electric buses at $0.55 per mile for a study on 16 electric buses (Frontier Group, US Pirg Education Fund, 2019).

3.7 Electricity Supply Costs

Utility electricity supply costs are calculated by multiplying the hourly marginal electricity supply costs with hourly electric PEV charging load. Recall that this study focuses only on adoption between 2020 – 2030 but to account for costs and benefits over the each PEVs' 12 year lifetime, electric supply costs are calculated for charging load out to 2042, when it is assumed all EVs adopted by 2030 will have been retired.

The marginal electricity supply cost used in this analysis is comprised of four components. Xcel Energy provided marginal energy costs ($/MWh), avoided distribution cost ($/kW-year) and avoided transmission cost ($/kW-year) from 2020 to 2042. The generation capacity cost ($/kW-year) provided is only available for 2020 to 2029 and the team applied the 2029 cost to future years, adjusted for inflation, assuming combustion turbine (CT) on the margin.

Table 13. Marginal Electricity Cost Components

Component[11]	Description
Energy	Increase in costs due to change in production from the marginal generator
Generation Capacity	Increase in fixed costs of building new generator to meet the incremental EV load
Transmission Capacity	Increase in fixed costs of building or maintaining transmission lines to meet the incremental EV load
Distribution Capacity	Increase in fixed costs of building or maintaining distribution lines to meet the incremental EV load

[11] All cost components have loss factors included.

To allocate the kW-year generation and transmission capacity costs to hourly values in $/kWh the PCAF (Peak Capacity Allocation Factor) methodology was used[12]. Using hourly net system load from 2020 to 2035 a threshold (MW) corresponding to the top 250 net load hours was selected. In hours where the net load exceeds the threshold, the exceeded load is divided by the total exceeded load for the 250 hours to create an hourly PCAF allocation factor that sums to 1 over the year. For years beyond 2035, the team used the 2035 PCAF shape.

$$\text{Exceeded load}_t = \min(0, \text{load}_t - \text{the } 250^{th} \text{ top load in a year})$$

$$\text{PCAF}_t\ (\%) = \text{Exceeded load}_t \,/\, \text{total exceeded load in a year}$$

$$\text{Capacity value}_t\ (\$/\text{kWh}) = \text{PCAF}_t\ (\%) * \text{capacity value } (\$/\text{kW-year})$$

This same methodology was applied to allocate the distribution capacity value using a typical 2019 residential distribution load provided by Xcel Energy from the Allison feeder.

3.8 Avoided Emissions

Avoided emissions are calculated based on the difference between electric vehicle emissions from charging load and gasoline or diesel combustion. For CO_2, E3 calculated avoided emissions for ICE vehicles based on 0.0085 metric ton/gallon of gasoline and 0.01098 metric ton/gallon of diesel.[13] Emissions from

[12] The methodology was first developed by PG&E in 1993 (California Public Utilities Commission, 2016) and has since been used in various regulatory reports, for example see (Energy & Environmental Economics, 2012)
[13] Derived from the Argonne GREET Model

electric vehicles are expected to decrease over time following the growth of renewables in Xcel Energy's generation mix. For this study, E3 looked at average hourly electricity emissions provided by Xcel Energy between 2019 and 2042 which decline by almost 70% over the period. To convert avoided emissions to costs, E3 assumed social costs of carbon of 46 $/metric ton.

3.9 Charging Infrastructure

3.9.1 CHARGER NETWORK DENSITY

E3 calculated the required number of EVSE chargers to support the vehicle adoption forecasts using NREL's EVI-Pro Lite model (NREL, 2018). EVI-Pro Lite can provide a state specific estimation of the number of workplace, public and DCFC charging required to meet a given adoption forecast. Note that this model only provides a value for meeting personal LDV adoption, does not account for the impacts of managed charging, and only provides values for a maximum PEV market penetration of 10% of total LDV stock. For buses specifically, E3 assumes a ratio of 1 transit bus per DCFC charger due to limited time available for charging, while school buses share 1 charger for every 2 buses. Under these assumptions, the PEV adoption forecast for the Xcel Energy Colorado territory requires the installation of 224,929 EVSE charging ports by 2030, 89% of which are L2 home chargers. Table 14 provides an overview of the number of EVSE chargers for 2020, 2025 and 2030.

Table 14. Number of required charging ports in Xcel Energy's Colorado territory

EVSE type	2020	2025	2030
Home L2	13,399	74,638	199,314
Public L2	648	3,619	9,638
Workplace L2	923	5,154	13,727
DCFC	132	650	2,250
Total	**15,101**	**84,061**	**224,929**

3.9.2 CHARGER COSTS

Charging infrastructure costs in this analysis are based on two components: EVSE hardware costs and installation costs ("make-ready" costs). The latter component includes all *behind the meter* costs required to get the charging unit working. We assume that infrastructure costs "in front of meter" are paid for by the utility and therefore included under electricity supply costs.

The costs of charging infrastructure are outlined in Table 15. These costs are based on data provided by the International Council on Clean Transportation, with installation costs of home charging averaged based on the proportion of existing types of homes in Colorado (ICCT, 2019). Installation costs for public, workplace and DCFC 150 kW chargers are based on costs per charger with 2 chargers per site, whereas installation costs for DCFC 20 and 50 kW chargers are based on costs per charger with multiple chargers on site (since these chargers are assumed to be installed at large-scale bus depots).

Table 15. Charging Infrastructure Costs

	Hardware		Installation		Total	
Home L2	$	742	$	1,299	$	2,040
Public L2	$	3,127	$	3,020	$	6,147
Workplace L2	$	3,127	$	3,020	$	6,147
DCFC (20 kW)	$	11,360	$	10,786	$	22,146
DCFC (50 kW)	$	28,401	$	26,964	$	55,365
DCFC (150 kW)	$	75,000	$	38,047	$	113,047

For DCFCs, the Benefit Cost Analysis includes the costs a utility is required to make to upgrade transformer capacity. These costs are utility specific and therefore provided by Xcel Energy for Colorado service territory.

For cases involving managed charging we assume there is an additional upfront cost of $100 per charger for networking and communication between the charger and the utility.

