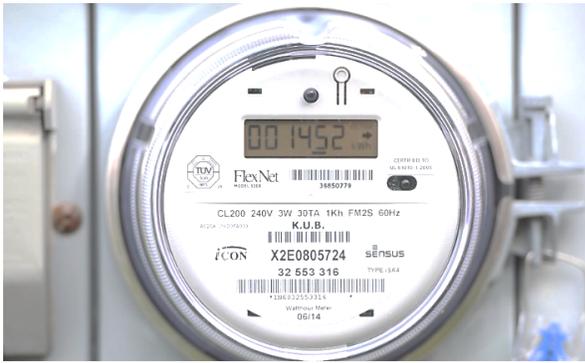


Electric Vehicle Cost-Benefit Analysis

Plug-in Electric Vehicle Cost-Benefit Analysis: Michigan



Contents

- Executive Summary ii
- Background - Michigan1
- Study Results2
 - Plug-in Vehicles, Electricity Use, and Charging Load2
 - Vehicles and Miles Traveled*2
 - PEV Charging Electricity Use*..... 3
 - PEV Charging Load* 4
 - Utility Customer Benefits7
 - Michigan Driver Benefits10
 - Other Benefits12
 - Total Societal Benefits15
- Study Methodology17
- References19
- Acknowledgements21

List of Figures

Figure 1 Comparison of PEV Penetration Scenarios.....	ii
Figure 2 NPV Cumulative Societal Net Benefits from MI PEVs – Moderate PEV (MISO) scenario.....	iv
Figure 3 NPV Cumulative Societal Net Benefits from MI PEVs – High PEV (Bloomberg) scenario.....	iv
Figure 4 Projected Michigan Light Duty Fleet.....	2
Figure 5 Projected Michigan Light Duty Fleet Vehicle Miles Traveled.....	3
Figure 6 Estimated Total Electricity Use in Michigan.....	4
Figure 7 2040 Projected Michigan PEV Charging Load, Baseline Charging (High PEV (Bloomberg) scenario).....	5
Figure 8 2040 Projected Michigan PEV Charging Load, Off-peak Charging (High PEV (Bloomberg) scenario).....	5
Figure 9 PEV Charging Load in Dallas/Ft Worth and San Diego areas, EV Project.....	6
Figure 10 NPV of Projected Utility Net Revenue from Baseline PEV Charging.....	7
Figure 11 NPV of Projected Utility Revenue and Costs from Off-peak PEV Charging.....	8
Figure 12 NPV of Projected Life-time Utility New Revenue per PEV.....	9
Figure 13 Potential Effect of PEV Charging Net Revenue on Utility Customer Bills (nominal \$).....	10
Figure 14 Cumulative Gasoline Savings from PEVs in Michigan.....	12
Figure 15 Projected GHG Emissions from the Light Duty Fleet in Michigan.....	13
Figure 16 NPV of Projected Social Value of PEV GHG Reductions.....	13
Figure 17 Projected NPV of Total Societal Benefits from Greater PEV use in MI – Baseline Charging.....	15
Figure 18 Projected NPV of Total Societal Benefits from Greater PEV use in MI – Off-peak Charging.....	15

List of Tables

Table 1 Projected Incremental Afternoon Peak Hour PEV Charging Load (MW).....	7
Table 2 Projected Fleet Average Vehicle Costs to Vehicle Owners (nominal \$).....	11

About M.J. Bradley & Associates

M.J. Bradley & Associates, LLC (MJB&A), founded in 1994, is a strategic consulting firm focused on energy and environmental issues. The firm includes a multi-disciplinary team of experts with backgrounds in economics, law, engineering, and policy. The company works with private companies, public agencies, and non-profit organizations to understand and evaluate environmental regulations and policy, facilitate multi-stakeholder initiatives, shape business strategies, and deploy clean energy technologies.

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

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

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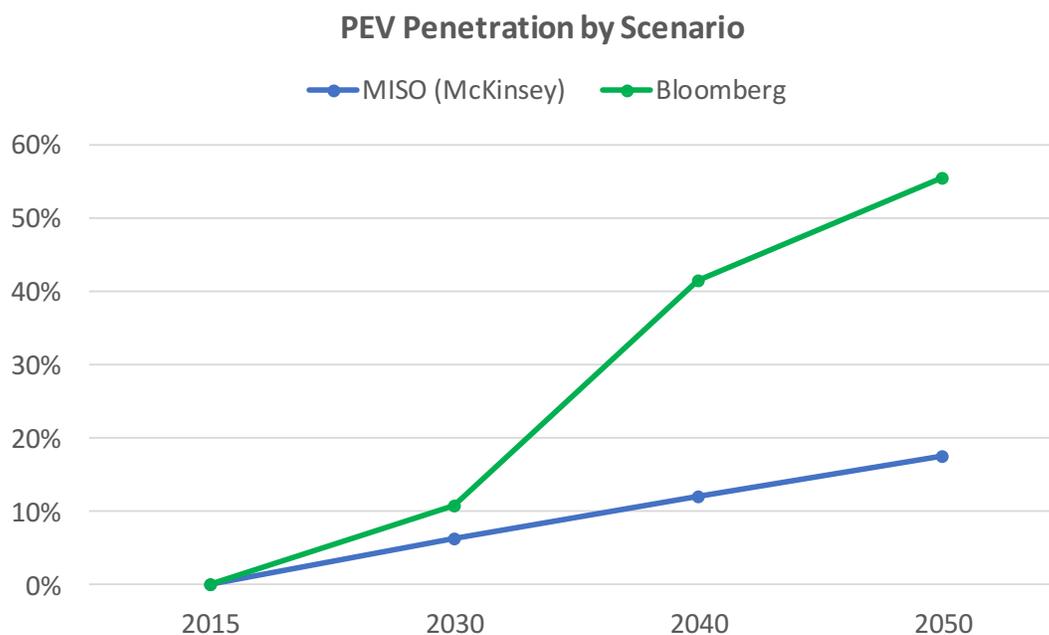
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Executive Summary

