Cost-Benefit Analysis of Plug-in Electric Vehicle Adoption in the AEP Ohio Service Territory

April, 2017

Energy+Environmental Economics

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Executive Summary

Study Aims and Methods:

Energy and Environmental Economics, Inc. (E3) modeled the economic and electric grid impacts of the adoption of plug-in electric vehicles (PEVs) in AEP Ohio's service territory.

This work aims to support the utility, policy-makers and other stakeholders in understanding:

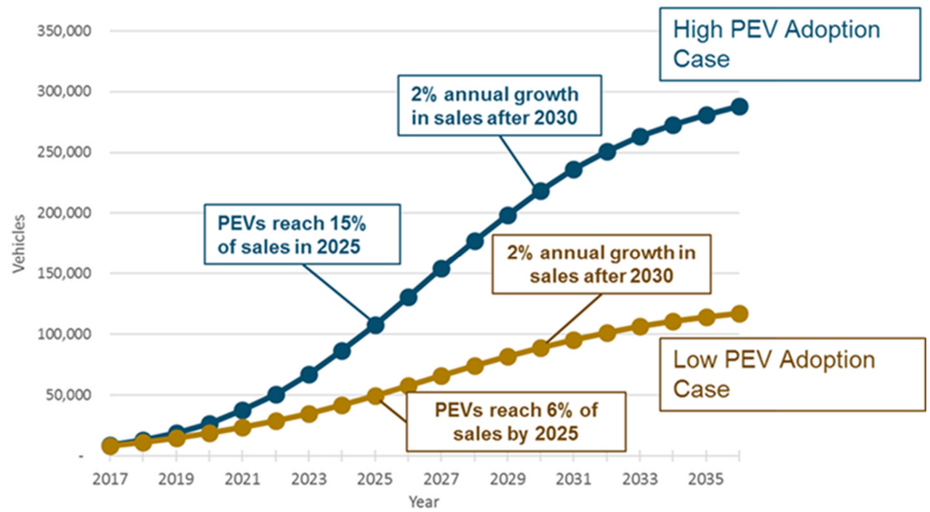
+ the **costs and benefits of plug-in electric vehicle (PEV) adoption**, from both the Ratepayer and broader Regional Perspectives,
+ the potential value of systems or **programs that manage the timing of PEV charging**,
+ potential **carbon dioxide reductions** from electrified transportation, and
+ potential **impacts of electric vehicles on utility planning**, specifically electricity consumption and planning loads, plus T&D costs.

To fulfill these aims, E3 used our EVGrid Model, which captures key interactions between drivers, vehicles, chargers, utility costs, incentives, and gasoline costs. In this study, we consider the impacts of PEV adoption over a 20-year time horizon. This means that we include all direct costs, benefits and CO_2 reductions attributable to PEVs sold in the years 2017 to 2036. We consider all costs and benefits that are incurred over each vehicle's useful lifetime. We also include pro-rated costs and benefits for PEVs placed on the road prior to 2017.

We analyzed two scenarios: a Base scenario and a Managed Charging scenario. The differences between the scenarios result in different per vehicle Regional and Ratepayer Perspective net benefits from PEV adoption. The Base scenario uses E3's best estimates of input values, and assumes that PEV owners do not try to minimize their electric bills when deciding to charge their cars. The Managed Charging scenario assumes that PEV charging is optimized to minimize the total cost to AEP Ohio of delivering electricity to PEVs while still satisfying the transportation needs of PEV drivers.

Since there is a large degree of uncertainty around any forecast of PEV adoption, each scenario was evaluated using two bookend PEV adoption cases developed by E3. We employed an S-curve function to model the growth of sales from current levels through 2025. In the Low PEV Adoption case, PEVs are assumed to reach 6% of all personal light-duty vehicle sales in Ohio by the year 2025. In the High PEV Adoption case, PEVs are assumed to reach 15% of all personal light-duty vehicle sales in Ohio by the year 2025. Beginning in 2030, we assume that the S-curve levels off, and PEV sales grow at a slower 2% per year for both scenarios.

Figure ES-1. PEV population in the AEP Ohio service territory for High and Low PEV Adoption cases



Cost-Benefit Perspectives:

E3 calculated costs and benefits from the Regional and a Ratepayer Perspectives. The components of each are shown in Figure ES-2. Results are presented on the basis of the total net present value (NPV) for the entire PEV population, and on the basis of the value per vehicle sold during the study horizon. The total cost and benefit results are useful for understanding the total magnitude of impacts resulting from PEV adoption generally, while the per vehicle results are more useful for evaluating the cost-effectiveness of PEV programs or incentives that involve a given number of vehicles.

+ The **Regional Perspective** considers all directly monetized benefits flowing in and out of a region due to PEV adoption. On the benefits side, this perspective includes federal PEV incentives, operation and maintenance (O&M) savings, and avoided gasoline purchases. Though not currently monetized, we have also included a cost for carbon emissions to represent a potential tax or emission allowance cost. The costs include those incurred by the utility to serve the added load, the incremental cost of the PEVs over conventional vehicles, and home, workplace and public charging infrastructure. Subtracting these costs from the benefits results in the *Regional net benefit* (or net cost) from consumer adoption of PEVs as a substitute for conventional internal combustion engine (ICE) vehicles.[1]

+ The **Ratepayer Perspective** considers the impact of PEV adoption on all electric utility customers. It compares the utility's cost of serving PEV charging load with revenue realized from PEV charging. The difference between these costs and benefits is the *Ratepayer net benefit* (or cost). If the utility incurs less cost to serve PEV charging load than the revenue it collects via PEV drivers' electric bills, then ratepayers as a whole benefit: utilities can use the savings to invest in programs that promote PEV adoption, reduce electricity rates, or make other grid investments. The net benefit represents the amount that a utility can spend on PEV adoption programs or other investments without increasing electric rates. This Ratepayer Perspective analysis is intended to provide a starting point for rate and program design by calculating net benefits under *current* rates. Ratepayer net benefits will change if rates applied to PEVs change, or if utilities implement PEV-specific rates.

[1] For those familiar with utility cost tests, this perspective can be thought of as the Total Resource Cost test *plus* the avoided cost of carbon that results from electricity emitting less carbon than gasoline (assuming that there is some future carbon tax applied to all carbon emissions).

Figure ES-2. Cost and Benefit Components Included in Each Cost-Benefit Perspective

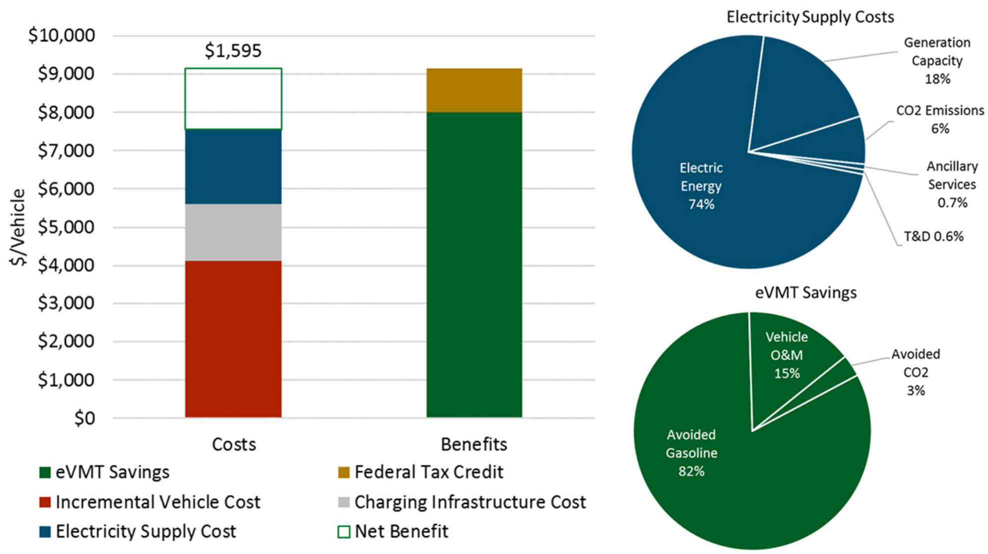
	Regional Perspective	Ratepayer Perspective
Electricity Supply Costs		
Electric Energy Cost	Cost	Cost
Generation Capacity Cost	Cost	Cost
T&D Cost	Cost	Cost
Ancillary Services Cost	Cost	Cost
Electric Energy CO2 Cost	Cost	Cost
PEV Costs and Benefits		
Incremental Electric Vehicle Cost	Cost	
Federal Tax Credit	Benefit	
Avoided Gasoline Cost	Benefit	
Avoided Gasoline CO2 Cost	Benefit	
Vehicle O&M Savings	Benefit	
Charging Costs		
Charging Infrastructure Cost	Cost	
Vehicle Charging Utility Bills		Benefit

Cost-benefit analysis of plug-in electric vehicle (PEV) adoption: Regional Perspective

PEV adoption is likely to bring significant net economic benefit to AEP Ohio's service territory. In the Base scenario, Regional net benefits from PEV adoption over the next 20 years range from $380 Million in the High PEV Adoption case to $256 Million in the Low PEV adoption case. In the High PEV Adoption case, there is a Regional net benefit of $1,595 per vehicle sold over the next 20 years. Figure ES-3 shows that from the Regional Perspective the key drivers of costs are energy, generation capacity, chargers and incremental vehicle cost. By far the biggest benefit is savings on gasoline, followed by O & M savings and the federal tax credit.[2]

[2] Note that the Federal Tax Credit shows as far less than the $7,500 currently offered per vehicle. This is because we assume the credit is only applicable to vehicles purchased in 2022 and earlier, and our results are shown as a net present value for the full cohort of PEVs sold by 2036.

Figure ES-3. Costs and Benefits of PEV Adoption from the Regional Perspective: Base Scenario, High PEV Adoption ($/vehicle)



Underlying the Regional net benefits are several specific benefits to residents of AEP's service territory:

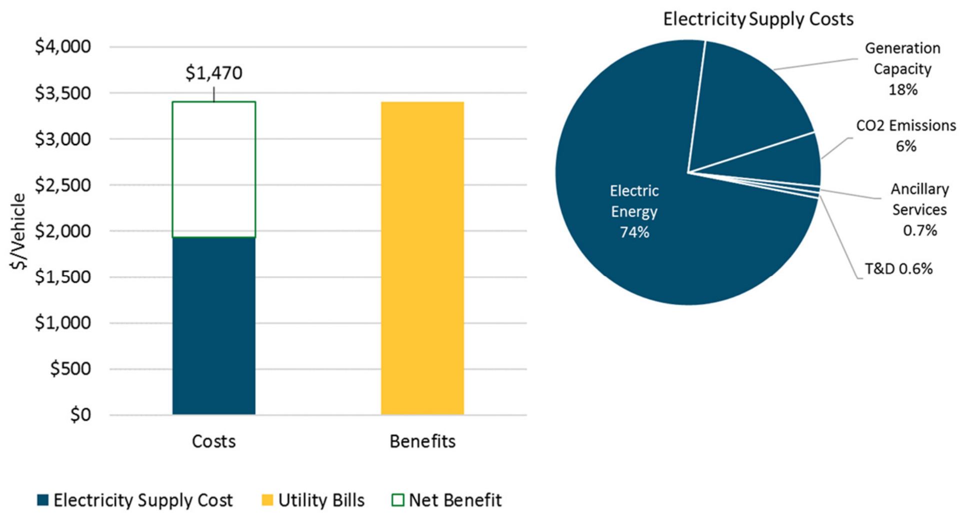
- **Reduced vehicle emissions:** On average, CO_2 emissions are reduced by 10.7 tons over the 10-year lifetime of each vehicle.
- **Overall lower CO2 emissions from fuel switching:** PEV adoption reduces total CO_2 emissions by 3.6 to 4.5 Million tons, depending on adoption levels.
- **Reduced vehicle fuel costs:** EV owners save from $6,589-6,694 in gasoline costs over the lifetime of their vehicles.
- **Energy independence:** PEVs adopted during the study horizon in AEP Ohio's service territory reduce gasoline consumption by just over 1 Billion gallons in total in the High PEV Adoption case, and 830 Million gallons in the Low PEV Adoption case.

In interpreting these results it is important to bear in mind that the net benefits do not include the cost of any programs that AEP Ohio may implement to incentivize PEV adoption. Rather, they are net benefits that accrue from adoption of PEVs in AEP Ohio's service territory.

Cost-benefit analysis of plug-in electric vehicle (PEV) adoption: Ratepayer Perspective

PEV adoption also benefits AEP Ohio's customers. From the Ratepayer Perspective net benefits from PEV adoption range from $351M to $278M in the Base scenario. This translates to a Ratepayer net benefit of $1,470 per vehicle sold over the next 20 years in the High PEV Adoption case. As illustrated below in Figure ES-4, PEVs in the AEP Ohio service territory pay more in electric utility bills than the incremental cost for the utility to supply them with electricity, assuming current rates. The utility can use the savings to invest in programs that promote PEV adoption, reduce electricity rates, or make other grid investments. The Ratepayer net benefit of $1,470 per vehicle can also be thought of as how much the utility can spend per vehicle on programs to promote PEV adoption without increasing costs to other ratepayers. To the extent the utility spends below that amount, a portion of the $1,470 in net revenue would be available to decrease the average kilowatt hour rate for all AEP Ohio customers.