4 Results

The first results section covers the impact of all PEV types combined under their respective base cases and provides some impacts on an annual basis such as energy consumption, ratepayer benefits, and emission savings. Subsequent sections explore each modelling scenario described in section 2.3 in detail. Cost-benefit results in these sections are shown on both a total net present value basis and an average per vehicle adopted basis. The total value results provide an understanding of the total magnitude of the costs and benefits from PEV adoption in the Xcel Energy Colorado service territory but are heavily influenced by the PEV population forecast input. The average per vehicle results are more robust to uncertainty in population forecast and can be useful in PEV program design since an incentive or program cost per-vehicle can be directly compared to the per vehicle net benefit.

4.1 Total Transportation Electrification Results

Overall, the results make a strong positive case for transportation electrification in Xcel Energy's Colorado territory across most vehicles types and from ratepayer, driver, and societal perspectives. This study finds that under the base scenario *ratepayers stand to benefit by nearly $1.07 billion* for PEV adoption between 2020 and 2030 across the four vehicle types studied. *Drivers or fleet owners would benefit by $358 million* in total cost of ownership and *Colorado would benefit by $1.51 billion* in avoided gasoline, reduced O&M and emission reductions. Table 16 summarizes the total Net Present Value (NPV) of all cases. These values represent the total costs and benefits over each vehicles' 12-year lifetime, summed for every vehicle adopted from 2020 to 2030 and discounted using Xcel Energy's weighted average cost of capital.[14]

Table 16. Net Present Value of net benefits for all vehicles adopted between 2020 – 2030 in ($ Million)

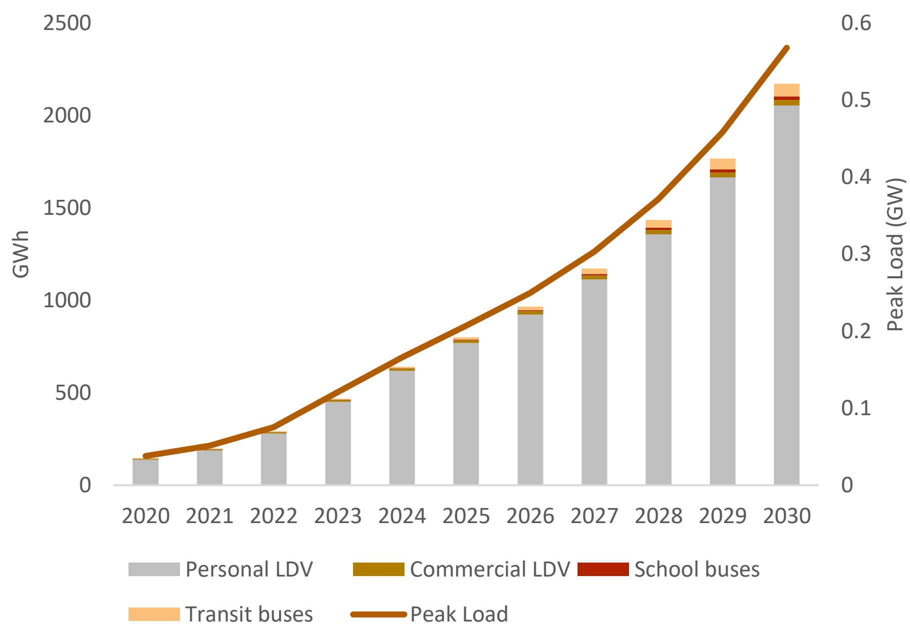
Case	RIM	PCT	SCT
Personal LDV - base case	$1,018	$326	$1,426
Commercial LDV	$16	$29	$42
School Buses	$7	($27)	($19)
Transit Buses	$27	$30	$59
Sensitivities			
Personal LDV - managed charging	$1,054	$555	$1,533
Personal LDV - high DCFC	$1,193	$577	$1,571
Personal LDV - 50% socialization	$703	$641	$1,426
Com LDV - expensive public charging rates	$16	($41)	$42

Annual electricity consumption of PEV charging from the four vehicle types studied rises from 172 GWh / year in 2020 (~0.4% of current total energy consumption Xcel Energy's Colorado Territory) to 2,172 GWh / year in 2030 (~5.6% of current total energy consumption), as shown in Figure 5. By 2030 charging load could contribute around 0.55 GW to Xcel Energy's Colorado peak load of 7.6 GW, which is around 7.5% of the peak load. Under the base charging scenario 37% of load occurs between 12pm and 9pm on weekdays and the

[14] Note that the costs and benefit streams that contribute to the NPV values calculated extend out to 2042 since all vehicles adopted in the last year of the study period, 2030, would continue to provide costs and benefits over their full lifetime which is assumed to be 12 years.

remaining 63% of load is either on weekends or outside of these hours on weekdays where its generally cheaper for Xcel Energy to supply the load.

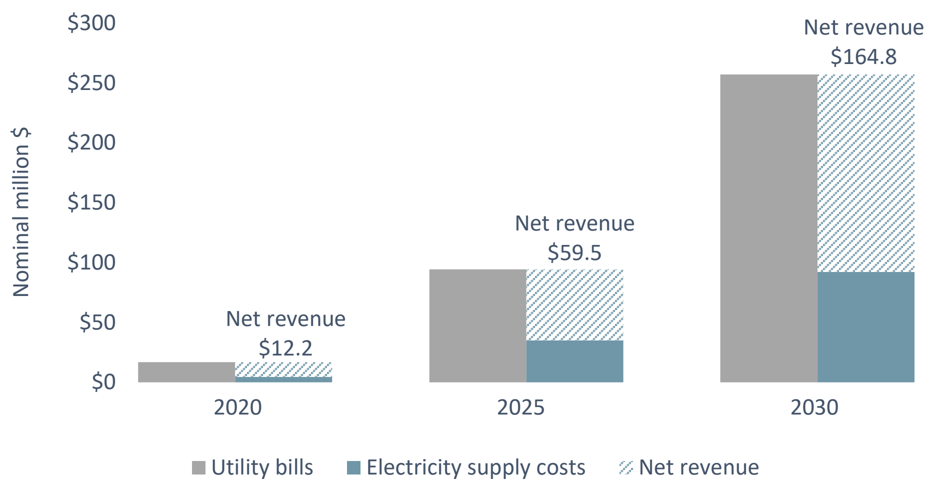
Figure 5. Annual Load of All Vehicle Types: 2020-2030 (GWh)



As shown in Figure 5, the vast majority of load and consequently the impact, arises from personal LDV vehicles. It should be noted that the load shape and timing of peak load does vary substantially across vehicle type.