This study estimated the costs and benefits of increased penetration of plug-in electric vehicles (PEV) in the state of Michigan. The study estimated the benefits that would accrue to all electric utility customers in Michigan due to greater utilization of the electric grid during off-peak hours, and increased utility revenues from PEV charging. In addition, the study estimated the annual financial benefits to Michigan drivers from owning PEVs— from fuel and maintenance cost savings compared to owning gasoline vehicles - and societal benefits resulting from reduced gasoline consumption and associated greenhouse gas (GHG) emissions.

Two different penetration levels between 2030 and 2050 are utilized to estimate costs and benefits.¹ The “Moderate PEV” scenario is based on levels of PEV penetration included in an on-going future planning analysis being conducted by the Midcontinent Independent System Operator (MISO), which is the regional transmission organization that covers Michigan. The “High PEV” scenario is based on Bloomberg New Energy Finance’s (Bloomberg) July 2017 forecast of U.S. PEV sales through 2040. See Figure 1 for a comparison of the two scenarios through 2050.

Figure 1 Comparison of PEV Penetration Scenarios



Under the Moderate PEV (MISO) scenario, the number of PEVs registered in Michigan would increase from approximately 14,000 today to 591,828 in 2030, 1.13 million in 2040, and 1.7 million in 2050. This equates to approximately 6 percent of in-use light duty vehicles in Michigan in 2030, 12 percent in 2040, and 17.6 percent in 2050. Under the High PEV (Bloomberg) scenario there would be 999,450 PEVs in Michigan by 2030, rising to 3.9 million in 2040, and 5.4 million in 2050. This equates to 10.8 percent of in-use light duty vehicles in Michigan in 2030, rising to 41.5 percent in 2040 and 55.7 percent in 2050.

¹ 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.

As shown in Figure 2, if Michigan PEV adoption follows the trajectory assumed by MISO, the net present value of **cumulative net benefits from greater PEV use in Michigan will exceed \$8.6 billion state-wide by 2050.**² Of these total net benefits:

- \$0.8 billion will accrue to electric utility customers in the form of reduced electric bills,
- \$6.3 billion will accrue directly to Michigan drivers in the form of reduced annual vehicle operating costs, and
- \$1.5 billion will accrue to society at large, as the monetized value of reduced GHG emissions.

As shown in Figure 3, if Bloomberg's projections for national EV sales are achieved in Michigan, which would result in even greater PEV penetration, the net present value of **cumulative net benefits from greater PEV use in Michigan could exceed \$31 billion state-wide by 2050.** Of these total net benefits:

- \$2.6 billion will accrue to electric utility customers in the form of reduced electric bills,
- \$23.1 billion will accrue directly to Michigan drivers in the form of reduced annual vehicle operating costs, and
- \$5.7 billion will accrue to society at large, as the monetized value of reduced GHG emissions.

A large portion of the direct financial benefits to Michigan drivers derives from reduced gasoline use - from purchase of lower cost, locally produced electricity instead of gasoline imported to the state. Under the Moderate PEV (MISO) scenario, PEVs will reduce cumulative gasoline use in the state by more than 5 billion gallons through 2050, helping to promote energy security and independence, and keeping more of vehicle owners' money in the local economy, thus generating even greater economic impact. In addition, this reduction in gasoline use will reduce cumulative net GHG emissions by 26 million metric tons³, which would provide an additional societal benefit of \$1.5 billion, from reduced pressure on climate warming.

With PEV penetration equivalent to the High PEV (Bloomberg) scenario, electrifying vehicles will reduce cumulative gasoline use in the state by more than 18 billion gallons through 2050, and will reduce cumulative net GHG emissions by more than 99 million metric tons, which would provide an additional societal benefit of \$5.7 billion.

In 2050, annual average gasoline savings will be approximately 209 gallons per PEV under the Moderate PEV (MISO) scenario, while savings under the High PEV (Bloomberg) scenario are nearly 250 gallons per PEV.

Compared to baseline emissions in 2050, PEVs are projected to reduce annual GHG emissions by up to 1.9 million tons under the Moderate PEV penetration scenario and as much as 7.7 million tons under the High PEV (Bloomberg) scenario.

