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Electric Vehicle Cost-Benefit Analysis

Plug-in Electric Vehicle Cost-Benefit Analysis: South Carolina

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About M.J. Bradley & Associates

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

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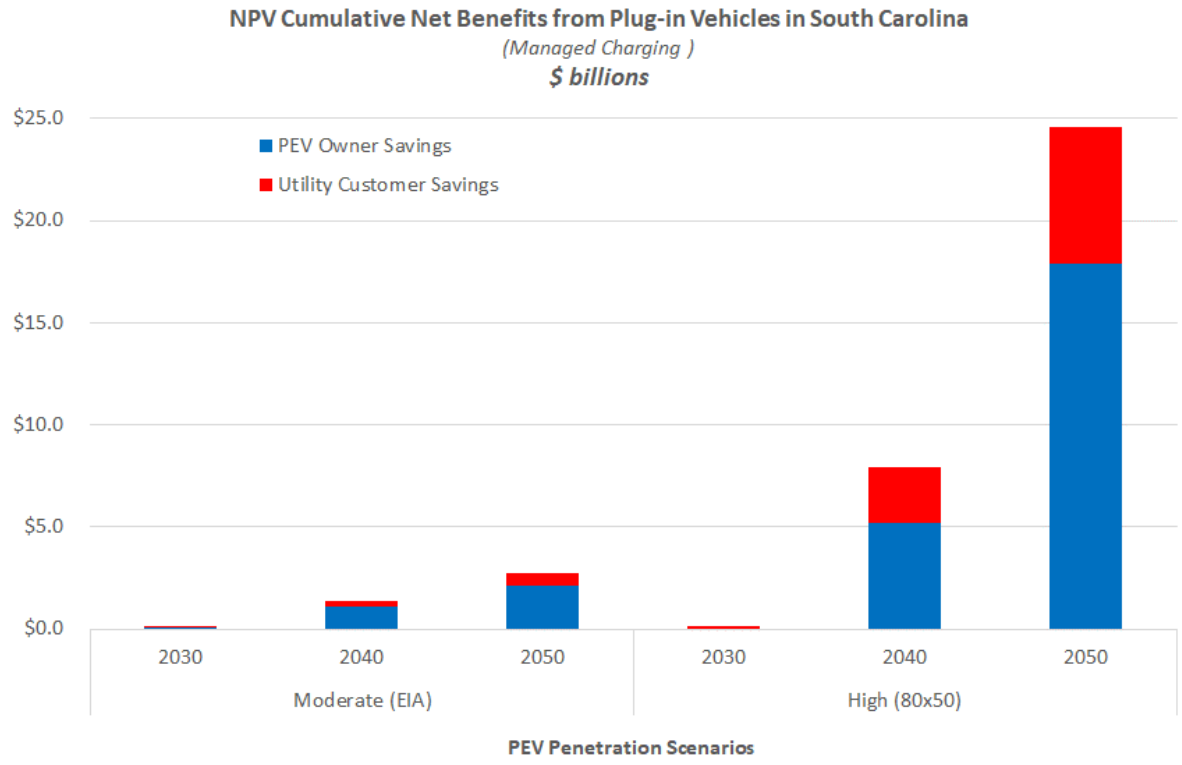
Executive Summary

This study estimated the costs and benefits of increased adoption of plug-in electric vehicles (PEVs) in the state of South Carolina. The study estimated the financial benefits that would accrue to all electric utility customers in South Carolina due to greater utilization of the electric grid during low load hours, and resulting increased utility revenues from PEV charging. In addition, the study estimated the annual financial benefits to South Carolina drivers from owning PEVs—from fuel and maintenance cost savings compared to owning gasoline vehicles. The study also estimated reductions in gasoline consumption, and associated greenhouse gas (GHG) and nitrogen oxide (NOx) emission reductions from greater use of PEVs instead of gasoline vehicles.

Figure 1 *NPV Cumulative Societal Net Benefits from SC PEVs*



This study evaluated PEV costs and benefits for two distinct levels of PEV adoption – essentially a "business as usual" scenario of modest PEV penetration (EIA), and a much more aggressive scenario based on the PEV penetration that would be required to get the state onto a trajectory to reduce light-duty GHG emissions by 70 – 80 percent from current levels by 2050 (80x50). The levels of PEV penetration in the high 80x50 scenario are unlikely to be achieved without aggressive policy action at the state and local level, to incentivize individuals to purchase PEVs, and to support the necessary roll-out of PEV charging infrastructure.

As shown in Figure 1, if South Carolina PEV adoption follows the moderate trajectory currently assumed by the Energy Information Administration (EIA), the net present value of **cumulative net benefits from greater PEV use in the state will exceed $2.7 billion state-wide by 2050**.[1] Of these total net benefits:

[1] Using a 3% discount rate

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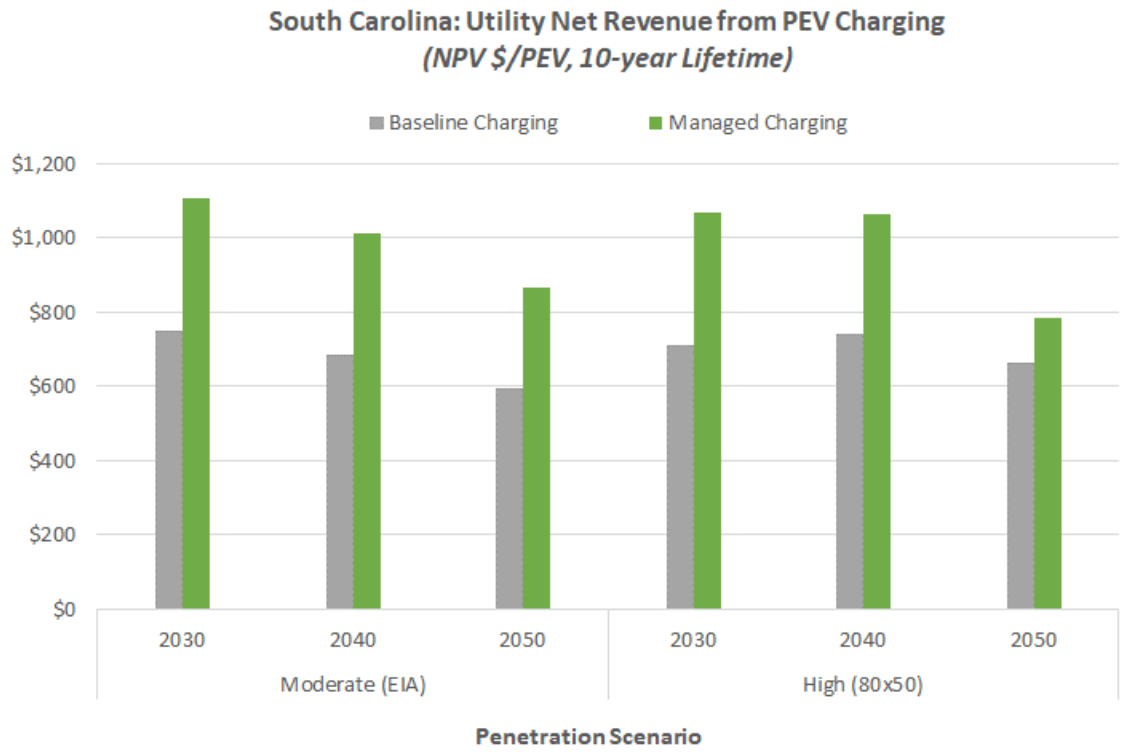
- $0.6 billion will accrue to electric utility customers in the form of reduced electric bills, and
- $2.1 billion will accrue directly to South Carolina drivers in the form of reduced annual vehicle operating costs.

Also shown in Figure 1, if PEV sales in South Carolina were high enough to get the state onto a trajectory to reduce light-duty GHG emissions by 70 – 80 percent from current levels by 2050 (80x50), the net present value of **cumulative net benefits from greater PEV use in South Carolina could exceed $24 billion state-wide by 2050**. Of these total net benefits:

- $6.7 billion would accrue to electric utility customers in the form of reduced electric bills, and
- $17.9 billion would accrue directly to South Carolina drivers in the form of reduced annual vehicle operating costs.

Utility customer savings result from net revenue received by the state's utilities, from selling electricity to charge PEVs. This net revenue is net of additional costs that would be incurred by utilities to secure additional generating capacity, and to upgrade distribution systems, to handle the incremental load from PEV charging. The NPV of projected life-time utility net revenue per PEV is shown in Figure 2. Assuming a ten-year life, the average PEV in South Carolina in 2030 is projected to increase utility net revenue by about $1,100 over its life-time, if charging is managed. PEVs in service in 2050 are projected to increase utility net revenue on average by about $820 over their life time (NPV) if charging is managed.

Figure 2 NPV of Projected Life-time Utility Net Revenue per PEV



In addition, by 2050 PEV owners are projected to save more than $750 per vehicle (nominal $) in annual operating costs, compared to owning gasoline vehicles. A large portion of this direct financial benefit to South Carolina 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 (EIA) scenario,

PEVs will reduce cumulative gasoline use in the state by more than 1.3 billion gallons through 2050 – this cumulative gasoline savings grows to 15.4 billion gallons through 2050 under the high PEV (80x50) scenario. In 2050, annual average gasoline savings will be approximately 194 gallons per PEV under the Moderate PEV (EIA) scenario, while projected savings under the High PEV (80x50) scenario are nearly 240 gallons per PEV.