The aggregate impact on Xcel Energy ratepayers under the base case scenario is summarized in Figure 6., and shows that by 2030 revenue collected from tariffs is over $257 million or an average of 0.12 $/kWh (in 2030 nominal dollars) which exceeds the total cost to serve PEV charging load at $92 million (0.04 $/kWh). Under all vehicle types and every case explored ratepayers benefited substantially from PEV adoption. Benefits generally scale directly with electricity consumption since bill revenue outweighs supply costs, although tariffs and load shape do play a role as described in subsequent result sections on each case.

Figure 6. Annual utility net revenue from transportation electrification ($ nominal)

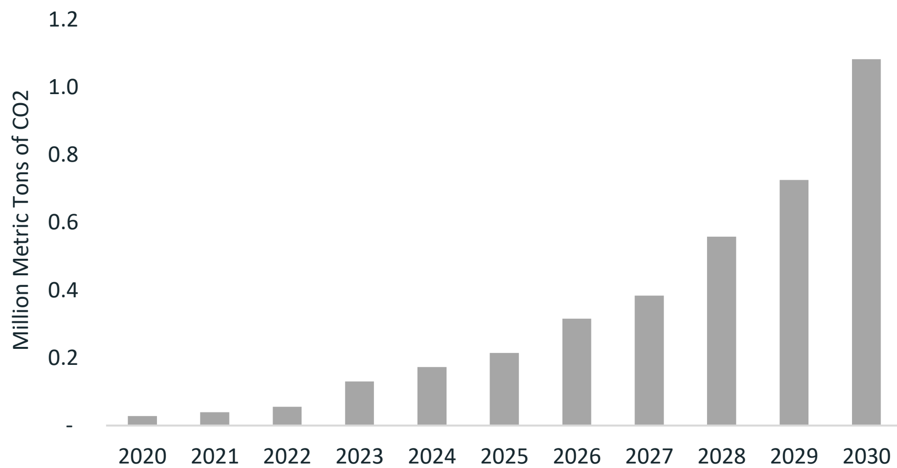


Driver or fleet owner benefits, as reported in the vehicle results sections on a per vehicle basis, show that for nearly all cases PEVs are cheaper in total cost of ownership than ICE vehicles. This is from the cost savings from reduced gasoline or diesel consumption and reduced O&M. These savings are very high and outweigh the higher upfront cost of PEVs, the charger installation costs, battery replacements, and charging costs. Drivers also benefit from tax credits at the federal and state level although these benefits only apply to PEVs adopted prior to 2027.

The societal benefits to Coloradans in Xcel Energy territory amount to nearly $1.51 billion for all PEVs adopted between 2020 and 2030 over each vehicles' lifetime. The benefits from eVMT savings and emission savings far exceed the charging infrastructure, electric supply, and incremental vehicle costs in all but the school bus cases. The vehicle results sections describe nuances between cases in greater detail. Note that the societal cost benefit results presented in this study do not include other indirect benefits such as the energy security value from lower reliance on fossil fuels and financial impact of reduced criteria pollutants (although emission values are reported).

For all vehicle types and scenarios explored in this study, the carbon emissions from electricity generation to meet charging load were lower than the emissions from gasoline or diesel combustion. The total carbon emission reduction impacts of all PEVs adopted between 2020 and 2030 sum to 11.7 MMTons over their lifetime, with annual carbon emissions savings peaking in 2030 at 1.1 MMTons /year. In line with annual energy consumption, personal LDVs make up nearly all the carbon emissions savings at 11.2 MMtons, while commercial LDVs, school buses and transit buses contribute 0.2, 0.1, and 0.2 MMtons respectively. Carbon emission savings vary based on the timing of charging throughout the day as grid emissions fluctuate depending on the marginal generator. Consequently, emission savings vary by vehicle type and whether managed charging occurs which is explored in the vehicle result sections.

Figure 7. Annual avoided CO_2 emissions from all vehicle types



Other pollutants were also included in the analysis, NO_x emissions were found to decrease with PEV adoption by 3,242 metric tons while SO_2 emissions *increase* by 1,151metric tons relative to the adoption of an ICE vehicle. The results show that new efficient ICE vehicles tend to have lower emission intensity for SO_2 than the average emissions from Xcel Energy Colorado's generation fleet. Note that under these emission calculations average emissions were used rather than marginal emissions. The average hourly electric system emission intensity tends to be lower than the emission intensity of the marginal generator and therefore these results may be a slight overestimate of the emission savings from PEVs.

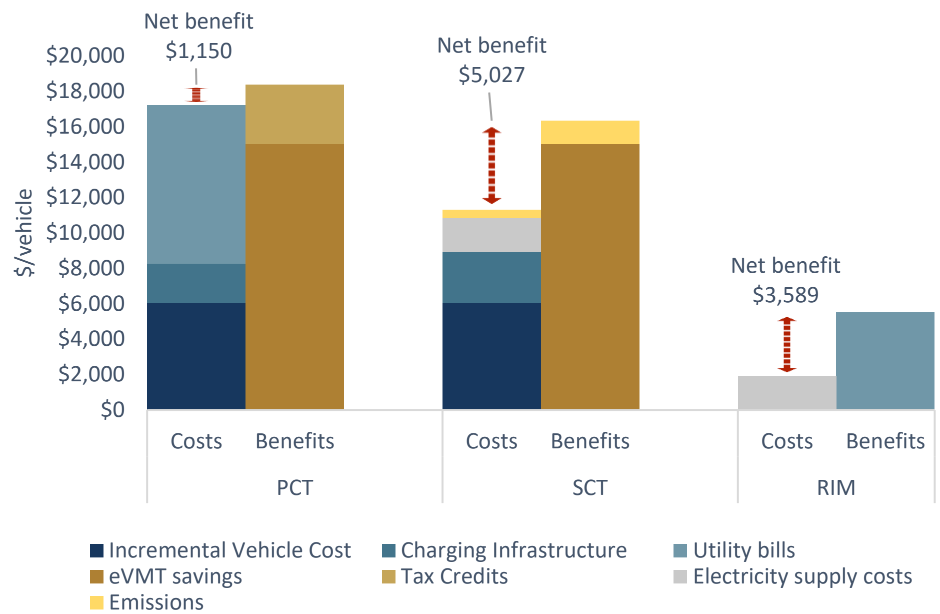
4.2 Personal Light Duty Vehicles

4.2.1 BASE CASE

Personal LDVs are by far the largest contributor to vehicle electrification benefits in Colorado simply because they make up 99% of vehicles adopted over the study horizon. Results show that personal LDVs adopted between 2020 and 2030 could provide $1,018M in NPV of benefit to Xcel Energy's Colorado ratepayers and $1,426M of benefit to Colorado state. The NPV of costs and benefits averaged per vehicle are shown in Figure 8. For drivers, the present value benefits total $1,150 per vehicle over its useful life. For the state of Colorado and for Xcel Energy ratepayers the NPV per vehicle benefits are $5,027 and $3,589, respectively.[15]

[15] As mentioned, the average NPV per vehicle values are calculated by taking the total NPV result for all vehicles adopted between 2020 – 2030 and dividing it by the total number of vehicles adopted during this period.

