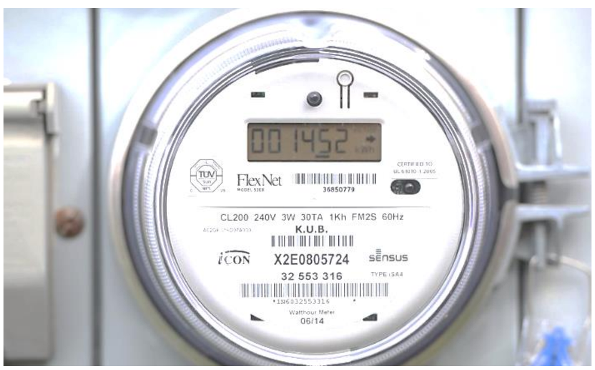
Electric Vehicle Cost-Benefit Analysis

Plug-in Electric Vehicle Cost-Benefit Analysis: Minnesota



MJB & A

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Our multi-national client base includes electric and natural gas utilities, major transportation fleet operators, clean technology firms, environmental groups and government agencies.

We bring insights to executives, operating managers, and advocates. We help you find opportunity in environmental markets, anticipate and respond smartly to changes in administrative law and policy at federal and state levels. We emphasize both vision and implementation and offer timely access to information along with ideas for using it to the best advantage.

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Executive Summary

This study estimated the costs and benefits of increased penetration of plug-in electric vehicles (PEV) in the state of Minnesota, for two different penetration levels between 2030 and 2050.[1] The "Moderate PEV" scenario is based upon near-term (2025) Zero Emission Vehicle goals adopted by states that together comprise about a third of the automotive market.[2] The "High PEV" scenario is based on the PEV penetration that would be required to achieve Minnesota's long-term goals for economy wide greenhouse gas (GHG) reduction of 80 percent below 2005 levels by 2050.

This study focused on passenger vehicles and trucks; there are additional opportunities for electrification of non-road equipment and medium- and heavy-duty trucks and buses, but evaluation of these applications was beyond the scope of this study.

The study estimated the benefits that would accrue to all electric utility customers in Minnesota due to increased utility revenues from PEV charging. This revenue could be used to support operation and maintenance of the electrical grid, thus reducing the need for future electricity rate increases. These benefits were estimated for a baseline scenario in which Minnesota drivers plug in and start to charge their vehicles as soon as they arrive at home or work. The study also evaluated the additional benefits that could be achieved by providing Minnesota drivers with price signals or incentives to delay the start of PEV charging until after the daily peak in electricity demand (managed off-peak charging).

Increased peak hour load increases a utility's cost of providing electricity and may result in the need to upgrade distribution infrastructure. As such, managed off-peak PEV charging can provide net benefits to all utility customers by shifting PEV charging to hours when the grid is underutilized, and the cost of electricity is lower.

See Figure 1 for a summary of how the projected utility net revenue from PEV charging might affect average residential electricity bills for all Minnesota electric utility customers.[3] As shown in the figure, under the High PEV scenario with managed off-peak charging the average Minnesota household could realize approximately $171 in annual utility bill savings in 2050 (nominal dollars).

In addition, the study estimated the annual financial benefits to Minnesota drivers – from fuel and maintenance cost savings compared to owning gasoline vehicles, and societal benefits that would result from reduced greenhouse gas (GHG) and nitrogen oxide (NOx) emissions due to vehicle electrification.

As shown in Figure 2 (Moderate PEV scenario), if Minnesota meets short term (2025) goals for PEV penetration, and the increase in percent PEV penetration then continues at the same annual rate in later years, the net present value of **cumulative net benefits from greater PEV use in Minnesota will exceed $4.6 billion state-wide by 2050**.[4] Of these total net benefits:

- At least $0.6 billion will accrue to electric utility customers in the form of reduced electric bills[5],
- $2.0 billion will accrue directly to Minnesota drivers in the form of reduced annual vehicle operating costs

[1] PEVs include battery-electric vehicles (BEV) and plug-in hybrid vehicles (PHEV).

[2] In 2013, six Northeast/Mid-Atlantic states (MD, MA, NY, CT, RI, VT) and two Pacific coast states (CA, OR) joined in a Zero Emission Vehicle Memorandum of Understanding to enact policies that will ensure the deployment of 3.3 million ZEVs by 2025. Minnesota is not a signatory of the MOU but has enacted policies found in the other states, such as state fleet procurement requirements, designed to accelerate EV sales.

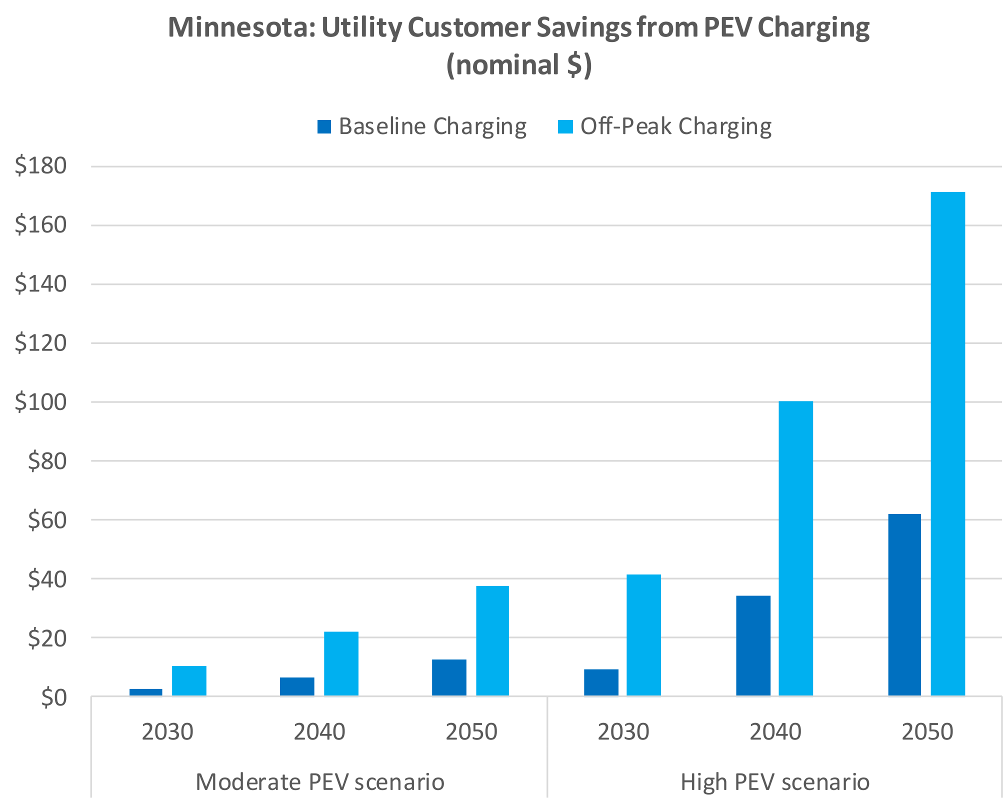
[3] Based on 2015 average electricity use of 8,792 kWh per housing unit in Minnesota.

[4] Using a 3 percent discount rate

[5] Figure 2 includes utility customer savings under the baseline charging scenario; savings would be higher under the managed off-peak charging scenario.

- $1.8 billion will accrue to society at large, as the value of reduced GHG emissions, and
- $0.15 billion will accrue to society at large, as the value of reduced NOx emissions.

Figure 1 Potential Effect of PEV Charging Net Revenue on Utility Customer Bills (nominal $)



As shown in Figure 3 (High PEV scenario), if the state meets long-term goals to reduce light-duty fleet and economy-wide GHG emissions by 80 percent from 2005 levels by 2050, which requires even greater PEV penetration, the net present value of **cumulative net benefits from greater PEV use in Minnesota could exceed $30 billion state-wide by 2050**. Of these total net benefits:

- $10.2 billion will accrue to electric utility customers in the form of reduced electric bills
- Up to $9.0 billion will accrue directly to Minnesota drivers in the form of reduced annual vehicle operating costs[6]
- $10.4 billion will accrue to society at large, as the value of reduced GHG emissions, and
- $0.7 billion will accrue to society at large, as the value of reduced NOx emissions

[6] Figure 3 includes utility customer savings under the managed off-peak charging scenario; savings would be lower under the baseline charging scenario.

Figure 2 *NPV Cumulative Societal Net Benefits from MN PEVs – Moderate PEV scenario*

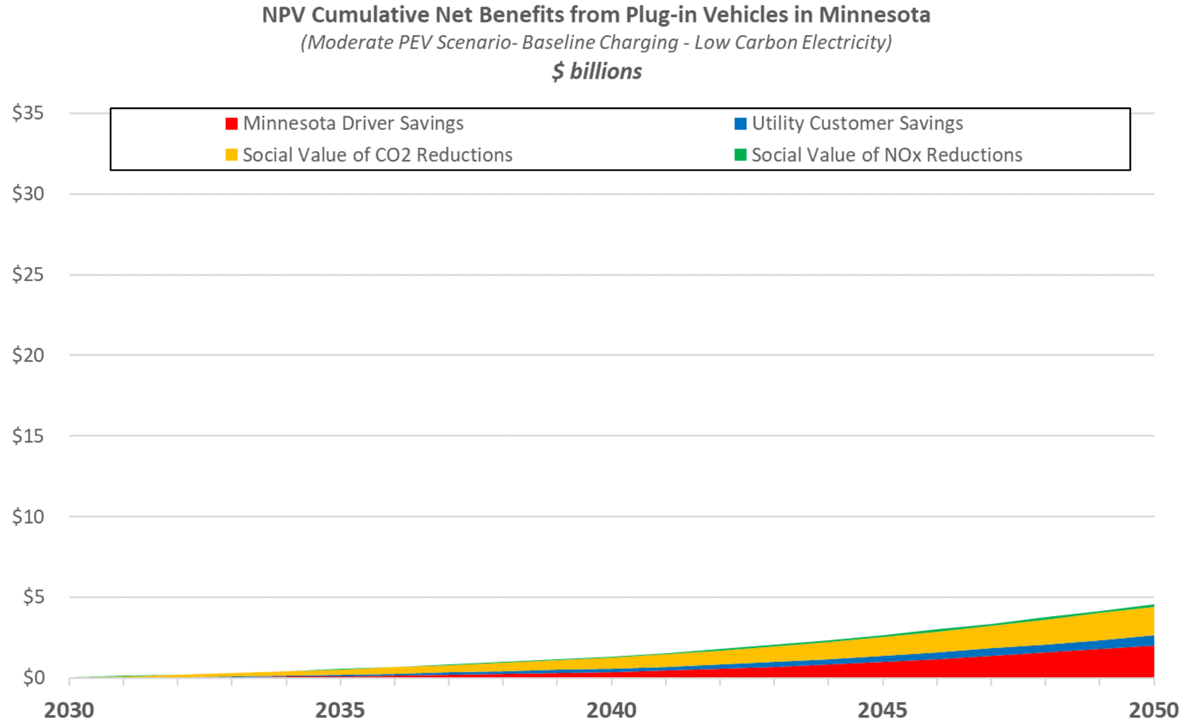
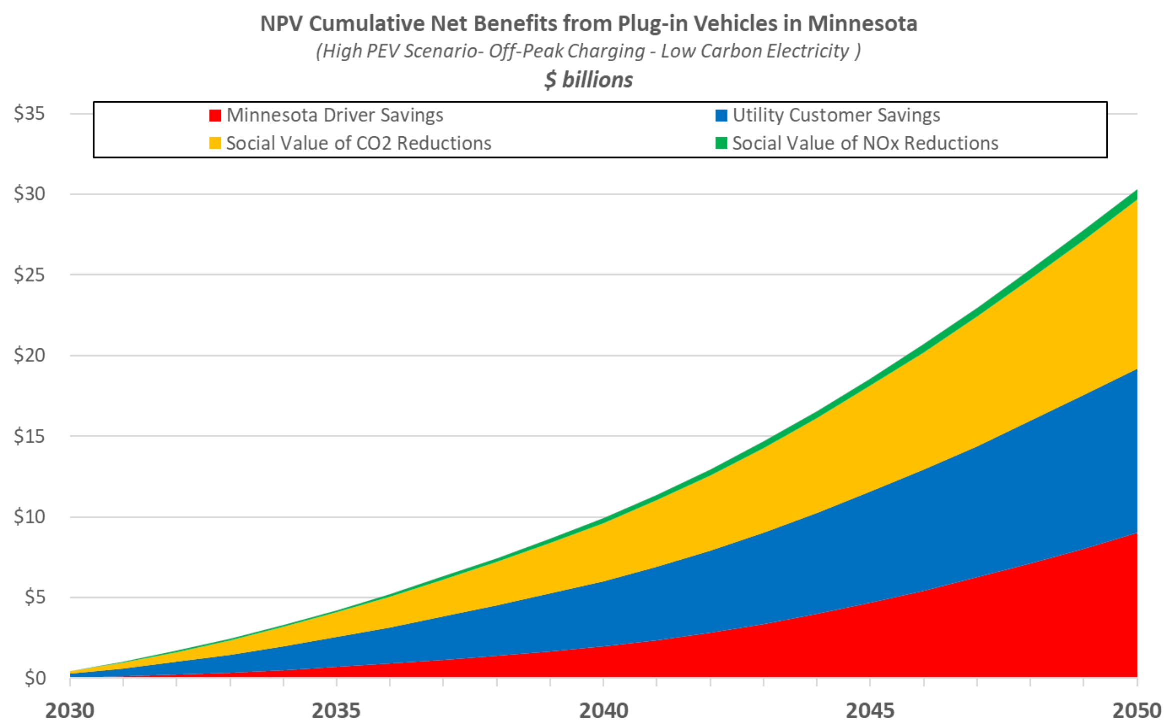