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

In addition, this reduction in gasoline use will reduce cumulative net GHG emissions by over 12 million metric tons[2] through 2050 under the moderate PEV scenario, and over 145 million metric tons under the high PEV scenario. The switch from gasoline vehicles to PEVs is also projected to reduce annual NOx emissions in the state by over 276 tons in 2050 under the moderate PEV (EIA) scenario, and by over 4,265 tons under the high PEV (80x50) scenario.

[2] Net of emissions from electricity generation

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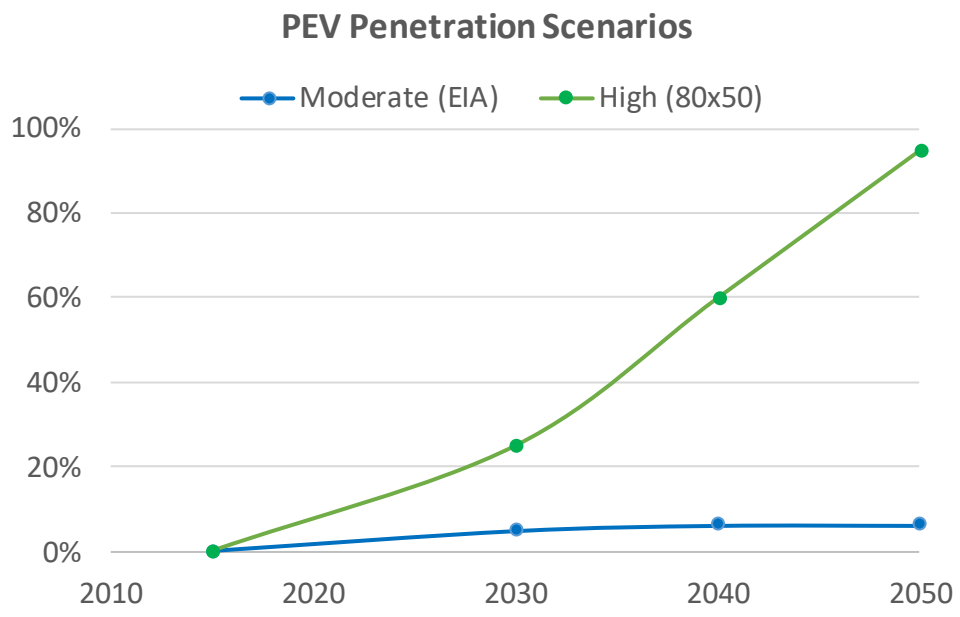
Study Results

This section summarizes the results of this study, including: the projected number of PEVs; electricity use and load from PEV charging; projected gasoline savings and GHG reductions compared to continued use of gasoline vehicles; financial benefits to utility customers from increased electricity sales; and projected financial benefits to South Carolina drivers compared to owning gasoline vehicles. All costs and financial benefits are presented as net present value (NPV), using a 3 percent discount rate.

Two different PEV penetration levels between 2030 and 2050 are utilized to estimate costs and benefits.[3] The "Moderate PEV" scenario is based on current projections of annual PEV sales from the Energy Information Administration (EIA). The "High PEV" scenario is based on the level of PEV penetration that would be required to get onto a trajectory to reduce light-duty GHG emissions in the state by 70 - 80 percent from current levels by 2050. The moderate PEV (EIA) scenario is essentially a "business as usual" scenario that continues current trends. However, the significantly higher levels of PEV penetration in the high 80x50 scenario are unlikely to be achieved without additional aggressive policy action at the state and local level, to incentivize individuals to purchase PEVs, and to support the necessary roll-out of PEV charging infrastructure. See Figure 3 for a comparison of the two scenarios through 2050.

Figure 3 Comparison of PEV Penetration Scenarios



[3] PEVs include battery-electric vehicles (BEV) and plug-in hybrid vehicles (PHEV). This study focused on passenger vehicles and trucks; there are opportunities for electrification of non-road equipment and heavy-duty trucks and buses, but evaluation of these applications was beyond the scope of this study.

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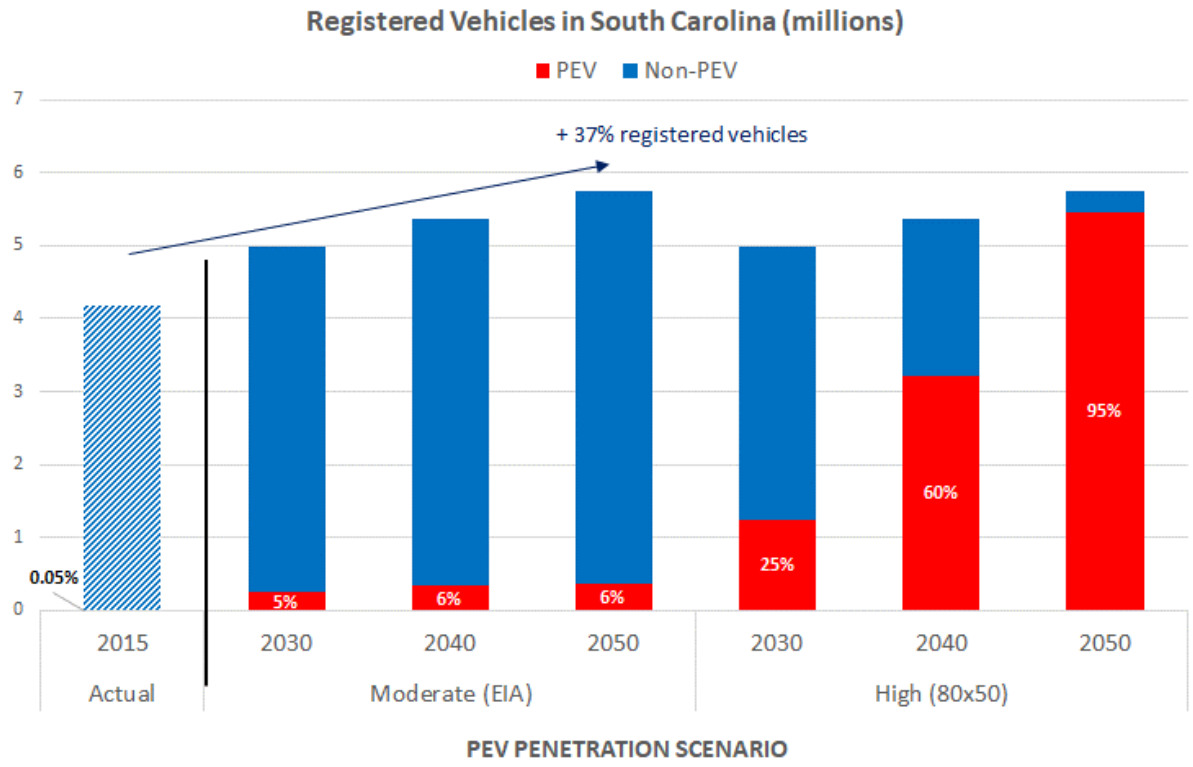
Plug-in Electric Vehicles, Electricity Use, and Charging Load

Vehicles and Miles Traveled

The projected number of PEVs and conventional gasoline vehicles in the South Carolina light duty fleet[4] under each PEV penetration scenario is shown in Figure 4, and the projected annual miles driven by these vehicles is shown in Figure 5. Under the Moderate PEV (EIA) scenario, the number of PEVs registered in South Carolina would increase from approximately 2,100 today to 244,400 in 2030, 332,500 in 2040, and 356,600 in 2050. Under the High PEV (80x50) scenario there would be 1.2 million PEVs in South Carolina by 2030, rising to 3.2 million in 2040, and 5.5 million in 2050.[5]