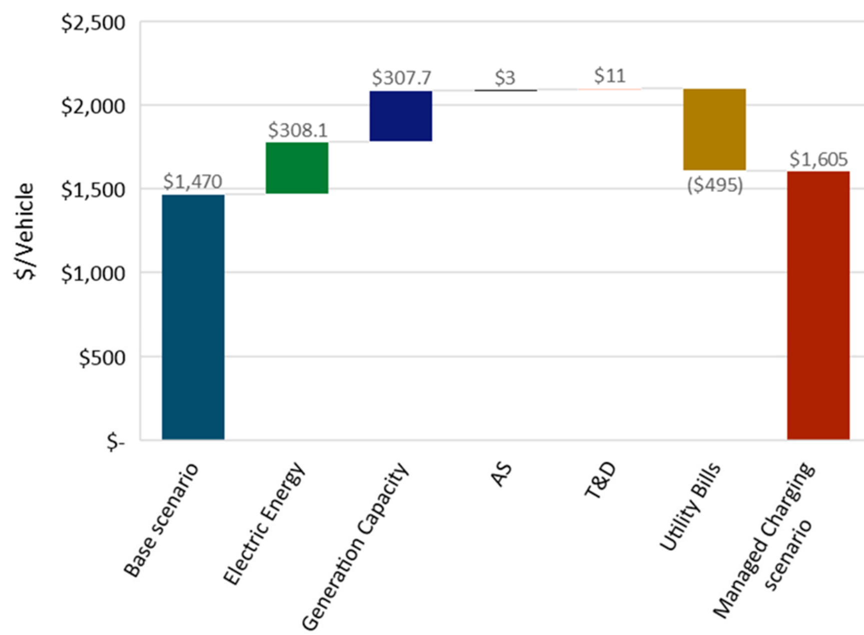
Figure ES-4. Costs and Benefits of PEV Adoption from the Ratepayer Perspective: Base Scenario, High PEV Adoption ($/vehicle)



<u>Potential value of managed charging programs</u>:

PEV charging is an inherently flexible load that can be shaped to improve utilization of fixed assets and/or integrate variable renewables. Managed charging can be accomplished via time-varying rates or by the utility or a third party controlling the level or timing of EV charging. To assess the potential value of managed charging E3 modeled how a perfectly rational EV owner would alter his charging behavior if exposed to rates reflecting AEP's actual cost of service. This approach provides an upper bound on the value of managed charging.

Figure ES-5. Impact of managed charging on Ratepayer net benefits



Our analysis shows that managed charging boosts the net benefits of PEV adoption from both the Regional and the Ratepayer perspectives. In the High PEV Adoption case, managed charging creates an incremental Regional net benefit of $629 per vehicle, a 44% increase from unmanaged charging. Under managed charging PEVs charge mostly overnight, using relatively inexpensive off-peak energy (a savings of $308 per vehicle). This nearly eliminates any need for incremental generating capacity to serve PEV load (an additional saving of $308 per vehicle). There are also small reductions in ancillary services and T&D upgrade costs, both of which were very small in the unmanaged case.

As illustrated in Figure ES-5, the increase in net benefits is smaller from the Ratepayer Perspective, yielding an incremental Ratepayer net benefit of $134 per vehicle in the High PEV Adoption case. This is because reductions in the cost of serving PEV load (which increase Ratepayer net benefits) are partially offset by reduced revenues from PEV charging (which decrease Ratepayer net benefits). Revenues are lower in our managed charging analysis because we calculated bills for PEV charging using TOU rates, which have lower energy prices and demand charges in the nighttime off-peak hours, and because managed charging shifts PEV load into these off-peak hours. Although reduced bills counteract the benefit of managed charging to ratepayers generally, reduced bills also lower the cost of charging for PEV owners, making PEV ownership more attractive.

1 Study Aims

This work aims to support the utility, policy-makers and other stakeholders in understanding:

+ the **costs and benefits of plug-in electric vehicle (PEV) adoption**, from both the Ratepayer and broader Regional perspectives,
+ the potential value of systems or **programs that manage the timing of PEV charging**,
+ potential **carbon dioxide reductions** from electrified transportation, and
+ potential **impacts of electric vehicles on utility planning**, specifically electricity consumption and planning loads, plus T&D network costs.

It is not the intention of this study to attribute any PEV adoption or net benefits from PEV adoption to AEP Ohio's proposed programs, or to evaluate the merits of any currently proposed programs.

2 Cost-Benefit Methodology

2.1 Introduction to Cost-Benefit Methodology

The cost-benefit methodology used in this report is based on the California Public Utilities Commission (CPUC) Standard Practice Manual (SPM) methodology developed for evaluating energy efficiency (EE), demand response (DR), distributed generation (DG), and distributed energy resources (DER) generally. The origins of cost-effectiveness tests for energy efficiency are found in the 1974 Warren-Alquist Act that established the California Energy Commission (CEC) and specified cost-effectiveness as a leading resource planning principle. Later, the California Standard Practice Manual of Cost-Benefit Analysis of Conservation and Load Management Programs (SPM) developed five cost-effectiveness tests for evaluating energy efficiency programs (CPUC 2001), (CPUC 2013).[3] These approaches, with minor updates, continue to be used today and are the principal approaches used for evaluating energy efficiency programs across the United States. The basic structure of each cost test involves a calculation of the total benefits and the total costs in dollar terms from a certain vantage point to determine whether or not the overall benefits exceed the costs. A test is positive if the benefit-to-cost ratio is greater than one, and negative if less than one. Results are reported either in net present value dollars (method by difference) or as a ratio (i.e., benefits/costs). The Total Resource Cost Test (TRC) is used in most

[3] The California SPM was first developed in February 1983. It was later revised and updated in 1987-88 and 2001 and a Correction Memo was issued in 2007. Subsequent updates are summarized in the 2013 Energy Efficiency Policy Manual – Version 5.

jurisdictions throughout the U.S. as the primary cost-effectiveness test for energy efficiency (RAP 2013).

The DER cost-effectiveness framework was developed to calculate the utility and societal costs “avoided” by load reductions from DER. The cost-effectiveness framework compares the incremental costs of distributed resources against the costs the utility would otherwise incur to deliver energy to the customer. E3 first developed the DER avoided cost methodology used by the CPUC and by the California Energy Commission (CEC) in 2004. E3 has updated and improved the methodology through several CPUC and CEC proceedings, most recently in 2016 (E3 2016). Though originally developed to evaluate the costs and benefits of load reductions, the methodology is equally applicable to load increases from PEVs or energy storage. In this section we describe how the cost-benefit methodology is applied to PEV adoption in AEP Ohio’s service territory.

2.2 Cost-Benefit Perspectives

In this study, E3 compares the costs and benefits of PEV adoption using the Regional and Ratepayer Perspectives as defined below. Figure 1 summarizes the cost and benefit components included in each cost-benefit perspective and Table 1 provides detailed definitions of the different cost and benefit components.

The Regional Perspective

The Regional Perspective considers all directly monetized benefits flowing into and out of AEP Ohio’s service territory as a result of PEV adoption. Figure 1 displays the components included in this cost-benefit perspective. These cost and benefit components are further defined in Table 1. Broadly, this perspective includes two types of costs: 1) the costs to the electric utility of serving added electric load from PEVs, and 2) the costs of driving a PEV (the incremental cost of the vehicles over traditional vehicles, plus associated home, workplace and public charging infrastructure). On the benefits side, this perspective includes federal PEV incentives, *avoided* gasoline costs, avoided gasoline CO_2 emissions costs, and operations and maintenance (O&M) savings. Note that the avoided CO_2 emissions costs included here are based on a forecast of a CO_2 emissions tax, as opposed to a full societal cost of CO_2 emissions. It is assumed that this future CO_2 emissions tax policy covers both electric generation and transportation emissions. Subtracting the costs from the benefits results in the *Regional net benefit* (or net cost) to the region from consumer adoption of PEVs as a substitute for conventional internal combustion engine (ICE) vehicles.

Excluded from these tests are a number of societal benefits and costs that are not directly monetized when purchasing and operating PEVs. These include, for example, benefits based on the full societal cost of CO_2 emissions, health benefits from improved air quality, reduced reliance on petroleum (which has historically been much more volatile in price and associated with some level of energy security risk),[4] and local employment benefits from in-state production of electricity. Thus, this Regional Perspective can be considered a more conservative measure of net benefits than a full Societal Cost Test as typically defined in utility economics[5].

[4] See, for example, Leiby, P. 2007. "Estimating the Energy Security Benefits of Reduced U.S. Oil Imports," http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.322.1497&rep=rep1&type=pdf.
[5] See SPM

The Ratepayer Perspective

The Ratepayer Perspective considers the impact on electric utility customers, taken as a whole. This perspective compares a) the costs to the electric utility of serving electric load from PEVs with b) customers' electric bills for charging their PEVs. Electric bills are shown as a benefit from the utility ratepayers' perspective, and are based on current utility rates applicable to each vehicle type.

The difference between these costs and benefits is the *Ratepayer net benefit* (or cost). If the utility's costs to serve PEV customers are lower than the revenue that is collected from PEV drivers' electric bills, then ratepayers benefit: the utility can either reduce electricity rates or spend funds on programs to encourage PEV adoption without increasing electricity rates. The Ratepayer Perspective used in this study does not include any technology or program costs associated with AEP Ohio's proposed PEV programs or the cost of implementing a managed charging program in the Managed Charging scenario.

Figure 1. Cost and benefit components included in each cost-benefit perspective

	Regional Perspective	Ratepayer Perspective
Electricity Supply Costs		
Electric Energy Cost	Cost	Cost
Generation Capacity Cost	Cost	Cost
T&D Cost	Cost	Cost
Ancillary Services Cost	Cost	Cost
Electric Energy CO2 Cost	Cost	Cost
PEV Costs and Benefits		
Incremental Electric Vehicle Cost	Cost	
Federal Tax Credit	Benefit	
Avoided Gasoline Cost	Benefit	
Avoided Gasoline CO2 Cost	Benefit	
Vehicle O&M Savings	Benefit	
Charging Costs		
Charging Infrastructure Cost	Cost	
Vehicle Charging Utility Bills		Benefit

Table 1. Cost and benefit component definitions

Component	Definition
Electric Energy Cost	The incremental cost of purchasing electric energy from the wholesale electricity market to supply PEVs
Generation Capacity Cost	The cost of procuring additional generation capacity to meet reliability standards with PEV charging loads added to the electric grid
T&D Cost	The incremental cost of upgrading electric transmission and distribution networks to serve new PEV loads.
Ancillary Services Cost	The cost of meeting any additional ancillary services obligations due to increased system loads from PEV charging
Electric Energy CO_2 Emissions Cost	The cost of a carbon tax paid on CO2 emissions associated with the incremental electric energy serving PEVs
Incremental Vehicle Cost	The incremental cost of purchasing a higher priced PEV instead of an otherwise comparable conventional ICE powered vehicle
Charging Infrastructure Cost	The cost of purchasing and installing home, workplace, and public electric vehicle service equipment (EVSE) for recharging PEVs
Avoided Gasoline Cost	The gasoline cost avoided by driving a PEV instead of a conventional ICE powered vehicle
Avoided Gasoline CO_2 Emissions Cost	The cost of a carbon tax associated with burning gasoline that is avoided by driving a PEV instead of a conventional ICE powered vehicle
Vehicle O&M Savings	The value of reduced upkeep and maintenance costs from driving a PEV instead of a conventional ICE powered vehicle
Federal Tax Credit	The value of federal tax credits received by those who purchase PEVs
Vehicle Charging Utility Bills	The incremental retail electric bills due to PEV charging load

3 E3's EVGrid Model & Inputs

3.1 Model Overview

E3's EVGrid model attributes costs, benefits, and physical impacts to PEVs by comparing outcomes associated with PEVs to outcomes associated with combustion engine (ICE) vehicles. The following subsections describe the methods, data, and assumptions involved in calculating each model output. Recall that Sections 2.1 and 2.2 provide detail on how these outputs come together to form our two cost-benefit perspectives.

3.2 Study Horizon

The analysis in this study accounts for the costs and benefits attributable to all PEVs purchased between 1/1/2017 and 12/31/2036. Costs and benefits accrue over the full 10-year assumed useful life of each vehicle, so costs and benefits from the last group of vehicles adopted in 2036 are included until 2045.

Costs and benefits attributable to PEVs already on the road in 2017 are also included, pro-rated according to how much of their 10-year life is remaining.

2.1.1 INFLATION AND DISCOUNTING

AEP Ohio provided E3 with an after-tax WACC of 7.21%, as well as annual inflation estimates. Since prices are gathered from different sources, we adjusted input prices to real 2017$ before entering them in our model. Future costs or benefits are then discounted to present value dollars using a real discount rate which adjusts the after-tax WACC using an average of AEP Ohio's inflation forecast. The real discount rate for calculating present value of future costs or benefits priced in fixed 2017 dollars is 5.05%.

3.3 PEV Population

Since there is a large degree of uncertainty around any forecast of PEV adoption, E3 created two bookend PEV adoption cases for AEP Ohio's service territory: a Low PEV Adoption case and a High PEV Adoption case. Both begin with the PEV population for Ohio as of January 1st, 2017 (Alliance of Automobile Manufacturers, 2016). AEP Ohio's share of the Ohio's current PEV population is assumed to be 24%, which is the share of Ohio's electricity customers served by AEP Ohio (EIA, 2015).