Figure 3 *NPV Cumulative Societal Net Benefits from MN PEVs – High PEV scenario*



By 2050, PEV owners are projected to save nearly $550 per vehicle (nominal $) in annual operating costs, compared to owning gasoline vehicles. A large portion of this direct financial benefit to Minnesota drivers derives from reduced gasoline use—from purchase of lower cost, regionally produced electricity instead of gasoline imported to the state. Under the Moderate PEV scenario, PEVs will reduce cumulative gasoline use in the state by more than 1.8 billion gallons through 2050 – this cumulative gasoline savings grows to 10.6 billion gallons through 2050 under the High PEV scenario. In 2050, annual average gasoline savings will be approximately 94 gallons per PEV under the Moderate PEV scenario, while projected savings under the High PEV scenario are 136 gallons per PEV.

This projected gasoline savings will help to promote energy security and independence and will keep more of vehicle owners' money in the local economy, thus generating even greater economic impact. Studies in other states have shown that the switch to PEVs can generate up to $570,000 in additional economic impact for every million dollars of direct savings, resulting in up to 25 additional jobs in the local economy for every 1,000 PEVs in the fleet [1].

In addition, this reduction in gasoline use will reduce cumulative net GHG emissions by nearly 19 million metric tons through 2050 under the Moderate PEV scenario, and over 110 million metric tons under the High PEV scenario.[7] The switch from gasoline vehicles to PEVs is also projected to reduce annual NOx emissions in the state by over 825 tons in 2050 under the Moderate PEV scenario, and by over 4,000 tons under the High PEV scenario.

[7] Net of emissions from electricity generation

Background - Minnesota

In December 2006, Minnesota Governor Tim Pawlenty unveiled his strategy to reduce Minnesota's emissions of greenhouse gases (GHG). As part of the initiative, the Governor tasked the Center for Climate Strategies with developing Minnesota's Climate Mitigation Action Plan and formation of the Minnesota Climate Change Advisory Group. The Action Plan contained strategy and policy recommendations for reducing emissions from the different sectors of Minnesota's economy. [2]

In May 2007, Gov. Pawlenty signed Minnesota's Next Generation Energy Act, which set out a plan to protect the state against climate impacts, including goals to reduce GHG emissions. The plan included the most aggressive renewable energy standard to date, requiring Minnesota's electric utilities to provide 25 percent renewable electricity by 2025. In addition, the bill established aggressive state-wide GHG reduction goals across all sectors; these targets are a reduction in GHG emissions of at least 15 percent below 2005 levels by 2015; 30 percent by 2025 and 80 percent by 2050. [3]

The electricity sector accomplished the state's first GHG reduction milestone (15 percent by 2015) and the sector is currently on pace to dramatically exceed the next milestone (30 percent by 2025). [4] In addition, there have been a number of clean energy commitments from utilities:

- Xcel Energy, which accounts for nearly half of the electricity sales in the state, projects its energy mix will be 76 percent carbon free by 2022 (a 50 percent GHG emissions reduction over 2005 levels), and it aims to get to 85 percent carbon free energy by 2030;
- Great River Energy has already reduced GHG emissions by 35 percent (relative to 2005 levels), and the Company has publicly committed to get 50 percent of its energy from renewables by 2030
- Minnesota Power projects its energy mix will be 44 percent renewable by 2025, which would reduce GHG emissions by roughly 45 percent below its 2005 level.
- Otter Tail Power's projected energy mix for 2021 is 31 percent renewable, which would exceed its 2025 Renewable Energy Standard requirement, and would be a GHG reduction of about 30 percent relative to 2005.

To further their commitment to clean energy and technology, Minnesota put forth a statute that requires electric utilities to create an EV-specific tariff that offers discounted off-peak EV charging to its customers. [5] Another state statute, tailored to state agencies, requires that, "the commissioner or the agency shall purchase a motor vehicle that is capable of being powered by cleaner fuels, or a motor vehicle powered by electricity or by a combination of electricity and liquid fuel, if the total life-cycle cost of ownership is less than or comparable to that of other vehicles and if the vehicle is capable of carrying out the purpose for which it is purchased."[6]

Dakota Electric, along with offering EV-specific charging rates, provides a rebate of up to $500 to cover the cost of installing a charger on their EV charging rate plans. [7]

As of January 2018, there were approximately 6,300 PEVs (including battery-electric and plug-in hybrid vehicles) registered in Minnesota and they comprised about 0.08 percent of the 5.1 million cars and light trucks registered in the State. In 2014 and 2015, sales of new PEVs in the state were less than one half of one percent of new vehicle sales. [8]

Study Methodology

This section briefly describes the methodology used for this study. For more information on how this study was conducted, including a general discussion of the assumptions used and their sources, see the report: *Mid-Atlantic and Northeast Plug-in Electric Vehicle Cost-Benefit Analysis, Methodology & Assumptions* (October 2016).[8] This report can be found at:

http://mjbradley.com/sites/default/files/NE_PEV_CB_Analysis_Methodology.pdf

This study evaluated the costs and benefits of two different levels of PEV penetration in Minnesota between 2030 and 2050. These PEV penetration scenarios bracket short and long-term policy goals for ZEV adoption and GHG reduction which have been adopted by other states, and localities.[9]

> **Moderate PEV Scenario:** Penetration of PEVs equivalent to Minnesota's participation in a program similar to the *8-state ZEV Memorandum of Understanding*. Compliance with this MOU would require approximately 6 percent of in-use light duty vehicles in Minnesota to be ZEV by 2025. Assuming the increase in percent PEV penetration then continues at the same annual rate in later years, PEV penetration is assumed to be 8.9 percent in 2030, 14.7 percent in 2040, and 20.6 percent in 2050.[10]
>
> **High PEV Scenario:** The level of PEV penetration required to reduce total light-duty GHG emissions in Minnesota in 2050 by 80 percent from 2005 levels with 80 percent carbon free electricity, to meet the goals specified in the Next Generation Energy Act. This will require PEV penetration of 35 percent in 2030, 65 percent in 2040 and 98 percent in 2050.

Both of these scenarios are compared to a baseline scenario with very little PEV penetration and continued use of gasoline vehicles. The baseline scenario is based on future annual vehicle miles traveled (VMT) and fleet characteristics (e.g., cars versus light trucks) as projected by the Minnesota Department of Transportation.

Based on assumed future PEV characteristics and usage, the analysis projects annual electricity use for PEV charging at each level of penetration, as well as the average load from PEV charging by time of day. The analysis then projects the total revenue that Minnesota' electric distribution utilities would realize from sale of this electricity, their costs of providing the electricity to their customers, and the potential net revenue (revenue in excess of costs) that could be used to support maintenance of the distribution system.

For each PEV penetration scenario this analysis calculates utility revenue, costs, and net revenue for two different PEV charging scenarios: 1) a baseline scenario in which all PEVs are plugged in and start to charge as soon as they arrive at home each day, and 2) a managed off-peak charging scenario in which a significant portion of PEVs delay the start of charging until non-peak periods each day.

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[8] This analysis used the same methodology as described in the referenced report, but used different PEV penetration scenarios, as described here. In addition, for this analysis fuel costs and other assumptions taken from the Energy Information Administration (EIA) were updated from EIA's Annual Energy Outlook 2016 to those in the Annual Energy Outlook 2018. For projections of future PEV costs, this analysis also used updated July 2017 battery cost projections from Bloomberg New Energy Finance. In addition, as further described in this section, this analysis used a modified methodology to calculate incremental energy, generation capacity and transmission/distribution costs associated with PEV charging. This analysis also includes an estimate of NOx reductions resulting from transportation electrification; the methodology used is not included in the cited report but is described here.

[9] The states of CA, CT, FL, MA, MD, ME, MN, NH, NJ, NY, OR, RI, and VT have all set economy-wide goals of 75-80 percent GHG reduction by 2050. The starting point for the target 2050 GHG reduction percentage varies by state, from 1990 to 2006. The District of Columbia has also adopted a goal to reduce GHG emissions by 80 percent from 2006 levels by 2050.

[10] While the 8-state MOU counts fuel cell vehicles and PEVs as zero emission vehicles, this scenario assumes that all ZEVs will be PEV given the fact fuel cell technology lags behind battery technology and fuel cell vehicles face a greater infrastructure challenge.

Real world experience from the EV Project demonstrates that, without a "nudge", drivers will generally plug in and start charging immediately upon arriving home after work (scenario 1), exacerbating system-wide afternoon/evening peak demand.[11] However, if given a "nudge" - in the form of a properly designed and marketed financial incentive - many Minnesota drivers will choose to delay the start of charging until off-peak times, thus reducing the effect of PEV charging on evening peak electricity demand (scenario 2). [9]

In fact, in Minnesota, Xcel Energy already offers a Residential EV Charging Service, which charges lower rates ($/kWh) for EV charging during off-peak hours - between 9 PM and 9 AM on weekdays, as well as on weekends and holidays. Over the last two years, the share of charging done during off-peak hours by customers on this rate has ranged from 90 to 95 percent. [10] The managed off-peak charging scenario modeled for this analysis is structured similar to the current Xcel program; the off-peak period is assumed to start at 9 PM, and 92 percent of all PEVs that arrive at home after noon each day are assumed to delay the start of charging until after 9 PM. This scenario further assumes that off-peak charging will be managed by staggering charge start times between 9 PM and 4 AM for individual PEVs, to avoid a sharp secondary peak at 9 PM.[12]

The costs of serving PEV load include the cost of electricity generation, the cost of transmission, incremental peak generation capacity costs for the additional peak load resulting from PEV charging, and annual infrastructure upgrade costs for increasing the capacity of the transmission and secondary distribution systems, to handle the additional load.

This analysis calculates average system-wide electricity generation costs based on projections by the Energy Information Administration, but then adds incremental costs associated specifically with PEV charging load under each charging scenario, based on timing of the charging load. This was done using MISO Locational Marginal Prices at the Minnesota hub for 2017 and 2016. [11] This data shows that the cost for Minnesota utilities to purchase bulk electricity varies by month and time of day, with average annual costs ($/MWh) about 40 percent higher during the day (9 AM – 9 PM) than at night. As discussed below, compared to baseline charging managed off-peak charging shifts load from the late afternoon/early evening to the early morning hours, thus reducing the cost to utilities to purchase the necessary electricity.