² Using a 3% discount rate

³ Net of emissions from electricity generation

Figure 2 NPV Cumulative Societal Net Benefits from MI PEVs – Moderate PEV (MISO) scenario

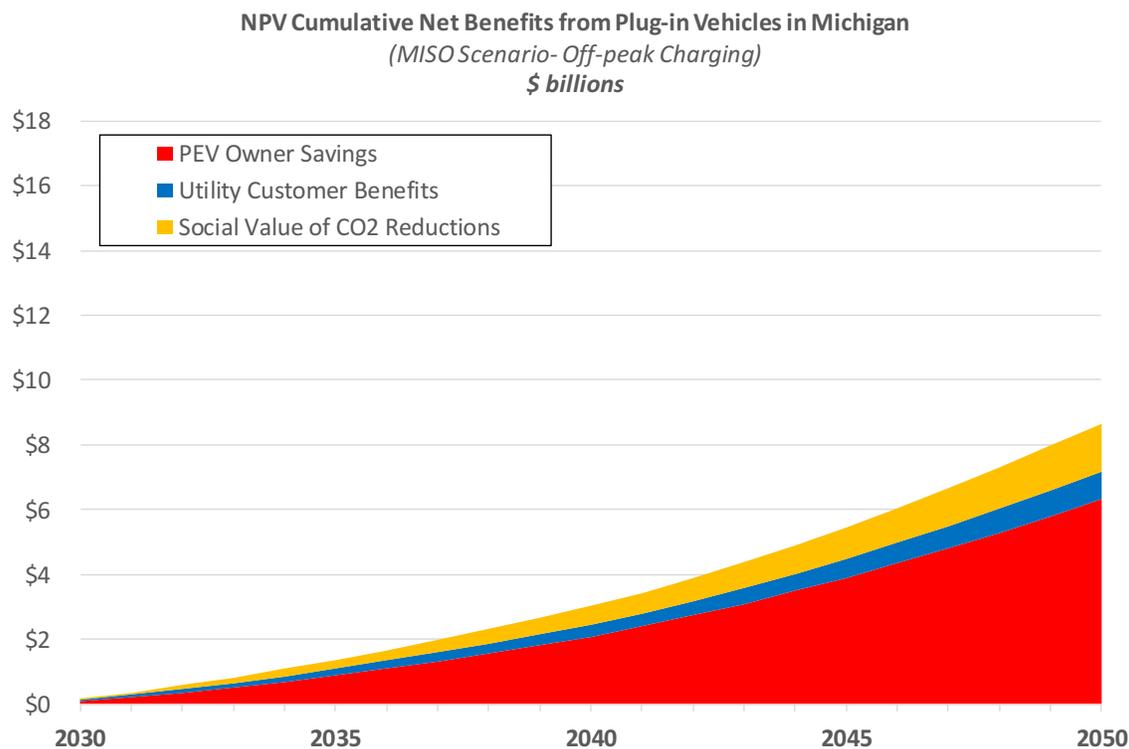
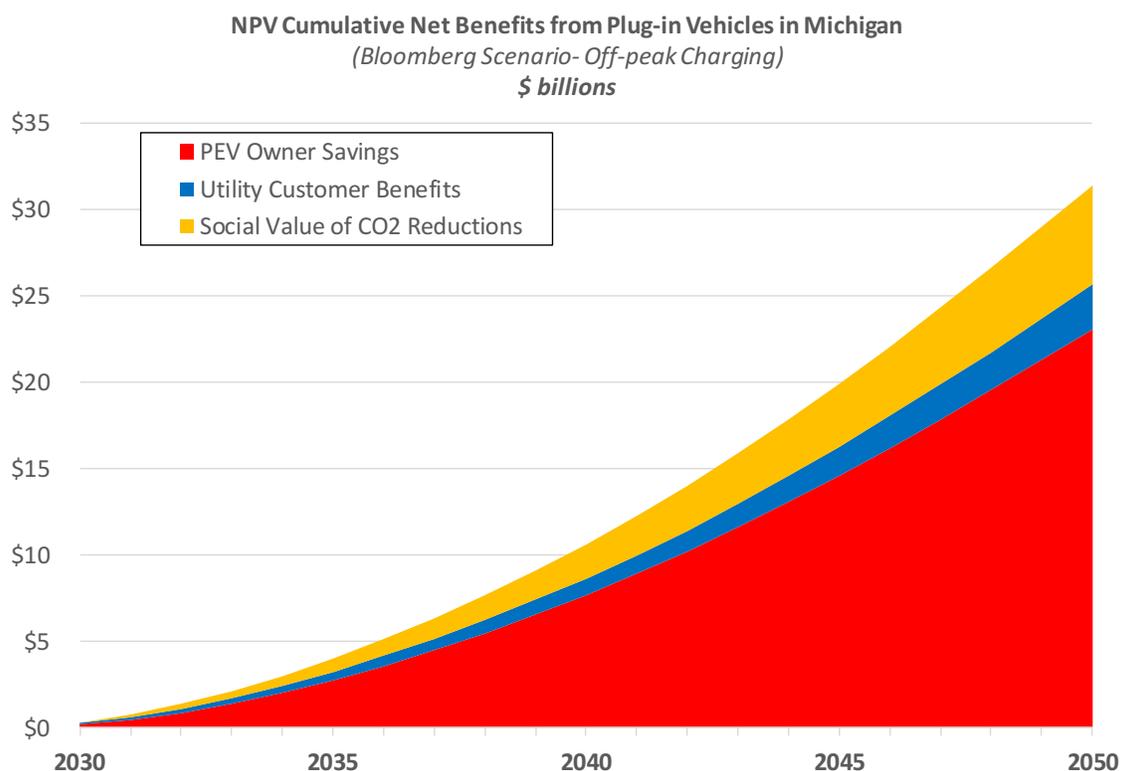


