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Electric Vehicle Cost-Benefit Analysis

Plug-in Electric Vehicle Cost-Benefit Analysis: Arizona

MJB & A

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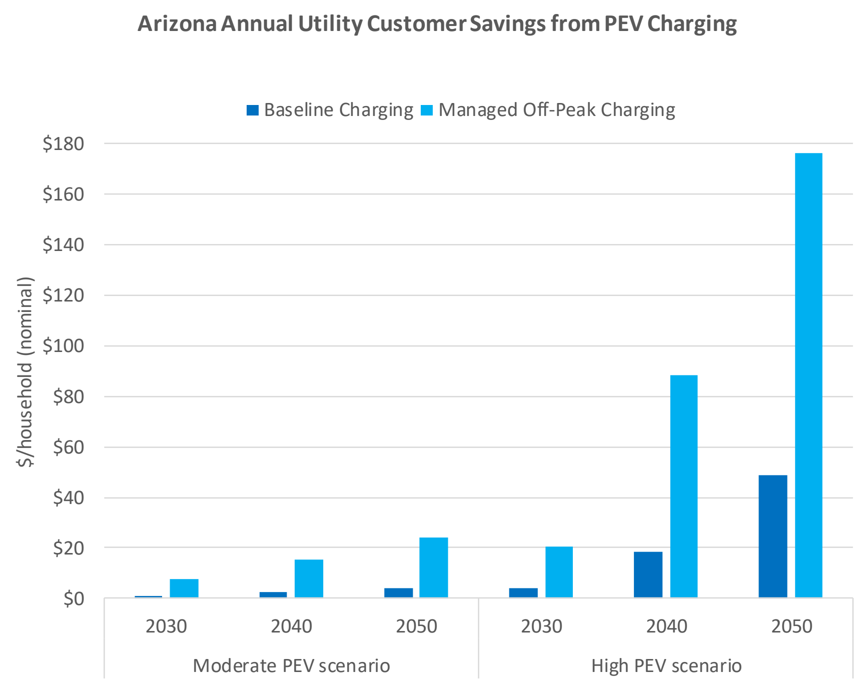
Executive Summary

This study estimated the costs and benefits of increased penetration of plug-in electric vehicles (PEV) in the state of Arizona, for two different penetration scenarios between 2030 and 2050.[1] The "Moderate PEV" scenario is based on the Transportation Electrification Goals in Arizona Corporation Commissioner Andy Tobin's *2018 Draft Energy Modernization Plan*, which includes a state-wide goal of one million PEVs registered in Arizona by 2050. [1] The "High PEV" scenario includes more aggressive PEV penetration levels that would be required to achieve deep reductions in vehicle air pollution emissions.

This study focused on passenger vehicles (cars and light 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 Arizona 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 Arizona drivers plug in and start to charge their vehicles as soon as they arrive at home or work (baseline charging). The study also evaluated the additional benefits that could be achieved by providing Arizona 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).

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



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.

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

See Figure 1 for a summary of how the projected utility net revenue from PEV charging might affect average residential electricity bills for all Arizona electric utility customers.[2] As shown in the figure, under the High PEV scenario with managed off-peak charging in 2050, the average Arizona household could realize approximately $176 in annual utility bill savings (nominal dollars) due to vehicle electrification.

In addition, the study estimated the annual financial net benefits to Arizona drivers – from net fuel and maintenance cost savings compared to owning gasoline vehicles. When evaluating costs to PEV owners, this study includes the cost of both home and "public" charging infrastructure required to support the modeled levels of PEV penetration. However, while this charging infrastructure represents a cost to PEV owners, it also represents a revenue opportunity for charging station owners by selling charging services. As such, this study includes as a net societal benefit the annual return on the capital that is invested by public charging station owners.

In addition to direct financial benefits to utility customers, PEV owners, and charging station owners, this study also estimates the societal benefits that would result from reduced nitrogen oxide (NOx) and greenhouse gas (GHG) emissions due to vehicle electrification.

As shown in Figure 2 (Moderate PEV scenario), if Arizona meets the transportation electrification goals included in the *2018 Draft Energy Modernization Plan*, the net present value (NPV) of **cumulative net benefits from greater PEV use in Arizona will exceed $3.7 billion state-wide by 2050**.[3] Of these total net benefits:

- At least $200 million will accrue to electric utility customers in the form of reduced electric bills[4],
- $2.6 billion will accrue directly to Arizona drivers in the form of reduced annual vehicle operating costs,
- $500 million will accrue to owners of public charging infrastructure in the state,
- $300 million will accrue to Arizona residents due to reduced costs of complying with future carbon reduction regulations, and
- $70 million will accrue to society at large, as the value of reduced NOx emissions.

As shown in Figure 3 (High PEV scenario), if PEV penetration were even higher - reaching 90 percent of the vehicle fleet in 2050 - the NPV of **cumulative net benefits from greater PEV use in Arizona could exceed $31 billion state-wide by 2050**. Of these total net benefits:

- Up to $9.0 billion will accrue to electric utility customers in the form of reduced electric bills,[5]
- $15.9 billion will accrue directly to Arizona drivers in the form of reduced annual vehicle operating costs,
- $3.9 billion will accrue to owners of public charging infrastructure in the state,
- $2.3 billion will accrue to Arizona residents due to reduced costs of complying with future carbon reduction regulations, and
- $400 million will accrue to society at large, as the value of reduced NOx emissions

[2] Based on 2016 annual average electricity use of 11,075 kWh per housing unit in Arizona.
[3] Using a three percent discount rate.
[4] Figure 2 includes utility customer savings under the baseline charging scenario; savings would be higher under the managed off-peak charging scenario.
[5] 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 AZ PEVs – Moderate PEV scenario*

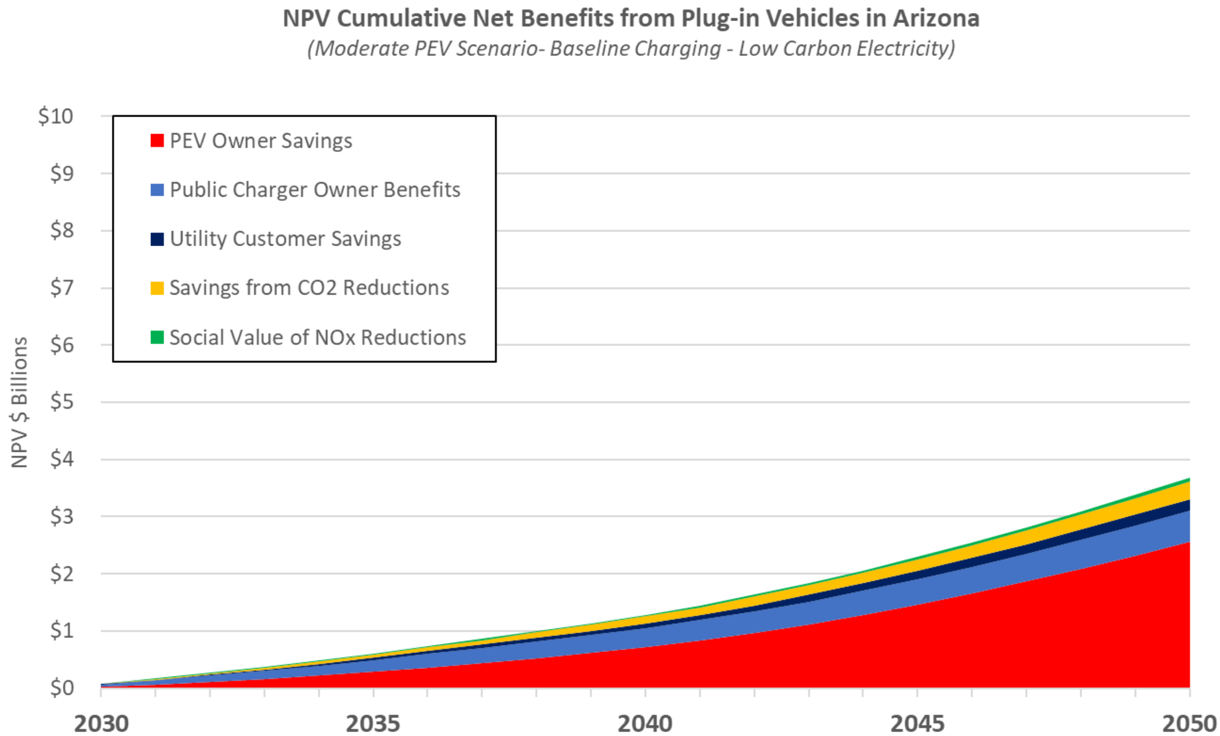
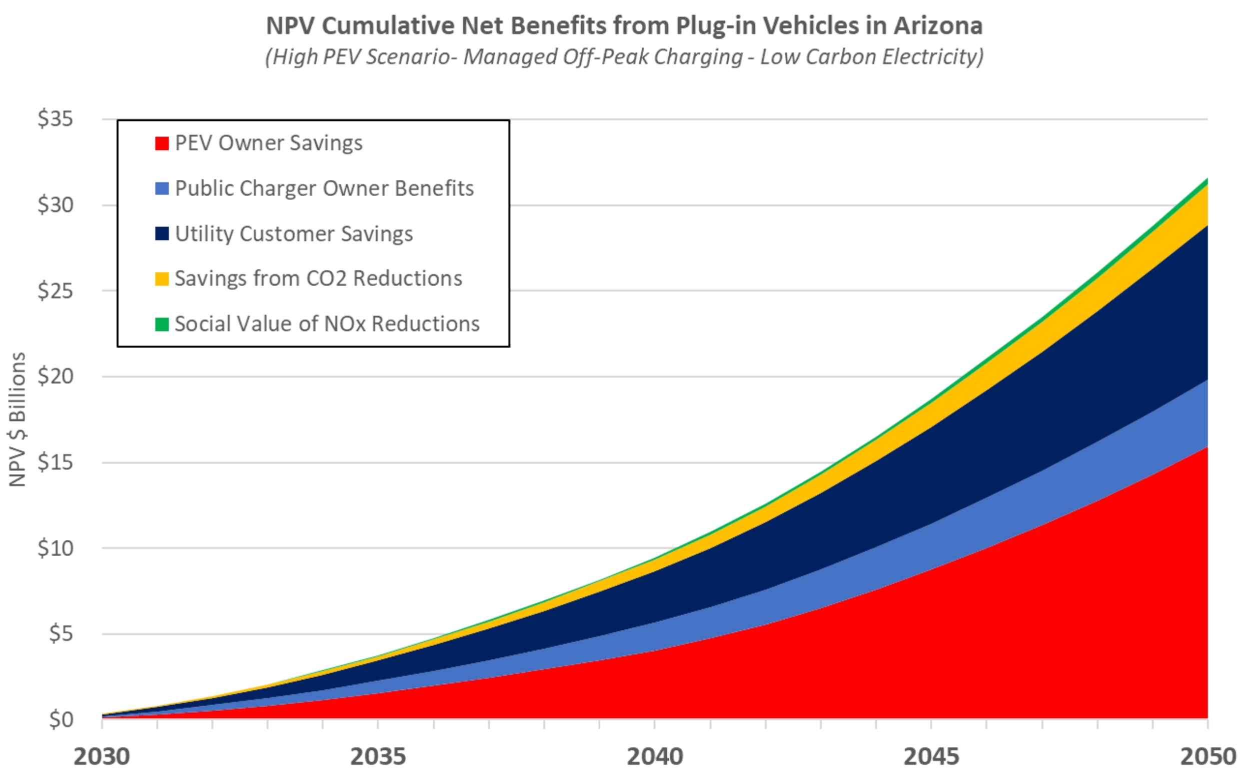


Figure 3 *NPV Cumulative Societal Net Benefits from AZ PEVs – High PEV scenario*



By 2050, PEV owners are projected to save more than $590 per vehicle (nominal $) in annual operating costs, compared to owning gasoline vehicles. A large portion of the direct financial benefit to Arizona 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 2.1 billion gallons through 2050 – this cumulative gasoline savings grows to 15.5 billion gallons through 2050 under the High PEV scenario. In 2050, annual average gasoline savings will be approximately 133 gallons per PEV under the Moderate PEV scenario, while projected savings under the High PEV scenario are 179 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. [2], [3], [4], [5], [6]

In addition, this reduction in gasoline use will reduce cumulative net greenhouse gas (GHG) emissions by more than 22 million metric tons through 2050 under the Moderate PEV scenario and over 160 million metric tons under the High PEV scenario.[6] The switch from gasoline vehicles to PEVs is also projected to reduce annual NOx emissions in the state by over 377 tons in 2050 under the Moderate PEV scenario and by over 2,900 tons under the High PEV scenario.