3.3.1 PEV SALES

We used an S-curve function to model the growth of sales from current levels through 2025:

- In the Low PEV Adoption case, PEVs are assumed to reach 6% of all personal light-duty vehicle sales in Ohio by the year 2025. This is the level of PEV sales in California as of January 1st, 2017, as a percentage of new vehicles sales in that state (Alliance of Automobile Manufacturers, 2016).
- In the High PEV Adoption case, PEVs are assumed to reach 15% of all personal light-duty vehicle sales in Ohio by the year 2025. This is the same level of sales that would be required for compliance with the Zero-

Emissions Vehicle (ZEV) Mandate, to which 8 states are currently signatories (Pacific Gas & Electric, 2016).

Beginning in 2030, we assume that the S-curve levels off, and PEV sales grow at a slower 2% per year in both cases.

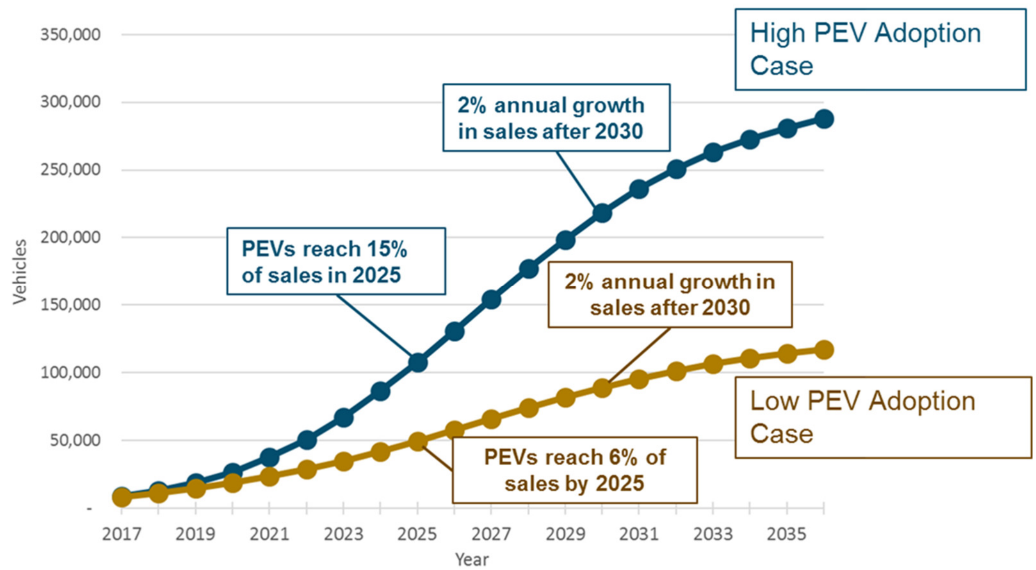
3.3.2 RETIREMENTS

Each PEV is assumed to have a 10-year useful lifetime, at which point it is replaced in our model with a new PEV of the same type, with associated costs.

3.3.3 RESULTING PEV POPULATION

In order to model the population of PEVs on the road at any given time, we considered both PEV sales and PEV retirements in a stock rollover model. Figure 2 shows the resulting population trajectory for personal light-duty PEVs in AEP Ohio's service territory with a 20-year study horizon. This figure portrays the number of PEVs on the road in any given year. The share of PEVs that are battery electric vehicles (BEVs) or plug-in hybrid electric vehicles (PHEVs) in future years was assumed to be fixed at the population mix seen in Ohio in 2016 of 41% BEVs and 59% PHEVs.

Figure 2. Projected PEV populations in the AEP Ohio service territory: Low and High PEV Adoption cases



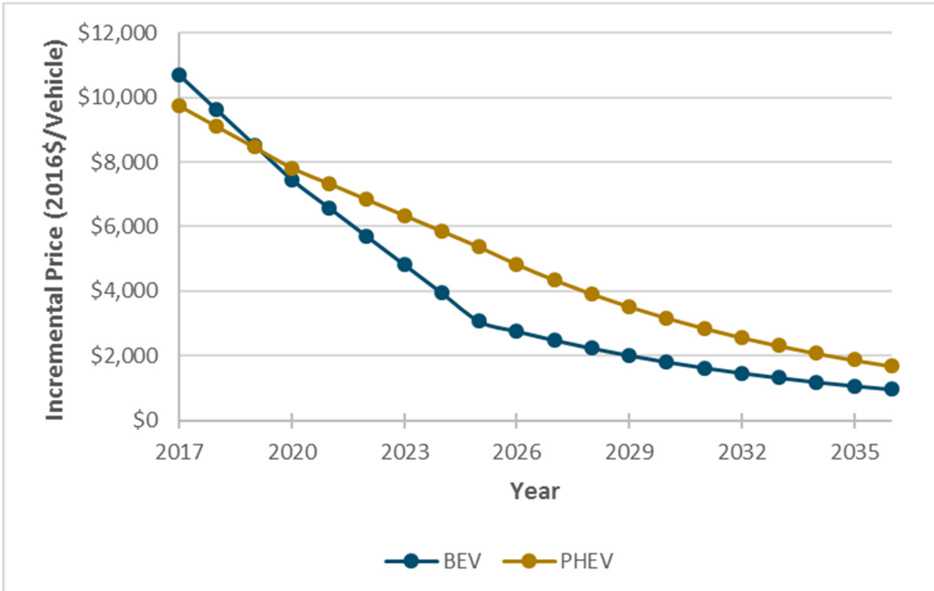
3.4 Incremental Vehicle Costs and Benefits

3.4.1 INCREMENTAL PEV COST

PEVs currently cost more than internal combustion engine (ICE) vehicles, and this cost is included in the Regional Perspective cost-benefit analysis. Given that this is an emerging market, forecasts of this price differential are inherently uncertain.

Figure 3 below shows the incremental vehicle price of BEVs or PHEVs over a conventional gasoline powered vehicle. The prices out to 2025 are taken from analysis by Ricardo (Pacific Gas & Electric, 2016). Afterwards, the incremental prices are assumed to decline at 10% per year.

Figure 3. Incremental vehicle price projections



3.4.2 REDUCED O&M COSTS ATTRIBUTABLE TO PEVS

PEV drivers enjoy lower operations and maintenance (O&M) costs over the lifetime of their vehicles than do ICE vehicle drivers, since PEVs do not require oil changes or parts repairs (and the associated labor costs) associated with exhaust systems, and because the regenerative breaking in PEVs causes less wear on vehicle brake pads.

Table 2 below gives the present value of total maintenance for BEVs PHEVs and conventional gasoline powered ICE vehicles used in this study (ORNL, 2010) .

Table 2. Lifetime maintenance costs for different vehicle technology types

	Lifetime Routine Maintenance Cost (2016$)
BEV	$3,095
PHEV	$3,677
ICE	$4,592

3.4.3 FEDERAL TAX CREDIT BENEFIT

PEVs under 14,000 lbs are currently eligible for a $7,500 federal tax credit. The future availability of this credit is highly uncertain: analysis by Ricardo indicates that vehicle manufacturers would begin to run out of credits starting in 2019, and all credits would be exhausted by 2025 (Pacific Gas & Electric, 2016). Therefore, the tax credit is assumed to apply only to PEVs purchased prior to 2023. The tax credit is viewed as an inflow of money to the AEP service territory, and is therefore counted as a benefit in the Regional Perspective.

3.5 PEV Driving and Charging Behavior

3.5.1 VEHICLE CLASSES

Six classes of PEVs were defined for this study based on the vehicle type and the type of electric vehicle service equipment (EVSEs) that they have access to, or 'charging behavior'. Each row of Table 3 defines a vehicle class. Several assumptions were made to define the vehicle classes. First, we assume that PHEVs would not use direct current fast chargers (DCFCs). Second, we assumed that all workplace and public electric vehicle service equipment (EVSEs) are higher voltage L2 devices. For PHEVs, we assumed that if there is access to an L2 EVSE at the workplace the owner would not use an L2 EVSE at home. For BEVs, we assumed that if there was no access to a workplace EVSE, then the owner would use an L2 EVSE at home.

Table 3. PEV vehicle classes and the EVSEs they use

Vehicle Type	Charging Behavior	Home EVSE Type	Workplace EVSE Type	Public EVSE Type
BEV	Home2	L2	None	L2 and DCFC
BEV	Mix1	L1	L2	L2 and DCFC
BEV	Mix2	L2	L2	L2 and DCFC
PHEV	Home1	L1	None	L2
PHEV	Home2	L2	None	L2
PHEV	Mix1	L1	L2	L2

Table 4 shows data used to model the PEVs. The electric vehicle miles travelled (eVMT) shows how many miles a vehicle travels in all electric mode each day. The vehicle miles travelled (VMT) shows how many miles a PHEV travels in hybrid drive mode after depleting the battery. The vehicle lifetime is used in the vehicle population stock rollover model to calculate vehicle replacements needed in each year. This data was provided by ICF and information about how access to charging influences miles travelled was taken from The EV Project and used to modify the eVMT or VMT of different vehicle classes (ICF and E3, 2016), (INL, 2014a), (INL, 2014b), (INL, 2014c), (INL, 2014d).

Table 4. PEV model input data

	BEV			PHEV40		
	Home2	Mix1	Mix2	Home1	Home2	Mix1
Weekday eVMT	30.8	33.6	33.6	31.9	31.9	34.8
Weekend eVMT	26.2	26.2	26.2	27.2	27.2	27.2
Weekday VMT	N/A	N/A	N/A	10.9	10.9	8.0
Weekend VMT	N/A	N/A	N/A	9.2	9.2	9.2
Vehicle Lifetime	10	10	10	10	10	10
Battery Size (kWh)	24	24	24	18	18	18
Maximum Charging Power (kW)	6.6	6.6	6.6	3.3	3.3	3.3

Table 5 and Table 6 show the data from the California Plug-In Electric Vehicle Driver Survey that was used to determine the split of BEVs or PHEVs into each vehicle class (Center for Sustainable Energy, 2013). This data is assumed to remain constant over the study horizon.

Table 5. Share of PEVs with access to workplace charging

	% of PEVs Without Workplace Charging	% of PEVs With Workplace Charging
BEV	54%	46%
PHEV	54%	46%

Table 6. Share of PEVs with an L2 Charger at home

	L2 Charger at Home	L1 Charger at Home
BEV	88%	12%
PHEV	46%	54%

The share of daily energy needs charged by the different vehicle classes at different locations is shown below in Table 7. The share of energy charged at each location depends on whether it is a weekday or a weekend. The shares of daily energy needs are based on data collected by *The EV Project.* Total energy needed each day is based on data on electric vehicle miles travelled (eVMT) and EPA fuel economy ratings of AC kWh/ 100mi; The 2017 Nissan Leaf fuel economy (30 kWh/100mi) is used for BEVs and the 2017 Chevrolet Volt fuel economy (31 kWh/100 mi) was used for PHEVs (EPA, 2017).

Table 7. Share of daily energy needs charged at each location by vehicle class

	BEV			PHEV40		
	Home2	Mix1	Mix2	Home1	Home2	Mix1
Weekday Energy Consumption (kWh)	8.8	9.6	9.6	11.1	11.1	12.1
% Weekday Energy from Home	93	60	60	89	89	46
% Weekday Energy from Work	N/A	39	39	N/A	N/A	53
% Weekday Energy from Public L2	5.25	0.75	0.75	11	11	1
% Weekday Energy from DCFC	1.75	0.25	0.25	N/A	N/A	N/A
Weekend Energy Consumption (kWh)	7.5	7.5	7.5	9.4	9.4	9.4
% Weekend Energy from Home	93	93	93	89	89	89
% Weekend Energy from Work	N/A	0	0	N/A	N/A	0
% Weekend Energy from Public L2	5	5	5	11	11	11
% Weekend Energy from DCFC	2	2	2	N/A	N/A	N/A

3.5.2 PEV CHARGING LOAD

Hourly profiles of unmanaged PEV charging used in this study were built based on data from The EV Project. Two types of profiles were developed to represent the aggregate charging demand of grid connected PEVs, with an average load shape representing energy consumption on an average day and a planning load shape representing the highest observed loads. The average load shape is used for calculating energy and carbon costs while the planning load shape is used for calculating generation capacity costs, T&D capacity costs, and retail demand charges. Per kWh unitized hourly profiles of each type were created for each EVSE type and for weekdays and weekends. The electrical grid impacts of PEVs are then based on these unitized shapes, data describing the daily energy consumption of each vehicle class, and the PEV population. Figure 4 shows the average weekday PEV charging load shape and Figure 5 shows the weekday planning load shape for AEP Ohio in various years under the High PEV Adoption case.