Figure 3 NPV Cumulative Societal Net Benefits from MI PEVs – High PEV (Bloomberg) scenario



Background - Michigan

For over 100 years, the auto industry has played a major role in Michigan's economy. Many of the major automakers, including Ford, General Motors and Chrysler began in Michigan. The auto industry employs thousands of workers in the state and have made commitments to develop and offer PEVs.

There are currently 3.4 million cars and 4.9 million light trucks registered in Michigan, and these vehicles travel 97.8 billion miles per year. Both the number of vehicles and total annual vehicle miles are projected to increase by 16 percent through 2050, to 9.6 million light duty vehicles traveling 113.4 billion miles annually. As of January 2016, there were about 14,000 PEVs (including battery-electric and plug-in hybrid vehicles) registered in Michigan and they comprised about 0.14 percent of the 8.3 million cars and light trucks registered in the State. In 2014 and 2015, sales of new PEVs in the state were less than one half of one percent of new vehicle sales. [1] Despite this relatively low percentage, Michigan ranks in the top ten states for PEV sales.

A wide range of policy makers and other stakeholders in Michigan have already demonstrated interest in accelerating PEV adoption in the state. Various policies, programs, and commitments adopted at the state, local, and company level have laid some of the groundwork necessary to support widespread transportation electrification.

The Michigan Public Service Commission has been considering the role of public utilities in promoting clean transportation since 2008, when it began a two-year, \$5 million study to assess the environmental and electric system impacts of electric vehicles, with a goal of expanding the state's EV economy. The commission will continue these efforts in August 2017, with a technical conference that will focus on the role of regulated utilities and the MPSC in facilitating deployment of EVSE infrastructure. [5] The conference will also study how the expansion of alternative fuel and electric vehicles will impact the infrastructure of Michigan's utilities, and consequentially, ratepayers. [6]

In addition, a number of Michigan utilities have already initiated their own PEV programs. Indiana Michigan Power and the Lansing Board of Water and Light both currently offer rebates to customers who purchase a qualified PEV and install a charging station at home [2], and both DTE and Consumers Energy previously offered residential charging infrastructure rebates as part of a pilot program. Consumers Energy Company recently withdrew a similar, proposed plan that included the installation of *public* electric vehicle supply equipment (EVSE) infrastructure. [3] These utilities all offer a variety of electric rate plans for EV owners who own a home charging station. [4]

Michigan's state government has also made recent commitments to reduce energy waste and increase the use of renewable power in the state. After significant debate and uncertainty, in December 2016 the state's energy policies were updated. Among the adopted provisions were requirements for Integrated Resource Planning by regulated utilities, an extension of the energy waste reduction (EWR) standard with incentives for exceeding the targets, and an extension of the state's renewable portfolio standard (RPS). The RPS now requires 12.5 percent of annual electricity to be generated with renewables in 2019 and 15 percent in 2021. [7]

In addition, Michigan's largest utility, DTE Energy, announced in May 2017 that it would reduce its carbon emissions by 80 percent from 2005 levels by 2050. [8] Several cities—including Detroit, Ann Arbor, and Grand Rapids – have committed to a variety of emission reduction and renewable energy goals. [9] As part of its sustainability commitments, Detroit has committed to a 10 percent plug-in electric vehicle carve out for all service vehicles purchased in 2017. The city has also set an annual goal to replace 10 percent of light-duty vehicles taken out of service with plug-in electric vehicles and use Low Speed Electric Vehicles for transit police and safety and security staff. [10] At least fourteen municipalities in the state have pledged to uphold and adopt the goals of the Paris Agreement as a response to the federal government's recent decision to withdraw from the accord. [11]

In short, policymakers, utilities, NGOs, and others have expressed interest in developing initiatives that accelerate PEV adoption and decarbonize energy use in the state.

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 Michigan drivers compared to owning gasoline vehicles. All costs and financial benefits are presented as net present value (NPV), using a 3 percent discount rate.