To calculate the costs associated with adding generation and transmission/distribution capacity to handle the incremental PEV charging load this analysis uses values calculated by Xcel Energy, and approved by the Minnesota Public Utilities Commission, for the purpose of calculating savings associated with the state's Conservation Improvement Program [12]. The values used were $60.07/kW-year for Generation Avoided Capacity Costs and $36.23/kW-year for Transmission and Distribution Avoided Costs.[13]

For each PEV penetration scenario, this analysis also calculates the total incremental annual cost of purchase and operation for all PEVs in the state, compared to "baseline" purchase and operation of gasoline cars and light trucks. For both PEVs and baseline vehicles annual costs include the amortized cost of purchasing the vehicle, annual costs for gasoline and electricity, and annual maintenance costs. For PEVs it also includes the amortized annual cost of the necessary home charger. This analysis is used to estimate average annual financial benefits to Minnesota drivers.

For each PEV penetration scenario this analysis also calculates annual greenhouse gas (GHG) emissions from electricity generation for PEV charging and compares that to baseline emissions from operation of gasoline

[11] The EV Project is a public/private partnership partially funded by the Department of Energy which has collected and analyzed operating and charging data from more than 8,300 enrolled plug-in electric vehicles and approximately 12,000 public and residential charging stations over a two-year period.

[12] Utilities have multiple policy and technical options for implementing managed charging. This analysis does not endorse any particular methodology.

[13] Under the Conservation Improvement Program these values are used to calculate savings associated with reducing load. We used the values to calculate costs associated with adding load. These values are for 2017. Costs in future years were escalated at 2.3 percent (generation) and 2.24 percent (transmission and distribution) per year, per Xcel assumptions.

vehicles. For the baseline and PEV penetration scenarios GHG emissions are expressed as carbon dioxide equivalent emissions (CO_2-e) in metric tons (MT). GHG emissions from gasoline vehicles include direct tailpipe emissions as well as "upstream" emissions from production and transport of gasoline.

For each PEV penetration scenario GHG emissions from PEV charging are calculated based on a "low carbon electricity" scenario. This low carbon electricity scenario is based on Minnesota reducing average GHG emissions from the electric grid to 80 percent below 2005 levels by 2050, in accordance with goals established under the Next Generation Energy Act.

Net annual GHG reductions from the use of PEVs are calculated as baseline GHG emissions (emitted by gasoline vehicles) minus GHG emissions from each PEV penetration scenario. The monetized "social value" of these GHG reductions from PEV use are calculated using the Social Cost of Carbon ($/MT), as calculated by the U.S. government's Interagency Working Group on Social Cost of Greenhouse Gases. The Interagency Working Group calculated GHG social values based on discount rates of 2.5 percent, 3 percent, and 5 percent; for this analysis we used the average values generated with a 3 percent discount rate, which is in the middle of the range of reported values. The values used are $41 per metric ton in 2015, rising to $79/MT in 2050 (constant 2015$).

The Minnesota Public Utilities Commission has also adopted high and low "externality values" for the social cost of the CO_2 associated with electricity production. [13] These values are $8.44 per ton (low) and $39.76/ton (high) in 2017, rising to $15.20/ton and $69.48/ton in 2050 (constant 2015$). This equates to $9.30 - $43.83/MT in 2017, rising to $16.76 - $76.59/MT in 2050. The values for social cost of GHGs used in this analysis are therefore very close to the "high" externality values adopted by the Minnesota PUC.

Finally, this analysis projected annual net reductions in nitrogen oxide (NOx) emissions under each PEV penetration scenario that would result from the use of electric vehicles instead of gasoline vehicles.[14] This projection is based on national-level modeling done in 2015 by the Electric Power Research Institute (EPRI), in conjunction with the Natural Resources Defense Council (NRDC) [14]. The monetized social value of these NOx reductions was calculated using a national average value of $15,909 per ton of NOx in 2018, escalated in future years using EIA inflation assumptions. The 2018 value was derived from modeling done by the Environmental Protection Agency using their Response Surface Model [15]; this value represents a national average for mobile source NOx.

The Minnesota Public Utilities Commission has also adopted high and low "externality values" for the social damage cost of NOx and other pollutants associated with electricity production. [16] These values range from $1,985/ton NOx (low – rural area) to $7,893/ton NOx (high – urban area), in 2016 dollars. For this analysis we chose to use EPA's values, rather than Minnesota PUC's values, because the projected reductions in NOx emissions will come from vehicles, rather than power plants. Differences in the location of emissions from vehicles and power plants, and resulting differences in population exposure, likely account for the difference in EPA NOx damage values compared to those adopted by the PUC.

[14] These reductions are net of projected NOx emissions from production of electricity required to charge the PEVs.

Study Results

This section summarizes the results of this study, including the projected number of PEVs; electricity use and load from PEV charging; projected GHG reductions compared to continued use of gasoline vehicles; benefits to utility customers from increased electricity sales; and projected financial benefits to Minnesota drivers compared to owning gasoline vehicles.

All costs and financial benefits are presented as net present value (NPV), using a 3 percent discount rate.

Plug-in Vehicles, Electricity Use, and Charging Load

Vehicles and Miles Traveled

The projected number of PEVs and conventional gasoline vehicles in the Minnesota light duty fleet under each PEV penetration scenario is shown in Figure 4, and the projected annual miles driven by these vehicles is shown in Figure 5. [15]

There are currently 2.081 million cars and 3.028 million light trucks registered in Minnesota, and these vehicles travel 59 billion miles per year. Both the number of vehicles and total annual vehicle miles are projected to increase by 15 percent through 2050, to 5.9 million light duty vehicles traveling 68.1 billion miles annually[16].

In order to meet the Moderate PEV scenario, the number of PEVs registered in Minnesota would need to increase from approximately 6,300 today, to 317,952 by 2025. Assuming the same annual increase in percent PEV penetration in later years, there would be 492,000 PEVs in the state in 2030, 842,000 in 2040, and 1.2 million in 2050 (Moderate PEV penetration scenario).

In order to put the state on a path to achieve an 80 percent reduction in light-duty GHG emissions from 2005 levels by 2050 (High PEV scenario) there would need to be approximately 1.9 million PEVs in Minnesota by 2030, rising to 3.7 million in 2040, and 5.8 million in 2050.

Note that under both PEV penetration scenarios the percentage of total VMT driven by PEVs each year is lower than the percentage of plug-in vehicles in the fleet. This is because PEVs are assumed to have a “utility factor” less than one – i.e., due to range restrictions neither a battery-electric nor a plug-in hybrid vehicle can convert 100 percent of the miles driven annually by a baseline gasoline vehicle into miles powered by grid electricity. In this analysis BEVs with 200-mile range per charge are conservatively assumed to have a utility factor of 90 percent in 2030 increasing to 95 percent in 2050, while PHEVs are assumed to have an average utility factor of 75 percent in 2030, rising to 85 percent in 2050. This analysis estimates that Minnesota could reduce light-duty fleet GHG in 2050 by 80 percent from 2005 levels if 88 percent of miles were driven by PEVs on electricity (Figure 5). However, in order to achieve this level of electric miles 98 percent of light-duty vehicles would need to be PEVs (Figure 4).

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[15] This analysis only includes cars and light trucks. It does not include medium- or heavy-duty trucks and buses.
[16] Vehicle fleet and VMT growth is assumed to mirror projected population growth.

Figure 4 Projected Minnesota Light Duty Fleet

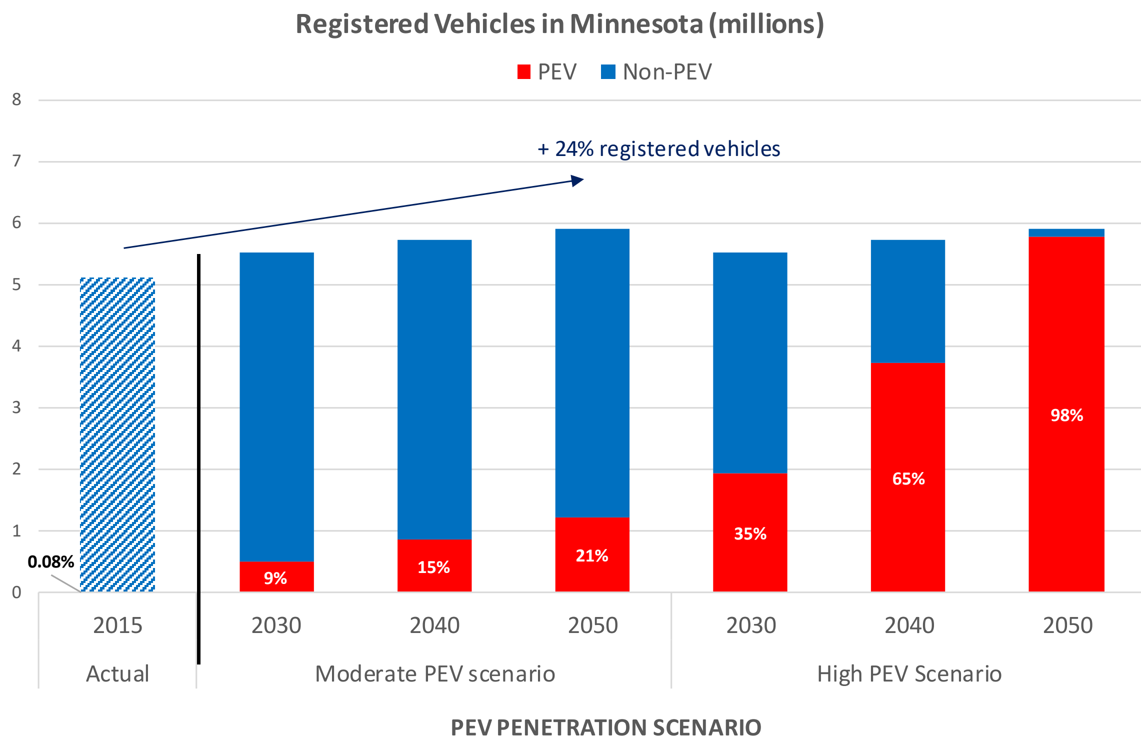
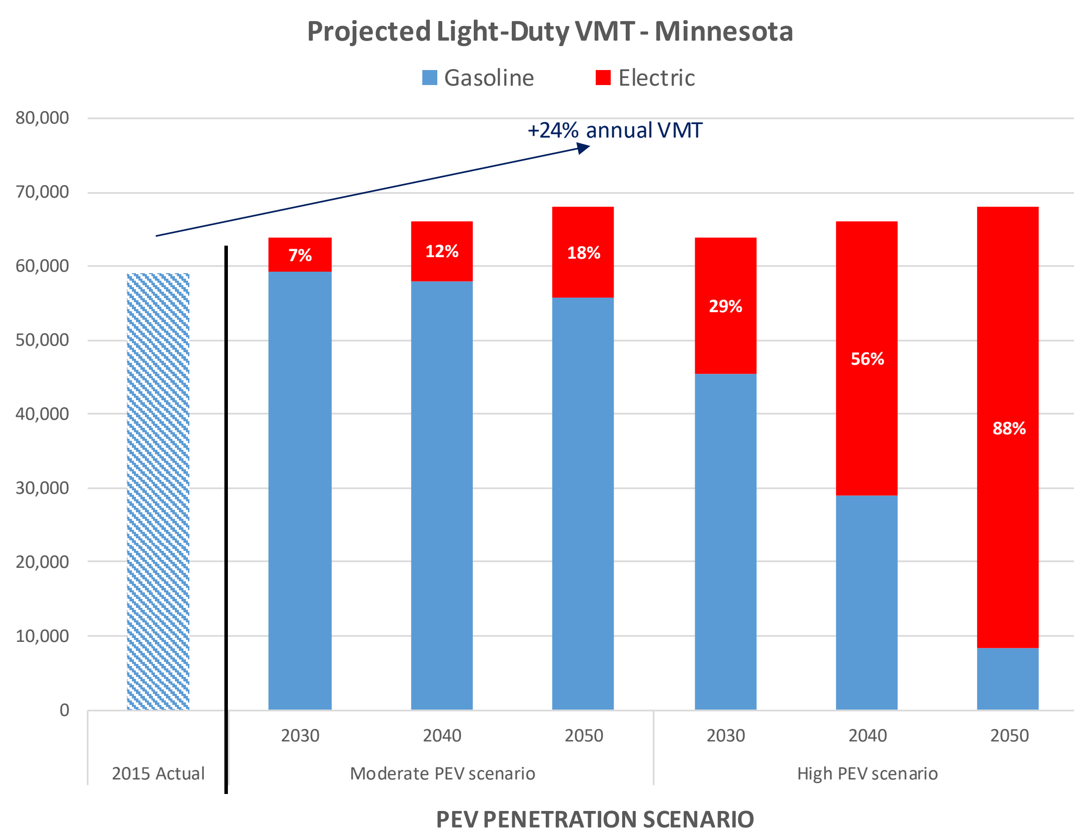