Figure 8. Costs and Benefits of Personal LDV Adoption – Base Case



This study finds that personal LDV drivers in Colorado would benefit from PEV adoption. Since Colorado drivers have a relatively high VMT and the per mile costs for PEVs are lower for than ICE vehicles, drivers would enjoy large cost savings from reduced O&M and gasoline. On average over vehicle lifetimes these benefits along with tax credits outweigh the incremental upfront cost of PEVs over ICE vehicles, the cost of charging infrastructure, and electricity bills.

Ratepayers see large net benefit from PEV adoption as the revenue collected from electricity bills exceeds Xcel Energy's cost to supply the additional load from PEV charging. Marginal energy costs constitute 57% of the total cost to serve PEV charging load, 37% is from increased generation capacity, and 6% from transmission and distribution capacity upgrades.

Colorado state benefits substantially from electrifying personal LDVs given the large eVMT cost savings and low electric supply costs. Lifetime vehicle emission reductions for all vehicles adopted between 2020 – 2030 total 11.2 MMt of CO_2 across Xcel Energy's Colorado territory. In addition, NO_x emissions are reduced by 3,157 metric tons whole SO_2 emissions are *increased* by 1,092 metric tons.

It is important to be aware of uncertainties in these cost-benefit projections. As discussed in the Inputs and Assumptions section, this study is not a detailed feeder by feeder level analysis of the distribution impacts from PEV charging. Our method uses marginal distribution impact costs provided by Xcel Energy and allocated using a single generalized residential feeder load. Higher resolution analysis of distribution grid impacts with greater EV penetrations, EV clustering, and higher powered charging could result in higher utility costs that would reduce ratepayer benefit. Furthermore, Xcel Energy's electric tariffs may evolve substantially over the next decade, which would have strong implications for these results. This analysis assumes tariffs stay constant in real terms but if rates were to shrink, ratepayer benefits could decrease.

4.2.2 MANAGED CHARGING SENSITIVITY

Recall that in this personal LDV sensitivity charging is managed to *minimize utility bills* at residential and workplace locations. The team assumed further charge management is performed by Xcel Energy at residential locations to mitigate 'rebound peaks' that occur when drivers begin charging as soon as the peak period ends causing very large peak loads. This additional charge management is through cascading or staggering the start time of different residential locations over a 45-minute period, and through 'load flattening' where the timing of each drivers' charging is adjusted to flatten peak load as much as possible whilst ensuring the vehicle is sufficiently charged before departure. Figure 9. shows the original base case load where charging is uncontrolled or unmanaged, Figure 10. shows the new managed load assuming 100% of drivers in Xcel Energy Colorado territory have their charging managed.

Figure 9. Base Case Personal LDV Charging Load in 2030 – Summer Week

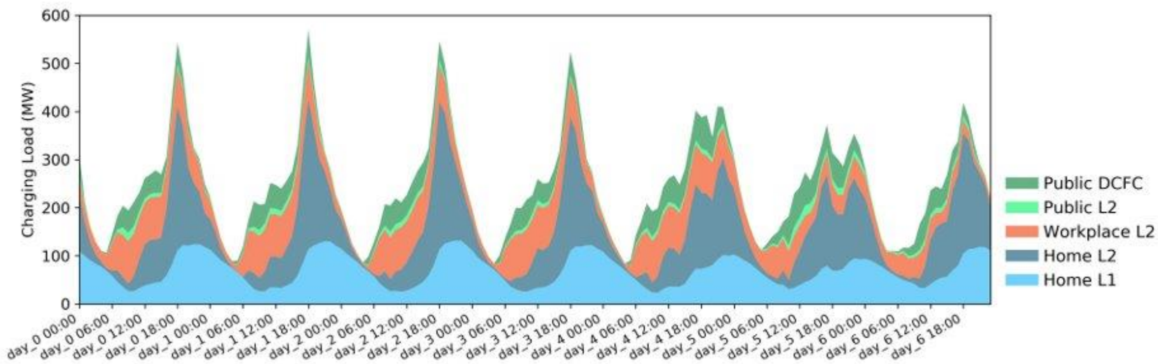
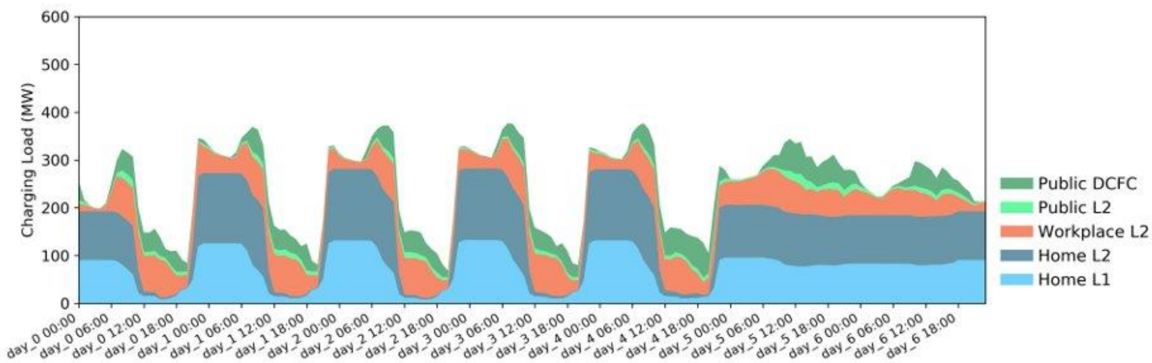