Figure 4 Projected South Carolina Light Duty Fleet

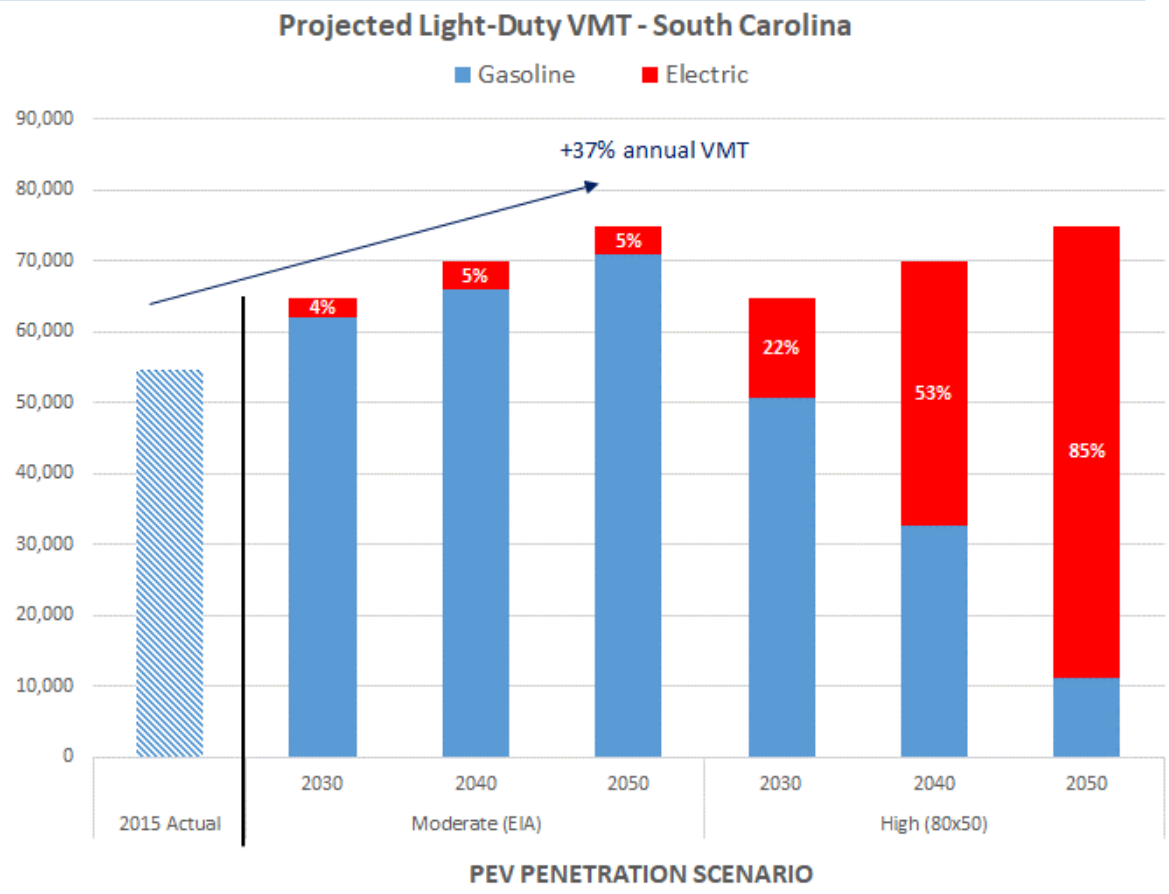


[4] This analysis only includes cars and light trucks. It does not include medium- or heavy-duty trucks and buses.

[5] Note that under both PEV penetration scenarios the percentage of total VMT driven by PEVs on electricity each year is lower than the percentage of PEVs in the fleet. This is because PHEVs are assumed to have a "utility factor" less than one – i.e., due to range restrictions a PHEV cannot convert 100 percent of the miles driven annually by a baseline gasoline vehicle into miles powered by grid electricity. In this analysis PHEVs are assumed to have an average utility factor of 85 percent.

This analysis estimates that under the High PEV (80x50) scenario South Carolina will reduce light-duty fleet gasoline consumption in 2050 by 73 percent compared to a baseline with no PEVs, due to 85 percent of fleet miles being driven by PEVs on electricity (Figure 5). However, to achieve this level of electric miles, 95 percent of light-duty vehicles will be PEVs, including PHEVs (Figure 4).

Figure 5 Projected South Carolina Light Duty Fleet Vehicle Miles Traveled (million miles)



PEV Charging Electricity Use

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

In Figure 6, projected baseline electricity use without PEVs is shown in blue and the estimated incremental electricity use for PEV charging is shown in red. State-wide electricity use in South Carolina is currently 79 million MWh per year. Annual electricity use is projected to increase to 85 million MWh in 2030 and continue to grow after that, reaching 100 million MWh in 2050 (27 percent greater than 2015 levels).

Under the Moderate PEV penetration scenario, electricity used for PEV charging is projected to be 0.9 million MWh in 2030 – an increase of about 1 percent over baseline electricity use. By 2050, electricity for PEV charging is projected to grow to 1.1 million MWh – an increase of 1.1 percent over baseline electricity use. Under the High PEV (80x50) scenario electricity used for PEV charging is projected to be 4.3 million MWh in 2030, growing to 19.1 million MWh and adding 19 percent to baseline electricity use in 2050.

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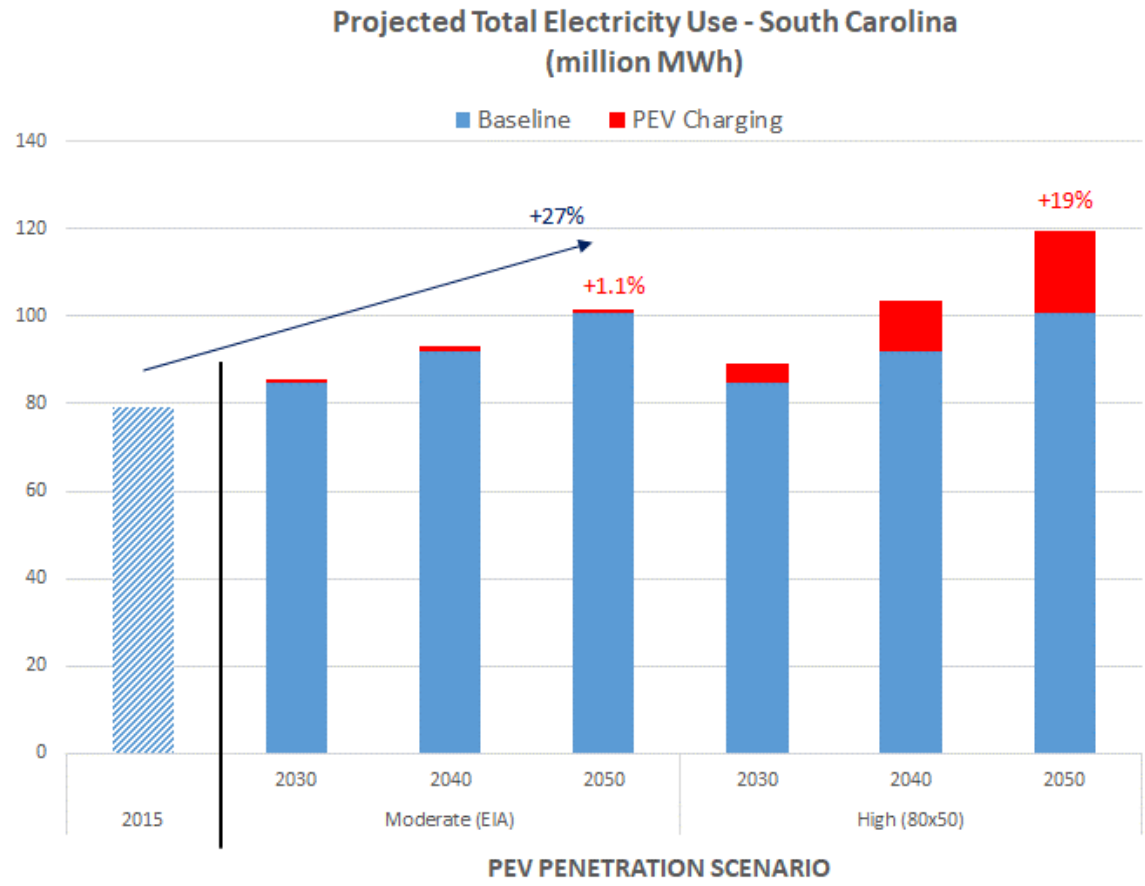
Figure 6 Estimated Total Electricity Use in South Carolina



PEV Charging Load

This analysis evaluated the effect of PEV charging on the South Carolina electric grid under two different charging scenarios. Under both scenarios 77 percent of all PEVs are assumed to charge exclusively at home and 23 percent are assumed to charge at locations other than at home (i.e. at work or at other "public" chargers). Under the baseline charging scenario all South Carolina drivers who charge at home are assumed to plug-in their vehicles and start charging as soon as they arrive at home each day, while under the managed charging scenario a significant portion of PEV owners are assumed to participate in a utility managed charging program to minimize PEV charging load in the late afternoon and early evening when other electricity demand is high.[6]

[6] Utilities have many policy options to incentivize managed PEV charging. This analysis does not compare the efficacy of different options. For this analysis, managed charging is modeled as 85% of PEV owners that arrive home between noon and 11 pm delaying the start of charging until between Midnight and 2 am. This is only one of many managed charging program options that are available to utilities.