Figure 4. Average weekday PEV charging load profiles for the AEP Ohio service territory in the High PEV Adoption case across study years

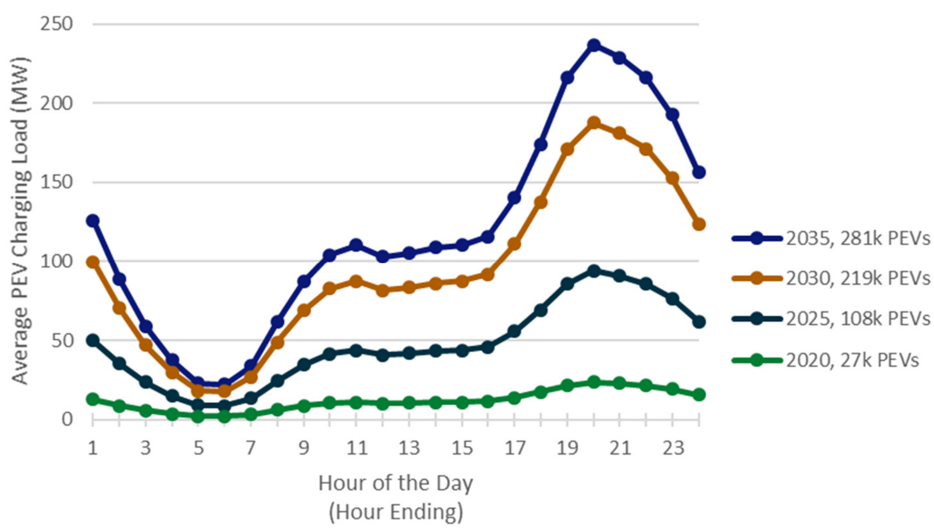
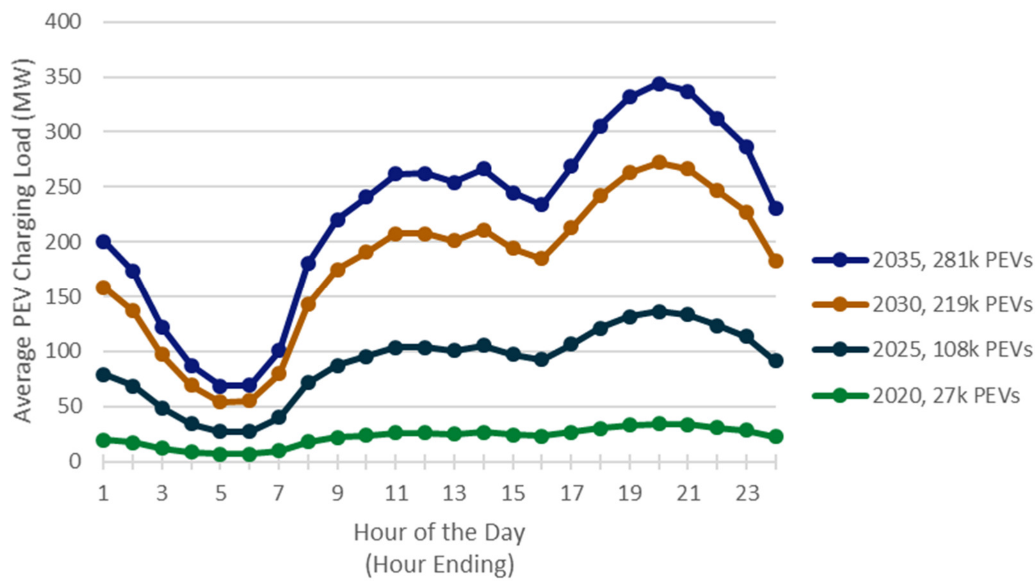


Figure 5. PEV planning load shape for the AEP Ohio service territory in the High Adoption scenario across study years

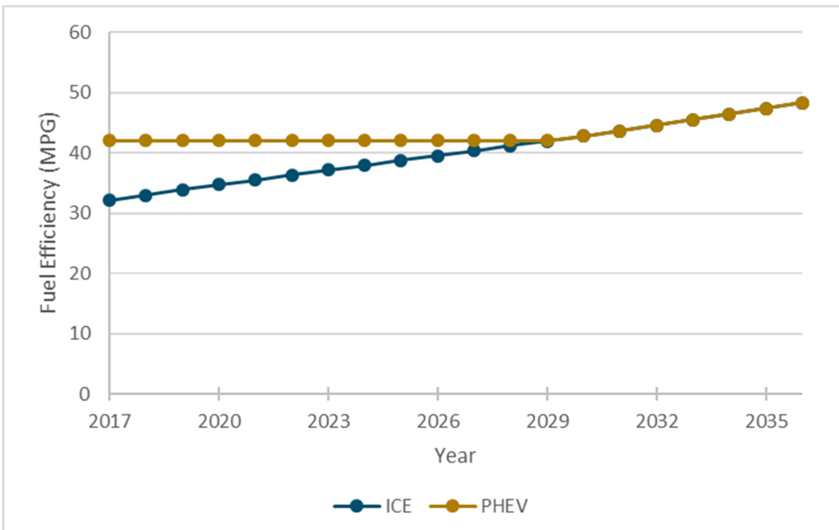


3.6 Avoided Gasoline Cost

3.6.1 QUANTITY OF AVOIDED GASOLINE

The EVGrid model calculates reductions in gasoline use due to displacement of ICE vehicles with PEVs. Four variables drive the accounting of the fuel displaced by replacing ICE vehicles with PEVs: 1) The electric vehicle miles travelled (eVMT) of a BEV or PHEV in all-electric mode, 2) the miles travelled by a PHEV in hybrid mode, 3) the fuel efficiency of PHEV vehicles in hybrid mode, and 4) the fuel efficiency of conventional ICE powered vehicles replaced by each vintage of PEVs. The data on miles driven are shown in Table 4. For projected fuel efficiency, we used ICF data consistent with increasing fuel efficiency and emissions standards. Figure 6 shows the fuel efficiency assumptions used. We assumed that PHEVs operating in hybrid mode would be at least as fuel efficient as conventional ICE vehicles, giving them the same fuel efficiency starting in 2030.

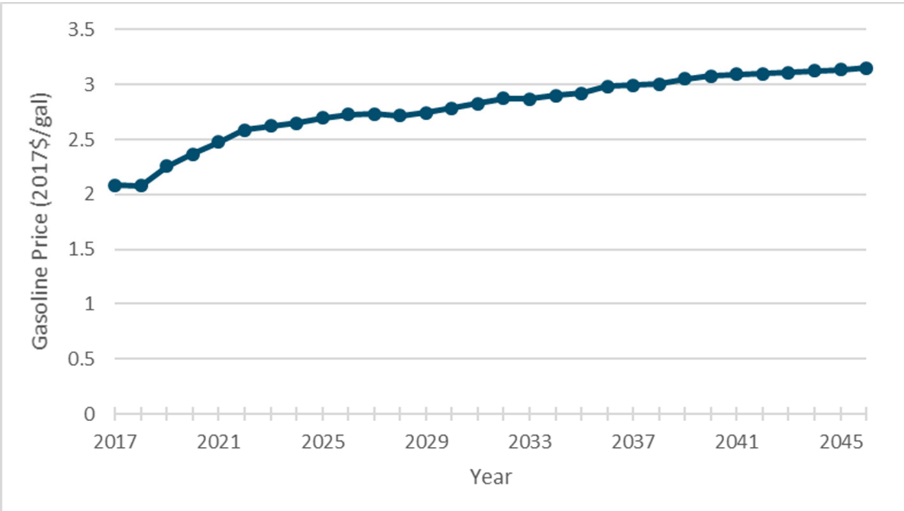
Figure 6. Fuel efficiency of conventional ICE vehicles and PHEV vehicles in hybrid drive mode



3.6.2 GASOLINE PRICES

Figure 7 shows the gasoline prices used in this study, which were taken from the EIA Annual Energy Outlook 2017 for Ohio's census region (EIA, 2017). Prices were adjusted to 2017 dollars and EIA's assumed state gasoline taxes of 27 cents per gallon were removed. State fuel taxes are removed because they are viewed as a transfer of money within the region being studied. However, federal fuel taxes are not removed because they represent an outflow of money from the region the same way federal tax credits for purchase of PEVs is viewed a net inflow.

Figure 7. Forecast gasoline prices



3.7 Charging Infrastructure Costs

The charging infrastructure cost included in the Regional Perspective analysis is a function of 1) PEV adoption, 2) the number of EVSEs required to support each PEV, 3) EVSE useful lifetime, and 4) the price of the EVSE. The first three of these parameters are used in a stock rollover model to determine the number of EVSEs purchased and retired in each year. The amount of PEV charging infrastructure required to support each PEV relies on two pieces of information about each type of EVSE: the number of charging events demanded by each vehicle type at each charger type per day, the number of vehicles that can be supported by each EVSE type per day. Data for these variables are provided below.

3.7.1 EVSE PARAMETERS

EVSE parameters are given in Table 8. 2017 prices are based on a literature review conducted by E3; other data was from ICF.

Table 8. EVSE parameters

EVSE Type	2017 Price (2016$)	Annual Price Reduction (%)	Maximum Power per Plug (kW)	Useful Lifetime (yrs.)
Residential L1	$200	-1.9	1.6	10
Residential L2	$1,700	-1.9	6.6	10
Work L2	$8,000	-1.9	6.6	10
Public L2	$4,000	-1.9	6.6	10
DCFC	$100,000	-1.9	50	10

3.7.2 VEHICLES SUPPORTED BY EACH EVSE

EVSEs per vehicle is shown below in Table 9 (NREL, 2014) (INL, 2014a). All vehicle types use public L2 chargers, but for this study we assumed that PHEVs do not use DCFCs. The data shows a greater demand for public L2 charging from PHEVs than from BEVs. This may be because they have smaller batteries and because they do not split their charging between public L2 chargers and DCFCs.

Table 9. Data used to determine charging infrastructure needs by EVSE type

Vehicle Type	Charging Behavior	EVSE Type: Home	Public L2	Work L2	DCFC
Events Supported/Day[6]					
All	All	1	4	4.8	6
Events/Vehicle/Day[7]					
BEV	Home2	1	0.065	N/A	0.022
BEV	Mix1	1	0.065	0.75	0.022
BEV	Mix2	1	0.065	0.75	0.022
PHEV	Home1	1	0.12	N/A	N/A
PHEV	Home2	1	0.12	N/A	N/A
PHEV	Mix1	1	0.12	1.04	N/A

Table 10 shows the resulting number of vehicles of each type that can be supported by each EVSE type under the assumptions in Table 9.

[6] Assumptions used by NREL for CA charging infrastructure study
[7] Observed EVSE utilization data from The EV Project

Table 10. Resulting vehicle charging infrastructure requirement by EVSE type

Vehicle Type	Charging Behavior	EVSE Type: Home	Public L2	Work L2	DCFC
		Vehicles per EVSE			
BEV	Home2	1	61	N/A	276
BEV	Mix1	1	61	6	276
BEV	Mix2	1	61	6	276
PHEV	Home1	1	33	N/A	N/A
PHEV	Home2	1	33	N/A	N/A
PHEV	Mix1	1	33	5	N/A

3.8 Incremental Utility Revenue

PEV adoption increases electricity consumption, which in turn increases drivers' electricity bills and therefore utility revenue. This is considered a benefit from the Ratepayer Perspective, since it can reduce average rates or allow spending on programs that benefit ratepayers. The analysis presented here is intended to provide a starting point for rate and program design by helping stakeholders to understand the potential magnitude of net benefits under *current* rates and rate projections.

E3's EVGrid model calculates retail electricity bills for four types of charging locations: Residential, Workplace, Public L2, and Public DCFC. Retail electricity bills are assumed to be time-of-use (TOU) rates. The rates used for each charging location are shown below in Table 11. We assume that EVSEs will are not separately metered at residential and workplace locations, and so PEV adoption does not incur new customer charges at these locations. At workplace charging locations, PEV charging would only incur demand charges if the charging is coincident with the existing customer load. In the absence of customer load data, we calculate incremental workplace demand charges using the average charging power during each TOU time period. The energy component of the incremental electric bills is calculated using the average day load shapes while any demand charges are calculated using the planning load shapes.

Table 11. Definitions of retail tariffs for calculating retail electric bills

Charging Location	Customer Charge ($/month)	TOU 1	TOU 2	TOU 1 Energy Charge ($/kWh)	TOU 2 Energy Charge ($/kWh)	TOU 1 Demand Charge ($/kW)	TOU 2 Demand Charge ($/kW)
Residential	N/A	7 a.m. to 10 p.m.	10 p.m. to 7 a.m.	0.1195	0.0995	N/A	N/A
Workplace	N/A	7 a.m. to 9 p.m.	9 p.m. to 7 a.m.	0.0697	0.0697	10.073	5.853
Public L2	9.04	7 a.m. to 9 p.m.	9 p.m. to 7 a.m.	0.0697	0.0697	10.073	5.853
Public DCFC	115.29	7 a.m. to 9 p.m.	9 p.m. to 7 a.m.	0.0652	0.0652	9.239	4.619

3.9 Electricity Supply Costs

PEV adoption increases electricity consumption, which increases electric grid costs, including costs associated with electric generation, generation capacity, ancillary service provision, forecasted electric CO_2 cost, and electric grid T&D. These costs are included in the Regional and Ratepayer perspectives wherever they are attributable to PEVs.

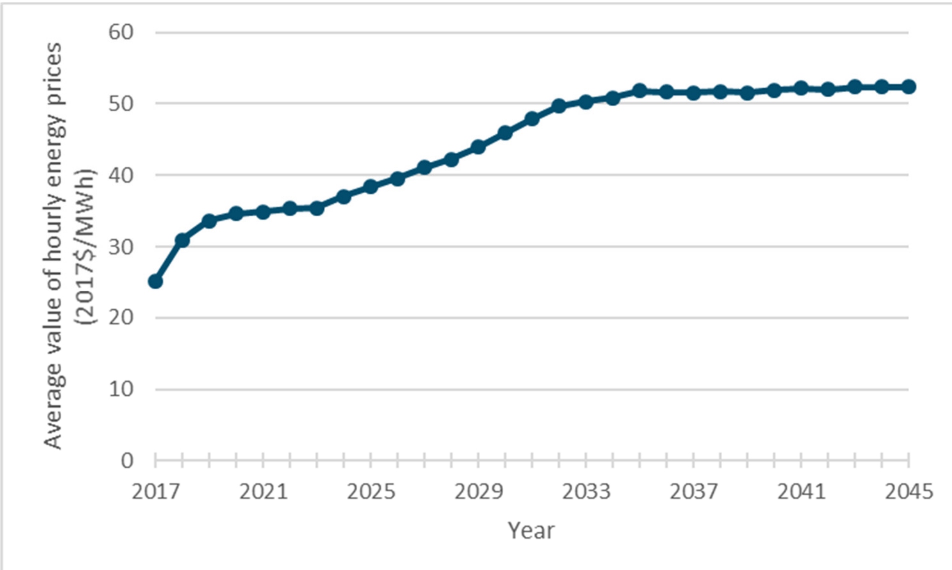
3.9.1 LOSSES

E3 models the energy consumption of PEVs at the meter and scales up energy and capacity impacts to the system level using a system loss factor. We assume all charging stations are connected to the secondary voltage level, with a loss factor of 1.0932.