[6] Net of emissions from electricity generation

Background - Arizona

In 2018, Arizona ranked 15th in the nation for electric vehicle (EV) sales. [7] EV sales have grown six-fold since 2011, and Arizona's share of total U.S. sales is projected to grow as the state invests in EV infrastructure. [8] This outstanding growth in EV ownership is in part due to the vision and leadership from the State of Arizona. For many years, Arizona has been supportive of the adoption of EVs and autonomous vehicle (AV) technology. In 2012, former Governor Jan Brewer took the initiative by founding Electric Vehicle Arizona (EVAZ), a policy working group that meets regularly to identify and address barriers to EV deployment in the state. [9]

Arizona's current Governor Doug Ducey has continued this leadership in both the EV and AV industries. In October 2017, Arizona along with Colorado, Idaho, Montana, Wyoming, Utah, New Mexico, and Nevada signed a Memorandum of Understanding to establish the Intermountain West Electric Vehicle Corridor. [10] This collaboration will help build infrastructure to promote EVs, drive tourism, and ensure major transportation corridors are seamless. Governor Ducey has also taken steps to make Arizona a leader in AV testing, safety and mobility. For instance, in October 2018, he signed Executive Order 2018-09 creating the Institute for Automated Mobility (IAM), a public-private consortium to collaborate on research and testing of AVs. [11] This followed a March 2018 Executive Order allowing AVs to operate without a human driver in the state. This support of AV deployment is important as some tests have shown that the voltage and storage capacity of an EV battery is more compatible with self-driving equipment than conventional vehicles with an internal combustion engine. [12]

Arizona has also enacted several policies to incentivize EV adoption including:

- Tax credits of up to $75.00 for the installation of residential electric vehicle supply equipment (EVSE). [13]
- Discounts on auto insurance. [14]
- Unrestricted access to high-occupancy vehicle (HOV) lanes for plug-in hybrid-electric vehicles (PHEVs), battery-electric vehicles (BEVs), and Zero-emissions vehicles (ZEVs) with special license plates issued by the Arizona Department of Transportation. [15]
- A lower annual vehicle license tax. [16]
- Exemption from emissions-testing programs in Phoenix and Tucson. [17] and,
- Permission to park in spots reserved for carpool vehicles. [18]

Numerous state agencies and municipalities have also completed or begun the process of adopting plans for integrating more electric vehicles into their networks, as well as providing incentives for PEV, BHEV, and ZEV owners. These entities include the Arizona Department of Health Services, and the Cities of Flagstaff, Tempe, Tucson, and Phoenix. [19], [20], [21], [22], [23] These actions suggest that state and local governments value the benefits of increased transportation electrification, including reduced air emissions. Increased transportation electrification may be a particularly important strategy for counties like Maricopa and Pima which have recently exceeded federal ozone standards. [24], [25], [26]

Electric utilities in Arizona have also developed policies to support transportation electrification:

- Salt River Project (SRP) offers a residential Electric Vehicle Price Plan that provides incentives to charge vehicles during low-priced, off-peak hours from 11:00 p.m. to 5:00 a.m. [27] SRP also offers rebates for workplace and multifamily charging and electric forklifts; partnered with Nissan North America to provide $3,000 off a new 2018 Nissan LEAF; hosts an online community of EV enthusiasts; and has partnered with the Electric Power Research Institute (EPRI) to pioneer research on the impact of PEVs on the electric grid. [28], [29], [30], [31]

- Arizona Public Service (APS) has similarly partnered with Nissan North America; and both APS and Tucson Electric Power (TEP) have electric vehicle plans pending before the by Arizona Corporation Commission (ACC) for approval. [32], [33], [34]

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).[7] 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 Arizona between 2030 and 2050. These PEV penetration scenarios bracket short and long-term policy goals for ZEV adoption and emissions reduction which have been adopted by various states and localities.[8]

Moderate PEV Scenario: Penetration of PEVs necessary to achieve the transportation electrification goals contained in Arizona Corporation Commissioner Andy Tobin's *2018 Draft Energy Modernization Plan*, which calls for one million electric vehicles registered in Arizona in 2050. To achieve this goal PEV penetration is assumed to be 6.2 percent of the vehicle fleet in 2030, 9.2 percent in 2040, and 11.9 percent in 2050.

High PEV Scenario: A more aggressive scenario, under which PEVs comprise 15 percent of the vehicle fleet in 2030, 50 percent in 2040 and 90 percent in 2050. In this scenario PEVs are powered with 80 percent carbon free electricity, which is consistent with the Draft Energy Modernization Plan. This level of PEV penetration and energy mix would reduce total light-duty GHG emissions in Arizona in 2050 by 70 to 80 percent from current levels, and lead to significant reductions in NOx emissions.

Both of these scenarios are compared to a baseline scenario with very little PEV penetration and significant 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 United States Energy Information Administration (EIA).

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 Arizona's electric utilities would realize from sale of this electricity, their costs

[7] 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 EIA were updated from EIA's Annual Energy Outlook 2016 to those in the Annual Energy Outlook 2018. Assumptions about home and work arrival times, to calculate PEV charging load, were updated from the 2009 Household Travel Survey to the recently released 2018 Household Travel Survey. 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 estimated costs and benefits associated with the public charging infrastructure required to support the modeled level of PEV penetration, and an estimate of NOx reductions resulting from transportation electrification; the methodologies used are not included in the cited report but are described here.

[8] 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.

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. For this analysis we have focused on managed charging that shifts the majority of home charging into off-peak, nighttime hours. Additional benefits are likely possible from managed day-time charging – for example applied to workplace charging or school bus fleets – where there is an ability to align charging load with periods of peak solar production, but quantitative analysis of these benefits was beyond the scope of this report.

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 (baseline charging), exacerbating system-wide afternoon/evening peak demand.[9] However, if given a "nudge" - in the form of a properly designed and marketed financial incentive - many Arizona drivers will choose to delay the start of charging until off-peak times, thus reducing the effect of PEV charging on late afternoon peak electricity demand (managed off-peak charging). [35]

In Arizona, SRP already offers a Residential EV Charging Service, which charges lower rates ($/kWh) for EV charging during off-peak hours - between 11 p.m. and 5 a.m. on weekdays, as well as on weekends and holidays. [27] The managed off-peak charging scenario modeled for this analysis is structured similar to current and proposed programs in Arizona; the off-peak period is assumed to start at 9 p.m., 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 p.m. This scenario further assumes that off-peak charging will be managed by staggering charge start times between 9 p.m. and 4 a.m. for individual PEVs, to avoid a sharp secondary peak at 9 p.m.[10]

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 EIA, but then adds incremental generation costs (either positive or negative) associated specifically with PEV charging load under each charging scenario, based on timing of the charging load. This was done using actual average hourly prices (day-ahead locational marginal pricing or LMP) for bulk power in Arizona during 2017 and 2018. [36] This data shows that the cost for Arizona utilities to purchase bulk electricity varies by month and time of day, with average annual costs ($/MWh) about 22 percent higher during the day (7 a.m. – 10 p.m.) 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.

Current electricity costs make nighttime PEV charging less expensive than day-time charging. However, as solar photovoltaic penetration increases, enhancing the "duck curve," Arizona utilities may prefer to incentivize a greater amount of midday, workplace charging to absorb excess solar generation. Such a scenario might further reduce net generation costs, increasing overall net benefits from fleet electrification beyond what is estimated here. However, it would likely also increase the number of public charging stations needed, so that the increase in net benefits would be shared between PEV owners and owners of public charging stations.

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

[10] Utilities have multiple policy and technical options for implementing managed charging. This analysis does not endorse any particular methodology. The modeled scenario is intended to be illustrative of what is possible.

To calculate the costs associated with adding generation and transmission/distribution capacity to handle the incremental PEV charging load, this analysis uses a value of $108.65/kW-year in 2018 (nominal dollars) increasing by 2.5 percent per year in later years. This value is based on data in the Arizona Public Service Company's 2017 Integrated Resource Plan. [37] For each scenario in each year, this value is multiplied by the estimated incremental load (kW) imposed by EV charging during the late afternoon peak load period (4 p.m. – 8 p.m.), to calculate incremental capacity costs resulting from PEV charging.

For each PEV penetration scenario the total incremental annual cost of purchase and operation for all PEVs in the state is calculated and 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 (with PEVs costing more than conventional vehicles), annual costs for gasoline and electricity, and annual maintenance costs (with PEVs having lower costs than conventional vehicles). For PEVs it also includes the amortized annual cost of the necessary home chargers, as well as the amortized annual costs of necessary public charging infrastructure. This analysis is used to estimate average annual financial benefits to Arizona drivers who choose to purchase a PEV rather than a conventional vehicle.

With respect to public charging infrastructure, the National Renewable Energy Laboratory's Electric Vehicle Infrastructure Projection Tool (EVI-Pro) Lite was used to estimate the number of publicly accessible chargers that would be required to support the levels of PEV penetration modeled. [38] EVI-Pro uses detailed data on personal vehicle travel patterns, electric vehicle attributes, and charging station characteristics in bottom-up simulations to estimate the quantity and type of charging infrastructure necessary to support state or regional adoption of light-duty electric vehicles. The Lite version of the tool allows an estimation of the total number of Level 2 and direct current fast charge (DCFC) charge ports[11] required specifically in Arizona to support different numbers of PEVs to be developed.

Installed costs for Level 2 public/workplace chargers are assumed to be $8,500/port [39] and $100,000/port for DCFC charge ports. [40], [41], [42] To calculate total capital costs for public charging infrastructure, these per-port costs for charger installation were multiplied by the projected number of ports required each year. To calculate annual carrying costs, the resulting total capital investment in public charging infrastructure is assumed to be amortized over 15 years, with an annual rate of return (to the charger owner) of 10 percent on invested capital. The resulting annual amortized cost of the necessary public charging infrastructure is assumed to be borne by PEV owners, via the rates charged by station owners to use their chargers. These public charger costs reduce net benefits to PEV owners, but the return on invested capital earned by the charging station owners is a benefit to the owners and their investors.

Annual net reductions in nitrogen oxide (NOx) emissions were also projected under each PEV penetration scenario that would result from the use of electric vehicles instead of gasoline vehicles. To do so the reduction in emissions due to reducing miles driven by conventional vehicles was estimated, then subtracted the emissions resulting from generation of the electricity required to charge the electric vehicles that replaced them. To calculate the reduction in emissions from conventional vehicles, for each year in the analysis the authors used emission factors (grams/mile) for new conventional vehicles purchased in that year. These emission factors were derived from the United States Environmental Protection Agency's (EPA) MOtor Vehicle Emissions Simulator (MOVES) model. [43]

Finally, for each PEV penetration scenario annual GHG emissions was calculated from electricity generation for PEV charging and compares that to baseline emissions from operation of gasoline 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.