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Figure 7 2040 Projected South Caroline PEV Charging Load, Baseline Charging (High PEV [80x50] scenario)

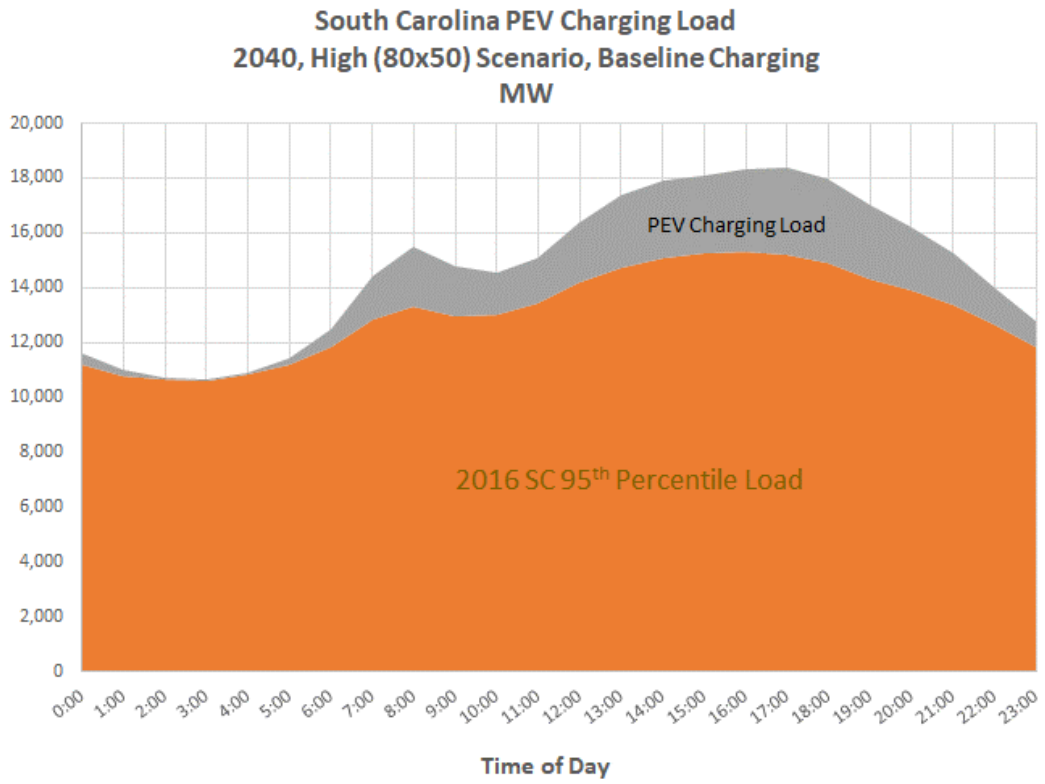
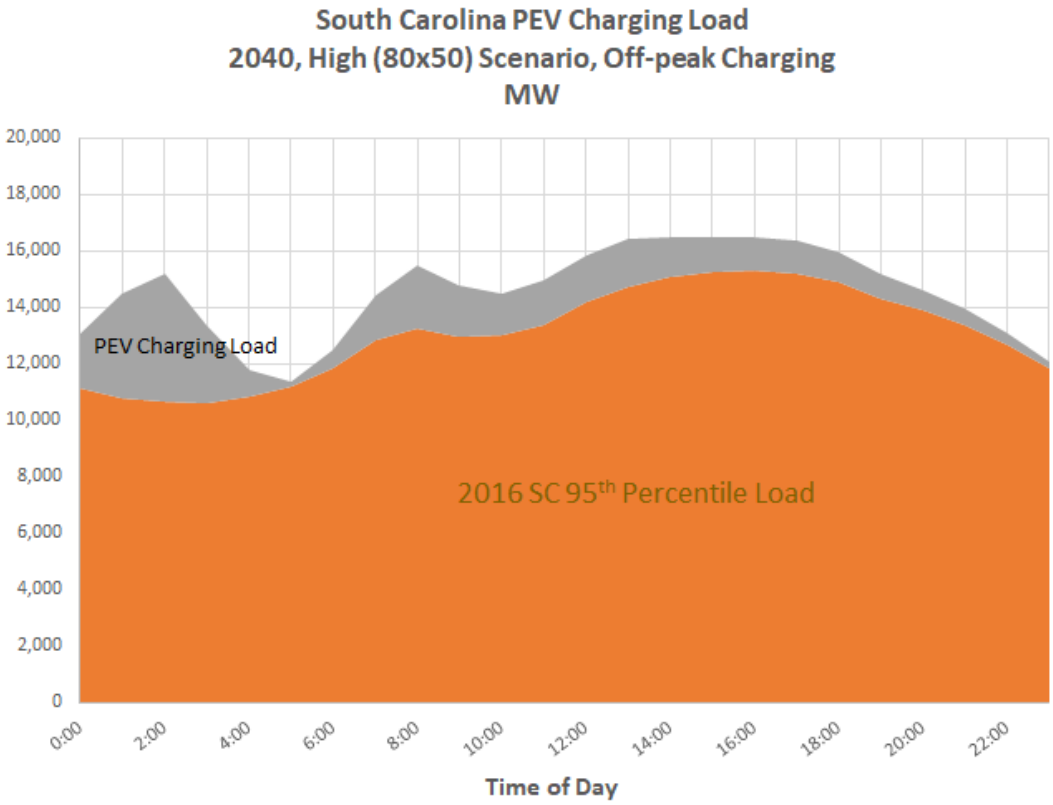


Figure 8 2040 Projected South Caroline PEV Charging Load, Managed Charging (High PEV [80x50] scenario)



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See Figure 7 (baseline) and Figure 8 (managed) for a comparison of PEV charging load under the baseline and managed charging scenarios, using the 2040 High (80x50) PEV penetration scenario as an example. In each of these figures the 2016 South Carolina 95th percentile load (MW)[7] by time of day is plotted in orange, and the projected incremental load due to PEV charging is plotted in grey.

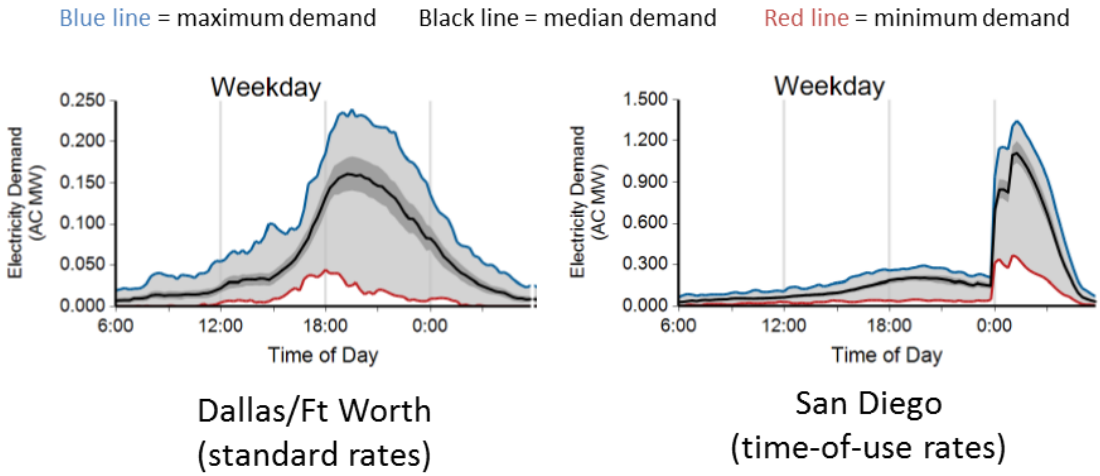
In 2016, daily electric load in South Carolina was generally less than 11,000 MW from midnight to 5 AM, ramping up to about 13,000 MW at 8 or 9 AM (during winter months), falling slightly through late morning and early afternoon, then ramping up again to peak at approximately 15,000 MW between 2 PM and 5 PM (during summer months), and then falling off through the evening hours.[8]

As shown in Figure 7, baseline PEV charging is projected to add load primarily between 8 AM and 8 PM, as some people charge at work early in the day, but most charge at home in the late afternoon and early evening. Under the baseline charging scenario, the PEV charging peak coincides with the existing summer afternoon peak load period between 2 PM and 5 PM.

As shown in Figure 8, managed charging significantly reduces the incremental PEV charging load during the summer afternoon peak load period, but creates a secondary peak in the early morning hours, between midnight and 3 AM. The shape of this early morning peak can potentially be controlled based on the design of managed charging incentives.

These baseline and managed 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 managed 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. [2]

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 South Carolina, from PEV charging under each penetration and charging scenario. This table also includes a calculation of how much

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

[8] In Figures 7 and 8, 95th Percentile Load is shown for the entire state of South Carolina across the entire year. The late morning peak shown is more prominent during the winter months, while the late afternoon peak is more prominent in the summer months. Within the Duke Energy service territory, the actual annual peak occurs in the winter months, during the late morning.

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this incremental PEV charging load would add to the 2016 95th percentile peak hour load. Under the Moderate PEV (EIA) penetration scenario, PEV charging would add 242 MW of load during the afternoon peak load period on a typical weekday in 2030, which would increase the 2016 baseline peak load by about 1.6 percent. By 2050, the afternoon incremental PEV charging load would increase to 319 MW, adding 2.1 percent to the 2016 baseline afternoon peak. By comparison the afternoon peak hour PEV charging load in 2030 would be only 57 MW for the managed charging scenario, increasing to 79 MW in 2050.

Under the High PEV (80x50) penetration scenario, baseline PEV charging would increase the total 2016 afternoon peak electric load by about 35percent in 2050, while managed charging would only increase it by about 24 percent.[9]

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, managed PEV charging can provide additional net benefits to all utility customers, by reducing the cost of providing electricity used to charge PEVs.

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

		Moderate PEV (EIA)			High PEV (80x50)		
		2030	**2040**	**2050**	**2030**	**2040**	**2050**
Baseline Charging	PEV Charging (MW)	242	329	319	1,231	3183	5,401
	Increase relative to 2016 Peak	1.6%	2.1%	2.1%	8.0%	20.8%	35.3%
Managed Charging	PEV Charging (MW)	57	77	79	289	748	3,755
	Increase relative to 2016 Peak	0.4%	0.5%	0.5%	1.9%	4.9%	24.5%

Utility Customer Benefits

The estimated NPV of annual revenues and costs in 2030, 2040, and 2050, for South Carolina's electric utilities to supply electricity to charge PEVs under each penetration scenario are shown in Figure 10, assuming the baseline PEV charging scenario.