3.9.2 ELECTRICITY COST

AEP Ohio's Fundamentals Group provided the '2016 H2 Base Case' forecast of PJM energy prices at the AEP Gen Hub. The annual average of the electricity prices is given below in Figure 8. These prices have been adjusted using other assumptions about CO_2 emissions prices and average emissions rates to not reflect any CO_2 costs.

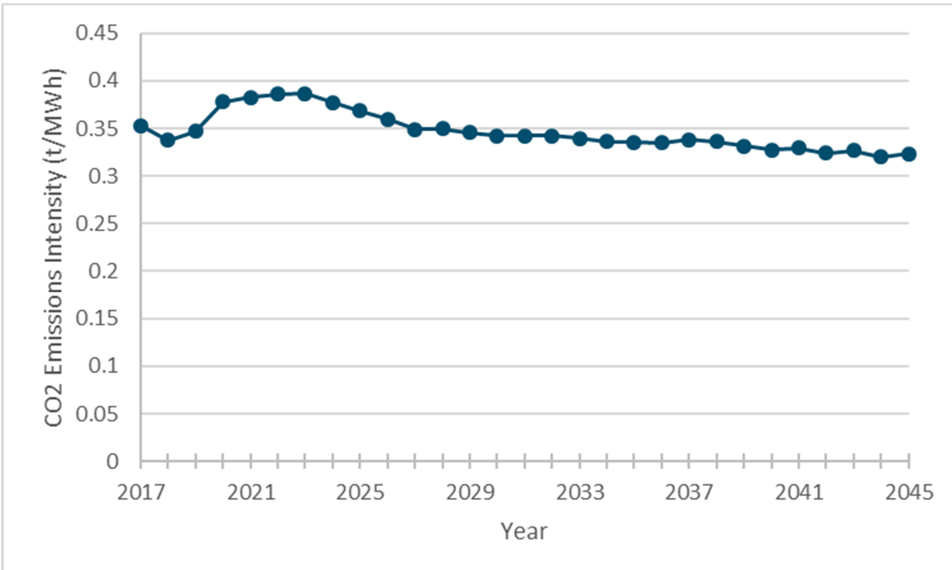
Figure 8. Annual average electric energy price forecast



3.9.3 CARBON COSTS

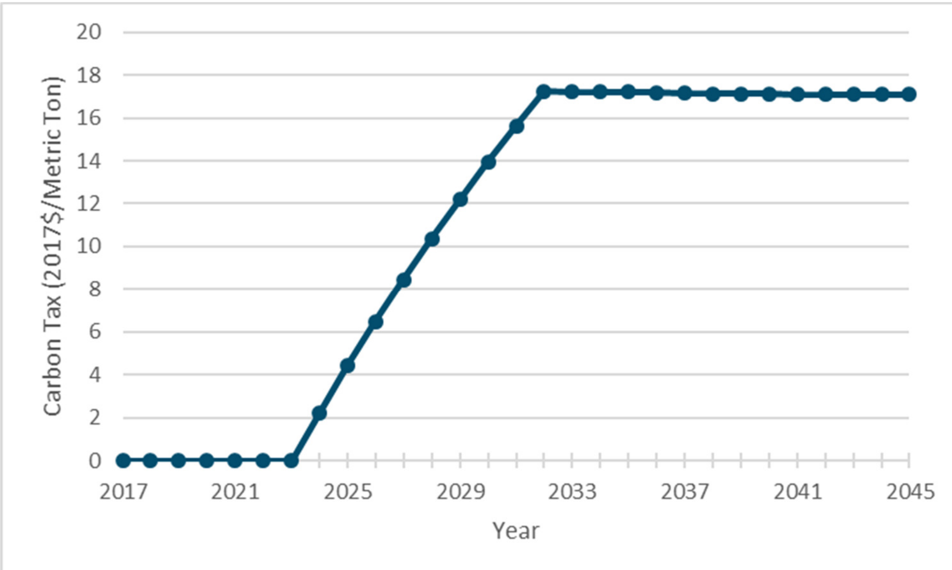
E3 used forecasts of total electric grid energy generation and CO_2 emissions for the Reliability First Corporation East region published by the EIA in the AEO 2017 to estimate the average emissions intensity of electric energy in each year of the study. The emissions intensity is shown below in Figure 9.

Figure 9. Average CO_2 emissions intensity forecast for electric energy in the Reliability First Corporation East region.



AEP's fundamentals group provided a forecast of future taxes on CO_2 emissions, as shown in Figure 10. This tax is assumed to apply to emissions from both electric energy generation and burning gasoline for transportation. The first year with a carbon tax is 2024. The forecast tax levels off around $17/metric ton in the year 2032.

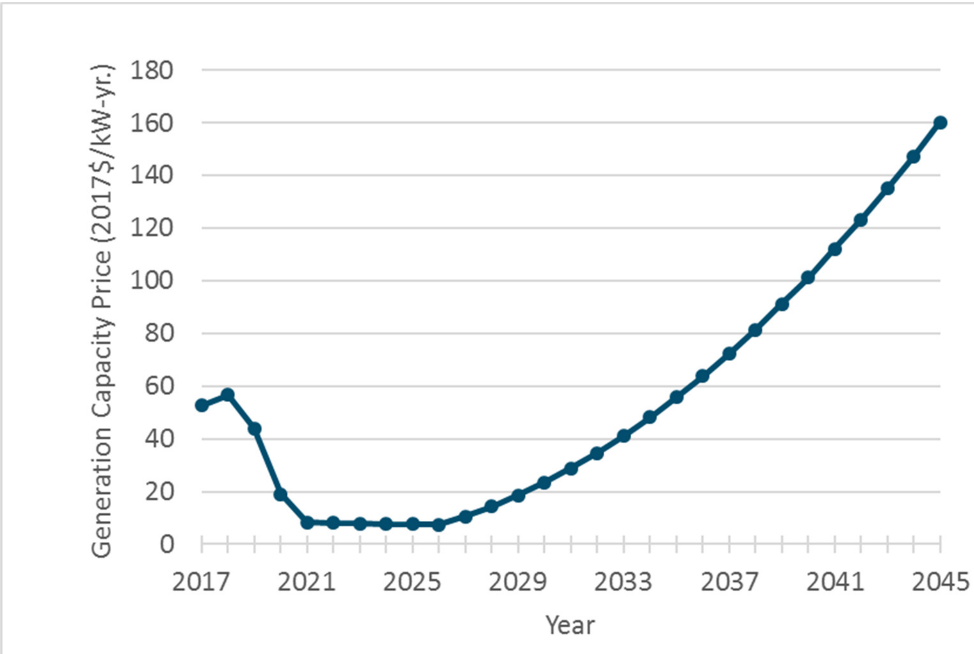
Figure 10. Carbon tax forecast



3.9.4 GENERATION CAPACITY COST

The generation capacity price represents the price of maintaining adequate generation capacity resources to satisfy the electric grid peak system demand. AEP's fundamentals group provided a forecast of generation capacity prices based on net cost of new entry (Net CONE) from production simulations, as shown in Figure 11 .

Figure 11. Generation capacity price forecast



In E3's methodology for calculating the incremental generation capacity cost of serving new PEV load, the annual generation capacity price is allocated to the hours of the year using peak capacity allocation factors (PCAFs). The PCAF methodology was first developed by PG&E in their 1993 General Rate Case and has since been used in many applications in California planning.[8] The threshold for peak hours used in the calculation of PCAF can be determined statistically (e.g. by standard deviation) or by a specific MW or number of hours threshold. In this case, E3 calculates PCAFs based on the top 200 load hours of the year. The relative importance of each hour is determined using weights assigned to each peak hour

[8] For example, PCAfs were used recently in a CPUC report quantifying distributed PV potential in California: http://www.cpuc.ca.gov/NR/rdonlyres/8A822C08-A56C-4674-A5D2-099E48B41160/0/LDPVPotentialReportMarch2012.pdf

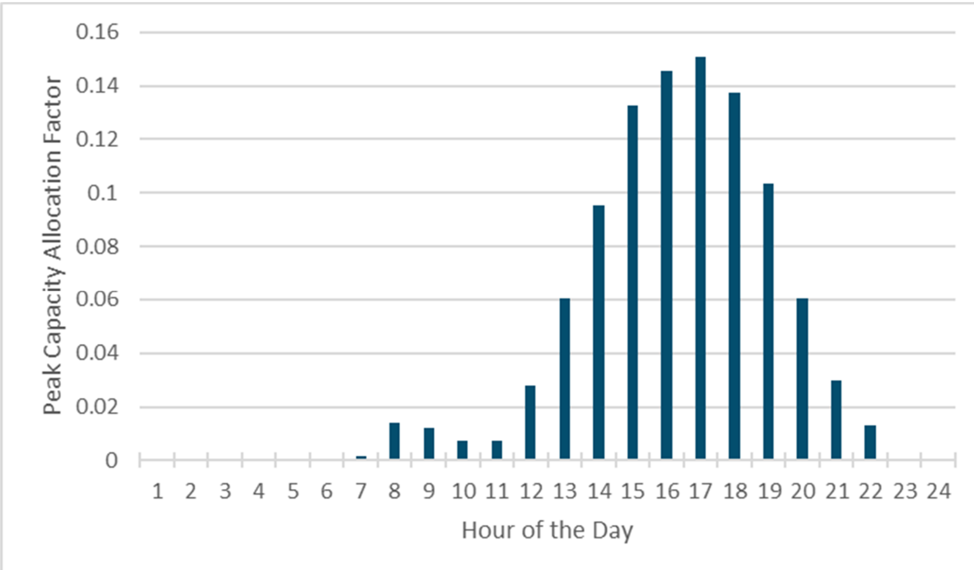
in proportion to their level above the threshold. The formula for peak capacity allocation factors (PCAFs) using proportional weights is shown below.

$$PCAF[yr][hr] = \frac{Max(0, Load[yr][hr] - Thresh[yr])}{\sum_{hr=1}^{8760} Max(0, Load[yr][hr] - Thresh[yr])}$$

Where *Thresh[yr]* is the load in the threshold hour or the highest load outside of the peak period.

Each of the top 200 load hours is given a $/kWh value using its PCAF value and the generation capacity price. The load used to calculate PCAFs was a 2017 AEP Generation Hub load forecast provided by AEP's fundamentals group. The distribution of PCAFs across the hours of the day is shown in Figure 12. The bars in Figure 12 represent the share of total generation capacity costs allocated to the different hours of the day.

Figure 12. Sum of generation capacity PCAF across the year for each hour of the day



Note that the PCAF methodology allocates capacity costs more broadly, that is to a higher number of hours throughout the day, than a coincident peak responsibility method. For example, a 1-CP approach allocates capacity cost based on the highest single hour system peak demand over the entire year. A 6-CP approach allocates capacity costs according to the highest single hour peak demand in each of 6 individual months. This analysis looks as the cost impacts of uncertain PEV load shapes over a long period during which both the system and PEV load shapes may change. The PCAF approach accounts for such uncertainty by capturing potential capacity costs over a wider number of hours.

3.9.5 T&D COST

E3's EVGrid model calculates the cost of T&D upgrades due to forecasted PEV adoption. AEP Ohio does not believe that any transmission upgrades will be required to support PEV adoption in their service territory, and therefore all of the T&D cost shown throughout this study is incurred on the distribution network.

PEV charging that occurs coincident with distribution system peak loads will require AEP to upgrade distribution equipment to reliably serve higher peak loads. E3 used AEP distribution capital costs and peak loads from 2010 and 2015 to estimate the $/kW cost of load growth related distribution upgrades over that time period. We apply these costs to PEV charging load that occurs on-peak to estimate future distribution costs that are driven specifically by increased PEV adoption.

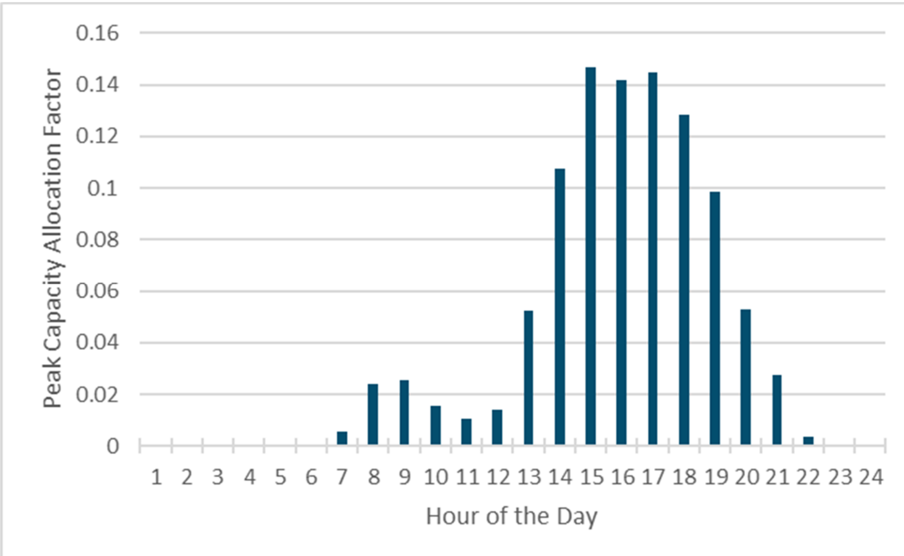
E3 has used this method for estimating load growth-related distribution costs in developing DER avoided cost estimates in California, New York, Hawaii and other jurisdictions. Most recently, E3 worked with the three investor owned utilities (IOUs) in California in to develop the Local Net Benefits Analysis (LNBA) tool in support of the CPUC Distributed Resource Planning proceeding. E3 updated the DER Avoided Cost Methodology for distribution system value to calculate both the system avoided costs and the local avoided costs attributable to demand side or distribution located resources. The approach for calculating distribution upgrade costs is described in the documentation for the LNBA tool filed by the utilities (PG&E 2016b).