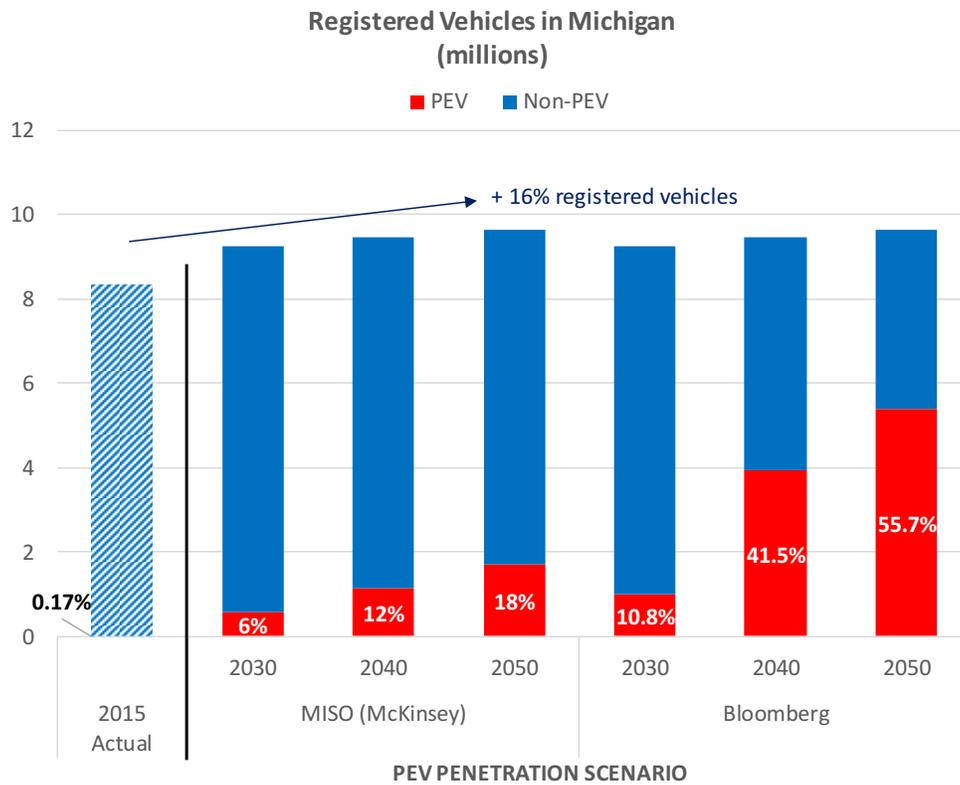
Plug-in Vehicles, Electricity Use, and Charging Load

Vehicles and Miles Traveled

The projected number of PEVs and conventional gasoline vehicles in the Michigan light duty fleet⁴ 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 (MISO) scenario, the number of PEVs registered in Michigan would increase from approximately 14,000 today to 591,828 in 2030, 1.13 million in 2040, and 1.7 million in 2050. Under the High PEV (Bloomberg) scenario there would be 999,450 PEVs in Michigan by 2030, rising to 3.9 million in 2040, and 5.4 million in 2050.

Note that under both PEV penetration scenarios the percentage of total VMT driven by PEVs each year is lower than the percentage of plug-in vehicles in the fleet. This is because PEVs are assumed to have a “utility factor” less than one – i.e., due to range restrictions neither a BEV nor a PHEV can convert 100 percent of the miles driven annually by a baseline gasoline vehicle into miles powered by grid electricity. In this analysis BEVs with 200-mile range per charge are conservatively assumed to have a utility factor of 87 percent, while PHEVs are assumed to have an average utility factor of 72 percent in 2030, rising to 79 percent in 2050.

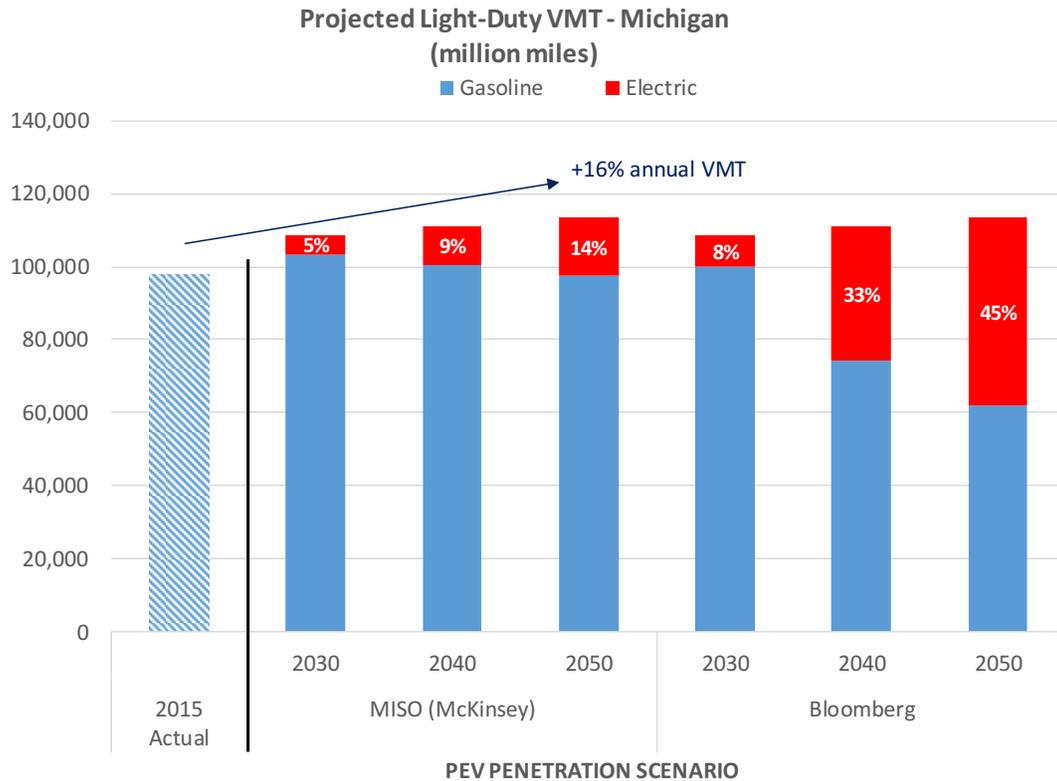
Figure 4 Projected Michigan Light Duty Fleet