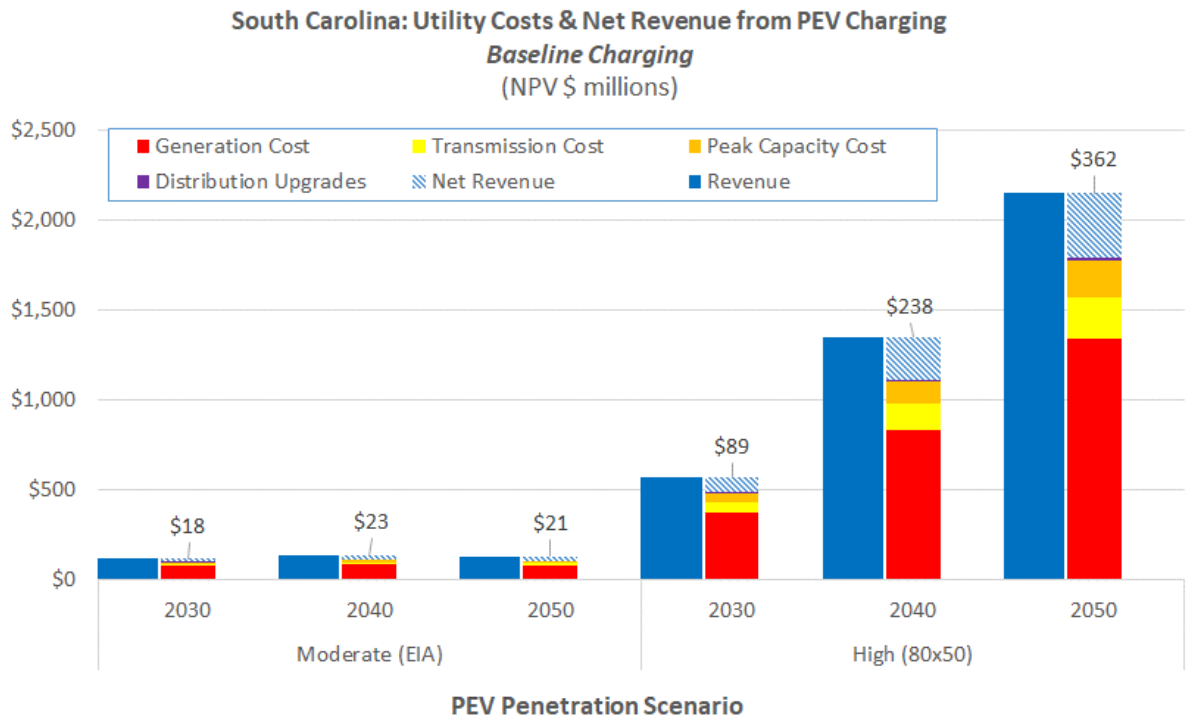
Under the Moderate PEV penetration scenario, the NPV of annual revenue from electricity sold for PEV charging in South Carolina is projected to total $113 million in 2030, rising to $123 million in 2050. Under the High PEV (80x50) scenario, the NPV of annual utility revenue from PEV charging is projected to total $558 million in 2030, rising to $2 billion in 2050.

In Figure 10, projected annual utility revenue is shown in dark blue. The different elements of incremental annual cost that utilities would incur to purchase and deliver additional electricity to support PEV charging are shown in red (generation), yellow (transmission), orange (peak capacity), and purple (infrastructure upgrade cost). Generation and transmission costs are proportional to the total power (MWh) used for PEV charging, while peak

[9] Given projected significant increases in total state-wide electricity use through 2050, baseline peak load (without PEVs) is also likely to be higher in 2050 than 2016 peak load; as such the percentage increase in baseline peak load due to high levels of PEV penetration is likely to be lower than that shown in Table 1. The incremental costs of adding this peak capacity are accounted for in the analysis. As discussed below, even when accounting for these costs there are still net rate-payer benefits from high levels of PEV penetration. As the analysis shows, the net rate-payer benefits are higher with managed charging, because the cost of serving the incremental peak load is lower.

capacity costs are proportional to the incremental peak load (MW) imposed by PEV charging. Infrastructure upgrade costs are costs incurred by the utility to upgrade their distribution infrastructure to handle the increased peak load imposed by PEV charging.

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



The striped light blue bars in Figure 10 represent the NPV of projected annual "net revenue" (revenue minus costs) that utilities would realize from selling additional electricity for PEV charging under each PEV penetration scenario in these years. Under the Moderate PEV penetration scenario, the NPV of net annual revenue in South Carolina is projected to total $18 million in 2030 and $21 million in 2050. Under the High PEV (80x50) scenario, the NPV of utility net annual revenue from PEV charging is projected to total $89 million in 2030, rising to $362 million in 2050. The NPV of projected annual utility net revenue averages $73 per PEV in 2030, and $59 - $66 per PEV in 2050.

Figure 11 summarizes the NPV of projected annual utility revenue, costs, and net revenue for managed charging under each PEV penetration scenario. Compared to baseline charging (Figure 10) projected annual revenue, and projected annual generation and transmission costs are the same, but projected annual peak capacity and infrastructure costs are lower due to a smaller incremental peak load (see Table 1).

Compared to baseline charging, managed charging will increase the NPV of annual utility net revenue by $8.7 million in 2030 and $9.7 million in 2050 under the Moderate PEV penetration scenario, due to lower costs. Under the High PEV (80x50) scenario, managed charging will increase the NPV of annual utility net revenue by $44.5 million in 2030 and $66 million in 2050. This analysis estimates that compared to baseline charging, managed charging will increase the NPV of annual utility net revenue by $35 per PEV in 2030 and $12 - $27 per PEV in 2050.

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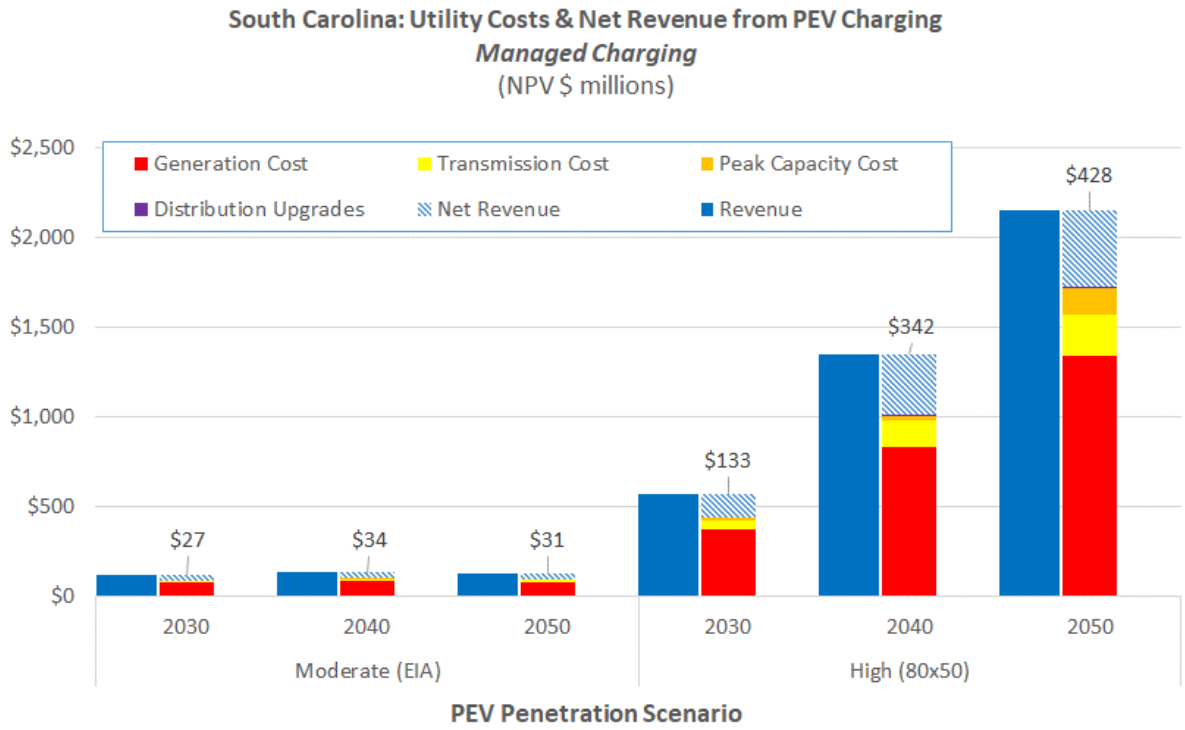
Figure 11 NPV of Projected Annual Utility Revenue and Costs from Managed PEV Charging



In general, a utility's costs to maintain their distribution infrastructure increase each year with inflation, and these costs are passed on to utility customers in accordance with rules established by the South Carolina Public Utility Commission (PUC), via periodic increases in residential and commercial electric rates. However, under the PUC rules net revenue from additional electricity sales generally offset the allowable costs that can be passed on via higher rates. As such, the majority of projected utility net revenue from increased electricity sales for PEV charging would in fact be passed on to utility customers in South Carolina, not retained by the utility companies.