Only a portion of total distribution capital costs are load growth driven. Some cost categories are driven primarily by the size of the area served and the number of customers, irrespective of peak load. We therefore identify substation and line transformers as the cost categories primarily driven by load growth. Total plant in service for these categories totaled nearly $1.1 Billion in 2010 (Case no. 11-351-EL-AIR). In 2015, these costs totaled almost $1.4 billion (from 2015 FERC Form 1), a total increase of $275 million over five years or $55 million per year. We use a revenue requirement gross up of

1.3 provided by AEP to account for additional authorized costs such as taxes, franchise fees, overhead and authorize rate of return that are included in the revenue requirement. Over the same period, the 6-CP load increased from 6.4 GW to 7.5 GW, a total increase of 1,070 MW or an annual increase of 214 MW (3.2%) over five years. We calculate a Real Economic Carrying Charge (RECC) factor of 4.76% using AEP's WACC of 7.2% and an inflation rate of 2%. We multiply the present value capital cost and the RECC, divide by the increase in peak load over the five- year period and multiply by the RECC to calculate a present value cost of $16.21/kW in 2017 dollars for load growth driven distribution upgrades. For this analysis, we used readily available system level data. Calculating load growth driven distribution costs at a substation or feeder level could yield higher (or lower) results. In addition, the figure calculated here represents a system average cost.

E3 allocated the distribution capacity cost to the 200 highest load hours of the year, following the same PCAF methodology as was used for generation capacity. E3 calculated PCAFs using AEP Ohio's total distribution network load, including SSO and CRES customers for both Ohio Power and Columbus Southern Power. The allocation of PCAFs across the hours of the day is shown in Figure 13. The bars in Figure 13 represent the share of total generation capacity costs allocated to the different hours of the day.

Figure 13. Sum of distribution capacity PCAFs across the year for each hour of the day



3.10 Avoided Carbon Dioxide

The carbon dioxide emissions reductions quantified in this analysis result from two consequences of PEV adoption:

+ PEVs are substitutes for conventional petroleum fueled ICE vehicles, avoiding emissions from transportation
+ The electrical system must generate additional electricity to supply PEVs, potentially increasing the emissions from thermal generators
+ The carbon dioxide emissions reduction is then the decrease in petroleum-related emissions less the magnitude of the increase in electricity-related emissions. This analysis does not consider emissions from the extraction, refining, or delivery of fossil fuels or vehicle fabrication and recycling.

E3 calculates emission reductions from reduced petroleum fuel usage by multiplying the gallons of avoided gasoline by an emissions factor. The increased emissions from the electrical grid are calculated using an annual emission factor of tons of CO_2/kWh multiplied by the total annual electric energy consumption of PEVs. The energy consumption of EVSE is grossed up to account for energy losses on the transmission and distribution grids during delivery of electricity to the PEVs.

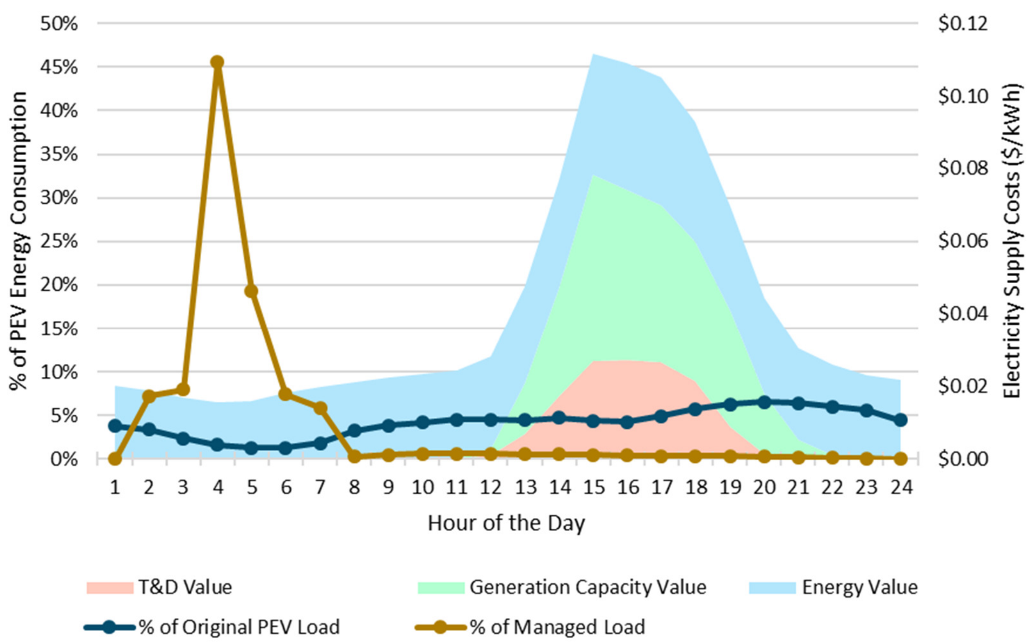
4 Scenarios and Cases Studied

Cost-benefit analysis of PEV adoption is performed for two scenarios: a Base scenario and a Managed Charging. The differences between the scenario inputs and assumptions result in different per vehicle Regional and Ratepayer Perspective net benefits from PEV adoption. The Base scenario uses E3's best estimate of input values, and assumes that PEV owners do not try to minimize their electric bills when deciding to charge their cars. The Managed Charging scenario assumes that PEV charging is optimized to minimize costs from the utility's perspective and is described in more detail below. Both scenarios are studied under a High and a Low PEV Adoption case.

4.1 Managed Charging Scenario

The Managed Charging scenario quantifies the maximum potential value of managed charging for PEVs. In this analysis, we assume that any charging that would normally take place at either home or work can be optimally scheduled within the constraints of driving needs and EVSE capabilities to minimize costs. Charging that takes place at public L2 EVSEs or DCFC EVSEs is assumed to be fixed and is not altered from the Base scenario. Vehicle charging is optimized to minimize costs from the utility's perspective. The costs that are minimized include the hourly cost of electric energy as well as, generation capacity cost, and T&D cost. The optimal charging profiles are found by solving a linear programming optimization problem. This approach assumes that driving behavior is known with certainty and well in advance. Figure 14 compares the resulting managed PEV charging load shape with the original unmanaged PEV charging load shape and the costs of delivering electricity in each hour for a June weekday. The share of charging load in each hour of the day is plotted against the left-hand axis for both the original load shape and for the managed charging load shape. The electricity supply costs are plotted against the right-hand side axis. Managed charging squeezes PEV charging load into the lowest cost hours in the early morning as much as possible.

Figure 14. Comparison of the distribution of PEV charging load across hours of the day with electricity supply costs for a weekday in June

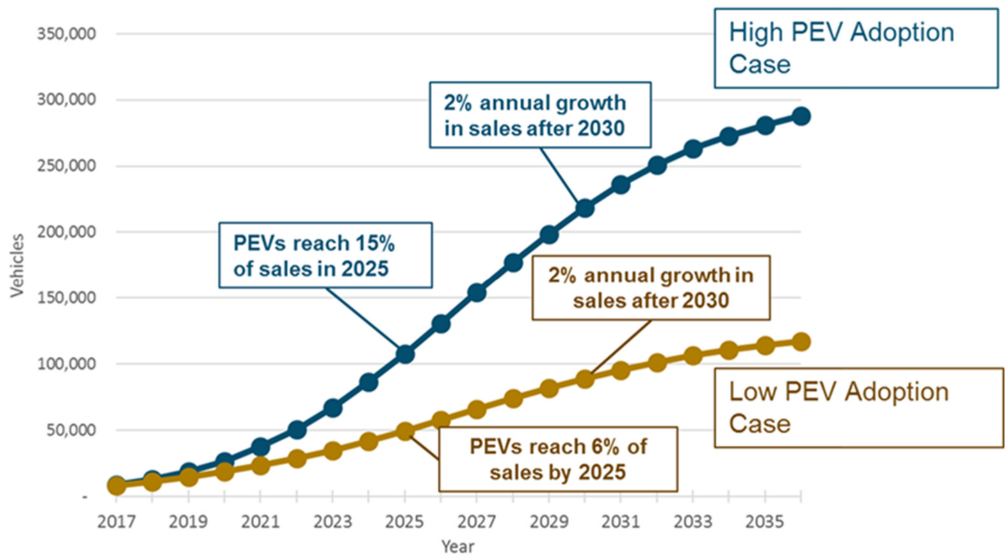


The difference in net benefits between the Managed Charging scenario and the Base scenario is then the incremental value of managed charging. The incremental value is calculated on a per vehicle basis for both the Regional Perspective and the Ratepayer Perspective. The per vehicle incremental value of managed charging from the Ratepayer Perspective represents the value to ratepayers from each vehicle enrolled a managed charging program, and can be compared with the program and technology costs necessary to enable managed charging. The cost-benefit analysis presented in this study does not include any technology or program costs that may be required to implement a managed charging program. The simplifying assumptions made in this approach to modeling and valuing managed charging result in an upper bound on the value of managed charging and a more detailed analysis may be needed to evaluate any specific managed charging program.

4.2 PEV Adoption Cases

Since any forecast of the future population of PEVs in the AEP service territory would be highly uncertain, we study High and Low PEV Adoption cases in both the Base and Managed Charging scenarios, placing reasonable bookends on the total Regional or Ratepayer benefit from PEV adoption for each scenario. Figure 15 below shows the PEV population projections in the High PEV Adoption and Low PEV Adoption cases. The High PEV Adoption case is consistent with meeting PEV sales goals established by California's ZEV mandate. The Low PEV Adoption case assumes that, in the year 2025, PEV sales in AEP's service territory reach the level seen in California today. The development of these PEV population projections is discussed in detail in section 3.3.

Figure 15. PEV population in the AEP Ohio service territory for High and low PEV Adoption cases



5 Cost-Benefit Analysis Results

5.1 Interpreting Results

The cost-benefit analysis results are shown in this report on both a total net present value basis, and on a per vehicle sold basis. The total value results help one to understand the total magnitude of the costs and benefits from PEV adoption in the AEP Ohio service territory and are heavily influenced by the PEV population forecast used as input. Because the PEV population forecast is highly uncertain, it is also useful to analyze results on a per-vehicle basis. Per vehicle results are more robust to uncertainty in population forecast, although they are influenced somewhat by the timing of PEV sales since the prevailing economics of PEV adoption change over time. Per vehicle results are also more useful in designing and evaluating PEV programs or incentives than total results, since an incentive or program cost per-vehicle could be directly compared to the per vehicle net benefit.

5.2 Regional Perspective Results

5.2.1 BASE SCENARIO

For the Base scenario, Regional net benefits from PEV adoption over the next 20 years range from $256 Million in the Low PEV Adoption case to $380 Million in the High PEV Adoption case. The High PEV Adoption case shows a Regional net benefit of $1,595 per vehicle sold over the next 20 years.

Per vehicle Regional Perspective costs and benefits for the Base scenario, High PEV Adoption case are illustrated below in Figure 16. The electricity supply cost is the total cost of delivering electric energy to a PEV. As shown in the top pie chart, around three-quarters of the electricity supply cost is for electric energy. Notably, T&D upgrades account for under 1% of electricity supply cost. The eVMT savings in Figure 16 represent the total savings due to driving a PEV instead of a conventional ICE vehicle. As shown in the lower pie chart, the majority of eVMT savings come from gasoline savings.