Figure 5 Projected Minnesota Light Duty Fleet Vehicle Miles Traveled

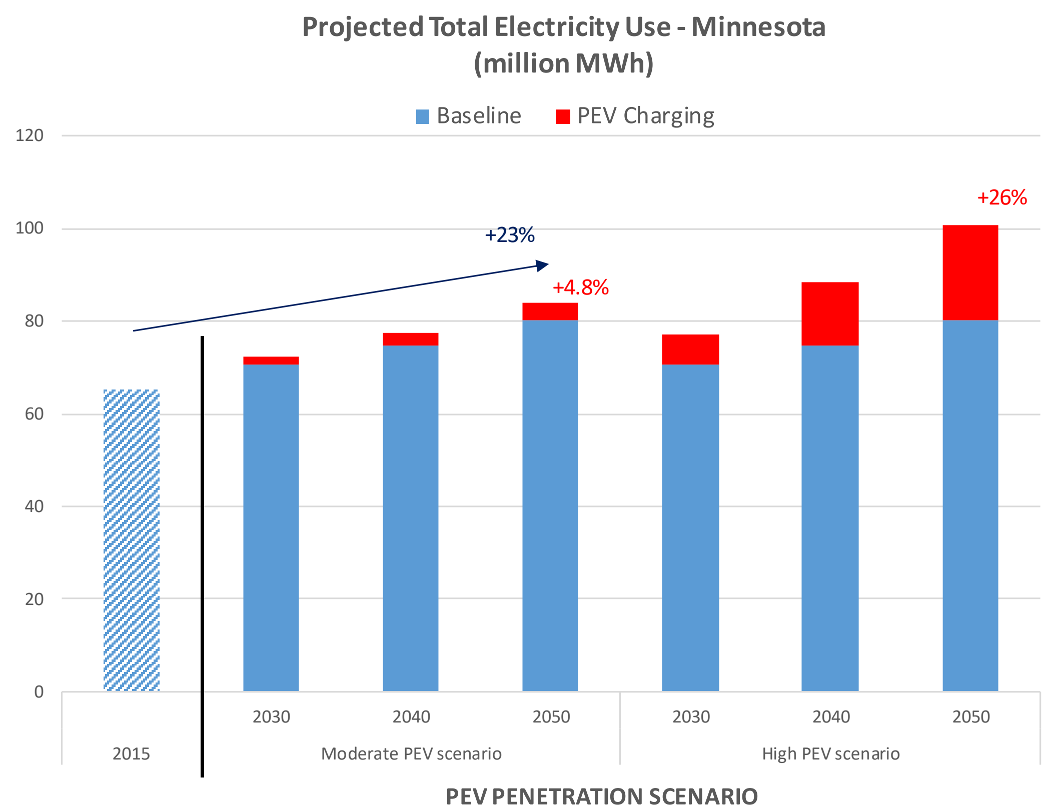


PEV Charging Electricity Use

The estimated total PEV charging electricity used in Minnesota each year under the PEV penetration scenarios is shown in Figure 6.

In Figure 6, projected baseline electricity use without PEVs is shown in blue and the estimated incremental electricity use for PEV charging is shown in red. State-wide electricity use in Minnesota is currently 65 million MWh per year. Annual electricity use is projected to increase to 70.6 million MWh in 2030 and continue to grow after that, reaching 80 million MWh in 2050 (23 percent greater than 2015 level).

Figure 6 Estimated Total Electricity Use in Minnesota



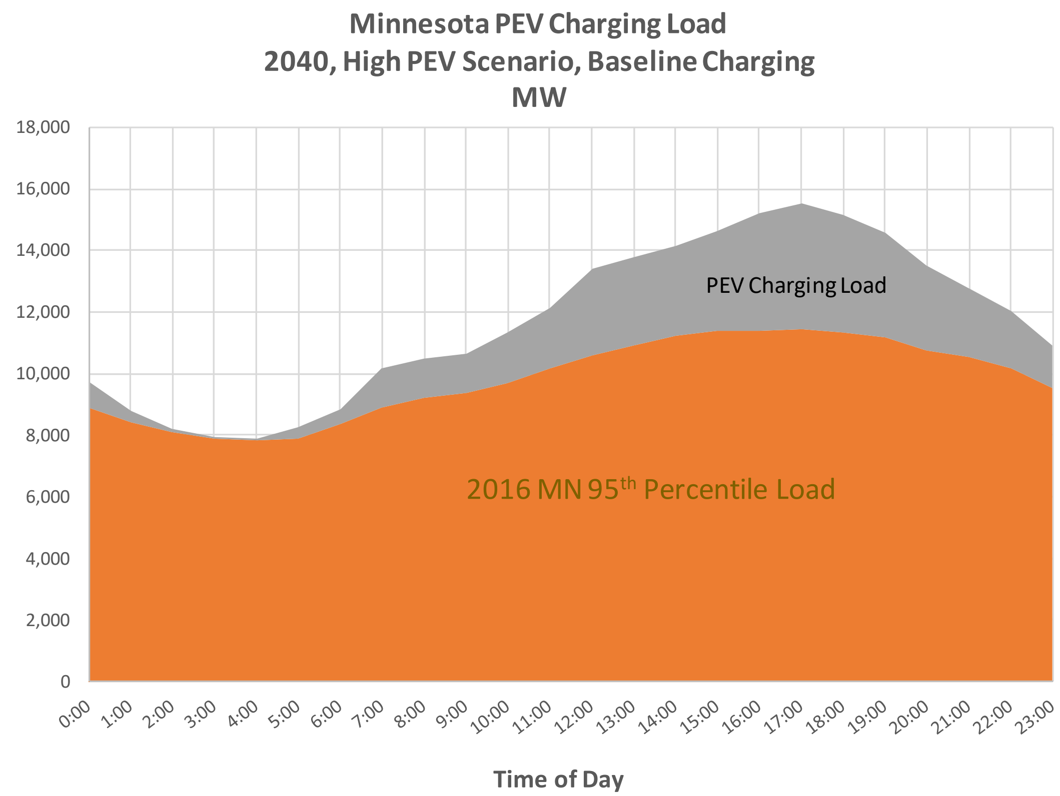
Under the Moderate PEV penetration scenario, electricity used for PEV charging is projected to be 1.6 million MWh in 2030 – an increase of 2.2 percent over baseline electricity use. By 2050, electricity for PEV charging is projected to grow to 3.8 million MWh – an increase of 4.8 percent over baseline electricity use. Under the High PEV scenario electricity used for PEV charging is projected to be 6.5 million MWh in 2030, growing to 20.6 million MWh and adding 26 percent to baseline electricity use in 2050.

PEV Charging Load

This analysis evaluated the effect of PEV charging on the Minnesota electric grid under two different charging scenarios. Under both scenarios, 81 percent of all PEVs are assumed to charge exclusively at home and 19 percent are assumed to charge both at home and at work. Under the baseline charging scenario, all Minnesota drivers are assumed to plug-in their vehicles and start charging as soon as they arrive at home or at work (if applicable) each day. Under the managed off-peak charging scenario 92 percent of Minnesota drivers who arrive at home after noon each day are assumed to delay the start of home charging until after 9 PM – in response to a price signal or incentive provided by their utility.[17] Further, this scenario assumes that off-peak charging will be managed by staggering charge start times between 9 PM and 4 AM for individual PEVs, to avoid a sharp secondary peak at 9 PM.[18]

See Figure 7 (baseline) and Figure 8 (managed off-peak) for a comparison of PEV charging load under the baseline and managed off-peak charging scenarios, using the 2040 High PEV penetration scenario as an example. In each of these figures, the 2016 Minnesota 95th percentile load (MW) by time of day is plotted in orange, and the projected incremental load due to PEV charging is plotted in grey.[19]

Figure 7 2040 Projected Minnesota PEV Charging Load, Baseline Charging (High PEV scenario)

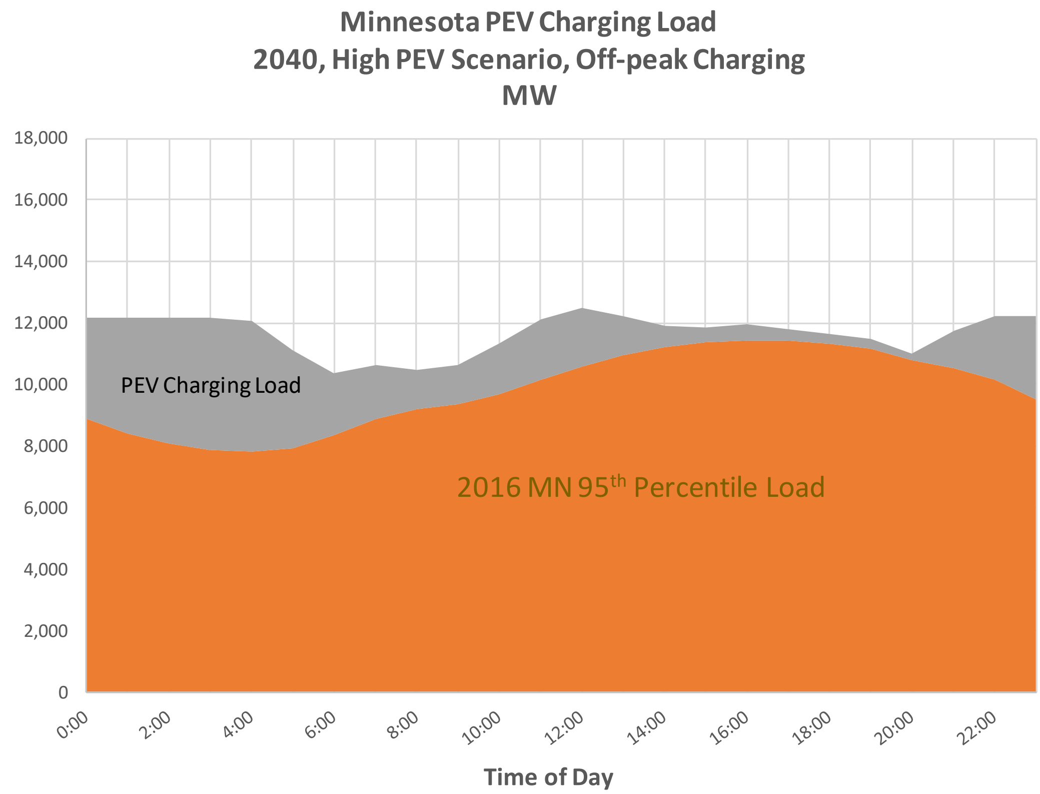


In 2016 daily electric load in Minnesota was generally in the range of 7,800 – 8,900 MW from midnight to 5 AM, ramping up through the morning and early afternoon to peak at approximately 11,422 MW between 3 PM and 5 PM, and then falling off through the late afternoon and evening hours.

17 Utilities have many policy options to incentivize off-peak PEV charging. This analysis does not compare the efficacy of different options.
18 Utilities have multiple policy and technical options for implementing managed charging. This analysis does not endorse any particular methodology.
19 For each hour of the day actual load in 2015 was higher than the value shown on only 5 percent of days (18 days).

As shown in Figure 7, baseline PEV charging is projected to add load primarily between 7 AM and midnight, as people charge at work early in the day and then at home later in the day. The PEV charging peak coincides with the existing afternoon peak load period between 3 PM and 5 PM. As shown in Figure 8, off-peak charging significantly reduces the incremental PEV charging load during the afternoon peak load period but distributes load through the late evening and continuing into the early morning hours, between 9 PM and 6 AM. The shape of this late evening/early morning peak can potentially be controlled based on the design of off-peak charging incentives[20]. It should also be noted that those early morning hours are often the hours of the day when wind generation peaks.