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

This analysis estimates that under the High PEV (Bloomberg) scenario Michigan will reduce light-duty fleet gasoline consumption in 2050 by 45 percent compared to a baseline with no PEVs, due to 45 percent of fleet miles being driven by PEVs on electricity (Figure 5). However, in order to achieve this level of electric miles, 55.7 percent of light-duty vehicles will be PEVs (Figure 4).

Figure 5 Projected Michigan Light Duty Fleet Vehicle Miles Traveled

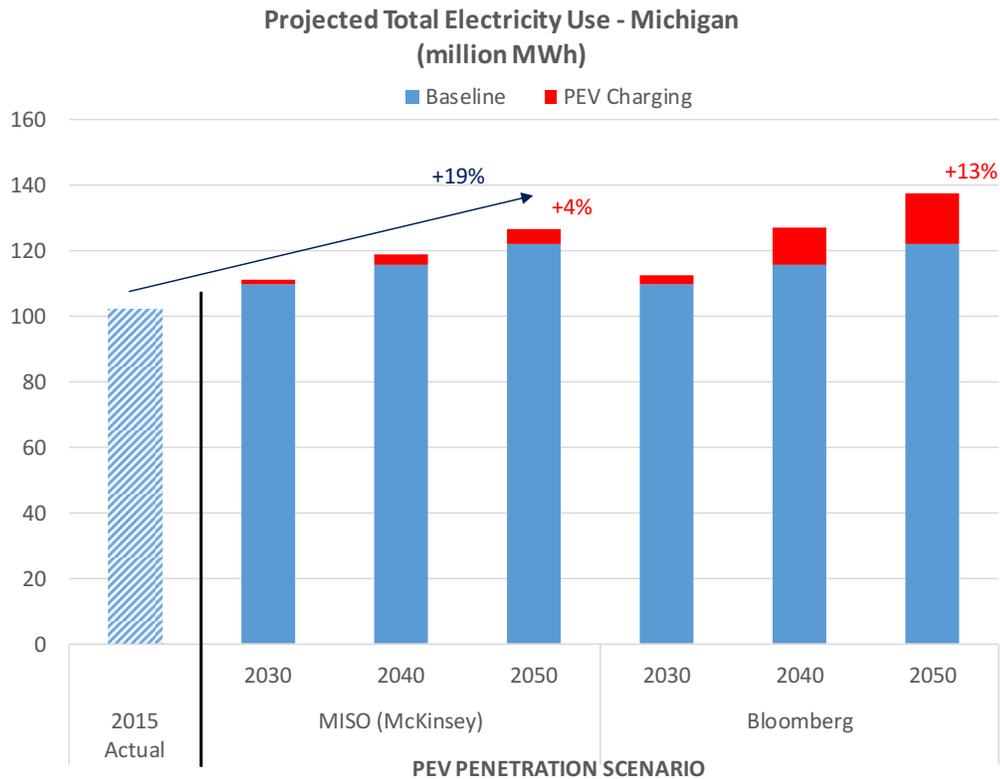


PEV Charging Electricity Use

The estimated total PEV charging electricity used in Michigan 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 Michigan is currently 102 million MWh per year. Annual electricity use is projected to increase to 110 million MWh in 2030 and continue to grow after that, reaching 122 million MWh in 2050 (19 percent greater than 2015 level).

Under the Moderate PEV penetration scenario, electricity used for PEV charging is projected to be 1.7 million MWh in 2030 – an increase of 1.5 percent over baseline electricity use. By 2050, electricity for PEV charging is projected to grow to 4.5 million MWh – an increase of 3.7 percent over baseline electricity use. Under the High PEV (Bloomberg) scenario electricity used for PEV charging is projected to be 2.8 million MWh in 2030, growing to 15.5 million MWh and adding 13 percent to baseline electricity use in 2050.



PEV Charging Load

This analysis evaluated the effect of PEV charging on the Michigan electric grid under two different charging scenarios. Under both scenarios 80 percent of all PEVs are assumed to charge exclusively at home and 20 percent are assumed to charge both at home and at work. Under the baseline charging scenario all Michigan drivers are assumed to plug-in their vehicles and start charging as soon as they arrive at home or at work (if applicable) each day. Under the off-peak charging scenario 65 percent of Michigan drivers who arrive at home in the afternoon and early evening are assumed to delay the start of home charging until after midnight – in response to a price signal or incentive provided by their utility.⁵

See Figure 7 (baseline) and Figure 8 (off-peak) for a comparison of PEV charging load under the baseline and off-peak charging scenarios, using the 2040 High PEV penetration scenario as an example. In each of these figures the 2016 Michigan 95th percentile load (MW)⁶ 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 Michigan was generally in the range of 11,900 – 13,100 MW from midnight to 5 AM, ramping up through the morning and early afternoon to peak at approximately 19,200 MW between 3 PM and 5 PM, and then falling off through the late afternoon and evening hours.