[11] Consistent with EVI-Pro Lite, this analysis assumes that Level 2 ports have a charging capacity of 6.2 kW/port and DCFC have a charging capacity of 150 kw/port.

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 Arizona reducing average GHG emissions from the electric grid to levels consistent with 80 percent of energy generated by zero-carbon resources by 2050, consistent with the goals outlined in the *Draft 2018 Energy Modernization Plan*.

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 value of these GHG reductions from PEV use are calculated using the cost of carbon values adopted by the Arizona Public Service Company in its 2017 Integrated Resource Plan. [44] These values are $13.11 per metric ton (MT) of carbon dioxide equivalent (CO_2-e) in 2017, rising to $18.07/MT in 2030, $23.13/MT in 2040, and $29.61/MT in 2050 (all in nominal dollars). These values represent the expected cost of complying with future GHG regulations. In addition, this analysis presents the monetized value of GHG reductions based on the "social cost of carbon emissions", which are estimated by the Federal Interagency Working Group on the Social Cost of Carbon as $41/MT today, rising to $57/MT in 2030, $69/MT in 2040, and $79/MT in 2050 (all in 2015 dollars).[12]

To calculate annual emissions from electricity generation the total electricity required to charge electric vehicles each year was multiplied by generation emission factors (g/kWh). For each year in the analysis, weighted average emissions factors were calculated based on the percentage of total charging electricity produced from renewable (solar and wind) and nuclear sources, and the percentage generated by natural gas combined cycle (NGCC) plants. NOx from renewable and nuclear sources are assumed to be zero. NOx emissions from NGCC plants are assumed to be 0.0313 g/kWh, per EPA's IPM power sector modeling platform. [45] Consistent with projections of GHG emissions, as noted above, 50 percent of electricity for PEV charging in 2030 is assumed to be generated by renewable and nuclear sources, increasing to 80 percent in 2050.

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 EPA using their Response Surface Model [46]; this value represents a national average for mobile source NOx.

Study Results

This section summarizes the results of this study, including the projected number of PEVs; and 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; projected financial benefits to Arizona PEV drivers compared to owning gasoline vehicles; and projected financial benefits to owners of public charging infrastructure.

All costs and financial benefits are presented as NPV, using a three percent discount rate.

Plug-in Vehicles, Electricity Use, and Charging Load

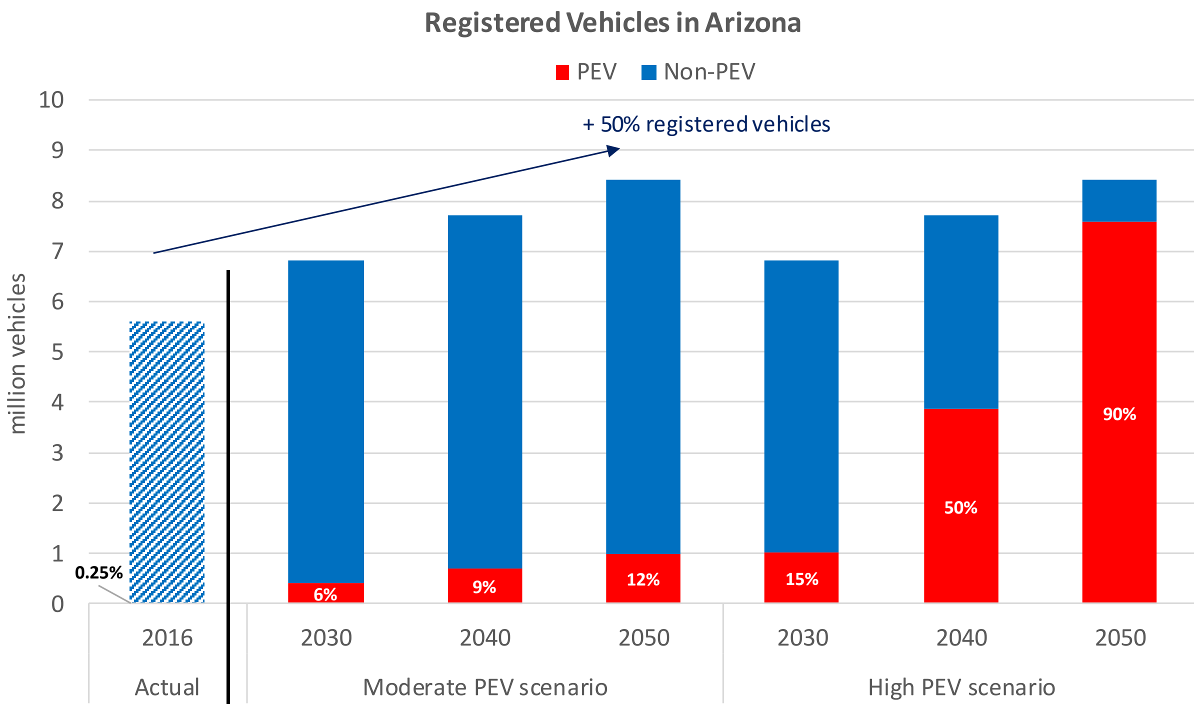
Vehicles and Miles Traveled

The projected number of PEVs and conventional gasoline vehicles in the Arizona 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. [13]

[12] These figures represent the central estimate of damages at the 3% discount rate.
[13] This analysis only includes cars and light trucks. It does not include medium- or heavy-duty trucks and buses.

There are currently 2.38 million cars and 3.23 million light trucks registered in Arizona, and these vehicles travel 66 billion miles per year. Both the number of vehicles and total annual vehicle miles are projected to increase by 50 percent through 2050, to 8.4 million light duty vehicles traveling 98.7 billion miles annually.[14]

Figure 4 Projected Arizona Light-Duty Fleet

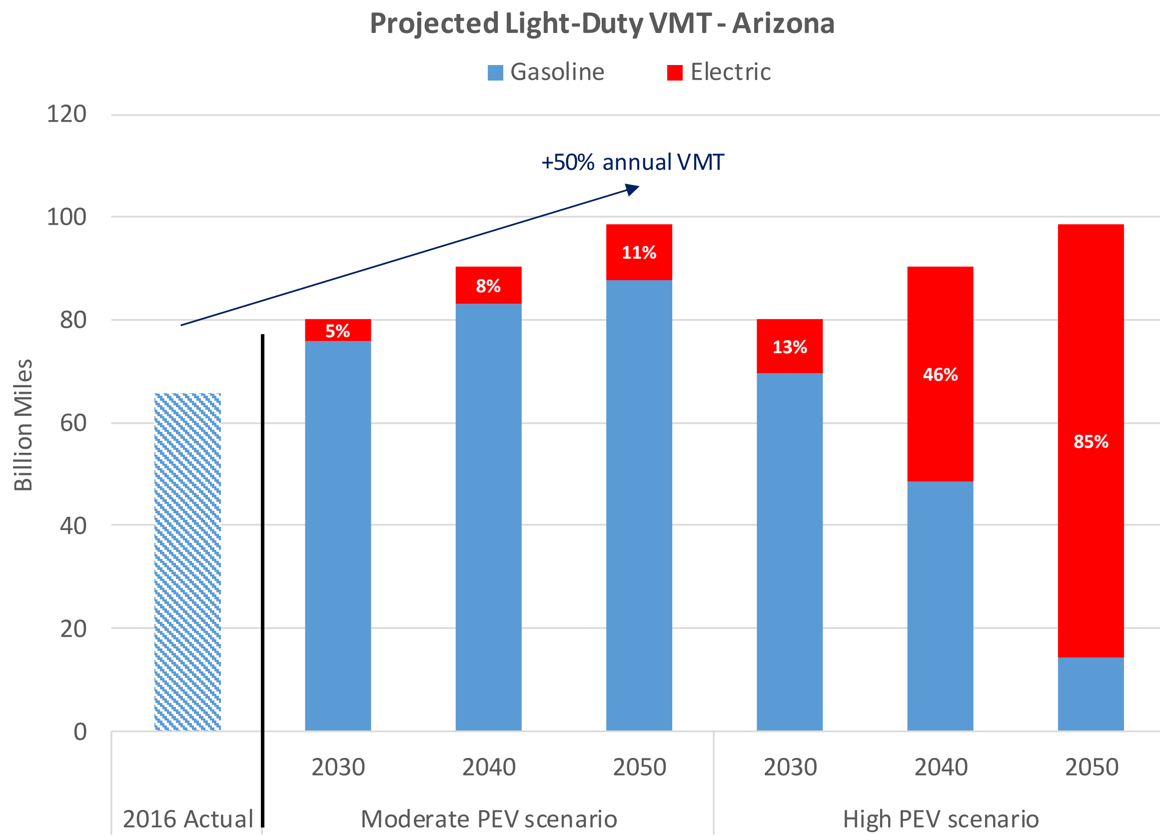


In order to meet the Moderate PEV scenario, the number of PEVs registered in Arizona would need to increase from approximately 13,900 today, to 420,000 by 2030, 710,000 by 2040, and 1.0 million by 2050.

In order to put the state on a path toward achieving the High PEV scenario, there would need to be approximately 1.02 million PEVs in Arizona by 2030, rising to 3.8 million in 2040, and 7.6 million in 2050.

[14] Vehicle fleet and VMT growth is assumed to mirror projected population growth.

Figure 5 Projected Arizona Light-Duty Fleet Vehicle Miles Traveled (billions)



Note that under both PEV penetration scenarios the percentage of total VMT driven by PEVs each year is lower than the percentage of PEVs 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 BEV nor a PHEV can convert 100 percent of the miles driven annually by a baseline gasoline vehicle into miles powered by grid electricity. In this analysis BEVs are conservatively assumed to have a utility factor of 92 percent in 2030 increasing to 99 percent in 2050 as vehicle range increases due to larger batteries, while PHEVs are assumed to have an average utility factor of 75 percent in 2030, rising to 90 percent in 2050.

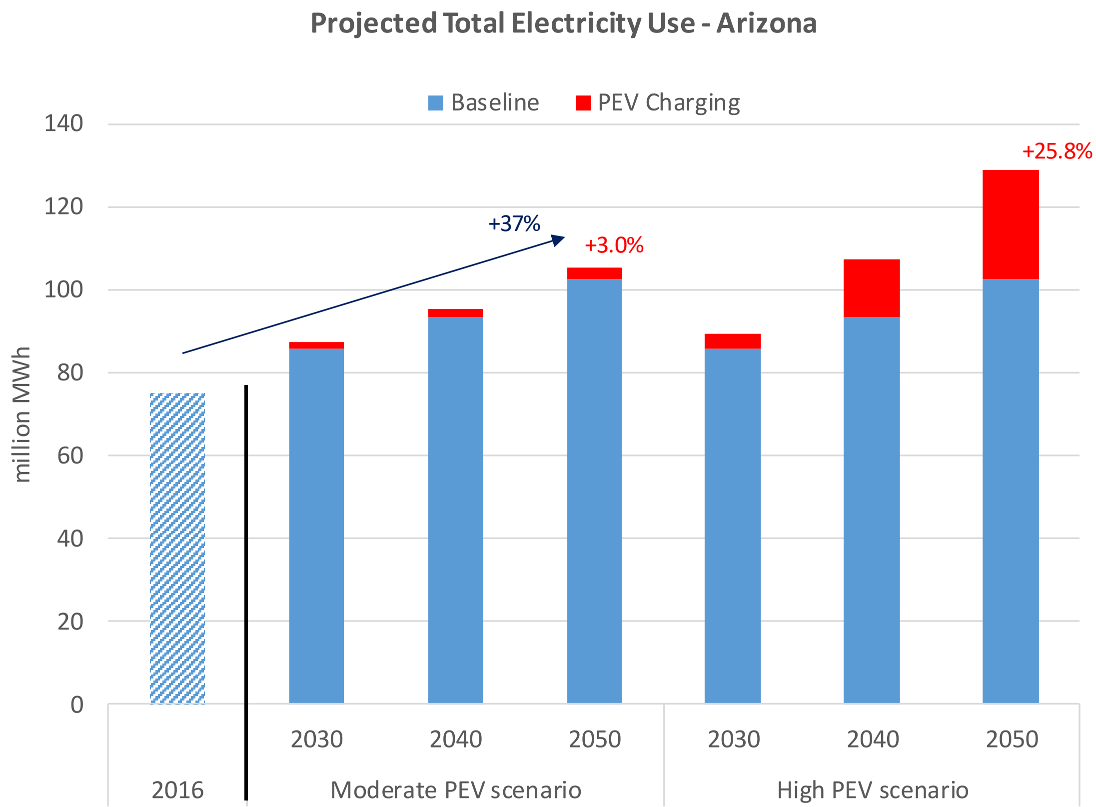
This analysis estimates that Arizona could reduce light-duty fleet GHG in 2050 by 80 percent from current levels if 85 percent of miles were driven by PEVs on electricity (Figure 5). However, in order to achieve this level of electric miles 90 percent of light-duty vehicles would need to be PEVs (Figure 4).