Figure 8 2040 Projected Minnesota PEV Charging Load, Off-peak Charging (High PEV scenario)



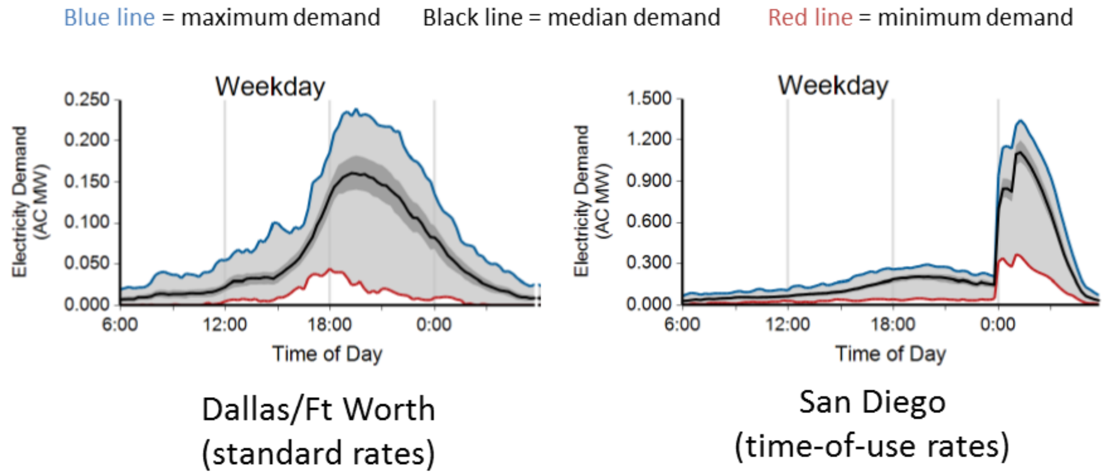
These baseline and off-peak load shapes are consistent with real world PEV charging data collected by the EV Project, as shown in Figure 9. In Figure 9 the graph on the left shows PEV charging load in the Dallas/Ft Worth area where no off-peak charging incentive was offered to drivers. The graph on the right shows PEV charging load in the San Diego region, where the local utility offered drivers a time-of-use rate with significantly lower costs ($/kWh) for charging during the "super off-peak" period between midnight and 5 a.m.[9] [21] In Minnesota, Xcel Energy already offers a Residential EV Charging Service, which charges lower rates ($/kWh) for EV charging during off-peak hours - between 9 PM and 9 AM on weekdays, as well as on weekends and holidays.

[20] This analysis assumes off-peak charging will be managed, with individual vehicles starting to charge between 9 PM and 4 AM. Based on annual mileage per vehicle, and projected PEV energy use, the average over-night charge is projected to take less than 3 hours using Level 1 and level 2 home chargers.

[21] Off-peak charging start times in San Diego are not actively controlled based on the design of the incentive, so there is typically a sharp peak in load at midnight, the start of the 'super off-peak" period with lower energy costs.

Over the last two years the share of charging done during off-peak hours by customers on this rate has ranged from 90 to 95 percent. [10]

Figure 9 PEV Charging Load in Dallas/Ft Worth and San Diego areas, EV Project



See Table 1 for a summary of the projected incremental afternoon peak hour load (MW) in Minnesota, from PEV charging under each penetration and charging scenario. This table also includes a calculation of how much this incremental PEV charging load would add to the 2016 95th percentile peak hour load.

Under the Moderate PEV penetration scenario, PEV charging would add 497 MW load during the afternoon peak load period on a typical weekday in 2030, which would increase the 2016 baseline peak load by about 4 percent. By 2050, the afternoon incremental PEV charging load would increase to 1,227 MW, adding almost 11 percent to the 2016 baseline afternoon peak. By comparison the afternoon peak hour PEV charging load in 2030 would be only 67 MW for the off-peak charging scenario, increasing to 164 MW in 2050.

Under the High PEV penetration scenario, baseline PEV charging would increase the total 2016 afternoon peak electric load by about 56 percent in 2050, while off-peak charging would only increase it by about 7 percent.[22]

Table 1 Projected Incremental Afternoon Peak Hour PEV Charging Load (MW)

		Moderate PEV			**High PEV**		
		2030	**2040**	**2050**	**2030**	**2040**	**2050**
Baseline Charging	PEV Charging (MW)	497.2	850.7	1,226.7	2,122.7	4,083.9	6,335.9
	Increase relative to 2016 Peak	*4.4%*	*7.4%*	*10.7%*	*18.6%*	*35.8%*	*55.5%*
Off-Peak Charging	PEV Charging (MW)	66.5	113.8	164.1	272.7	524.6	813.9
	Increase relative to 2016 Peak	*0.6%*	*1.0%*	*1.4%*	*2.4%*	*4.6%*	*7.1%*

[22] Given projected significant increases in total state-wide electricity use through 2050, baseline peak load (without PEVs) is also likely to be higher in 2050 than 2016 peak load; as such the percentage increase in baseline peak load due to high levels of PEV penetration is likely to be lower than that shown in Table 1.

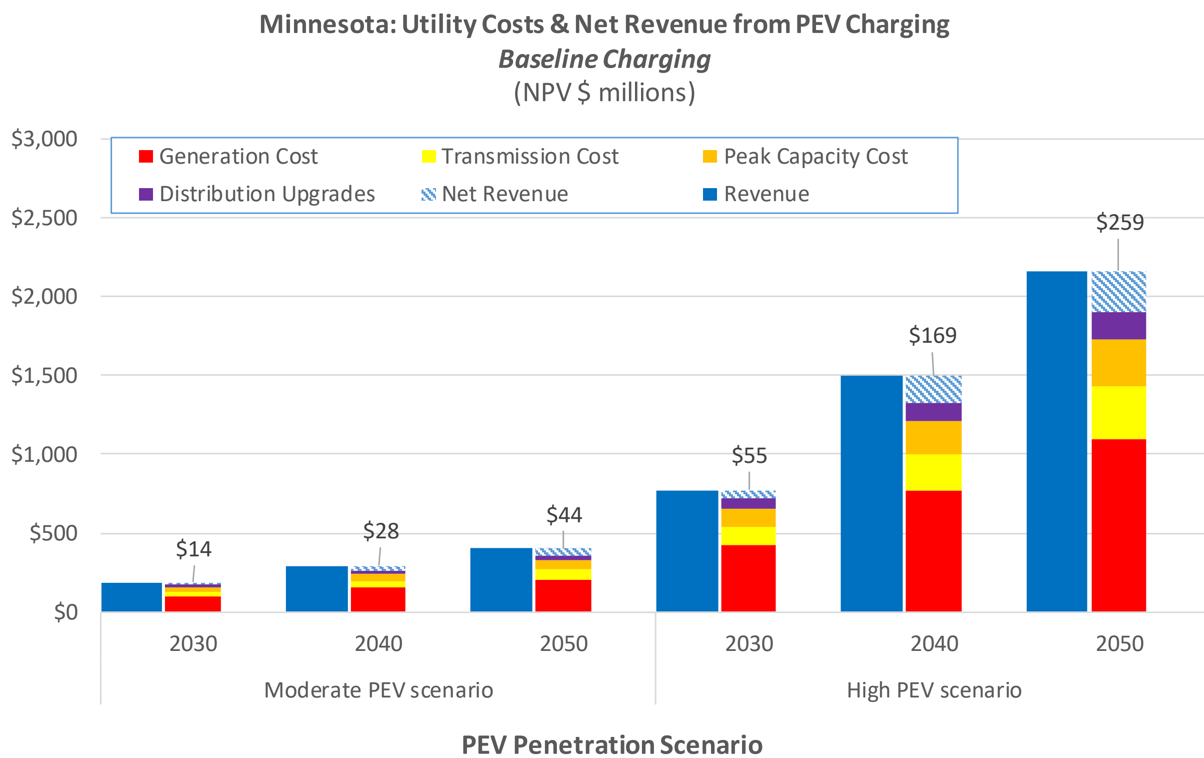
As discussed below, increased peak hour load increases a utility's cost of providing electricity, and may result in the need to upgrade distribution infrastructure. As such, off-peak PEV charging can provide net benefits to all utility customers by bringing in significant new revenue in excess of associated costs.

Utility Customer Benefits

The estimated NPV of revenues and costs for Minnesota' electric utilities to supply electricity to charge PEVs under each penetration scenario are shown in Figure 10, assuming the baseline PEV charging scenario.

In Figure 10, projected utility revenue is shown in dark blue. Under the Moderate PEV penetration scenario, the NPV of revenue from electricity sold for PEV charging in Minnesota is projected to total $185 million in 2030, rising to $401 million in 2050. Under the High PEV scenario, the NPV of utility revenue from PEV charging is projected to total $773 million in 2030, rising to $2.2 billion in 2050.

Figure 10 NPV of Projected Utility Revenue and Costs from Baseline PEV Charging



The different elements of incremental cost that utilities would incur to purchase and deliver additional electricity to support PEV charging are shown in red (generation), yellow (transmission), orange (peak capacity), and purple (transmission and distribution upgrade cost). Generation and transmission costs are proportional to the total power (MWh) used for PEV charging, while peak capacity costs are proportional to the incremental peak load (MW) imposed by PEV charging. Transmission and distribution upgrade costs are costs incurred by the utility to upgrade their own distribution infrastructure to handle the increased peak load imposed by PEV charging.

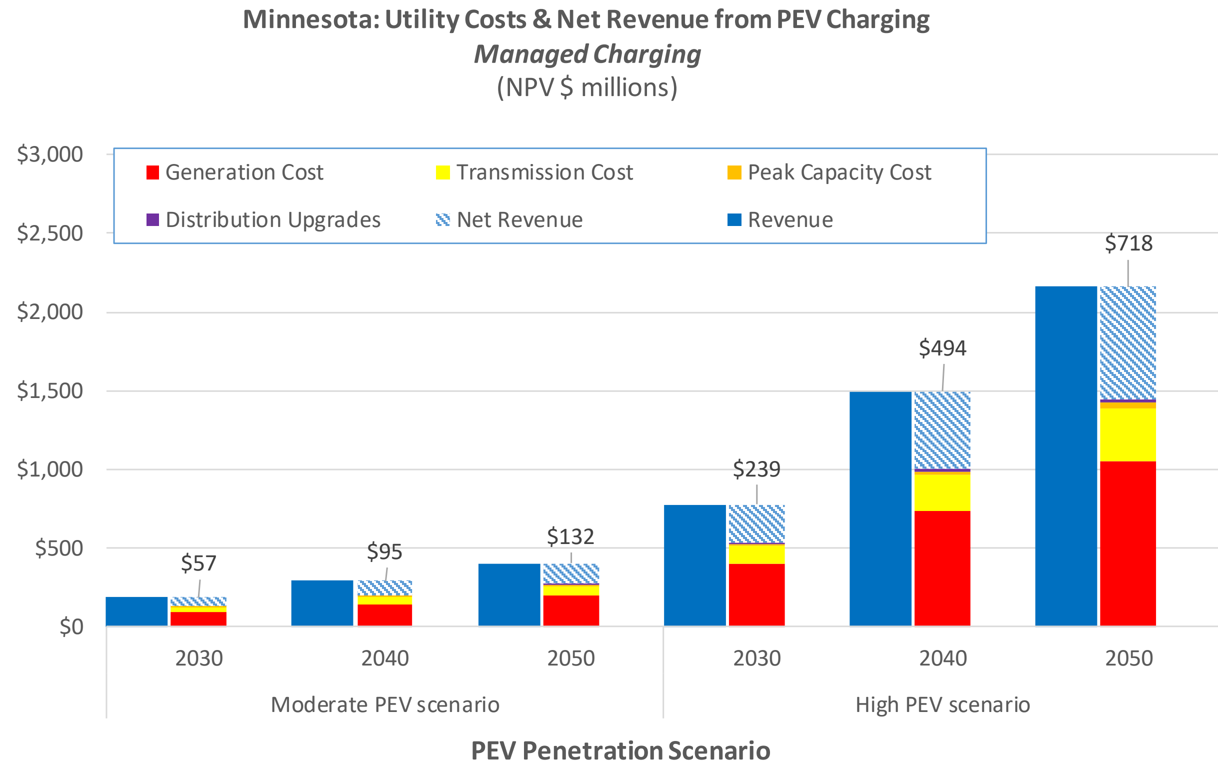
The striped light blue bars in Figure 10 represent the NPV of projected "net revenue" (revenue minus costs) that utilities would realize from selling additional electricity for PEV charging under each PEV penetration scenario. Under the Moderate PEV penetration scenario, the NPV of net revenue in Minnesota is projected to total $14 million in 2030, rising to $44 million in 2050. Under the High PEV scenario, the NPV of utility net revenue from

PEV charging is projected to total $55 million in 2030, rising to $259 million in 2050. The NPV of projected annual utility net revenue averages $28 per PEV in 2030, and $36 - $45 per PEV in 2050.