Figure 10. Managed Personal LDV Charging Load in 2030 – Summer Week

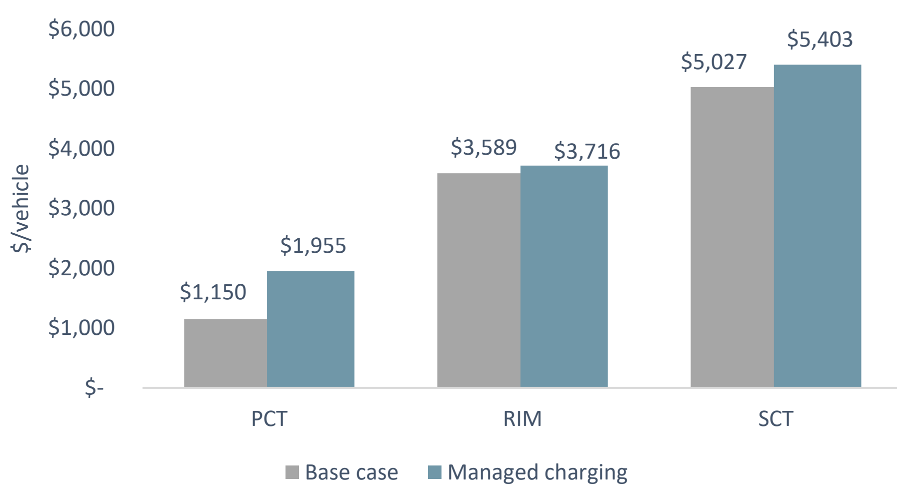


The objective of managed charging in this scenario is to minimize customers' bills, not to reduce system costs, hence charging during TOU peak periods for residential and workplace locations is drastically reduced. Peak load management enables a reduction in peak charging load from 536 MW to 377 MW in 2030.

Under this scenario net benefits for drivers increase across all costs tests with benefits increasing 70% for drivers, 5% for ratepayers, and 8% for Colorado (Figure 11.). Managed charging also increases total avoided CO_2 emissions by 100,000 metric tons over the vehicle lifetime of all PEV's adopted between 2020 – 2030.

Since the objective of managed charging in this scenario is to minimize customer bills, there is a large reduction in utility revenue. However, this is narrowly outweighed by a reduction in supply costs leading to a ratepayer benefit of $127 per vehicle over its lifetime or $36M if every PEV adopted was managed between 2020 – 2030.

Figure 11. Net Benefit Comparison of Personal LDV Base Case vs. Managed Charging



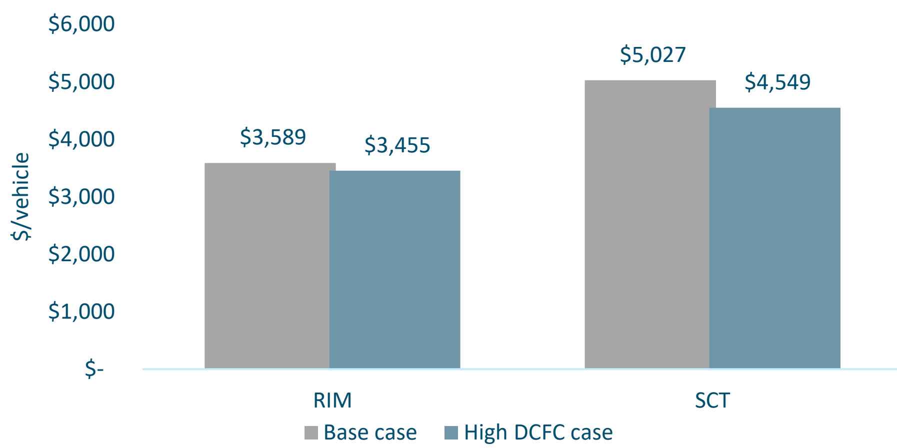
In this managed charging scenario the $100 upfront cost to ensure chargers have network communication is easily offset by annual electric bill savings resulting in a net gain of $805 per vehicle from managed charging for each driver over the 12-year vehicle lifetime. Drivers are assumed to be much more price sensitive and therefore shift slightly more charging from public to work and home where they can enjoy cheap off-peak charging rates. Recall that drivers in this scenario pay the typical price for public charging which is much higher than the revenue collected by Xcel Energy through the S-EV tariff. Therefore, changes in the amount of public charging result in a much greater reduction in driver charging costs than reduction in utility bill revenue.

It is important to highlight that these results are sensitive to the price signal used to manage charging. If charging were instead managed to minimize electric supply costs it is likely that the ratepayer benefit would be much greater but at the expense of drivers who would not receive as large bill savings. It should also be noted that for this case the team assumed no change in adoption despite the reduction in total cost of ownership for PEVs. There is likely to be slightly increased adoption due to price elasticity effects, but these are not modelled here.

4.2.3 HIGH DCFC SENSITIVITY

The High DCFC sensitivity explores a scenario where the number of DCFC's deployed in Colorado doubles to 2,875 across Xcel Energy's Colorado territory by 2030 versus the base scenario of 1,437. The primary benefit of having a denser network of public fast charger stations is greater adoption of PEVs through a reduction in range anxiety and increased consumer awareness, often referred to in economic literature as indirect network effects.[16] Based on a survey of the literature the team assumed that increasing DCFC deployment by 100% causes an increase in PEV adoption of 20% but that VMT for each vehicle remained the same as the base case. It should be stressed that the impact of denser DCFC networks on PEV adoption and driving behavior is highly uncertain, as is discussed later in this section.

Figure 12. Net Benefit Comparison of Personal LDV Base Case vs. High DCFC Case



Since more vehicles are adopted in this scenario and ratepayers benefit by around $3,500 for each vehicle, the total ratepayer benefits over the vehicle lifetime increases by 17% to $1,193 million for all vehicles adopted between 2020 – 2030. The ratepayer benefit on a per vehicle basis decreases slightly because the additional DCFC charging increases energy supply cost by 21% due to the higher peaking load shape (lower load factor) but only increases utility revenue by 18%.

[16] For a detailed review of evidence for network effects see (Li, et al., 2016; Sierzchula, et al., 2014; Slowik & Lutsey, 2017) for an example of network effect theory being used to inform a transportation electrification plan see (PGE, 2017)

Colorado state also sees an overall rise in net-benefits of 10% but a lower per vehicle value due to the infrastructure costs of building additional DCFC's. Driver benefits remain relatively unchanged under this scenario.