⁵ Utilities have many policy options to incentivize off-peak PEV charging. This analysis does not compare the efficacy of different options.

⁶ For each hour of the day actual load in 2016 was higher than the value shown on only 5 percent of days (18 days).

Figure 7

2040 Projected Michigan PEV Charging Load, Baseline Charging (High PEV (Bloomberg) scenario)

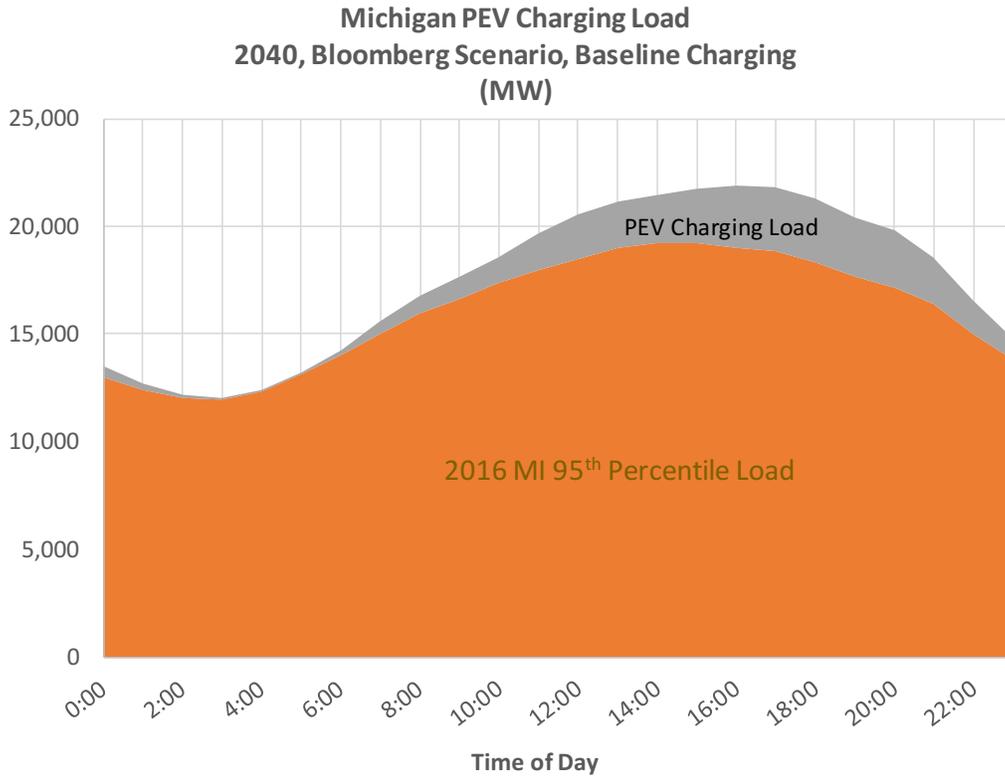
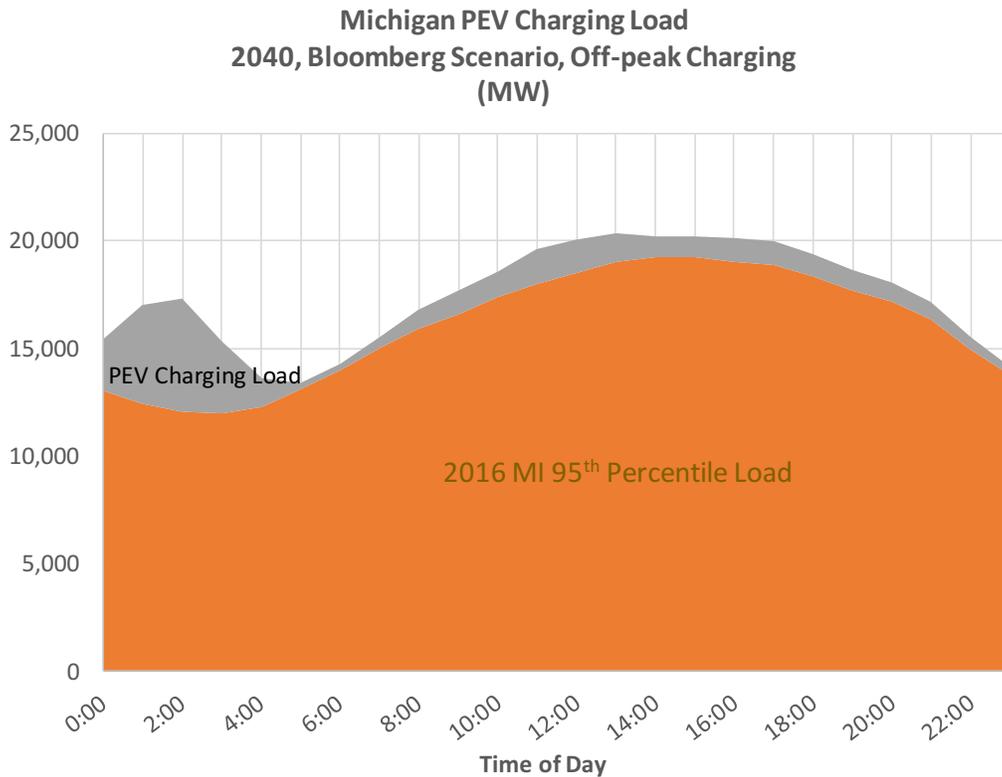