Figure 11 summarizes the NPV of projected utility revenue, costs, and net revenue for off-peak charging under each PEV penetration scenario. Compared to baseline charging (Figure 10) projected revenue, and projected transmission costs are the same, but projected generation, peak capacity and transmission and distribution upgrade costs are lower due to a smaller incremental peak load (see Table 1), and shifting of load to night-time hours when utilities' cost to purchase bulk electricity is lower.

Compared to baseline charging, off-peak charging will increase the NPV of annual utility net revenue by $43 million in 2030 and $88 million in 2050 under the Moderate PEV penetration scenario, due to lower costs. Under the High PEV scenario, off-peak charging will increase the NPV of annual utility net revenue by $184 million in 2030 and $459 million in 2050. This analysis estimates that compared to baseline charging, off-peak charging will increase the NPV of annual utility net revenue by $91 per PEV in 2030 and $76 per PEV in 2050.

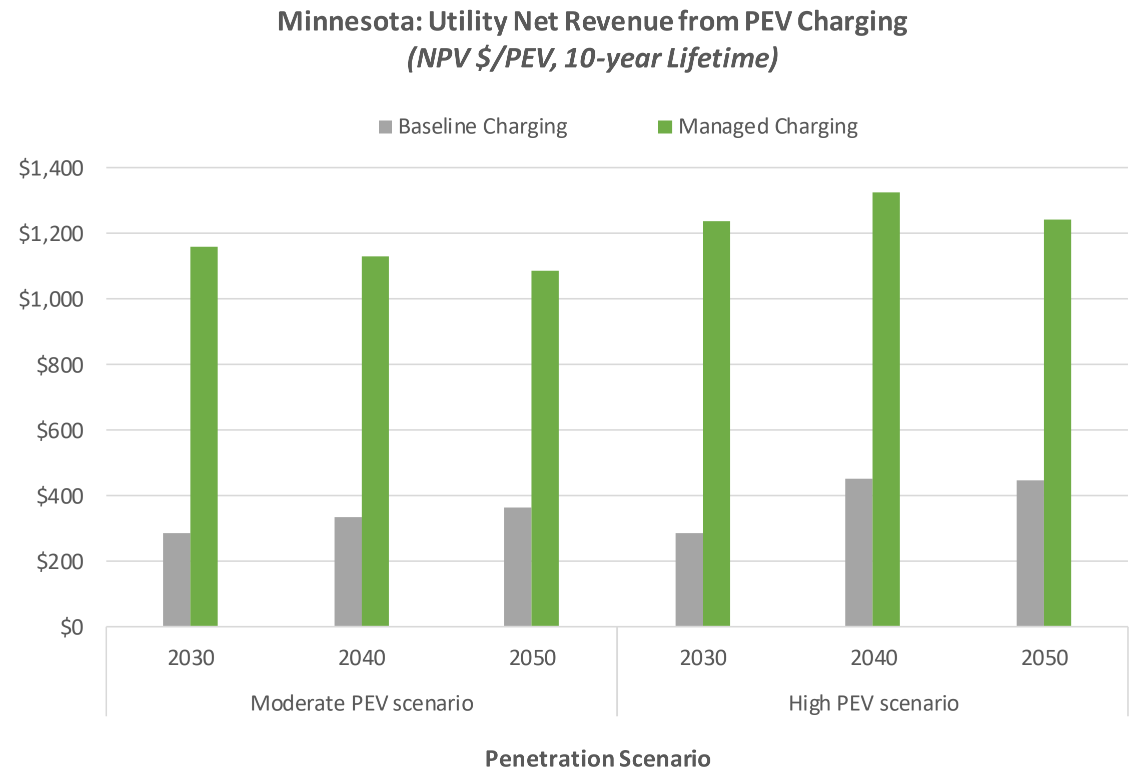
Figure 11 NPV of Projected Utility Revenue and Costs from Off-peak PEV Charging



Of note is the effect of managed off-peak charging on generation costs. Based on the 2016 daily load shape, and MISO Locational Marginal Prices at the Minnesota hub [11], this analysis estimates that Minnesota utilities paid an average of approximately $23.44/MWh for bulk power in 2016 and 2017. Under the baseline charging scenario the cost of the power needed to charge PEVs would average almost $26/MWh, approximately 11 percent more than the current average, due to the timing of the load, with a greater percentage during high-cost day-time hours. Under the managed off-peak charging scenario, load shifting to lower-cost night-time hours will reduce average bulk power costs for PEV charging to just over $20/MWh, more than a 20 percent reduction compared to the baseline scenario. This reduction is reflected in the net revenue figures shown in Figures 11 and 12.

The NPV of projected life-time utility net revenue per PEV is shown in Figure 12. Assuming a ten-year life, the average PEV in Minnesota in 2030 is projected to increase utility net revenue by over $1,088 over its life-time, if charged off-peak. PEVs in service in 2050 are projected to increase utility net revenue by almost $1,242 over their life time (NPV) if charged off-peak.

Figure 12 NPV of Projected Life-time Utility Net Revenue per PEV



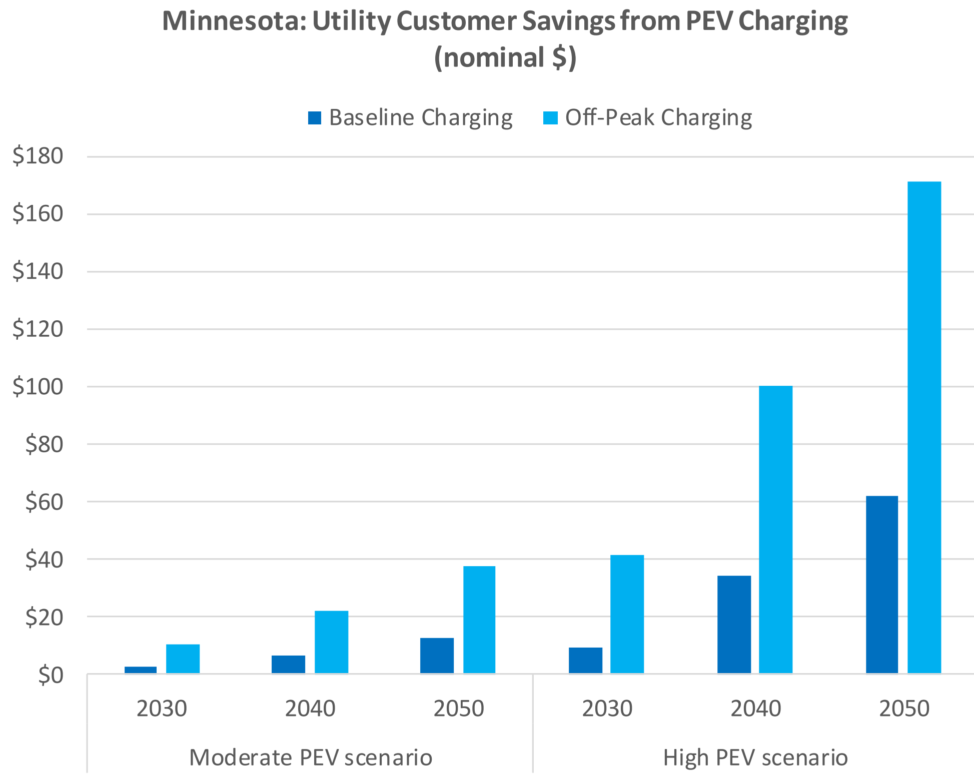
In general, a utility's costs to maintain their distribution infrastructure increase each year with inflation, and these costs are passed on to utility customers in accordance with rules established by the state's Public Utilities Commission (PUC), via periodic increases in residential and commercial electric rates. However, under the PUC's "revenue decoupling" regulations, the majority of projected utility net revenue from increased electricity sales for PEV charging would in fact be passed on to utility customers in Minnesota, not retained by the utility companies. In effect this net revenue would put downward pressure on future rates, delaying or reducing future rate increases, thereby reducing customer bills.[23] The revenue decoupling mechanism in place in Minnesota would ensure this happens automatically.

See Figure 13 for a summary of how the projected utility net revenue from PEV charging might affect average residential electricity bills for all Minnesota electric utility customers.[24] As shown in the figure, under the High PEV scenario projected average electric rates in Minnesota could be reduced up to 5 percent by 2050, resulting in an annual savings of approximately $171 (nominal dollars) per household in Minnesota in 2050.

[23] Some of this net revenue may also be passed directly to PEV owners as an incentive to charge off-peak, in recognition of the significant benefits this would provide.

[24] Based on 2016 average electricity use of 8,792 kWh per housing unit in Minnesota.

Figure 13 Potential Effect of PEV Charging Net Revenue on Utility Customer Bills (nominal $)



Minnesota Driver Benefits

Current PEVs are more expensive to purchase than similar sized gasoline vehicles, but they are eligible for various government purchase incentives, including up to a $7,500 federal tax credit. These incentives are important to spur an early market, but PEVs are projected to provide a total lower cost of ownership than conventional vehicles in Minnesota on an unsubsidized basis by 2030, as described below.

The largest contributor to incremental purchase costs for PEVs compared to gasoline vehicles is the cost of batteries. Battery costs for light-duty plug-in vehicles have fallen from over $1,000/kWh to less than $400/kWh in the last 5 years; many analysts and auto companies project that battery prices will continue to fall – to below $125/kWh by 2025. [17]

Based on these battery cost projections, this analysis projects that the average annual cost of owning a PEV in Minnesota will fall below the average cost of owning a gasoline vehicle by 2030, even without government purchase subsidies.[25] See Table 2 which summarizes the average projected annual cost of Minnesota PEVs and gasoline vehicles under each penetration scenario. All costs in Table 2 are in nominal dollars, which is the primary reason why costs for both gasoline vehicles and PEVs are higher in 2040 and 2050 than in 2030 (due to inflation). In addition, the penetration scenarios assume that the relative number of PEV cars and higher cost PEV light trucks will change over time; in particular the High PEV scenario assumes that there will be a significantly higher percentage of PEV light trucks in the fleet in 2050 than in 2030, which further increases the average PEV purchase cost in 2050 compared to 2030.

[25] The analysis assumes that all battery electric vehicles in-use after 2030 will have 200-mile range per charge and that all plug-in hybrid vehicles will have 50-mile all-electric range.

Table 2 Projected Fleet Average Vehicle Costs to Vehicle Owners (nominal $)

GASOLINE VEHICLE		**Moderate PEV scenario**			**High PEV scenario**		
		2030	**2040**	**2050**	**2030**	**2040**	**2050**
Vehicle Purchase	$/yr	$4,399	$5,650	$7,579	$4,639	$6,851	$9,071
Gasoline	$/yr	$1,206	$1,416	$1,806	$1,248	$1,648	$2,105
Maintenance	$/yr	$260	$328	$423	$264	$344	$443
TOTAL ANNUAL COST	**$/yr**	**$5,865**	**$7,393**	**$9,807**	**$6,151**	**$8,843**	**$11,620**

PEV -MN		**Moderate PEV scenario**			**High PEV scenario**		
Baseline Charging/Standard Rate		**2030**	**2040**	**2050**	**2030**	**2040**	**2050**
Vehicle Purchase	$/yr	$4,878	$6,070	$7,809	$5,121	$7,375	$9,544
Electricity	$/yr	$567	$703	$902	$604	$817	$1,023
Gasoline	$/yr	$188	$183	$165	$166	$188	$189
Personal Charger	$/yr	$81	$102	$129	$81	$102	$129
Maintenance	$/yr	$143	$188	$253	$147	$196	$261
TOTAL ANNUAL COST	**$/yr**	**$5,858**	**$7,246**	**$9,259**	**$6,120**	**$8,678**	**$11,147**
Savings per PEV	**$/yr**	**$7**	**$147**	**$548**	**$31**	**$166**	**$473**

As shown in Table 2, even in 2050 average PEV purchase costs are projected to be higher than average purchase costs for gasoline vehicles (with no government subsidies), but the annualized effect of this incremental purchase cost is outweighed by significant fuel cost savings, as well as savings in scheduled maintenance costs. In 2030, the average Minnesota driver is projected to save $7 – $31 per year compared to the average gasoline vehicle owner, without government subsidies. These annual PEV savings are projected to increase to an average of $147 - $166 per PEV in 2040, and $473 - $548 per PEV in 2050, as relative PEV purchase costs continue to fall, and the projected price of gasoline continues to increase faster than projected electricity prices. The NPV of annual savings for the average PEV owner in Minnesota is projected to be $14 in 2030, rising to $187 in 2050.