Under current rate structures this net revenue would in effect put downward pressure on future rates, delaying or reducing future rate increases, thereby reducing electric bills for all customers. See Figure 12 for a summary of how the projected utility net revenue from PEV charging could affect average annual residential electricity bills for all South Carolina electric utility customers.[10] As shown in the figure, under the High PEV (80x50) scenario, if current rate structures do not change projected average electric rates in South Carolina could be reduced up to 3.3 percent in 2050 due to net revenue from PEV charging, resulting in an annual savings of approximately $137 (nominal dollars) per household in South Carolina.

It must be noted that how this utility net revenue from PEV charging gets distributed is dependent on rate structure. Potential changes to current rates - to specifically incentivize off-peak PEV charging - could shift some or all of this benefit to PEV owners, thus reducing their electricity costs for vehicle charging without reducing costs for non-PEV owners. In either case, rate payers who do not own a PEV will not be harmed by transportation electrification, and may benefit indirectly even if they continue to own gasoline vehicles.

[10] Based on 2016 average electricity use of 13,630 kWh per housing unit in South Carolina

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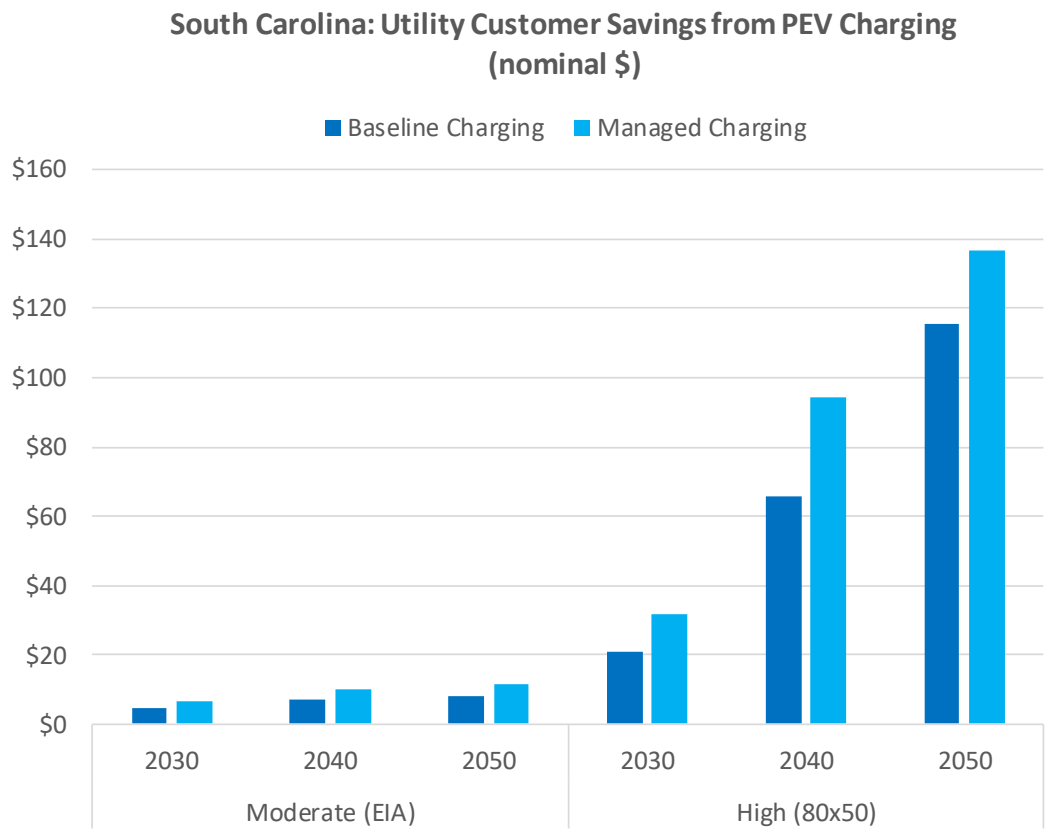
Figure 12 Potential Effect of PEV Charging Net Revenue on Utility Customer Bills (nominal $)



South Carolina 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 as described below PEVs are projected to provide a lower total cost of ownership than conventional vehicles in South Carolina by about 2035, even without government purchase subsidies.

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 $300/kWh in the last six years; many analysts and auto companies project that battery prices will continue to fall – to below $110/kWh by 2025, and below $75/kWh by 2030. [3]

Based on these battery cost projections, this analysis projects that the average annual cost of owning a PEV in South Carolina will fall below the average cost of owning a gasoline vehicle by 2035, even without government purchase subsidies.[11] See Table 2 which summarizes the average projected annual cost of South Carolina PEVs and gasoline vehicles under each penetration scenario.

[11] 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.

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All costs in Table 2 are in nominal dollars, which is the primary reason why costs for both gasoline vehicles and PEVs are higher in 2040 and 2050 than in 2030 (due to inflation). In addition, the penetration scenarios assume that the relative number of PEV cars and higher cost PEV light trucks will change over time; in particular the High PEV (80x50) 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.

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

GASOLINE VEHICLE		Moderate (EIA)			High (80x50)		
		2030	2040	2050	2030	2040	2050
Vehicle Purchase	$/yr	$5,317	$5,922	$7,249	$4,505	$6,196	$8,400
Gasoline	$/yr	$1,369	$1,552	$1,860	$1,336	$1,666	$2,173
Maintenance	$/yr	$298	$361	$446	$295	$370	$468
TOTAL ANNUAL COST	**$/yr**	**$6,984**	**$7,835**	**$9,555**	**$6,136**	**$8,231**	**$11,041**

PEV -SC		Moderate (EIA)			High (80x50)		
Baseline Charging/Standard Rate		2030	2040	2050	2030	2040	2050
Vehicle Purchase	$/yr	$5,317	$5,922	$7,249	$5,101	$6,337	$8,607
Electricity	$/yr	$739	$839	$995	$716	$878	$1,107
Gasoline	$/yr	$91	$108	$128	$89	$116	$147
Personal Charger	$/yr	$81	$99	$122	$81	$99	$122
Maintenance	$/yr	$182	$221	$273	$181	$224	$281
TOTAL ANNUAL COST	**$/yr**	**$6,410**	**$7,189**	**$8,767**	**$6,169**	**$7,654**	**$10,264**
Savings per PEV	**$/yr**	**$574**	**$646**	**$787**	**-$33**	**$578**	**$777**

As shown in Table 2, under the High PEV Scenario (80x50) 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. For the Moderate PEV Scenario in 2030, the average South Carolina PEV owner is projected to have annual operating savings of $574 due to reduced maintenance as well as electricity costs being lower than gasoline[12]. For both scenarios, this annual savings is projected to increase to $777 - $787 per PEV per year by 2050, as projected gasoline prices continue to increase faster than projected electricity prices.

The NPV of total annual cost savings to South Carolina drivers from greater PEV ownership are projected to be $90 million in 2030 rising to $100 million in 2050 under the moderate PEV penetration scenario. Under the High PEV (80x50) scenario, the NPV of total annual cost savings to South Carolina drivers from greater PEV ownership are projected to be $888 million in 2040, rising to $1.5 billion in 2050.

[12] Under the moderate PEV (EIA) scenario, this analysis assumes that PEV owners will pay the same net purchase price for gasoline vehicles and PEVs, despite the higher projected purchase price of comparable PEVs. There is evidence that current PEV purchasers are foregoing the purchase of more expensive vehicles to purchase higher-priced PEVs within their target budget. With only modest future PEV penetration this analysis assumes that this behavior will continue. However, for the High PEV scenario net PEV owner benefits reflect the fact that PEV purchasers will pay a higher price for their PEVs than they would have paid for a similar gasoline vehicle.

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Other Benefits

Energy Security and Emissions Reductions

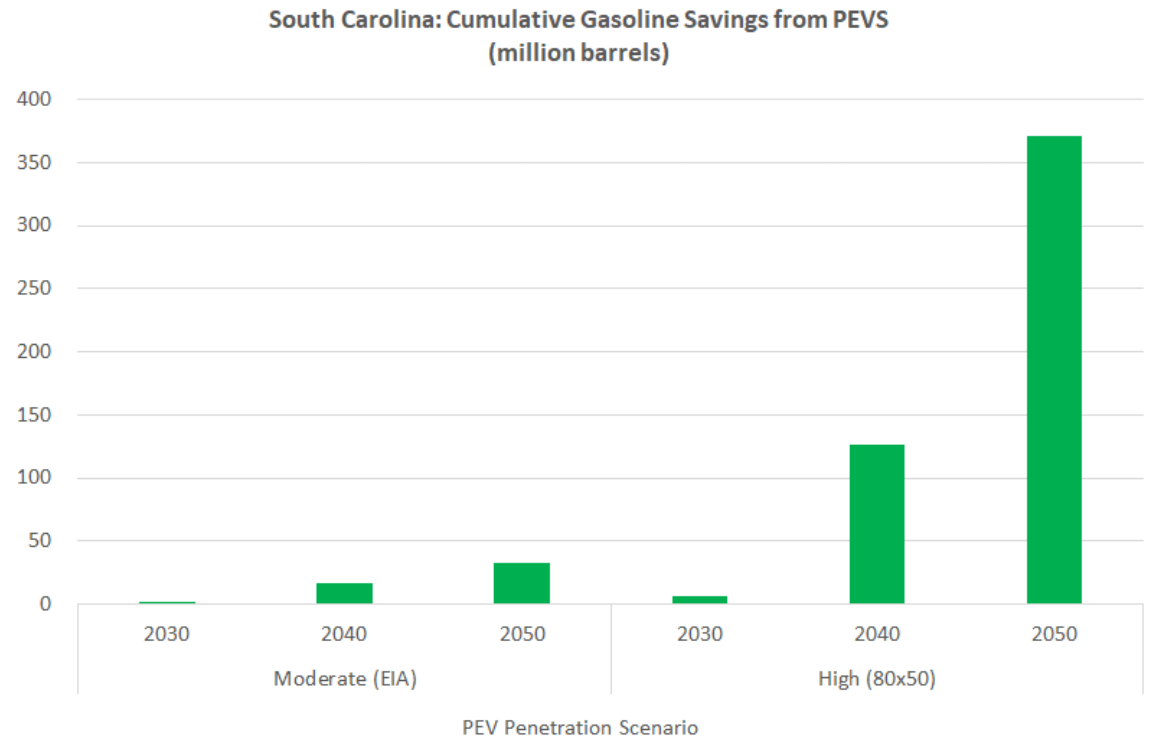
Along with the financial benefits to electric utility customers and PEV owners described above, light-duty vehicle electrification can provide additional benefits, including significant reductions in gasoline fuel use and transportation sector emissions.