PEV Charging Electricity Use

The estimated total PEV charging electricity used in Arizona 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. Statewide electricity use in Arizona is currently 75 million MWh per year. Annual baseline electricity use is projected to increase to 86 million MWh in 2030 and continue to grow after that, reaching 102 million MWh in 2050 (37 percent greater than 2016 levels).

Figure 6 Estimated Total Electricity Use in Arizona



Under the Moderate PEV penetration scenario, electricity used for PEV charging is projected to be 1.3 million MWh in 2030 – an increase of 1.5 percent over baseline electricity use. By 2050, electricity for PEV charging is projected to grow to 3.1 million MWh – an increase of 3.0 percent over baseline electricity use. Under the High PEV scenario electricity used for PEV charging is projected to be 3.3 million MWh in 2030, growing to 26.4 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 Arizona electric grid under two different charging scenarios. Under both scenarios, 78 percent of all PEVs are assumed to charge exclusively at home and 22 percent are assumed to charge both at home and at work. Under the baseline charging scenario, all Arizona 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 Arizona drivers who arrive at home after noon each day are assumed to delay the start of home charging until after 9 p.m. – in response to a price signal or incentive provided by their utility.[15] Further, this scenario assumes that off-peak charging will be managed by staggering charge start times between 9 p.m. and 4 a.m. for individual PEVs, to avoid a sharp secondary peak at

[15] Utilities have many policy options to incentivize off-peak PEV charging. This analysis does not compare the efficacy of different options.

9 p.m., and that public charging start times will be managed to avoid an early morning peak as drivers arrive at work between 7 a.m. and 9 a.m.[16]

Figure 7 (baseline) and Figure 8 (managed off-peak) show comparisons 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 Arizona 95th percentile load (MW) by time of day is plotted in orange, and the projected incremental load due to PEV charging is plotted in gray. [17]

In 2016, daily electric load in Arizona was generally in the range of 9,925 – 11,278 MW from midnight to 5 a.m., ramping up through the morning and early afternoon to peak at approximately 17,010 MW between 3 p.m. and 5 p.m., and then falling off through the late afternoon and evening hours.

As shown in Figure 7, baseline PEV charging is projected to add load primarily between 7 a.m. 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 p.m. and 5 p.m. As shown in Figure 8, off-peak charging significantly reduces the incremental PEV charging load during the afternoon peak load period and distributes the load through the late evening and early morning hours, between 9 p.m. and 6 a.m. The load shape during the late evening/early morning hours could vary depending on the design of off-peak charging incentives[18].

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

[17] For each hour of the day actual load in 2016 was higher than the value shown on only 5 percent of days (18 days).

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

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

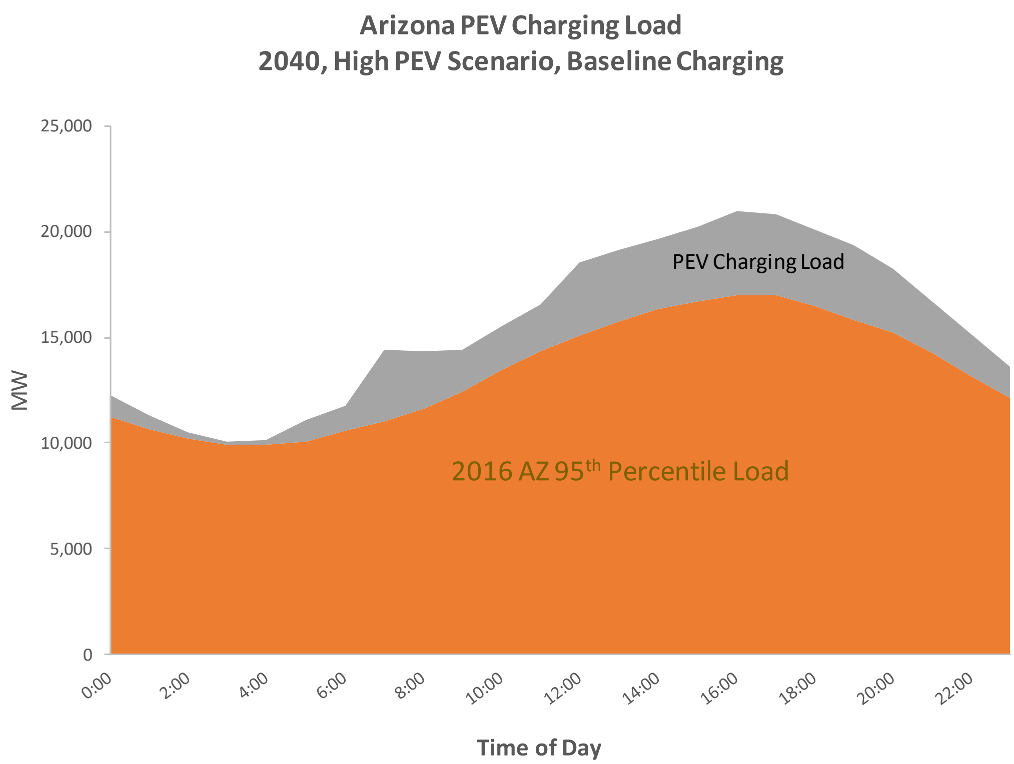
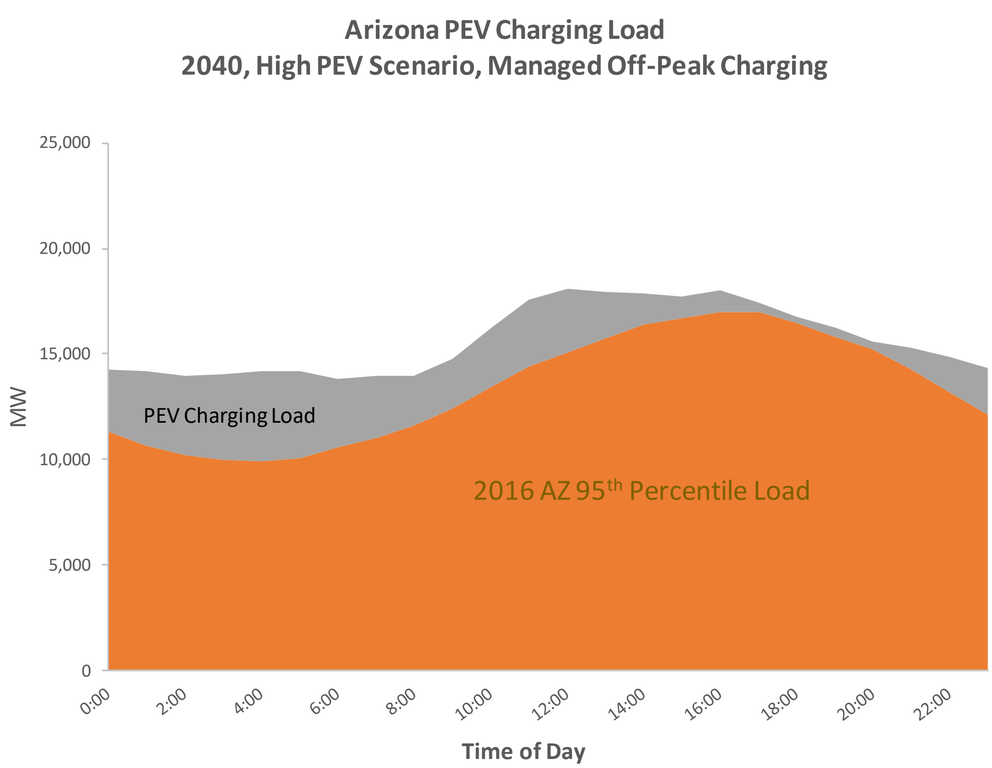
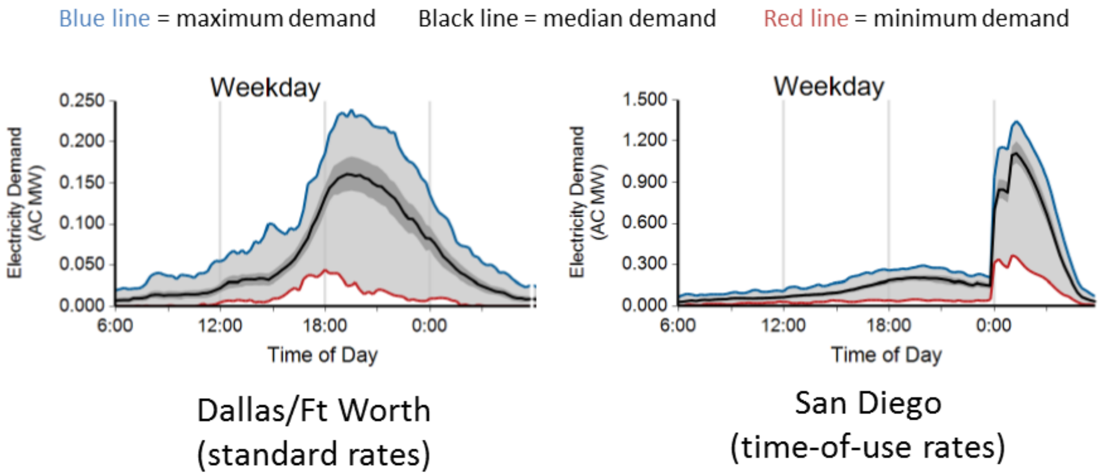


Figure 8 2040 Projected Arizona PEV Charging Load, Managed Off-Peak Charging (High PEV scenario)



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 ($/kWh) for charging during the "super off-peak" period between midnight and 5 a.m.[47] [19] In Arizona, SRP already offers a Residential EV Charging Service, which charges lower rates ($/kWh) for EV charging during off-peak hours - between 11 p.m. and 5 a.m. on weekdays, as well as on weekends and holidays.

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 Arizona, 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.

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)	400.9	677.8	954.7	977.8	4,006.2	7,232.1
	Increase relative to 2016 Peak	*2.4%*	*4.0%*	*5.6%*	*5.7%*	*23.6%*	*42.5%*
Off-Peak Charging	PEV Charging (MW)	108.0	182.6	257.2	263.4	1,017.6	1,948.4
	Increase relative to 2016 Peak	*0.6%*	*1.1%*	*1.5%*	*1.5%*	*6.0%*	*11.5%*

Under the Moderate PEV penetration scenario, PEV charging would add 401 MW load during the afternoon peak load period on a typical weekday in 2030, which would increase the 2016 baseline peak load by about 2 percent. By 2050, the afternoon incremental PEV charging load would increase to 955 MW, adding almost 6 percent to the

[19] 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.