Figure 16. Regional Perspective costs and benefits, per vehicle. Base scenario, High PEV Adoption case

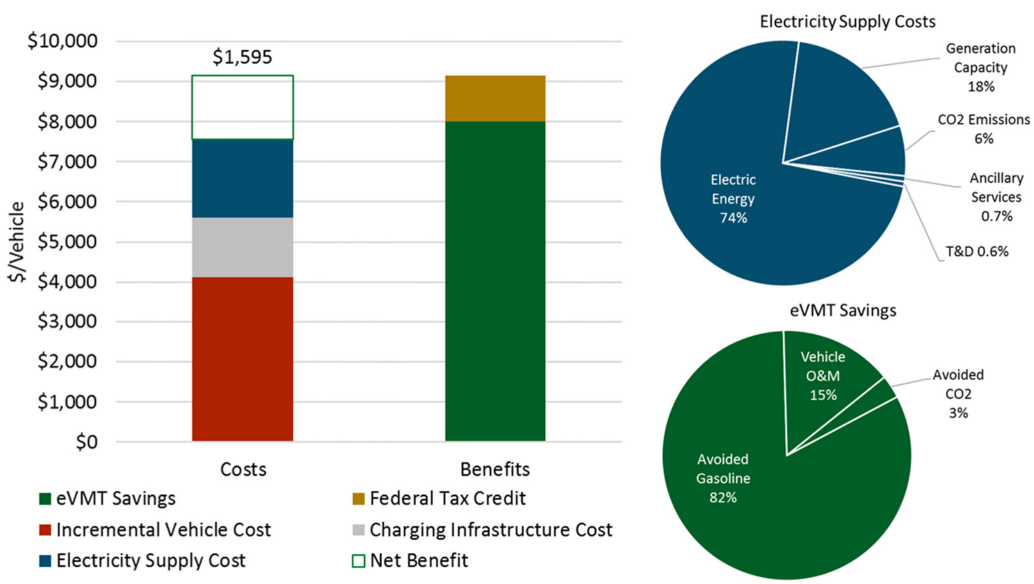


Table 12 presents the results of both the High PEV Adoption and Low PEV Adoption cases for the Base scenario. Results are presented on both a total present value and per vehicle basis. There are slight differences in the per vehicle costs and benefits due to the timing of vehicle purchases: in the High PEV Adoption case, a larger share of vehicle purchases occurs in later years than in the Low PEV Adoption case.

Table 12 . Regional Perspective costs and benefits, Base scenario

	High Adoption		Low Adoption	
	Total (MM$)	Per Vehicle ($)	Total (MM$)	Per Vehicle ($)
Costs				
Electric Vehicle	982	4,118	817	4,476
Charging Infrastructure	357	1,495	252	1,382
Generation Capacity	83	347	64	349
Ancillary Services	3	14	3	14
T&D	3	12	2	12
Electric Energy CO_2	31	128	23	128
Electric Energy	341	1,431	264	1,445
Benefits				
Avoided Gasoline	1571	6,589	1,222	6,694
Avoided Gasoline CO_2	57	238	44	238
Vehicle O&M Savings	280	1,174	196	1,075
Federal Tax Credit	272	1,141	220	1,204
Regional Net Benefits				
Total	380	1,595	256	1,404

5.2.2 MANAGED CHARGING SCENARIO

In the Managed Charging scenario, Regional Perspective total net benefits from PEV adoption over the next 20 years range from $371 Million in the Low PEV adoption case to $531 Million in the High PEV Adoption case. This equates to an incremental value of managed charging from the Regional Perspective of $115 Million to $150 Million. In the High PEV Adoption case with managed charging, there is a Regional net benefit of $2,225 per vehicle sold over the next 20 years. Therefore, managed charging creates an incremental Regional benefit of $629 per vehicle. Per vehicle Regional Perspective costs and benefits are illustrated in Figure 17 for the Managed Charging scenario and High PEV Adoption case.

Figure 17. Regional Perspective costs and benefits, per vehicle. Managed Charging scenario, High PEV Adoption case

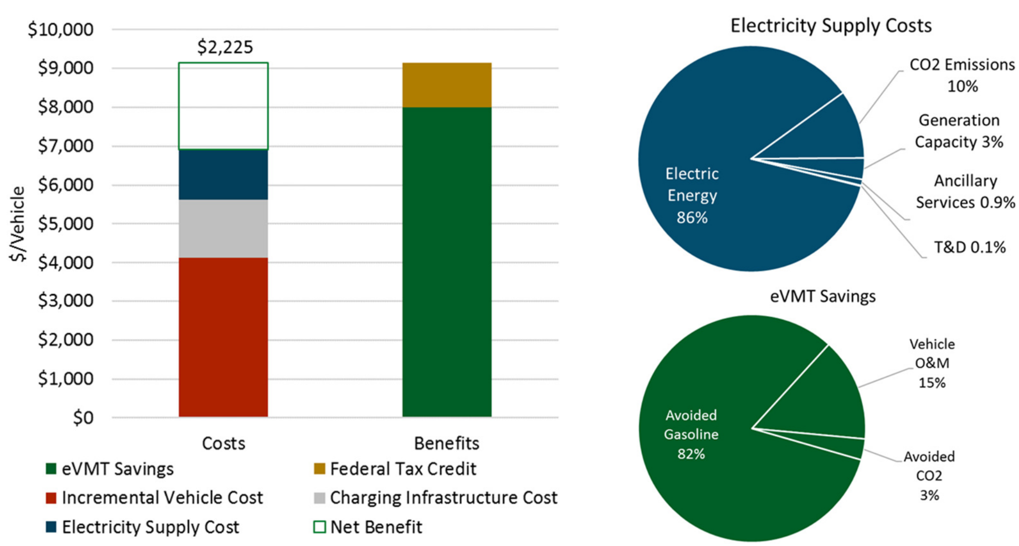


Table 13 shows the results for the Managed Charging scenario on a total and per vehicle basis.

Table 13. Regional Perspective costs and benefits, Managed Charging scenario

	High Adoption		Low Adoption	
	Total (MM$)	Per Vehicle ($)	Total (MM$)	Per Vehicle ($)
Costs				
Electric Vehicle	982	4,118	817	4,476
Charging Infrastructure Cost	357	1,495	252	1,382
Generation Capacity	9	40	8	42
Ancillary Services	3	11	2	11
T&D	0.3	1	0.3	1
Electric Energy CO_2	31	128	23	128
Electric Energy	268	1,123	208	1,137
Benefits				
Avoided Gasoline	1,571	6,589	1,222	6,694
Avoided Gasoline CO_2	57	238	44	238
Vehicle O&M Savings	280	1,174	196	1,075
Federal Tax Credit	272	1,141	220	1,204
Regional Net Benefits				
Total	531	1,413	371	1,222

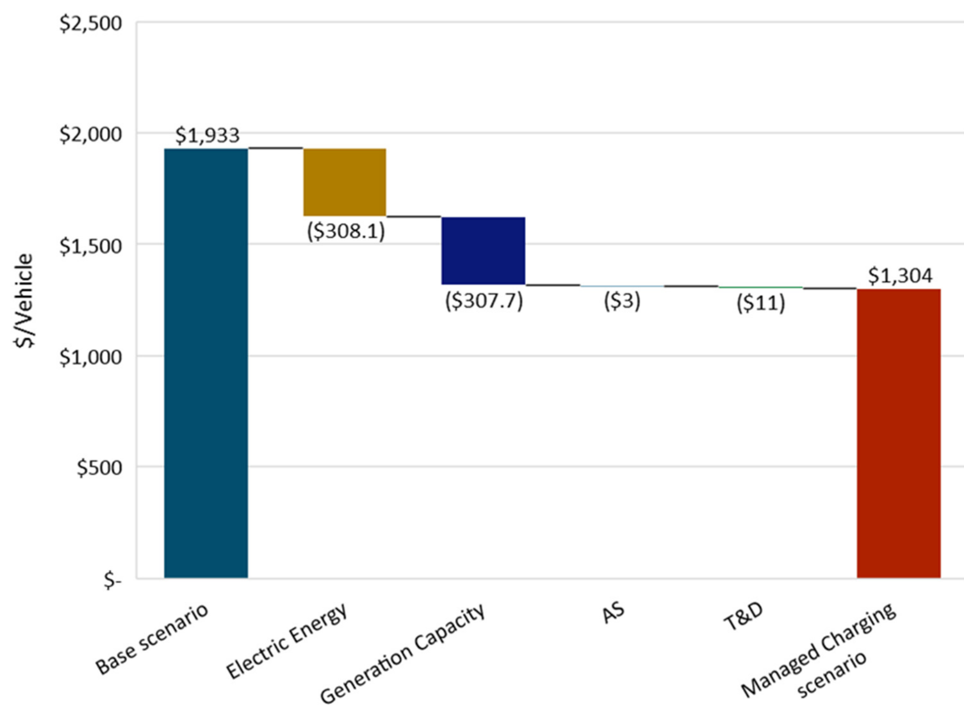
Table 14 shows the decrease in each electricity supply cost component and the total increase in Regional Perspective net benefit attributable to managed charging (versus the Base scenario). Managed charging reduces generation capacity and T&D costs nearly 90% by shifting PEV charging load to off-peak hours. Managed charging also reduces electric energy and ancillary services costs by 21% to 22%. In absolute terms, the largest cost reductions are in generation capacity and electric energy costs, which are nearly equal. Total Regional net benefits are increased 39% to 45% due to managed charging.

Table 14. Difference in total electricity supply costs and Regional net benefits, Managed Charging scenario minus Base scenario

Component	High Adoption		Low Adoption	
	Change (MM$)	% Change	Change (MM$)	% Change ($)
Generation Capacity Cost	-73.4	-89%	-56.1	-88%
Ancillary Services Cost	-0.7	-22%	-0.6	-21%
T&D Cost	-2.6	-89%	-2.0	-89%
Electric Energy Cost	-73.5	-22%	-56.2	-21%
Regional Net Benefits	150	39%	115	45%

Figure 18 illustrates the reduction in electricity supply cost per vehicle from the Base Scenario due to managed charging. In the Base scenario, there is an electricity supply cost of $1,933 per vehicle in the High PEV Adoption case. Managed charging reduces the electric energy and generation capacity costs by $308 per vehicle, reduces the ancillary services cost by $3 per vehicle, and reduces the T&D cost by $11 per vehicle. The remaining electricity supply cost in the Managed Charging scenario is $1,304 per vehicle, a 33% reduction.

Figure 18. Reductions in electricity supply costs due to managed charging



5.3 Ratepayer Perspective Results

5.3.1 BASE SCENARIO

In the Base scenario, Ratepayer Perspective total net benefits from PEV adoption over the next 20 years range from $278 Million to $351 Million in the Low and High PEV Adoption cases, respectively. This translates to a Ratepayer net benefit of $1,470 per vehicle sold over the next 20 years in the High PEV Adoption case. Per vehicle Regional Perspective costs and benefits are illustrated in Figure 19 for the Base scenario, High PEV Adoption case. Under current rates, PEV drivers in AEP Ohio's service territory pay $1,470 more, on average, in electric utility bills than it costs for the utility to supply them with electricity. This represents a net Ratepayer Perspective benefit. The Ratepayer net benefit per vehicle can also be thought of as the maximum amount that the utility can spend, per vehicle, on a PEV program without increasing costs to other ratepayers.

Figure 19. Ratepayer Perspective costs and benefits, per vehicle. Base scenario, High PEV Adoption case

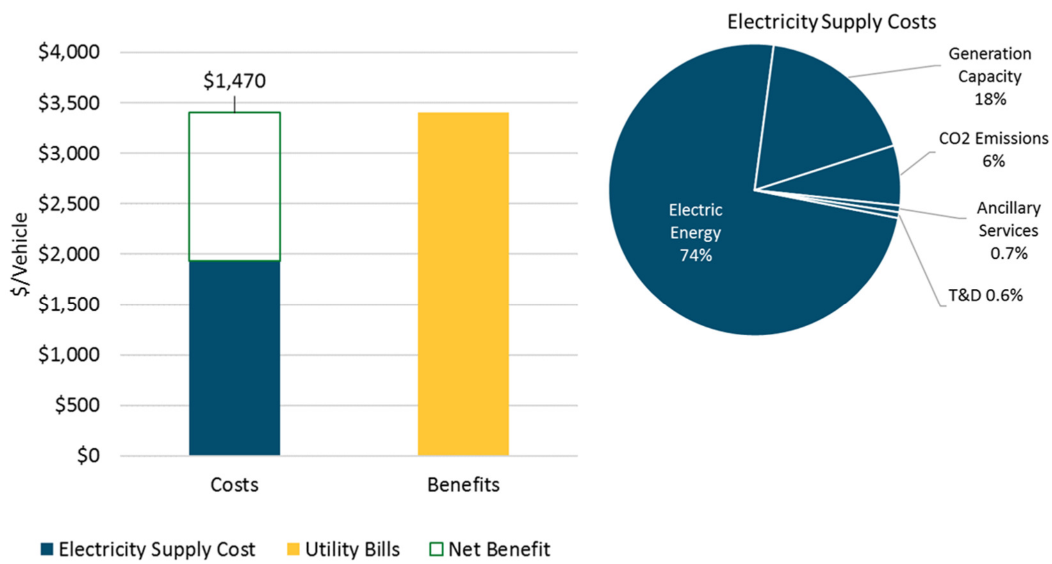


Table 15 presents detailed results of both the High and Low PEV Adoption cases.

Table 15. Ratepayer perspective cost-benefit analysis results in the Base scenario

	High Adoption		Low Adoption	
	Total (MM$)	Per Vehicle ($)	Total (MM$)	Per Vehicle ($)
Costs				
Generation Capacity	83	347	64	349
Ancillary Services	3	14	3	14
T&D	3	12	2	12
Electric Energy CO_2	31	128	23	128
Electric Energy	341	1,431	264	1,445
Benefits				
Utility Bills	812	3,403	634	3,475
Net Benefits				
Total	351	1,470	278	1,526

5.3.2 MANAGED CHARGING SCENARIO

Total Ratepayer Perspective net benefits from PEV adoption over the next 20 years range from $300 Million to $380 Million in the Low and High PEV Adoption cases, respectively. Compared to the Base scenario, managed charging increases Ratepayer net benefits by 8% or $21 Million in the Low PEV Adoption case, and 9% or $32 Million in the High PEV Adoption case. In the High PEV Adoption case with managed charging, there is a Ratepayer net benefit of $1,604 per vehicle. Therefore, managed charging creates an incremental Ratepayer benefit of $134 per vehicle in the High PEV Adoption case. Figure 20 illustrates per vehicle Ratepayer Perspective costs and benefits for the High PEV Adoption case in the Managed Charging Scenario.