The NPV of total annual cost savings to Minnesota drivers from greater PEV ownership are projected to be $2 million in 2030 under the Moderate PEV penetration scenario, rising to $61 million in 2040 and $244 million in 2050. Under the High PEV scenario, the NPV of total annual cost savings to Minnesota drivers from greater PEV ownership are projected to be $40 million in 2030, rising to $303 million in 2040 and $1.0 billion in 2050.

Other Benefits

Fuel and Emissions Reductions

Along with the financial benefits to electric utility customers and PEV owners described above, light-duty vehicle electrification can provide additional benefits, including significant reductions in gasoline fuel use and transportation sector emissions.

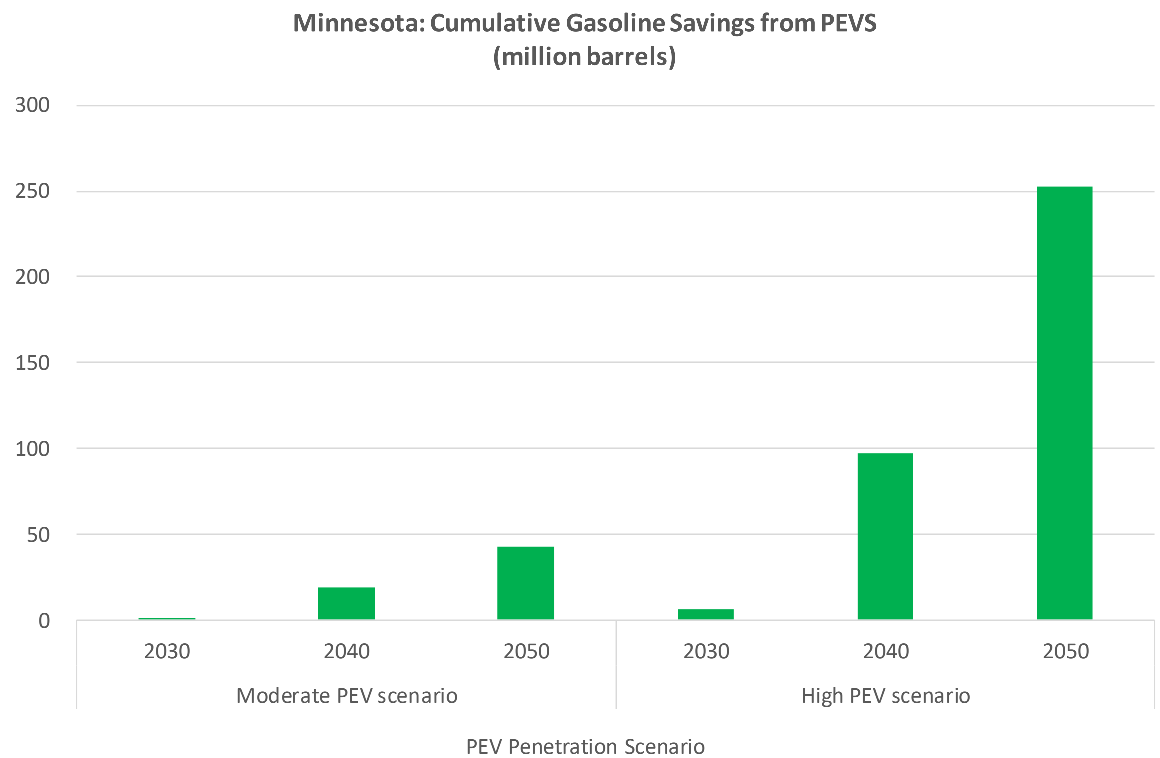
The estimated cumulative fuel savings (barrels of gasoline) from PEV use in Minnesota under each penetration scenario are shown in Figure 14.[26] Annual fuel savings under the Moderate PEV penetration scenario are projected to total 1.6 million barrels in 2030, with cumulative savings of more than 43 million barrels by 2050. For the High PEV scenario, annual fuel savings in 2030 are projected to be 6.1 million barrels, and by 2050 cumulative savings will exceed 252 million barrels.

[26] One barrel of gasoline equals 42 US gallons.

These fuel savings can help put the U.S. on a path toward energy independence, by reducing the need for imported petroleum. In addition, a number of studies have demonstrated that EVs can generate significantly greater local economic impact than gasoline vehicles - including generating additional local jobs - by keeping more of vehicle owners' money in the local economy rather than sending it out of state by purchasing gasoline.

Economic impact analyses for the states of California, Florida, Ohio and Oregon have estimated that for every million dollars in direct PEV owner savings, an additional $0.29 - $0.57 million in secondary economic benefits will be generated within the local economy, depending on PEV adoption scenario. These studies also estimated that between 13 and 25 additional in-state jobs will be generated for every 1,000 PEVs in the fleet. [1]

Figure 14 Cumulative Gasoline Savings from PEVs in Minnesota



The projected annual greenhouse gas (GHG) emissions (million metric tons carbon-dioxide equivalent, CO_2-e million tons) from the Minnesota light duty fleet under each PEV penetration scenario are shown in Figure 15. In this figure, projected baseline emissions from a gasoline fleet with few PEVs are shown in red for each year; the values shown represent "wells-to-wheels" emissions, including direct tailpipe emissions and "upstream" emissions from production and transport of gasoline. Projected total fleet emissions for each PEV penetration scenario are shown in blue; this includes GHG emissions from generating electricity to charge PEVs, as well as GHG emissions from gasoline vehicles in the fleet.

For the PEV penetration scenarios, projected GHG emissions are shown for a "low carbon" electricity scenario (light blue). This low carbon electricity scenario is based on Minnesota achieving long-term goals to reduce total GHG emissions from electricity generation by 80 percent from 2005 levels by 2050.

Figure 15 Projected GHG Emissions from the Light Duty Fleet in Minnesota

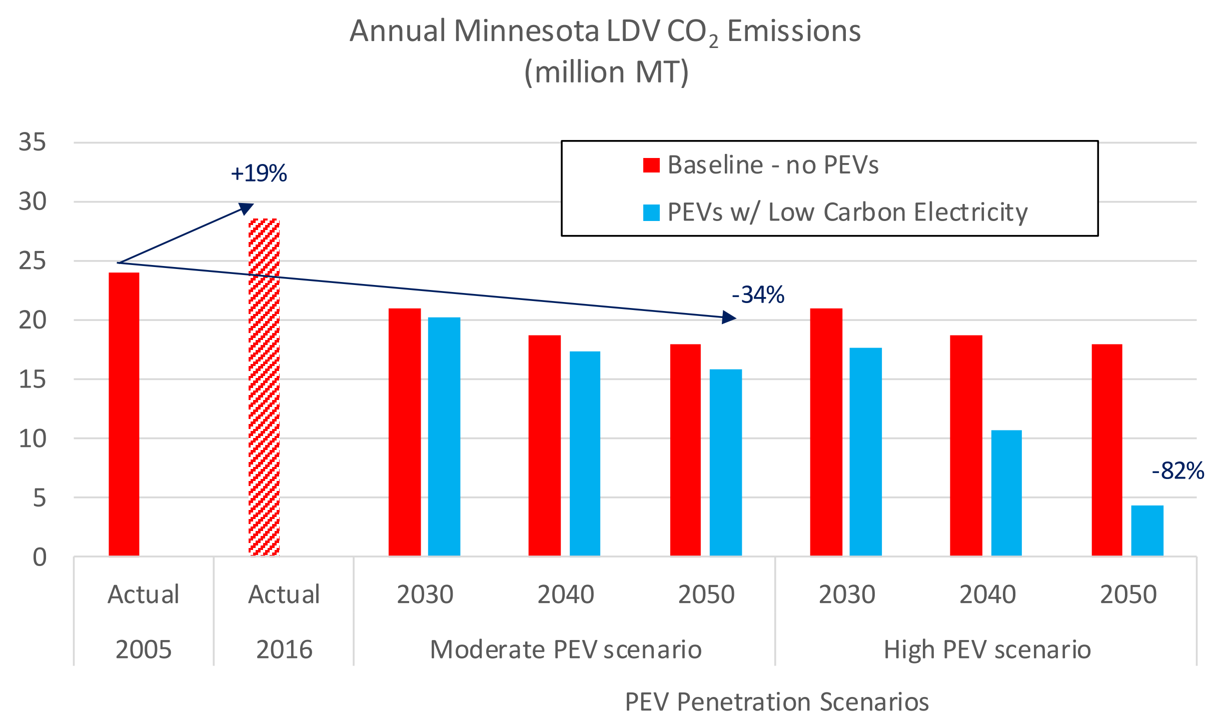
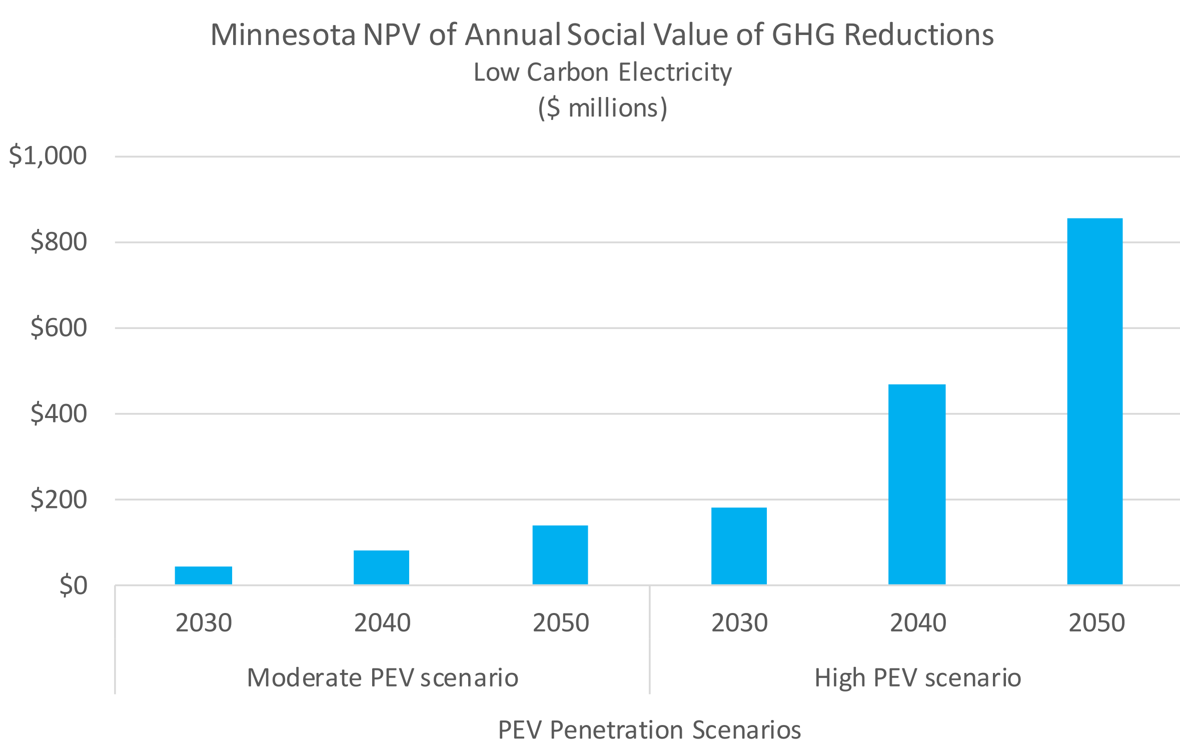


Figure 16 NPV of Projected Social Value of PEV GHG Reductions



As shown in Figure 15, GHG emissions from the light duty fleet were approximately 24.0 million tons in 2005, but they increased by 19 percent through 2016, to 28.5 million tons. However, even without significant PEV penetration, baseline annual fleet emissions are projected to fall to 17.9 million tons by 2050, a reduction of 25 percent from 2005 levels and 37 percent from current levels. This projected reduction is based on turnover of the existing vehicle fleet to more efficient vehicles that meet more stringent fuel economy and GHG standards issued by the Department of Transportation and Environmental Protection Agency. Under the Moderate PEV penetration scenario, PEVs are projected to reduce annual light duty fleet emissions by up to 11.5 million tons in 2050 compared to baseline emissions (-34 percent). Under the High PEV scenario, annual GHG emissions in 2050 will be as much as 17.2 million tons lower than baseline emissions (-82 percent).