2016 baseline afternoon peak. By comparison the afternoon peak hour PEV charging load in 2030 would be only 108 MW for the off-peak charging scenario, increasing to 257 MW in 2050.

Under the High PEV penetration scenario, baseline PEV charging would increase the total 2016 afternoon peak electric load by about 42 percent in 2050, while off-peak charging would only increase it by about 11 percent.[20]

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.

In addition, moving some PEV charging into midday hours provides a unique opportunity for utilities to sell electricity at a time that is cost-effective and allows for greater use of renewables. Because of the duck curve phenomenon, the times of greatest renewables generation are during times in which the grid sees relatively low demand. If energy demand shifts toward the late morning and early afternoon – from late afternoon/early evening hours - it allows utilities to utilize inexpensive renewable assets. The use of such assets could also make midday workplace EV charging more economically viable, and greater access to more charging options should also make EVs more attractive to consumers.

This consumer benefit could also serve as a mechanism for decreasing a utilities' average marginal costs. One study showed that when a smart charging EV rate plan is implemented, the average Marginal Cost/PEV is approximately ten times lower when compared to rate plans that have no Time-of-Use component. [48] An exploration of interactions between PEV charging and renewables utilization is beyond the scope of this analysis but does suggest that there are additional net benefits that could be generated by widespread transportation electrification if daytime workplace and fleet charging can be managed to capture these benefits.

Utility Customer Benefits

The estimated NPV of revenues and costs for Arizona's 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 Arizona is projected to total $151 million in 2030, rising to $325 million in 2050. Under the High PEV scenario, the NPV of utility revenue from PEV charging is projected to total $400 million in 2030, rising to $2.8 billion in 2050.

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), and orange (peak capacity). 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.

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 Arizona is projected to total $6 million in 2030, rising to $14 million in 2050. Under the High PEV scenario, the NPV of utility net revenue from PEV charging is projected to total $23 million in 2030, rising to $209 million in 2050. The NPV of projected annual utility net revenue averages $18 per PEV in 2030, and $14 - $28 per PEV in 2050.

[20] Given projected significant increases in total state-wide electricity use through 2050, baseline peak load (without PEVs) is also likely to be significantly 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.

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

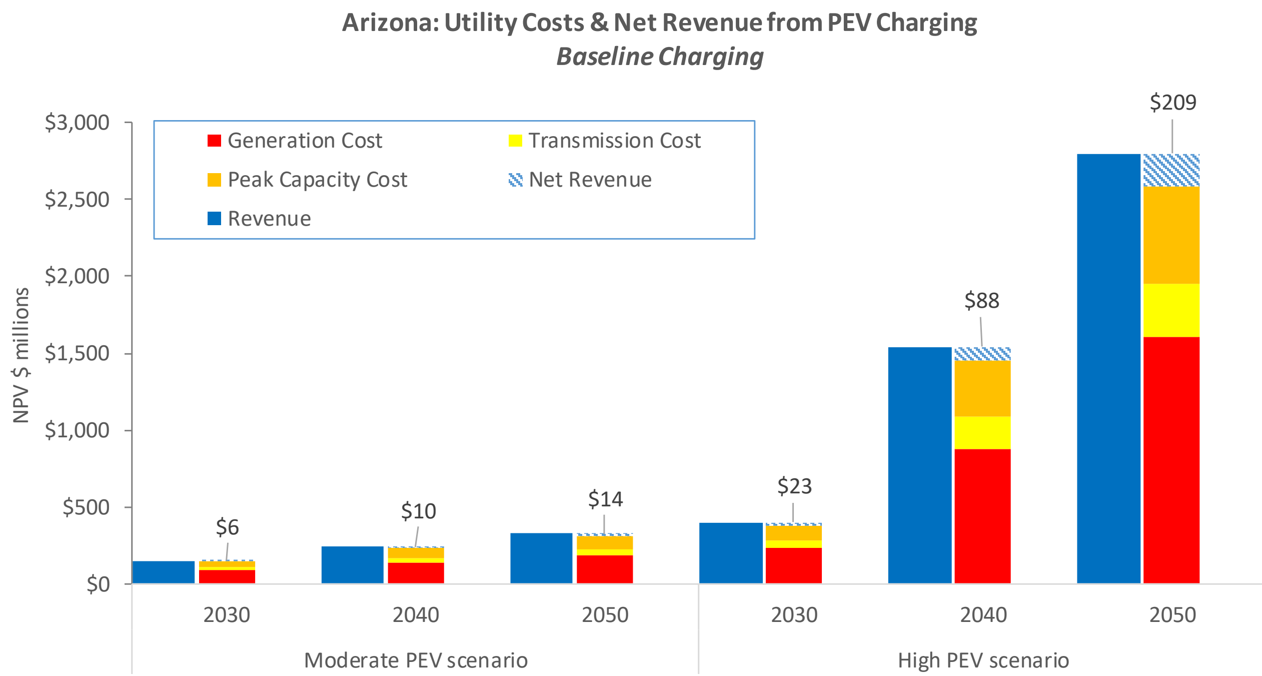
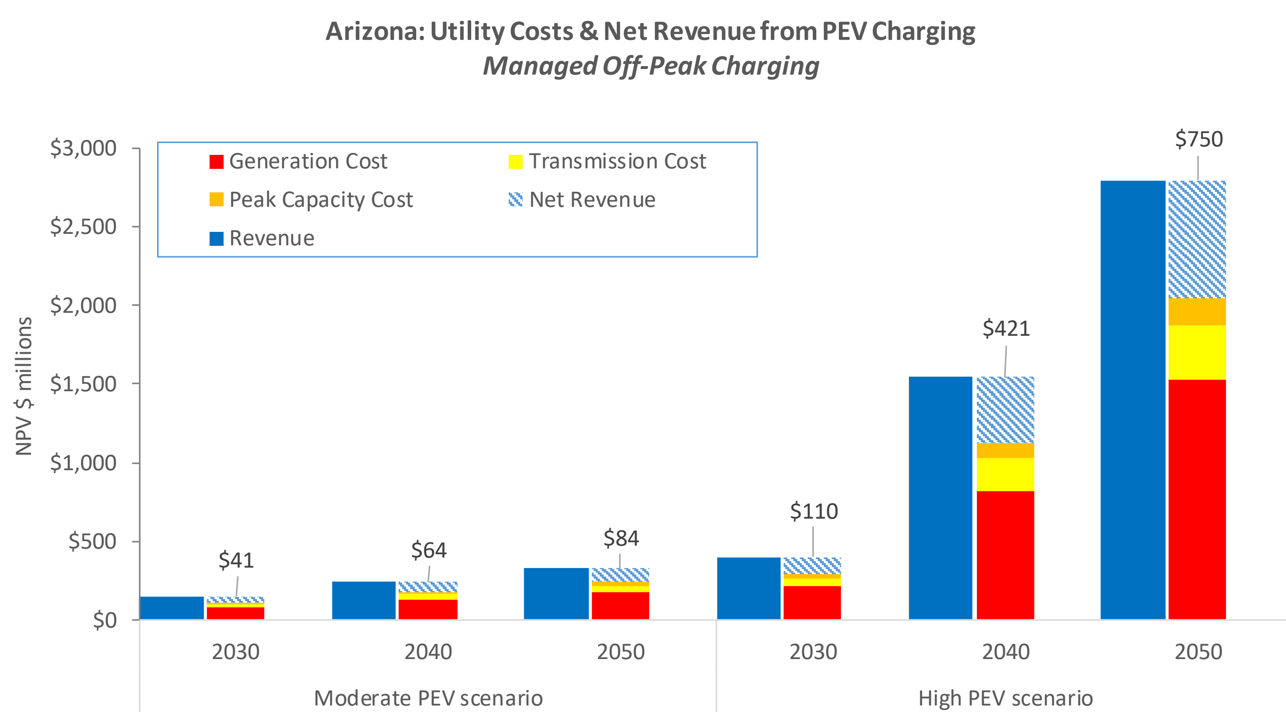


Figure 11 NPV of Projected Utility Revenue and Costs from Managed Off-Peak PEV Charging



Managed off-peak charging results in greater financial savings. Figure 11 summarizes the NPV of projected utility revenue, costs, and net revenue for managed 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 and peak capacity costs are lower due to a smaller incremental peak load (see Table 1) and shifting of load to nighttime hours when utilities' cost to purchase bulk electricity is lower.

Compared to baseline charging, managed off-peak charging will increase the NPV of annual utility net revenue by $35 million in 2030 and $70 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 $87 million in 2030 and $541 million in 2050. This analysis estimates that compared to baseline charging, off-peak charging will increase the NPV of annual utility net revenue by $84 per PEV in 2030 and $71 per PEV in 2050.

Of this utility net revenue from PEV charging, approximately 40 percent will accrue to Arizona Public Service, 39 percent to the Salt River Project, 11 percent to Tucson Electric Power, and 9 percent to the remaining local distribution companies in the state. See Table 2 for a summary of estimated net revenue, by local distribution company, under each scenario.

Table 2 Projected NPV of Net Revenue from PEV Charging for Arizona Local Distribution Companies

		Moderate PEV scenario			High PEV scenario		
		2030	2040	2050	2030	2040	2050
Arizona Public Service	Baseline Charging	$2.2	$3.9	$5.7	$9.0	$35.0	$83.0
	Managed Off-peak	$16.2	$25.5	$33.6	$43.5	$167.5	$298.2
Salt River Project	Baseline Charging	$2.2	$3.9	$5.6	$9.0	$34.6	$82.2
	Managed Off-peak	$16.0	$25.2	$33.3	$43.1	$165.8	$295.2
Tucson Electric Power	Baseline Charging	$0.6	$1.1	$1.6	$2.6	$10.0	$23.8
	Managed Off-peak	$4.6	$7.3	$9.6	$12.5	$48.0	$85.5
All others	Baseline Charging	$0.5	$0.9	$1.4	$2.2	$8.3	$19.8
	Managed Off-peak	$3.9	$6.1	$8.0	$10.4	$39.9	$71.1

Of note is the effect of managed off-peak charging on generation costs. Based on the 2016 daily load shape, and day-ahead LMP hourly prices, this analysis estimates that Arizona utilities paid an average of approximately $36.60/MWh for bulk power in 2016 and 2017. Under the baseline charging scenario the cost of the power needed to charge PEVs would average about $49/MWh, approximately 34 percent more than the current average, due to the timing of the load, with a greater percentage during high-cost daytime hours. Under the managed off-peak charging scenario, load shifting to lower-cost nighttime hours will reduce average bulk power costs for PEV charging to just over $19/MWh, more than a 46 percent reduction compared to the baseline scenario. This increase for baseline charging, and reduction for managed charging, is reflected in the net revenue figures shown in Figures 10 and 11.

Assuming a ten-year life, the average PEV in Arizona in 2030 is projected to increase utility net revenue by over $1,000 over its lifetime, if charged off-peak. PEVs in service in 2050 are projected to increase utility net revenue by almost $920 over their life time (NPV) if charged off-peak. The NPV of projected life-time utility net revenue per PEV is shown in Figure 12.