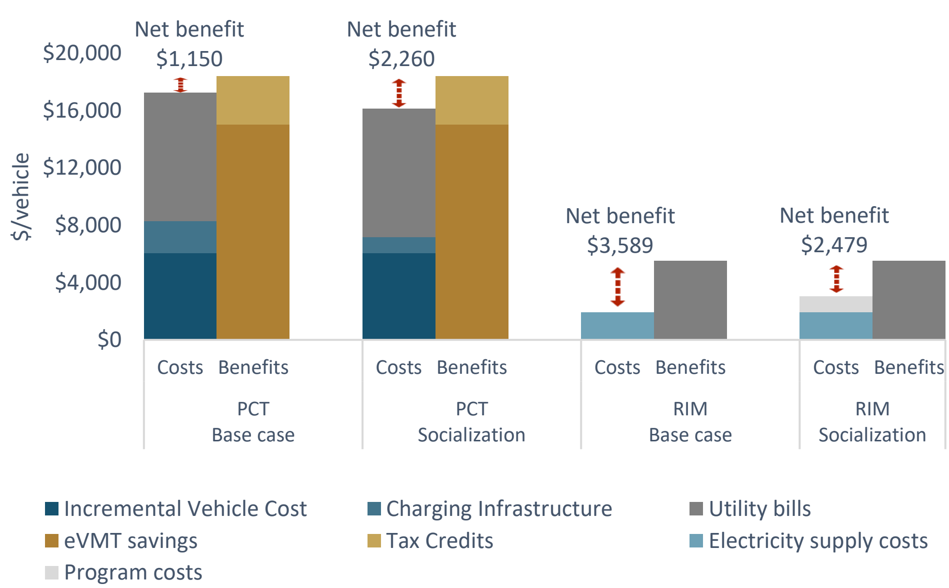
It is important to emphasize that while total ratepayer benefits from this scenario appear high there is great uncertainty around indirect network effects and the causal effect of DCFC deployment on PEV adoption. This sensitivity is intended as a high-level analysis for one scenario and it is far from guaranteed that heavy investment in DCFC infrastructure will yield a 20% lift in adoption through 2030. Indirect network effect studies rely on empirical data and therefore are based on today's PEV market conditions rather than a future market. Studies show that the size of the effect depends strongly on a host of factors such as PEV range, home and workplace charging access, socio economics, geography, and others, many of which are rapidly evolving. Therefore, it is highly likely indirect network effects will vary over time and may well diminish. To get a fuller understanding of how the DCFC deployment could impact PEV sales further study on this subject that is specific to Colorado would be required.

4.2.4 SOCIALIZING CHARGING INFRASTRUCTURE COSTS

This scenario explored the impacts of splitting half of all residential charging infrastructure costs on the customer side of the meter between drivers and Xcel Energy. For simplicity, the team did not explore the elasticity of demand for PEVs from altering the cost of charging infrastructure for those drivers that have access to charging at home. Therefore, it was assumed that PEV adoption in this scenario is the same as the base case.

Residential charger infrastructure costs total $630 Million for all PEVs adopted between 2020 – 2030. Sharing this cost between drivers with residential charging and Xcel Energy results in ratepayers still seeing net present benefits of $703 Million for all PEVs adopted between the 2020 – 2030 over the vehicle lifetime. Adding $315 Million in charger infrastructure increases costs by 58% but overall revenue from electricity consumption of around 54.6 MWh over each vehicle's 12-year lifetime still leads to net benefits for ratepayers. Drivers see average lifetime net benefits nearly double to $2,260 per driver or $641 million across Xcel Energy's Colorado territory over the 2020 – 2030 period. There is no impact on net benefits to Colorado state since costs are only reallocated from participants to ratepayers in this case.

Figure 13. per vehicle results for the socialized program cost sensitivity



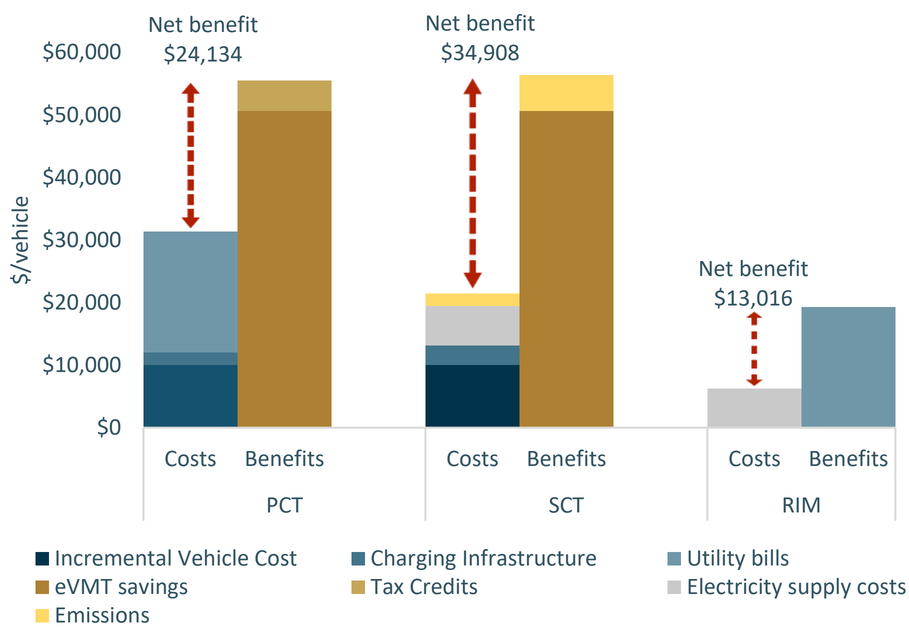
As with the managed charging sensitivity, for simplicity, this case assumed no change in adoption relative to the base case. It is likely that reducing upfront costs for drivers would result in higher PEV adoption due to price elasticity effects. Increased adoption would result in greater benefits to Colorado compared to the base case. It would also narrow the gap between the $1,018 million of ratepayer benefit seen in the base case and the $703 million of ratepayer benefit in this case. However modelling price elasticity effects in detail is beyond the scope of this study.