Figure 16 summarizes the NPV of the projected monetized "social value" of GHG reductions that will result from greater PEV use in Minnesota. The social value of GHG reductions represents potential cost savings from avoiding the negative effects of climate change, if GHG emissions are reduced enough to keep long term warming below two degrees Celsius from pre-industrial levels. The values summarized in Figure 16 were developed using the Social Cost of CO_2 ($/MT) as calculated by the U.S. government's Interagency Working Group on Social Cost of Greenhouse Gases.

The NPV of the monetized social value of GHG reductions resulting from greater PEV use is projected to total $43 million per year in 2030 under the Moderate PEV penetration scenario, rising to as much as $138 million per year in 2050. Under the High PEV scenario the NPV of the monetized social value of GHG reductions from greater PEV is projected to be $179 million per year in 2030, rising to as much as $856 million per year in 2050.[27]

The NPV of the projected monetized social value of annual GHG reductions averages $48 per PEV in 2030, and $47 - $73 per PEV in 2050.

NOx Emissions

In 2015 the Electric Power Research Institute (EPRI), in conjunction with the Natural Resources Defense Council (NRDC), conducted national-level modeling to estimate GHG and air quality benefits from high levels of transportation electrification [14]. Under their electrification scenario EPRI estimated that NOx would be reduced by 11.4 tons and VOCs would be reduced by 5.5 tons, for every billion vehicle miles traveled.[28]

Extrapolating from this data, under the Moderate PEV Scenario, by 2050 light-duty vehicle electrification in Minnesota could reduce annual NOx emissions by 827 tons and reduce annual VOC emissions by 399 tons. Under the High PEV Scenario, total NOx reductions in 2050 could reach more than 4,005 tons per year, and total VOC reductions could reach almost 1,933 tons per year.[29]

Based on EPA's national average damage value of $15,909/ton of mobile source NOx, these NOx reductions would have a social value of $6.4 million in 2030 under the Moderate PEV Scenario, rising to $27.7 million in 2050. Under the High PEV Scenario the social value of these NOx reductions would be $25.9 million in 2030, rising to $134 million in 2050.

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[27] These figures are roughly equivalent to estimates of the value of GHG reduction that would be derived by using the high end of CO_2 externality values adopted by the Minnesota PUC. If the low CO_2 externality values adopted by the Minnesota PUC were used the totals would be approximately 78 percent lower.

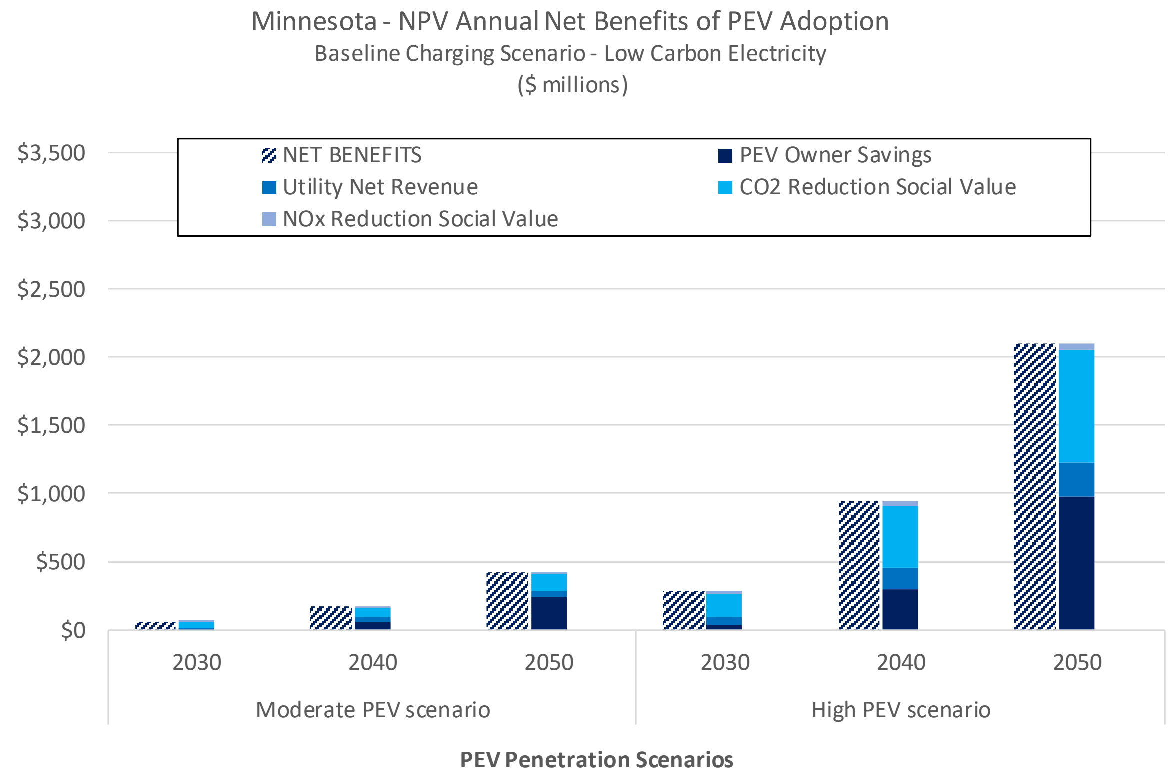
[28] For light-duty vehicles the analysis assumed that by 2030 approximately 17 percent of annual vehicle miles would be powered by grid electricity, using PEVs. Based on current and projected electric sector trends the analysis also assumed that approximately 49 percent of the incremental power required for transportation electrification in 2030 would be produced using solar and wind, with the remainder produced by combined cycle natural gas plants.

[29] Across the entire state, estimated annual light-duty vehicle miles traveled (VMT) totals 0.73 trillion miles in 2050. Of these miles approximately, 6 percent are powered by grid electricity under the Moderate PEV penetration scenario, and 87 percent are powered by grid electricity under the High PEV penetration scenario

Total Societal Benefits

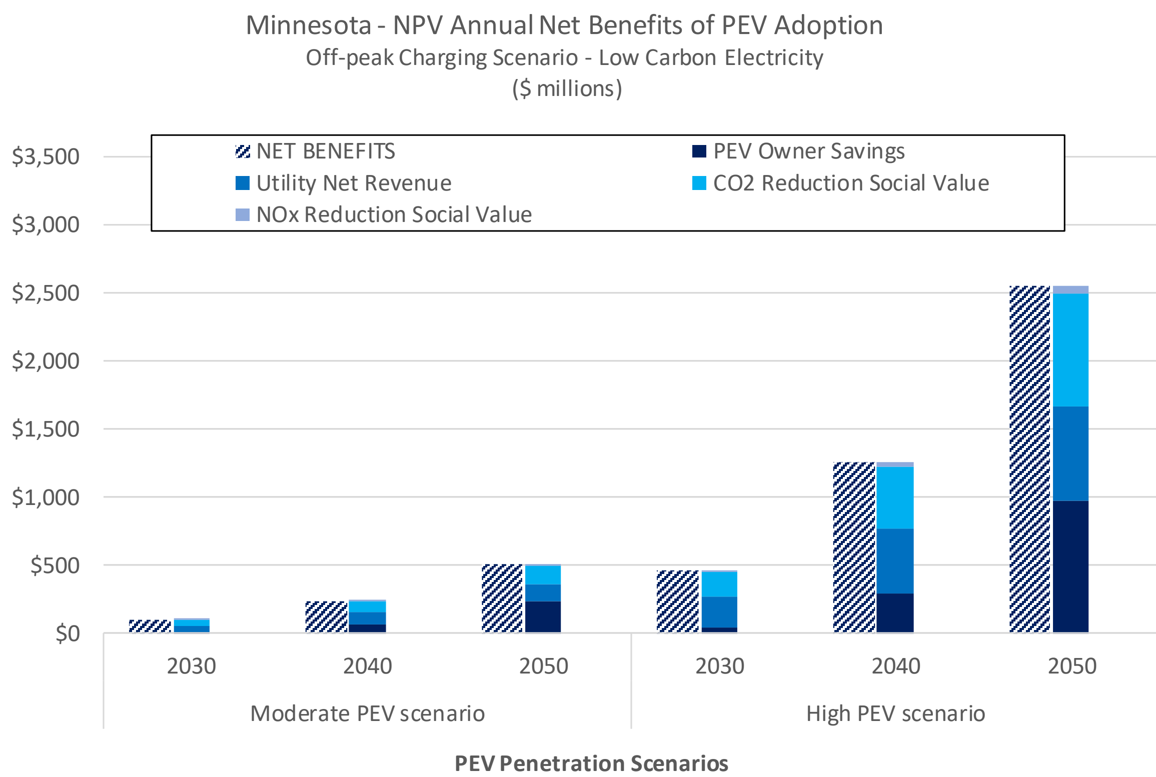
The NPV of total estimated societal benefits from increased PEV use in Minnesota under each PEV penetration scenario are summarized in Figures 17 and 18. These benefits include cost savings to Minnesota drivers, utility customer savings from reduced electric bills and the monetized benefit of reduced GHG and NOx emissions. Figure 17 shows the NPV of projected societal benefits if Minnesota drivers charge in accordance with the baseline charging scenario. Figure 18 shows the NPV of projected societal benefits if Minnesota drivers charge off-peak.

Figure 17 Projected NPV of Total Societal Benefits from Greater PEV use in MN – Baseline Charging



As shown in Figure 17, the NPV of annual societal benefits are projected to be a minimum of $424 million per year in 2050 under the Moderate PEV penetration scenario and $2.1 billion per year in 2050 under the High PEV scenario. Approximately 46 percent of these annual benefits will accrue to Minnesota drivers as a cash savings in vehicle operating costs, 12 percent will accrue to electric utility customers as a reduction in annual electricity bills, 2 percent will accrue to society at large in the form of reduced damage costs associated with reduced NOx emissions, and 40 percent will accrue to society at large in the form of reduced pressure on climate change due to reduced GHG emissions.

Figure 18 Projected NPV of Total Societal Benefits from Greater PEV use in MN – Off-peak Charging



As shown in Figure 18, the NPV of annual societal benefits in 2050 will increase by $86 million under the Moderate PEV penetration scenario, and $446 million under the High PEV scenario if Minnesota drivers charge off-peak. Of these increased benefits, all will accrue to electric utility customers as an additional reduction in their electricity bills.

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Charge Up Midwest is a partnership of environmental and clean energy organizations actively working to increase electric vehicle deployment throughout the region in Illinois, Missouri, Michigan, Minnesota, and Ohio. Fresh Energy is a non-profit organization that works to speed Minnesota's transition to a clean energy economy – including putting Minnesota on the pathway to being a national renewable energy leader, and promoting clean transportation options for Minnesota's growing economy.

This study is one of nine state-level analyses of plug-in electric vehicle costs and benefits developed for different U.S. states, including Colorado, Connecticut, Illinois, Maryland, Massachusetts, Michigan, Minnesota, New York, and Pennsylvania.

These studies are intended to provide input to state policy discussions about actions required to promote further adoption of electric vehicles.

This report, and the other state reports, are available at www.mjbradley.com.