The estimated cumulative fuel savings (barrels of gasoline[13]) from PEV use in South Carolina under each penetration scenario are shown in Figure 13. Annual fuel savings under the Moderate PEV penetration scenario are projected to total 1.4 million barrels in 2030, with cumulative savings of more than 32 million barrels by 2050. For the High PEV (80x50) scenario, annual fuel savings in 2030 are projected to be 6.6 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 $0.29 - $0.57 million in secondary economic benefits will be generated within the local economy, depending on PEV adoption scenario. These studies also estimated that between 13 and 25 additional in-state jobs will be generated for every 1,000 PEVs in the fleet. [1]

Figure 13 Cumulative Gasoline Savings from PEVs in South Carolina



[13] One barrel of gasoline equals 42 US gallons

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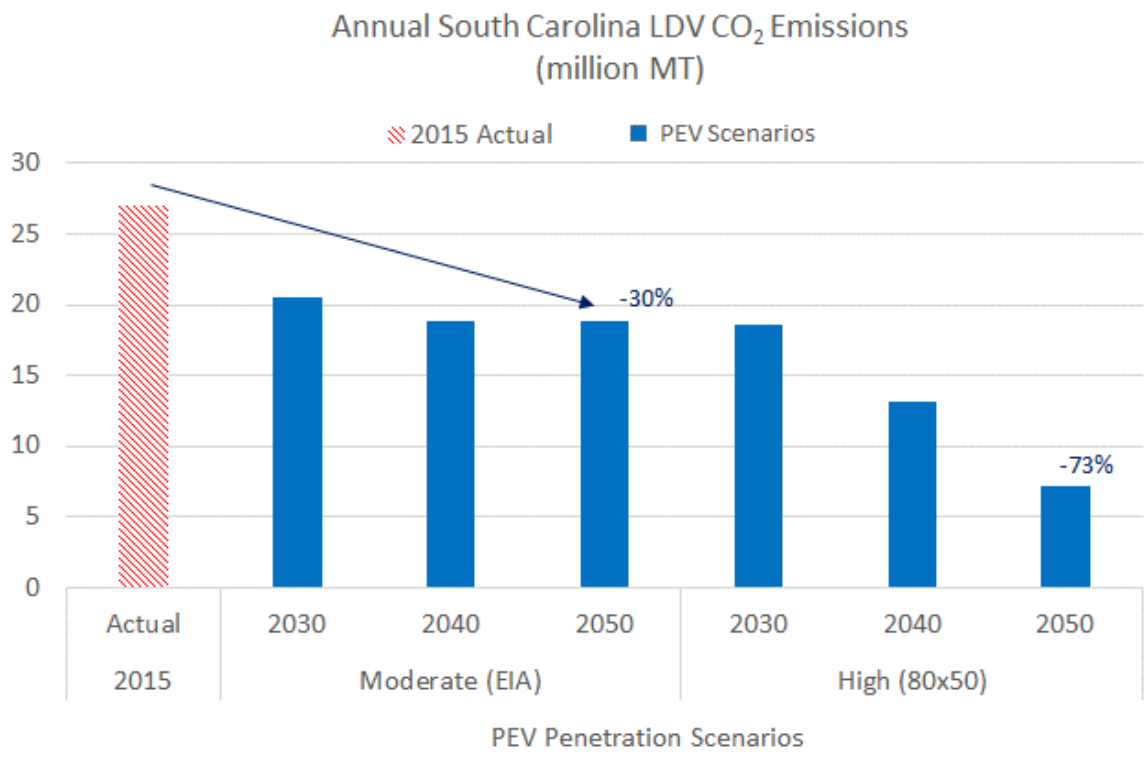
The projected annual greenhouse gas (GHG) emissions (million metric tons carbon-dioxide equivalent, CO_2-e million tons) from the South Carolina light duty fleet under each PEV penetration scenario are shown in Figure 14. In this figure, projected emissions under the PEV scenarios are shown in blue. The values shown represent "wells-to-wheels" emissions, including direct tailpipe emissions and "upstream" emissions from production and transport of gasoline. Estimated emission for the PEV scenarios includes GHG emissions from generating electricity to charge PEVs, as well as GHG emissions from gasoline vehicles in the fleet. Estimated emissions from PEV charging are based on EIA projections of average carbon intensity for the SERC Reliability Corporation /Virginia-Carolina electricity market module region, which includes South Carolina.

Figure 14 Projected GHG Emissions from the Light Duty Fleet in South Carolina



As shown in Figure 14, GHG emissions from the light duty fleet in South Carolina were approximately 27 million metric tons in 2015.

Compared to 2015 baseline emissions, in 2050 GHG emissions are projected to be reduced by up to 8.1 million tons under the Moderate PEV penetration scenario and as much as 20 million tons under the High PEV (80x50) scenario. Through 2050, cumulative net GHG emissions are projected to be reduced by nearly 161 million tons under the Moderate PEV penetration scenario and 294 million metric tons under the High PEV (80x50) scenario.

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NOx Emissions

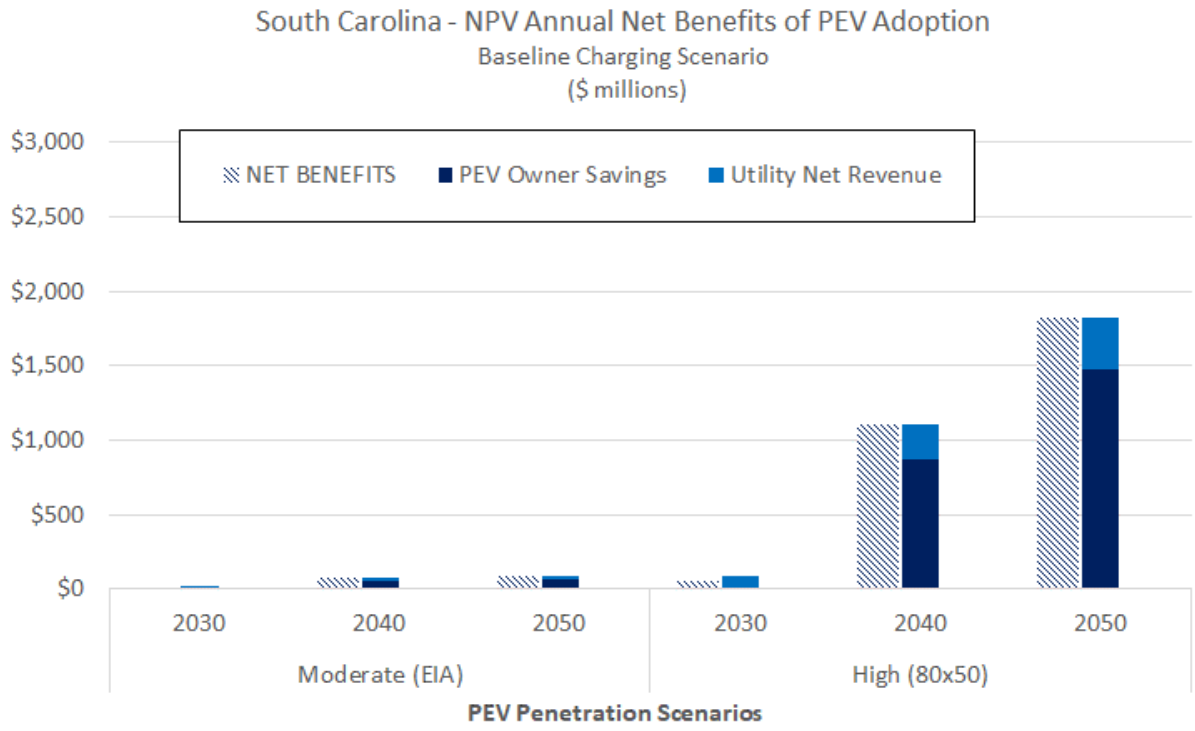
In 2015 the Electric Power Research Institute (EPRI), in conjunction with the Natural Resources Defense Council (NRDC), conducted national-level modeling to estimate GHG and air quality benefits from high levels of transportation electrification [4]. Under their electrification scenario EPRI estimated that NOx would be reduced by 11.4 tons and VOCs would be reduced by 5.5 tons, for every billion vehicle miles traveled[14].