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

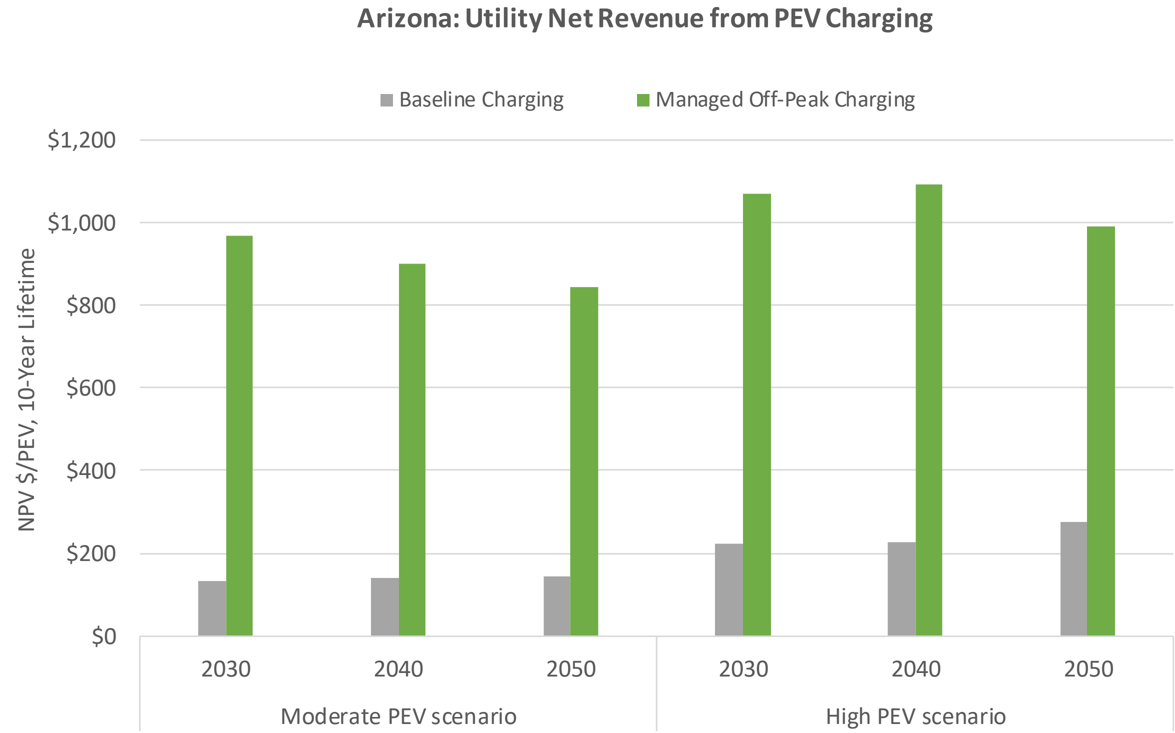
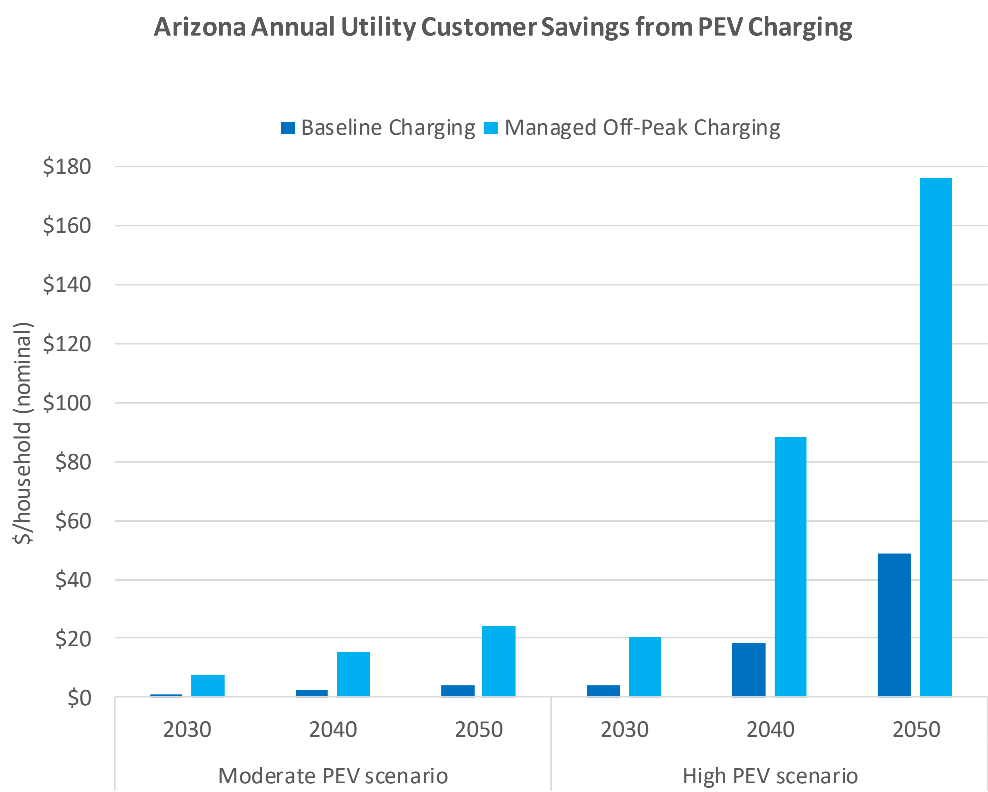


Figure 13 Potential Effect of PEV Charging Net Revenue on Arizona Utility Customer Bills (nominal $)



In general, a utility's costs to maintain their distribution infrastructure increases each year with inflation, and these costs are passed on to utility customers in accordance with rules established by the ACC, via periodic increases in residential and commercial electric rates. However, under ACC 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 Arizona, 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.[21]

See Figure 13 for a summary of how the projected utility net revenue from PEV charging might affect average residential electricity bills for all Arizona electric utility customers.[22] As shown in the figure, under the High PEV scenario projected average electric rates in Arizona could be reduced up to 5.5 percent by 2050, resulting in an annual savings of approximately $176 (nominal dollars) per household in Arizona in 2050.

Arizona 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 Arizona 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. [49], [50], [51]

Based on these battery cost projections, this analysis estimates that the average annual cost of owning a PEV in Arizona will fall below the average cost of owning a gasoline vehicle by 2030, even without government purchase subsidies.[23] See Table 3 which summarizes the average projected annual cost of Arizona PEVs and gasoline vehicles under each penetration scenario. All costs in Table 3 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.

As shown in Table 3, 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 Arizona driver is projected to save $101 – $194 per year compared to the average gasoline vehicle owner, without government subsidies. These annual PEV savings are projected to increase to an average of $283 - $306 per PEV in 2040, and $591 - $680 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 Arizona is projected to be $97 in 2030, rising to $233 in 2050.

The NPV of total annual cost savings to Arizona drivers from greater PEV ownership are projected to be $28 million in 2030 under the Moderate PEV penetration scenario, rising to $99 million in 2040 and $249 million in

[21] 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.
[22] Based on 2016 average electricity use of 11,075 kWh per housing unit in Arizona.
[23] 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.

2050. Under the High PEV scenario, the NPV of total annual cost savings to Arizona drivers from greater PEV ownership are projected to be $131 million in 2030, rising to $581 million in 2040 and $1.6 billion in 2050.

Table 3 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	$4,441	$5,704	$7,652	$4,684	$6,917	$9,159
Gasoline	$/yr	$1,607	$1,690	$1,965	$1,663	$1,967	$2,291
Maintenance	$/yr	$264	$333	$429	$268	$350	$450
TOTAL ANNUAL COST	**$/yr**	**$6,312**	**$7,727**	**$10,046**	**$6,614**	**$9,233**	**$11,900**

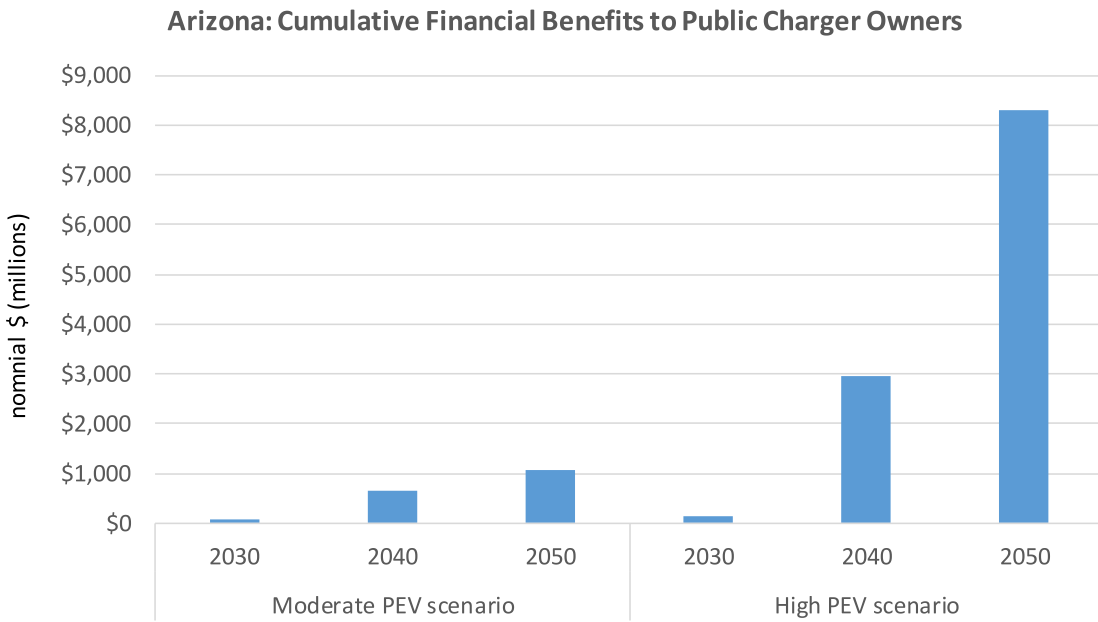
PEV -AZ		Moderate PEV scenario			High PEV scenario		
		2030	2040	2050	2030	2040	2050
Vehicle Purchase	$/yr	$4,946	$6,126	$7,825	$5,189	$7,455	$9,584
Electricity	$/yr	$545	$693	$888	$590	$814	$1,009
Gasoline	$/yr	$217	$144	$85	$161	$122	$97
Personal Charger	$/yr	$73	$91	$116	$73	$91	$116
Public Charger Costs	$/yr	$288	$197	$190	$258	$241	$233
Maintenance	$/yr	$143	$195	$262	$150	$204	$270
TOTAL ANNUAL COST	**$/yr**	**$6,211**	**$7,444**	**$9,366**	**$6,421**	**$8,927**	**$11,309**
Savings per PEV	**$/yr**	**$101**	**$283**	**$680**	**$194**	**$306**	**$591**

Public Charger Owner Benefits

As discussed previously, PEV owners will not only charge their vehicles at home but will utilize public charging infrastructure across the state. This public charging infrastructure will be required for three reasons: 1) to allow long-distance trips (greater than vehicle range) in battery electric vehicles, 2) to allow owners of plug-in hybrids to maximize all-electric miles, and 3) to allow charging for PEV owners without access to a dedicated home charger – for example those that live in large apartment buildings without dedicated parking spaces. NREL's EVI-Pro Lite tool estimates that to support the levels of PEV penetration modeled here approximately 31,397 public L2 and 2,336 DCFC charge ports will be required state-wide in 2030 under the Moderate PEV scenario and by 2050 62,000 public L2 and 3,600 DCFC ports will be required. Under the High PEV scenario 61,736 public L2 and 3,303 DCFC charge ports will be required in 2030, rising to 439,384 and 22,727 respectively by 2050.

Costs associated with PEV owners charging their vehicles using public infrastructure are shown in Table 3 as a cost to PEV owners. However, the owners of public vehicle charging infrastructure will benefit from increased PEV penetration in the form of revenue (and net profits) from the fees they charge PEV owners for vehicle charging. See Figure 14 for estimated cumulative financial benefits to public charger owners under both penetration scenarios, assuming an average annual return of 10 percent on invested capital, amortized over 15 years.