4.3 Commercial Light Duty Vehicles

4.3.1 BASE CASE

The objective of the commercial LDV case was to calculate net benefits arising from electrification of rideshare drivers such as Uber or Lyft. Rideshare drivers do significantly more mileage (nearly 60,000 miles annually) and around 40% have access to charging at home with the remainder rely purely on public charging infrastructure. Results shows that electrifying rideshare vehicles could benefit ratepayers by over $13,000 per vehicle over its lifetime or $16 million for all rideshare PEVs adopted between 2020 – 2030. Since rideshare drivers do over four times as much driving annually than personal LDVs, ratepayer benefits scale similarly as revenue from electricity bills exceeds supply costs. Colorado state also benefits substantially from rideshare electrification with each PEV providing an average of $34,908 over its lifetime or $42.4 million across all vehicles adopted between 2020 – 2030 in Xcel Energy territory. The high mileage leads to very large avoided maintenance and gasoline savings as well as a net reduction in carbon emissions that are well beyond the incremental upfront cost of PEVs and extra PEV battery replacements due to the high mileage.

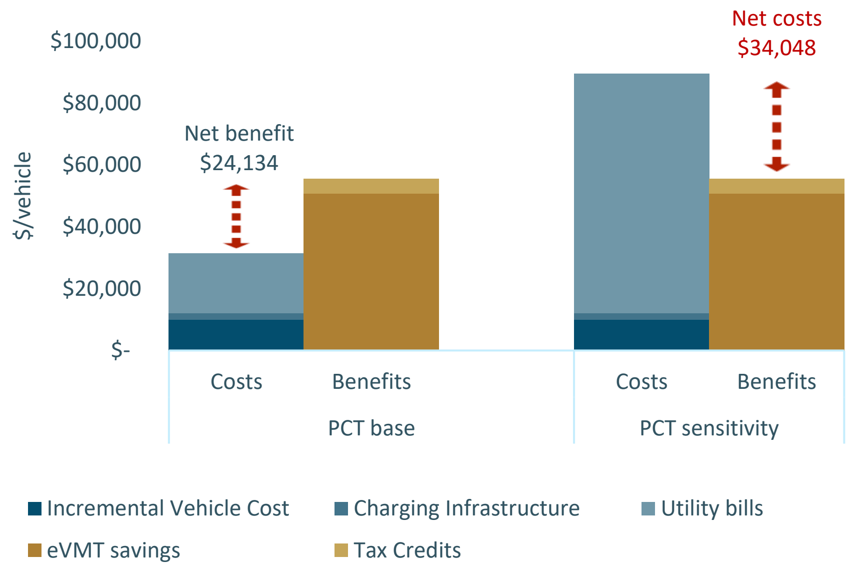
Figure 14. Costs and Benefits of Commercial LDV Adoption



4.3.2 EXPENSIVE PUBLIC CHARGING RATES

Rideshare drivers could see vehicle lifetime net benefits as high as around $24,000 per vehicle due to the large eVMT savings of around $50,000 from their very high mileage. However, this result assumes that drivers pay the Xcel Energy S-EV tariff when charging in public. If rideshare drivers were to pay a typical rate for public charging today it would be far more expensive on average to adopt a PEV than an ICE vehicle and *cost* rideshare drivers around $34,000 per vehicle. The dramatic fluctuation stems from the high VMT resulting in heavy reliance on fast charging which accounts for around 65% of all energy consumed and because of the wide variation in charging cost between the S-EV tariff (0.06 ~ 0.18 $/kWh) and the typical cost for DCFC charging today (~0.54 $/kWh). If DCFC charging sessions are paid at the S-EV tariff rate then over the vehicle lifetime drivers would pay around $26,000 for the electricity charged, if these sessions were paid at today's DCFC charging rates then lifetime charging costs jump to $77,000 per vehicle. Note that these two scenarios only affect the PCT since Xcel Energy will always collect revenue at the utility tariff rate (S-EV).

Figure 15. Comparing driver costs and benefits of the base commercial LDV case against the commercial LDV public charging rate sensitivity



Pubic charging costs for commercial PEV drivers may be lower than the rates paid by personal LDV drivers today. Rideshare companies may secure better deals for these drivers or full utility ownership of some DCFCs could enable public charging prices much closer to utility tariffs. Given this speculation, the team chose to present these two bookend cases and with the more economically favorable assumption as the base case since it better aligns with the adoption forecast anticipated for these vehicles.

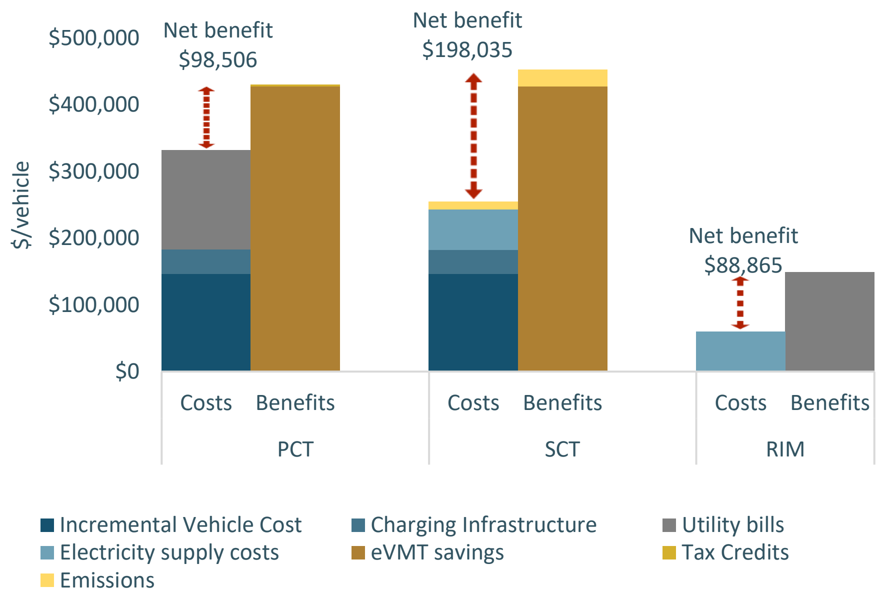
To ensure rideshare electrification is economically favorable for drivers one alternative to lowering the cost of public charging is to increase residential charging access. Since residential charging costs, particularly during off-peak periods, are significantly lower than today's public charging prices, the economics for drivers that have access to charging at home is considerably more favorable than those who depend entirely on public charging. Rideshare drivers generally have lower incomes and are more likely to live in multi-unit dwellings compared to the average personal light duty PEV driver (Colorado PUC, 2019). Therefore, increasing the number of chargers at multi-unit dwellings might also be an effective way to lower charging costs for rideshare drivers and make PEVs more attractive.