Figure 20. Ratepayer Perspective costs and benefits, per vehicle. Managed Charging scenario, High PEV Adoption case

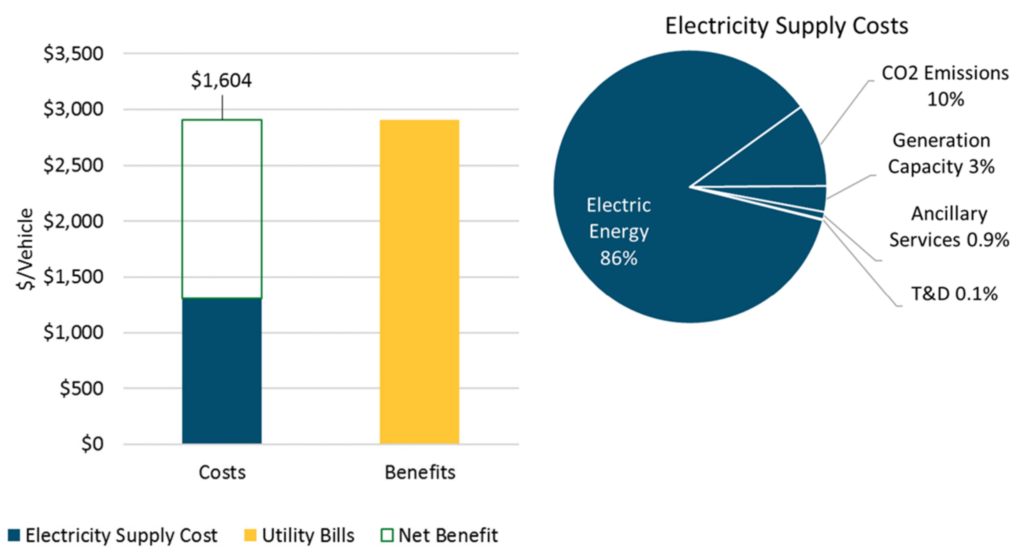


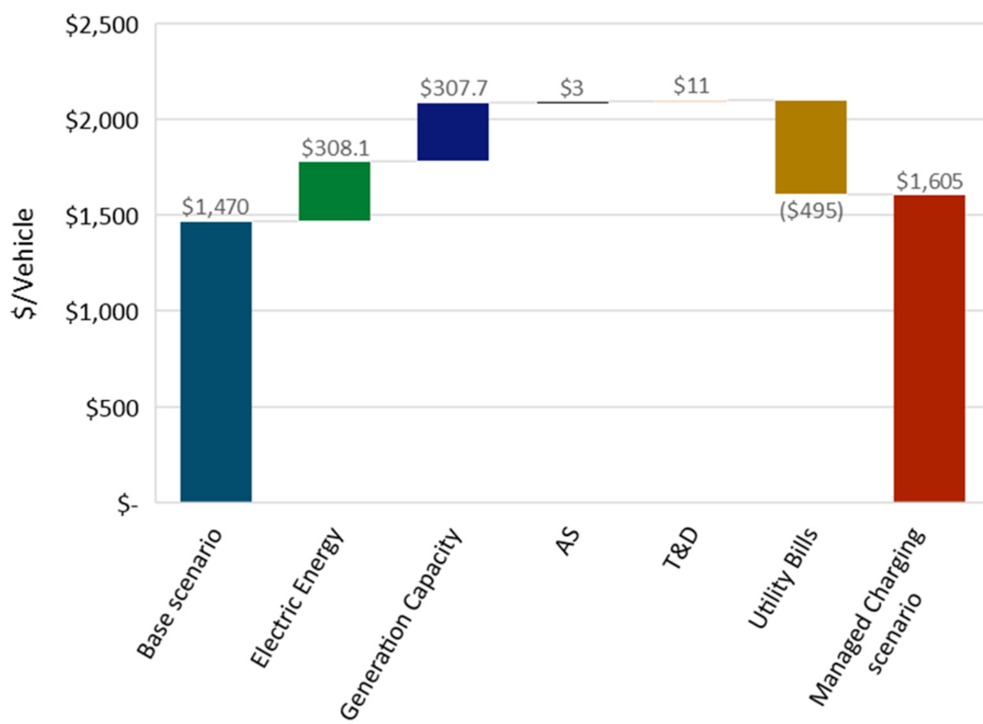
Table 16 contains results for each cost and benefit component.

Table 16. Ratepayer Perspective cost-benefit analysis results in the Managed Charging scenario

	High Adoption		Low Adoption	
	Total (MM$)	Per Vehicle ($)	Total (MM$)	Per Vehicle ($)
Costs				
Generation Capacity	9	40	8	42
Ancillary Services	3	11	2	11
T&D	0.3	1	0.3	1
Electric Energy CO_2	31	128	23	128
Electric Energy	268	1,123	208	1,137
Benefits				
Utility Bills	693	2,908	541	2,961
Ratepayer Net Benefits				
Total	383	1,604	300	1,641

Figure 21 below illustrates the influence of managed charging on the different cost and benefit components, resulting in increased Ratepayer net benefits per vehicle sold.

Figure 21. Effect of managed charging on per vehicle cost and benefit components and Ratepayer net benefits in the High PEV Adoption case



Managed charging has more impact on Regional net benefits than on Ratepayer net benefits. The Ratepayer Perspective includes the same electric supply cost reductions as the Regional Perspective, $629 per vehicle in both Low and High PEV Adoption cases, but managed charging also reduces utility bills (by $514 per vehicle in the Low PEV Adoption case and $495 per vehicle in the High PEV Adoption case). Bills are reduced by managed charging because it shifts PEV load into nighttime, off-peak hours, which have lower energy and demand charges under TOU rates. Although reduced bills counteract the benefit of managed charging to ratepayers generally, reduced bills also lower the cost of charging for PEV owners, making PEV ownership more attractive. Table 17 shows the total and percentage changes in electricity supply costs, utility bills, and Ratepayer Perspective net benefits due to managed charging.

Table 17. Difference in total electricity supply costs and Ratepayer net benefits, Managed Charging scenario minus Base scenario

Component	High Adoption		Low Adoption	
	Change (MM$)	% Change	Change (MM$)	% Change ($)
Generation Capacity Cost	-73.4	-89%	-56.1	-88%
Ancillary Services Cost	-0.7	-22%	-0.6	-21%
T&D Cost	-2.6	-89%	-2.0	-89%
Electric Energy Cost	-73.5	-22%	-56.2	-21%
Utility Bills	-118.1	-15%	-94	-15%
Ratepayer Net Benefits	32.0	9%	21.1	8%

5.4 Additional Results

E3 also quantified several outputs related to the impact of PEVs on the environment, oil dependence for transportation, electricity system planning, and the economics of PEV ownership.

Table 18 shows the aggregate changes in energy consumption and carbon dioxide emissions due to PEV adoption for the Low and High PEV Adoption cases in the Base scenario. The results of the Managed Charging scenario are omitted because they match those of the Base scenario. PEVs adopted during the study horizon in AEP Ohio's service territory reduce gasoline consumption by 830 Million gallons in the Low PEV Adoption case, and just over 1 Billion gallons in the High PEV Adoption case. By substituting electric energy for gasoline, PEVs increase electric generation by up to 15,088 GWh and reduce CO_2 emissions by up to 4.5 Million tons.

Table 18. Total incremental energy consumption and carbon emissions attributable to PEVs

	Base Scenario	
	High Adoption	Low Adoption
Incremental Electric Energy Generation (GWh)	15,088	11,621
Avoided Gasoline (Million gallons)	1,072	830
Incremental CO_2 from electric energy (Million tons)	5.2	3.9
Avoided CO_2 from Gasoline (Million tons)	9.7	7.5
Net Reduction in CO_2 Emissions (Million tons)	4.5	3.6

Table 19 translates the High PEV Adoption case results from Table 18 into average results per vehicle sold during the study horizon. The per vehicle results differ by less than 2% between the High PEV Adoption and Low PEV Adoption cases. In the Base scenario, on average a PEV sold in the AEP service territory during the study horizon results in a net reduction of CO_2 emissions of 10.7 tons over its 10-year useful life.

Table 19. Incremental energy consumption and carbon emissions per vehicle

	Base Scenario
Incremental Electric Energy Generation (MWh)	36
Avoided Gasoline (gallons)	2,560
Incremental CO_2 from electric energy (tons)	12.3
Avoided CO_2 from Gasoline (tons)	23
Net Reduction in CO_2 Emissions (tons)	10.7

Table 20 compares the cost of fueling PEVs with electric energy against the cost of fueling conventional ICE vehicles with gasoline. The cost of fueling a PEV is the retail electric utility bills that would be incurred for charging. The total and per vehicle avoided gasoline costs are not affected by the scenario and only vary with the level of PEV adoption. The slight differences between the avoided gasoline cost per vehicle in the two PEV adoption cases is due to the timing of PEV sales and changes in both ICE and PEV fuel efficiency over time. In the High PEV Adoption case, a larger share of the PEVs are sold in the later years, when conventional vehicles are more fuel efficient, than in the Low PEV Adoption case.

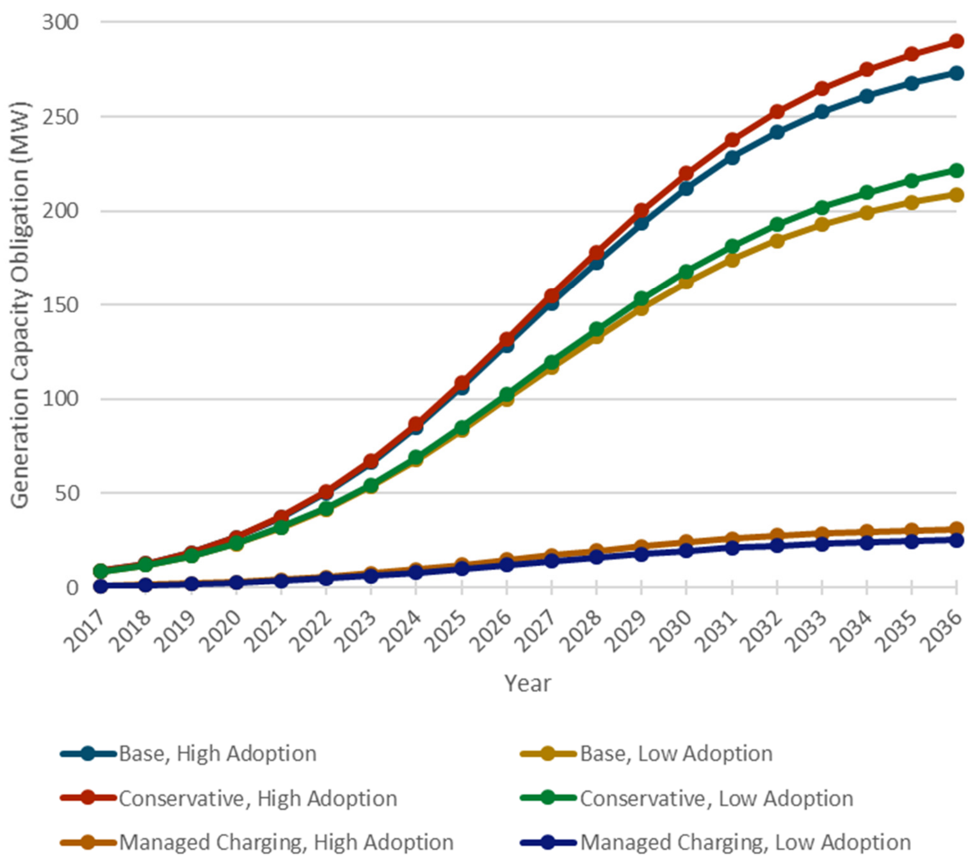
In the Managed Charging scenario, PEV charging is optimized to minimize the utility's cost to supply the electricity, generally shifting charging into the early morning hours when energy is cheapest. This also reduces utility bills versus the Base scenario. However, the utility's costs to supply electricity do not perfectly align with the TOU retail rate used for calculating PEV charging utility bills, so even lower utility bills are theoretically possible. In the cases studied, the average cost of fueling a PEV is between $3,186 and $3,733 less over its lifetime than fueling a conventional vehicle. These savings do not include the additional O&M and avoided CO_2 emissions benefits that would also accrue to PEV drivers as described in the discussion of the Regional Perspective above.

Table 20. Avoided fuel costs of PEVs

		High Adoption		Low Adoption	
Scenario	Result	Total (MM$)	Per Vehicle ($)	Total (MM$)	Per Vehicle ($)
All	Avoided Gasoline Cost	1,571	6,589	1,222	6,694
Base	Utility Bills	811	3,403	634	3,475
	Net Fuel Savings	760	3,186	588	3,219
Managed Charging	Utility Bills	693	2,908	541	2,961
	Net Fuel Savings	878	3,681	681	3,733

Figure 22 shows the impact of PEV adoption on the load serving entity's obligation to procure generation capacity. This obligation is calculated using the PCAF methodology explained in section 3.9.4 , and represents a weighted average of the PEV charging load based on its coincidence with the total PJM AEP generation hub load. Without managed charging, it will be necessary to procure between 200MW and 300MW of additional generation capacity to support new PEV load through 2036. However, with managed charging, only 31 MW of additional generation capacity is needed to support new PEV charging load in the High PEV Adoption case.

Figure 22. Incremental generation capacity procurement obligation attributable to PEVs



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