Figure 14 Cumulative Financial Benefits to Public Charger Owners in Arizona



As shown in Figure 14, annual financial benefits to public charger owners under the Moderate PEV penetration scenario are projected to total $59.5 million in 2030, with cumulative benefits of more than $1 billion by 2050 (nominal dollars). Under the High PEV scenario, annual benefits in 2030 are projected to be about $128 million, with cumulative benefits exceeding $8.3 billion through 2050.

Other Benefits

Fuel and Emissions Reductions

Along with the financial benefits to electric utility customers, PEV owners, and public charging infrastructure 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 Arizona under each penetration scenario are shown in Figure 15.[24] Annual fuel savings under the Moderate PEV penetration scenario are projected to total 1.7 million barrels in 2030, with cumulative savings of about 50 million barrels by 2050. For the High PEV scenario, annual fuel savings in 2030 are projected to be 4.2 million barrels, and by 2050 cumulative savings will exceed 370 million barrels.

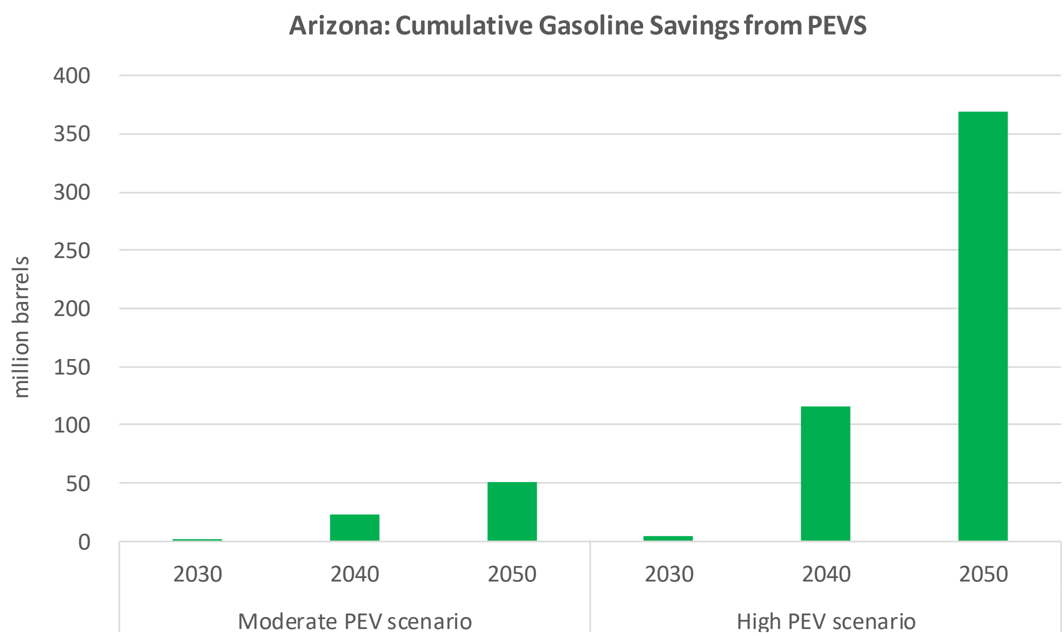
These fuel savings can help put the U.S. on a path toward energy independence, by reducing the need for imported petroleum. In addition, a number of studies have demonstrated that EVs can generate significantly greater local economic impact than gasoline vehicles - including generating additional local 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 $290,000 - $570,000 in secondary economic benefits will be generated within the local economy, depending on PEV adoption scenario. These studies also estimated

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

that between 13 and 25 additional in-state jobs will be generated for every 1,000 PEVs in the fleet. [2], [3], [4], [5], [6]

Figure 15 Cumulative Gasoline Savings from PEVs in Arizona



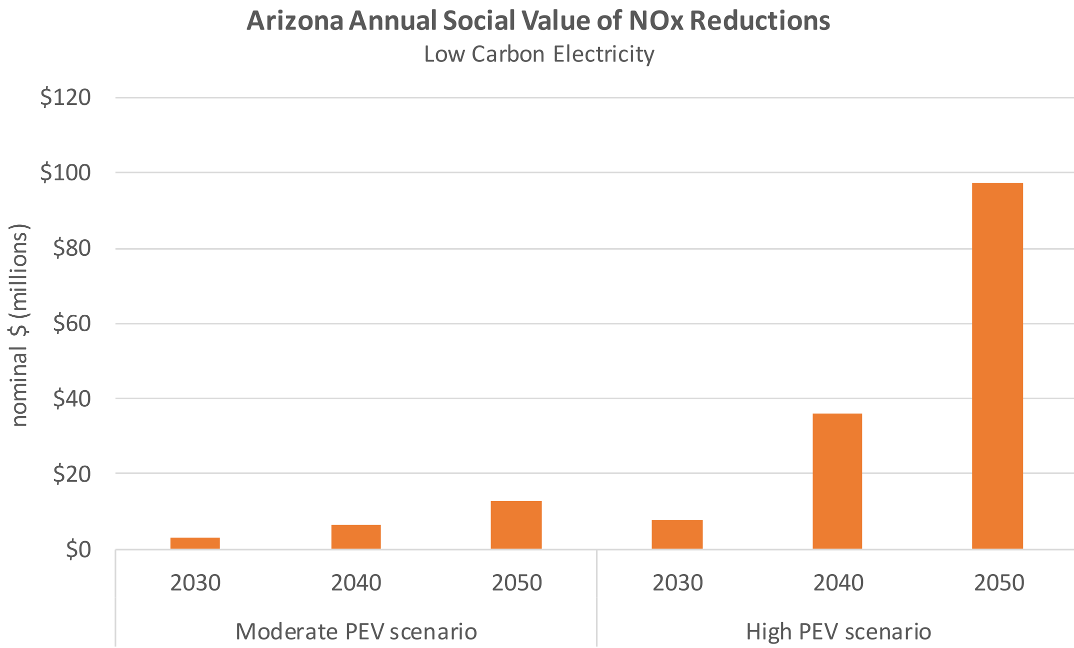
NOx Emission Reductions

Light-duty fleet electrification can reduce net nitrogen oxide (NOx) emissions from vehicles due to the switch from internal combustion engines used in conventional vehicles. Electric vehicles do not emit any tailpipe emissions, however; they are not necessarily zero emission vehicles. Depending on the electricity grid mix, NOx can be emitted when generating electricity for vehicle charging. PEVs in Arizona charging with the existing grid mix already have lower NOx emissions (grams per mile) than new gasoline and diesel vehicles. This gap is projected to increase in future years, as zero-emission renewable generation (wind, solar) makes up a greater percentage of the new capacity required to meet rising electricity demand.

Under the low carbon electricity scenario modeled here, in 2030 the Moderate PEV scenario will reduce annual NOx emissions by approximately 139 metric tons compared to continued use of conventional vehicles. By 2050, this annual reduction increases to 377 metric tons. Under the High PEV scenario annual NOx reductions would be 356 metric tons in 2030, rising to 2,908 metric tons in 2050.

See Figure 16 for nominal social values of NOx reductions based on EPA's national average damage value of $15,909/ton of mobile source NOx. [46] As shown in the figure, these NOx reductions would have a social value of $2.9 million in 2030 under the Moderate PEV Scenario, rising to $12.6 million in 2050. Under the High PEV Scenario the social value of these NOx reductions would be $7.5 million in 2030, rising to $97 million in 2050.

Figure 16 Projected Social Value of PEV NOx Reductions (nominal $ millions)



GHG Emissions

In addition to NOx reductions, widespread transportation electrification will also lead to reductions in greenhouse gas (GHG) emissions. The projected annual GHG emissions (million metric tons carbon-dioxide equivalent, CO_2-e) from the Arizona light-duty fleet under each PEV penetration scenario are shown in Figure 17. 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 Arizona achieving the proposed goal of meeting 80 percent of electricity demands with zero carbon resources by 2050.

As shown in Figure 17, GHG emissions from the light-duty fleet were approximately 31.8 million tons in 2016. Even without significant PEV penetration, baseline annual fleet emissions are projected to fall to 25.8 million tons by 2050, a reduction of 19 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 8.0 million tons in 2050 compared to 2016 baseline emissions (-25 percent). Under the High PEV scenario, annual GHG emissions in 2050 will be as much as 26.1 million tons lower than baseline emissions (-82 percent).