It should also be noted that these calculations do not factor in the opportunity cost of charging during shift hours which could also impact the economics of rideshare electrification. Average earnings for taxi drivers in Boulder are roughly $15.7 per hour, presenting a high opportunity cost of charging during shift hours especially at slower level 2 charging rates where charging sessions are often multiple hours (Henao, 2017). Moving more charging outside of rideshare drivers' shift hours such as overnight at home is therefore likely to be even more economically favorable.

4.4 Transit Buses

To analyze the electrification of transit buses in Xcel Energy Colorado territory the team assumed buses are only charged at their depot locations, where they would always be parked if not on shift. Transit buses have demanding schedules with high mileage and little downtime and therefore need lots of fast charging infrastructure to ensure batteries can adequately be replenished between shifts. Only daily bus schedules that cover fewer miles than the effective range of the electric transit bus were electrified in the analysis, leading to a lower annual VMT of 42,500 miles compared to the Colorado average of 51,000 miles. Charging was assumed to be managed to mitigate large demand charges under the S-EV rate from fast charging.

Figure 16. Per vehicle costs and benefits for transit buses in Xcel Energy Colorado territory



Electric transit buses provide significant net benefit for Xcel Energy ratepayers, transit fleet operators, and Colorado. Ratepayer net benefits of approximately $27 million could be obtained by 2042 for all buses adopted between 2020 – 2030 or an average of nearly $90,000 per bus. With charge management to reduce peak loads, the cost of suppling the new charging load is offset by the revenue collected under the S-EV tariff.

Transit agencies or transit bus fleet owners would see net benefits of $98,506 per bus on average over the vehicles' 12-year lifetime. Despite the higher up-front cost of electric buses compared to diesel, the cost of installing 1 DCFC per bus, and the cost of battery replacements every 200,000 miles, these costs are still outweighed by the diesel and O&M costs for ICE buses as a result of high annual mileage, resulting in net benefits for transit agencies.

The significant O&M and diesel savings along with the net emissions benefit far exceed the incremental vehicle cost, charger costs and battery replacement costs leading to a societal benefit of $59 million for the Colorado population in Xcel Energy territory for all buses adopted between 2020 – 2030 over their lifetime. In addition, a net emissions reduction of approximately 0.21 million metric tons of CO_2 is achieved by 2042 for all vehicles adopted between 2020 – 2030.

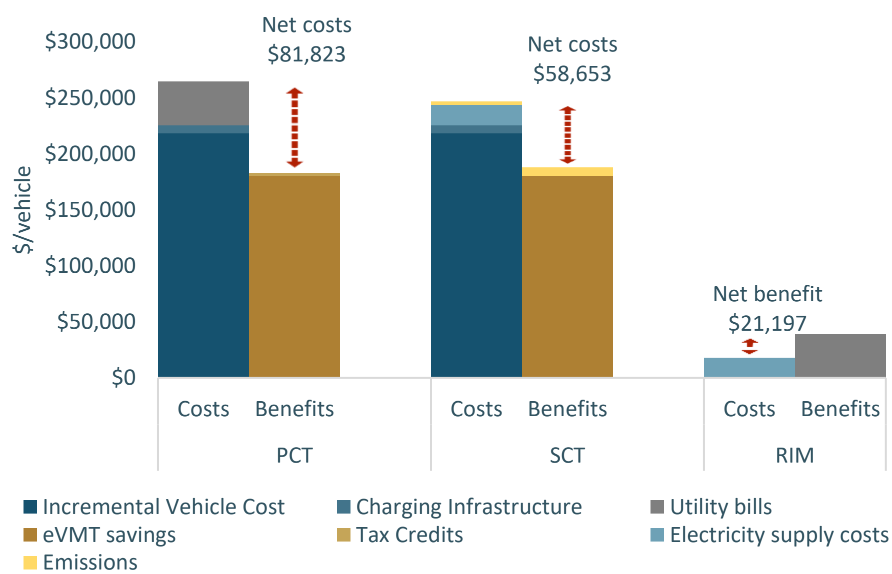
It should be noted that transit bus schedules do vary significantly regionally and this study utilized NREL's fleetDNA database rather than Colorado specific transit agency bus block schedules (NREL, 2019). Results with Colorado specific bus data are likely to alter the results. Furthermore, the makeup of the current Colorado bus fleet was unknown so it was assumed the default ICE bus use diesel fuel. However, CNG buses have lower fuel costs and therefore could alter the results substantially if used for comparison.

4.5 School Buses

School buses were modelled similarly to transit buses with charging only occurring at depot locations where they were assumed to always be parked when not driving. School buses cover less mileage than transit buses and have longer overnight parked periods but have narrow midday windows for charging between school drop-offs. The team assumed that the buses were only operated during school semesters and only 10% of buses were used on weekends for extracurricular activities. Like transit buses it was assumed that charging was managed to mitigate large demand charges under the S-EV rate.

Unlike transit buses, school buses are not cost effective for bus fleet owners or for Colorado state but are still beneficial to ratepayers. For reasons very similar to transit buses, net benefit of school bus electrification is high, around $7.0 million for all buses adopted between 2020 – 2030 or an average of $21,197 per bus over its lifetime.

Figure 17. Per vehicle costs and benefits for school buses in Xcel Energy Colorado territory



Based on current cost data the incremental upfront cost of an electric school bus over an ICE school bus is far higher than the difference for transit buses and due to the lower VMT (12,792 miles annually on average), these upfront costs cannot be recovered by savings in avoided diesel and O&M. Results show that adopting an electric bus would cost fleet owners on average nearly $82,000 over the vehicle lifetime while societal impacts for the Xcel Energy territory population in Colorado would be around $19 million for vehicles adopted between 2020 – 2030.

School buses have long periods of downtime throughout the year in which additional use could allow them to recover the high upfront costs. One potential future avenue that has been explored through various pilot programs across the US is vehicle-to-grid technology. Either to reduce onsite electric bills, participate in demand response, or potentially participate in ISO markets through energy, or ancillary service products. Pursuing these additional sources of revenue during weekends and holidays throughout the year could start to close the gap and make school buses more attractive for fleet owners.

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