Extrapolating from this data, under the Moderate PEV Scenario (EIA), by 2050 light-duty vehicle electrification in South Carolina could reduce annual NOx emissions by 276 tons and reduce annual VOC emissions by 133 tons. Under the High PEV Scenario (80x50), total NOx reductions in 2050 could reach more than 4,200 tons per year, and total VOC reductions could reach almost 2,100 tons per year.[15]

Total Societal Benefits

The NPV of total annual estimated benefits from increased PEV use in South Carolina under each PEV penetration scenario are summarized in Figures 15 and 16. These benefits include cost savings to South Carolina drivers and utility customer savings from reduced electric bills. Figure 15 shows the NPV of annual projected societal benefits if South Carolina drivers charge in accordance with the baseline charging scenario. Figure 16 shows the NPV of projected annual benefits with managed charging.

Figure 15 Projected NPV of Total Societal Benefits from Greater PEV use in SC – Baseline Charging



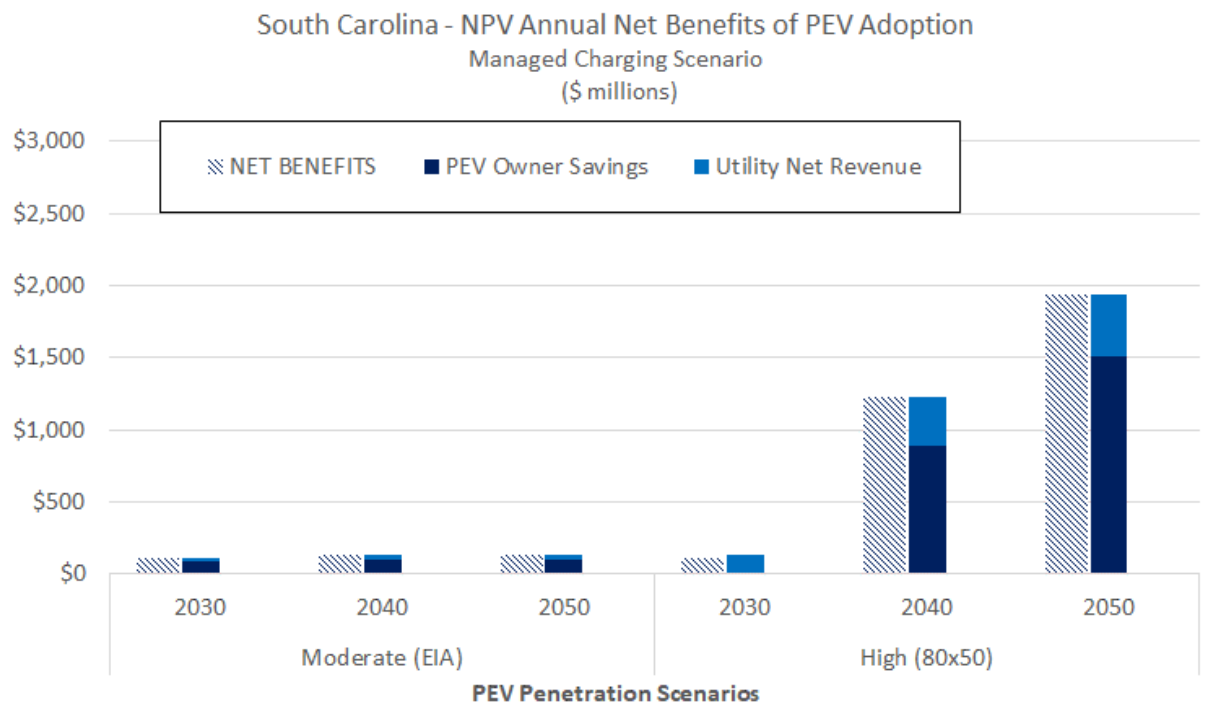
[14] For light-duty vehicles the analysis assumed that by 2030 approximately 17 percent of annual vehicle miles would be powered by grid electricity, using PEVs. Based on current and projected electric sector trends the analysis also assumed that approximately 46 percent of the incremental power required for transportation electrification in 2030 would be produced using solar and wind, with the remainder produced by combined cycle natural gas plants.

[15] Across the entire state, estimated annual light-duty vehicle miles traveled (VMT) totals 0.74 trillion miles in 2050. Of these miles approximately, 6 percent are powered by grid electricity under the EIA penetration scenario, and 87 percent are powered by grid electricity under the 80x50 penetration scenario

As shown in Figure 15, the NPV of annual benefits is projected to be a minimum of $82 million per year in 2050 under the Moderate PEV penetration scenario and $1.8 billion per year in 2050 under the High PEV (80x50) scenario. Approximately 80 percent of these annual benefits will accrue to South Carolina drivers as a cash savings in vehicle operating costs and 19 percent will accrue to electric utility customers as a reduction in annual electricity bills.

As shown in Figure 16, the NPV of annual benefits in 2050 will increase by $9.7 million under the Moderate PEV (EIA) penetration scenario, and $66.1 million under the High PEV (80x50) scenario with managed charging. Of these increased benefits, all will accrue to electric utility customers as an additional reduction in their electricity bills.

Figure 16 Projected NPV of Total Societal Benefits from Greater PEV use in SC – Managed



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Study Methodology

This section briefly describes the methodology used for this study. For more information on how this study was conducted, including a complete 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).[16] 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 distinct levels of PEV penetration in South Carolina between 2030 and 2050, based on the range of publicly available PEV adoption estimates from various analysts.

Moderate PEV Scenario –EIA: Based on EIA's current projections for new PEV sales between 2015 and 2050, as contained in the 2017 Annual Energy Outlook (AEO). Under this scenario approximately 4.9 percent of in-use light duty vehicles in South Carolina will be PEV in 2030, rising to 6.2 percent in 2040 and remaining steady through 2050.

High PEV Scenario – 80x50: PEV penetration levels each year that would put the state on a trajectory to reduce total annual light-duty fleet GHG emissions by 70 – 80 percent from current levels in 2050. Under this scenario 25 percent of in-use vehicles will be PEV in 2030, rising to 60 percent in 2040 and 95 percent in 2050.

Both of these scenarios are compared to a baseline scenario with very little PEV penetration, and continued use of gasoline vehicles. The baseline scenario is based on future annual vehicle miles traveled (VMT) and fleet characteristics (e.g., cars versus light trucks) as projected by the Energy Information Administration in their most recent Annual Energy Outlook (AEO 2017).

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 South Carolina's electric distribution utilities would realize from sale of this electricity, their costs of providing the electricity to their customers, and the potential net revenue (revenue in excess of costs) that could be used to support maintenance of the distribution system.

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 secondary distribution system to handle the additional load.

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 charging scenario in which a significant portion of PEVs that arrive home between noon and 11 PM each day delay the start of charging until after midnight.

Real world experience from the EV Project demonstrates that, without a "nudge", drivers will generally plug in and start charging immediately upon arriving home after work (scenario 1), exacerbating system-wide evening peak demand.[17] However, if given a "nudge" - in the form of a properly designed and marketed financial

[16] This analysis used the same methodology as described in the referenced report, but used different PEV penetration scenarios, as described here. In addition, for this analysis fuel costs and other assumptions taken from the Energy Information Administration (EIA) were updated from EIA's Annual Energy Outlook 2016 to those in the Annual Energy Outlook 2017. Finally, for projections of future PEV costs this analysis used updated July 2017 battery cost projections from Bloomberg New Energy Finance.

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

incentive - many South Carolina drivers will choose to delay the start of charging until later times, thus reducing the effect of PEV charging on evening peak electricity demand (scenario 2). [5]

For each PEV penetration scenario, this analysis also calculates the total incremental annual cost of purchase and operation for all PEVs in the state, compared to "baseline" purchase and operation of gasoline cars and light trucks. For both PEVs and baseline vehicles annual costs include the amortized cost of purchasing the vehicle, annual costs for gasoline and electricity, and annual maintenance costs. For the Moderate PEV Scenario, it was assumed that PEV vehicle costs are the same as baseline gasoline vehicles, with the reasoning that consumers have a set budget and will purchase what they can afford, regardless of technology type. For the High PEV Scenario, the same logic could not be applied, as it is assumed that nearly all vehicle purchases will be PEV. For PEVs it also includes the amortized annual cost of the necessary home charger. This analysis is used to estimate average annual financial benefits to South Carolina drivers.

Finally, for each PEV penetration scenario this analysis calculates annual greenhouse gas (GHG) emissions 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.

For each PEV penetration scenario GHG emissions from PEV charging are calculated based on an electricity scenario that is consistent with the latest Energy Information Administration (EIA) projections for future SERC Reliability Corporation / Virginia -Carolina.

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.

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This study was conducted by M.J. Bradley & Associates for Duke Energy. It is one of six state-level analyses that will be conducted of plug-in electric vehicle costs and benefits in the different U.S. states in which Duke operates. These studies are intended to provide input to state policy discussions about actions required to promote further adoption of electric vehicles, as well as to inform internal Duke planning efforts.