Figure 17 Projected GHG Emissions from the Light-Duty Fleet in Arizona

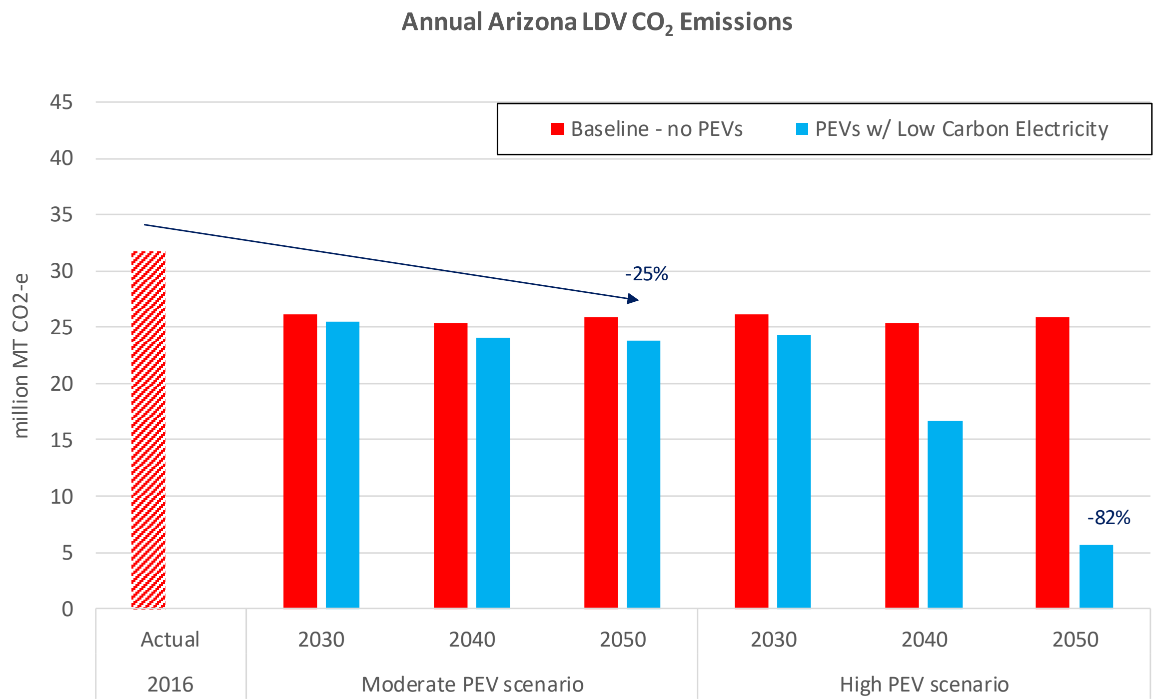


Figure 18 NPV of Projected Value of PEV GHG Reductions

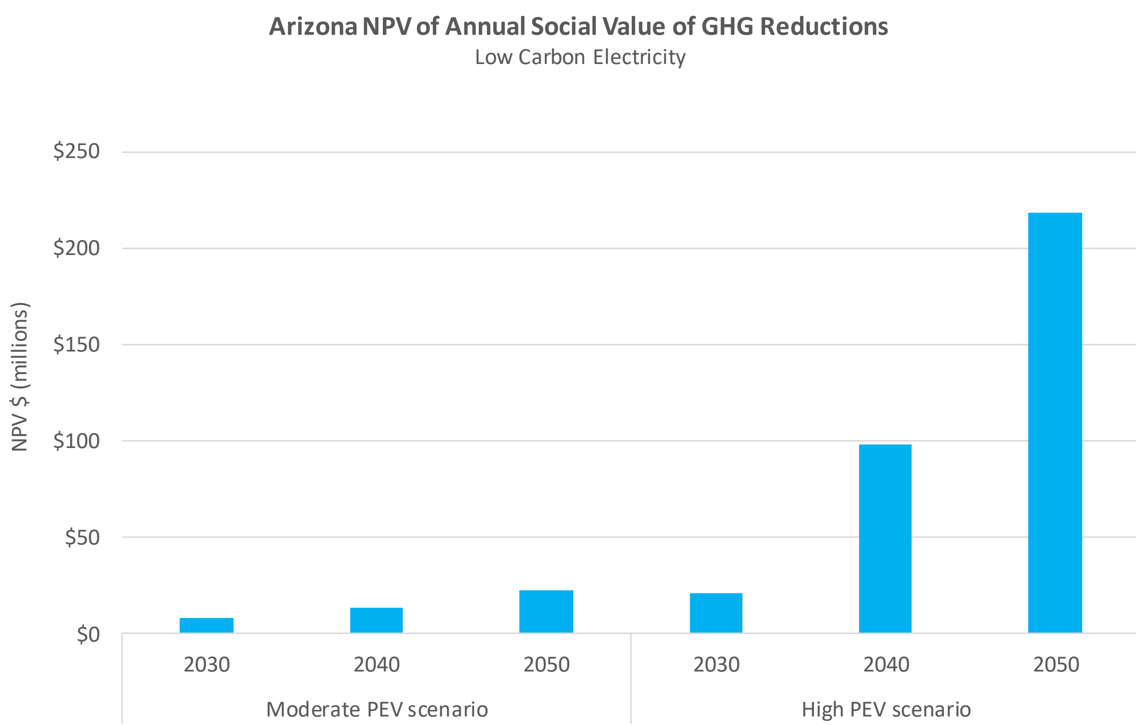


Figure 18 summarizes the NPV of the projected value of GHG reductions that will result from greater PEV use in Arizona. These values reflect the potential savings from avoided emissions under a future GHG regulatory program. The values summarized in Figure 17 were developed using the "cost of carbon" values ($/MT) adopted by Arizona Public Service in its 2017 Integrated Resource Plan. According to Arizona Public Service, these values are based on the actual trading price of CO_2 allowances in the California market. [52]

The NPV of the value of GHG reductions resulting from greater PEV use is projected to total $7.9 million per year in 2030 under the Moderate PEV penetration scenario, rising to as much as $22.6 million per year in 2050. Under the High PEV scenario the NPV of the value of GHG reductions from greater PEV is projected to be $21.4 million per year in 2030, rising to as much as $218.4 million per year in 2050.

The NPV of the projected value of annual GHG reductions averages $20 per PEV in 2030, and $23 - $29 per PEV in 2050.

The avoided GHG emissions also reduce the damages associated with climate change, such as increased frequency or intensity of wildfires, hurricanes, and droughts, as well as impacts on human health. The federal Interagency Working Group (IWG) has developed estimates of the monetized value of these damages ($/MT CO_2-e), which were published in 2016. Using the IWG's central estimate of damage values at the 3 percent discount rate, the NPV of the total societal benefits that would accrue from reduced GHG emissions are $34 million in 2030, rising to $131 million per year in 2050 under the Moderate PEV scenario. Under the high PEV penetration scenario, the monetized total social value of GHG reductions is $93 million in 2030 rising to $1.27 billion per year in 2050.[25]

Total Societal Benefits

The NPV of total estimated societal benefits from increased PEV use in Arizona under each PEV penetration scenario are summarized in Figures 19 and 20. These benefits include cost savings to Arizona drivers, utility customer savings from reduced electric bills, public charger owner financial benefits, and the monetized value of reduced GHG and NOx emissions. Figure 19 shows the NPV of projected societal benefits if Arizona drivers charge in accordance with the baseline charging scenario. Figure 20 shows the NPV of projected societal benefits if Arizona drivers charge off-peak.

As shown in Figure 19, the NPV of annual societal benefits are projected to be a minimum of $298 million per year in 2050 under the Moderate PEV penetration scenario and $2.3 billion per year in 2050 under the High PEV scenario. In 2050 approximately 70 percent of these annual benefits will accrue to Arizona drivers as a cash savings in vehicle operating costs, 9 percent will accrue to electric utility customers as a reduction in annual electricity bills, 11 percent will go to owners of public charging infrastructure in the state, 0.4 percent will accrue to society at large in the form of reduced damage costs associated with reduced NOx emissions, and 9 percent will accrue to Arizona residents in the form of reduced future costs of GHG emissions.

As shown in Figure 20, the benefits are even greater when PEVs are charged at off-peak times. The NPV of annual societal benefits in 2050 will increase by $68 million under the Moderate PEV penetration scenario, and $525 million under the High PEV scenario if Arizona drivers charge off-peak. Of these increased benefits, all will accrue to electric utility customers as an additional reduction in their electricity bills.

[25] These values are not in addition to the compliance costs of carbon but would include the compliance costs and the externality costs (or damages) not captured by the compliance costs.

Figure 19 Projected NPV of Total Societal Benefits from Greater PEV use in AZ – Baseline Charging

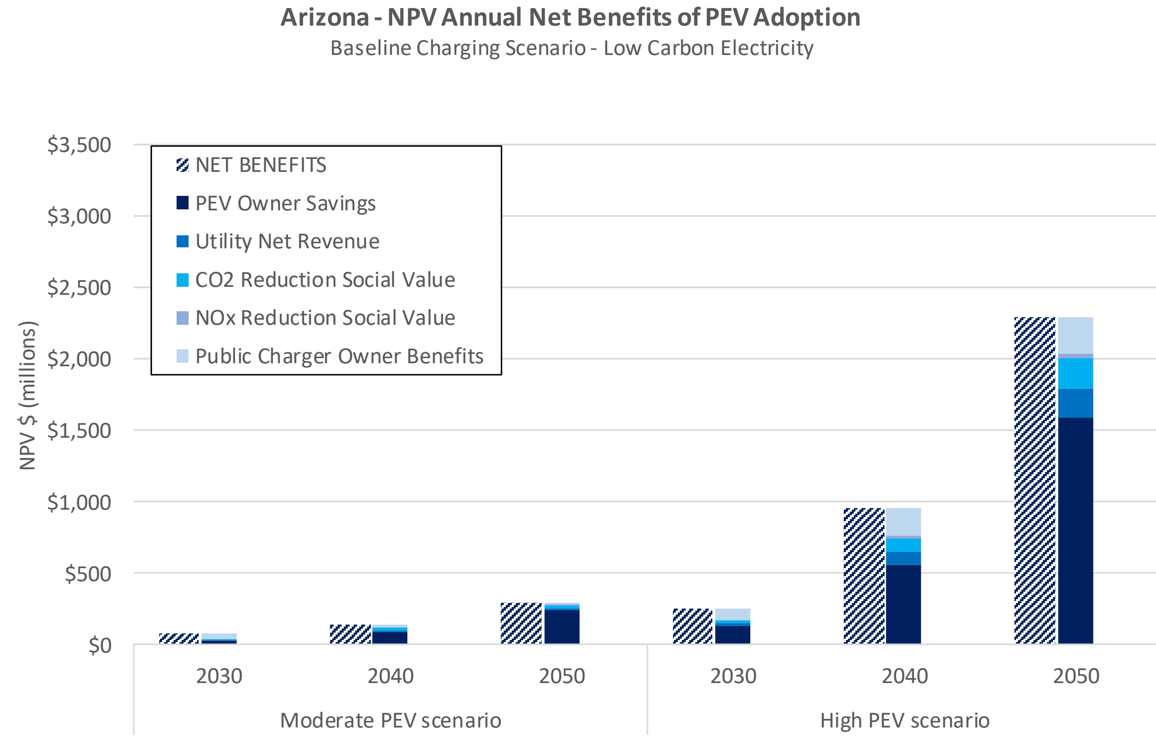
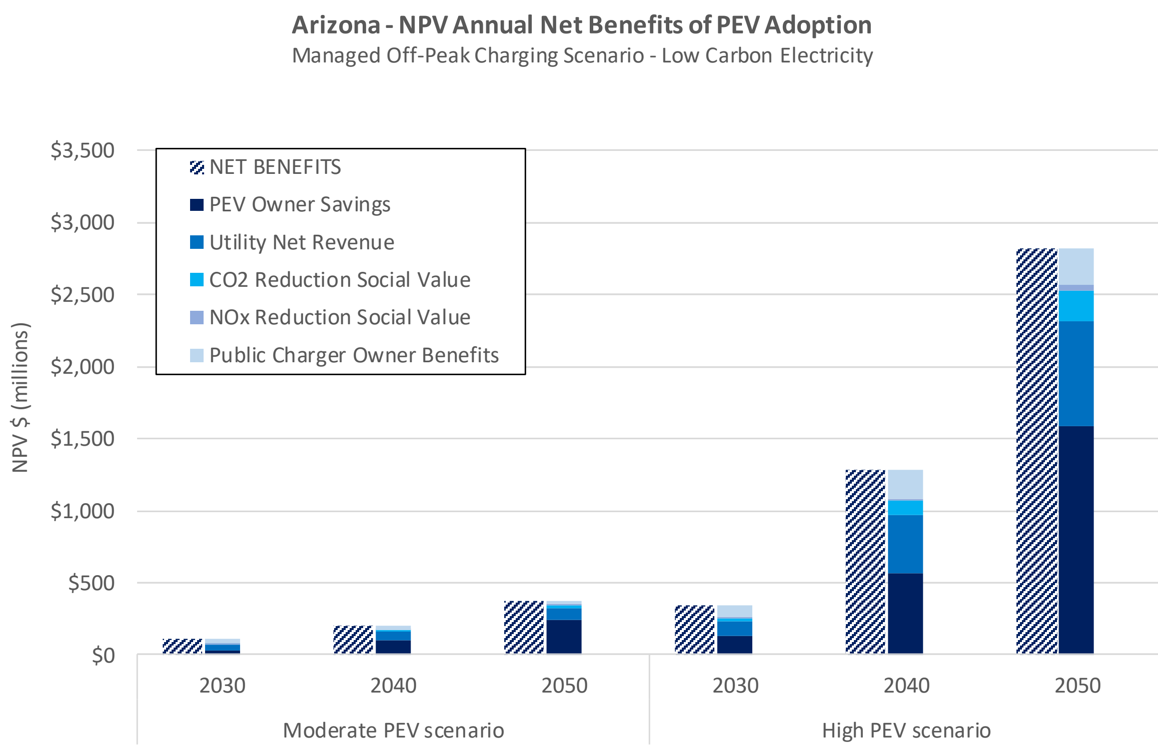


Figure 20 Projected NPV of Total Societal Benefits from Greater PEV use in AZ – Managed Off-Peak Charging



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Founded in 1989, WRA is dedicated to protecting the West's land, air, and water to ensure that vibrant communities exist in balance with nature. WRA uses law, science, and economics to craft innovative solutions to the most pressing conservation issues in the region.

This study is one of 15 state-level analyses of plug-in electric vehicle costs and benefits developed by M.J. Bradley & Associates for different U.S. states, including Arizona, Colorado, Connecticut, Illinois, Indiana, Kentucky, Maryland, Massachusetts, Michigan, Minnesota, New York, North Carolina, Ohio, Pennsylvania and South Carolina.

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 as part of a suite of analysis tools.