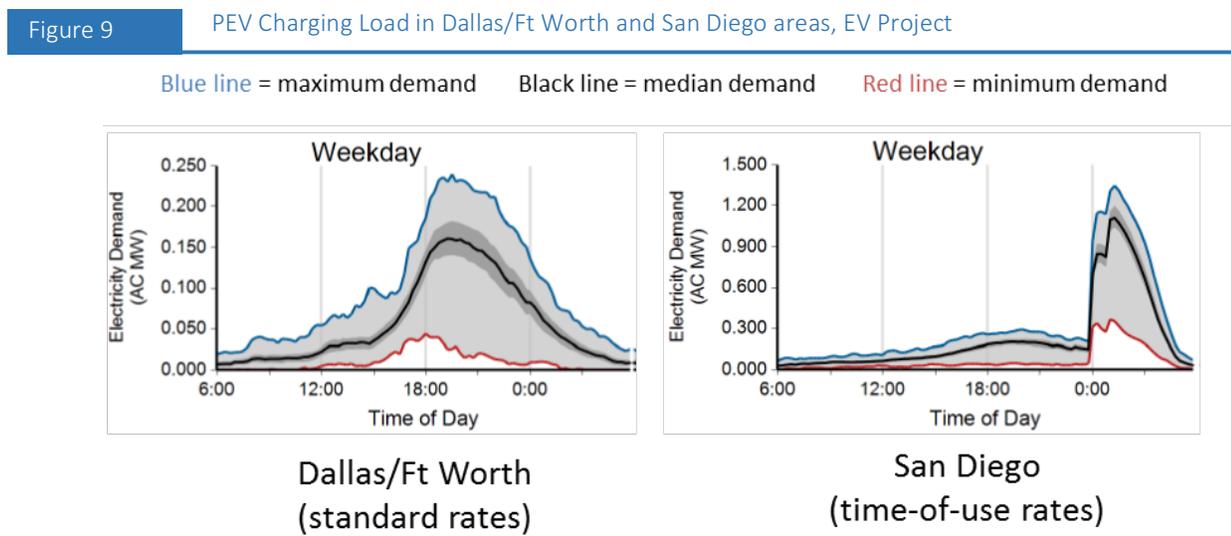
Figure 8

2040 Projected Michigan PEV Charging Load, Off-peak Charging (High PEV (Bloomberg) scenario)



As shown in Figure 7, baseline PEV charging is projected to add load primarily between 8 AM and 11 PM, as people charge at work early in the day and then at home later in the day. The PEV charging peak coincides with the existing afternoon peak load period between 3 PM and 5 PM. As shown in Figure 8, off-peak charging significantly reduces the incremental PEV charging load during the afternoon peak load period, but 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 off-peak charging incentives. It should also be noted that those early morning hours are often the hours of the day when wind generation peaks.

These baseline and off-peak load shapes are consistent with real world PEV charging data collected by the EV Project, as shown in Figure 9. In Figure 9 the graph on the left shows PEV charging load in the Dallas/Ft Worth area where no off-peak charging incentive was offered to drivers. The graph on the right shows PEV charging load in the San Diego region, where the local utility offered drivers a time-of-use rate with significantly lower costs (\$/kWh) for charging during the “super off-peak” period between midnight and 5 a.m. [12]



See Table 1 for a summary of the projected incremental afternoon peak hour load (MW) in Michigan, from PEV charging under each penetration and charging scenario. This table also includes a calculation of how much this incremental PEV charging load would add to the 2016 95th percentile peak hour load. Under the Moderate PEV (MISO) penetration scenario, PEV charging would add 453 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 2 percent. By 2050, the afternoon incremental PEV charging load would increase to 1,242 MW, adding almost 7 percent to the 2016 baseline afternoon peak. By comparison the afternoon peak hour PEV charging load in 2030 would be only 166 MW for the off-peak charging scenario, increasing to 453 MW in 2050.

Under the High PEV penetration scenario, baseline PEV charging would increase the total 2016 afternoon peak electric load by about 21 percent in 2050, while off-peak charging would only increase it by about 8 percent.⁷

⁷ 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.

Table 1

Projected Incremental Afternoon Peak Hour PEV Charging Load (MW)

		Moderate PEV (MISO)			High PEV (Bloomberg)		
		2030	2040	2050	2030	2040	2050
Baseline Charging	PEV Charging (MW)	452.5	829.4	1,242.2	764.1	3,000.5	4,113.5
	<i>Increase relative to 2016 Peak</i>	2.4%	4.3%	6.5%	4.0%	15.6%	21.4%
Off-Peak Charging	PEV Charging (MW)	165.8	302.1	452.5	280.0	1,099.4	1,507.2
	<i>Increase relative to 2016 Peak</i>	0.9%	1.6%	2.4%	1.5%	5.7%	7.8%

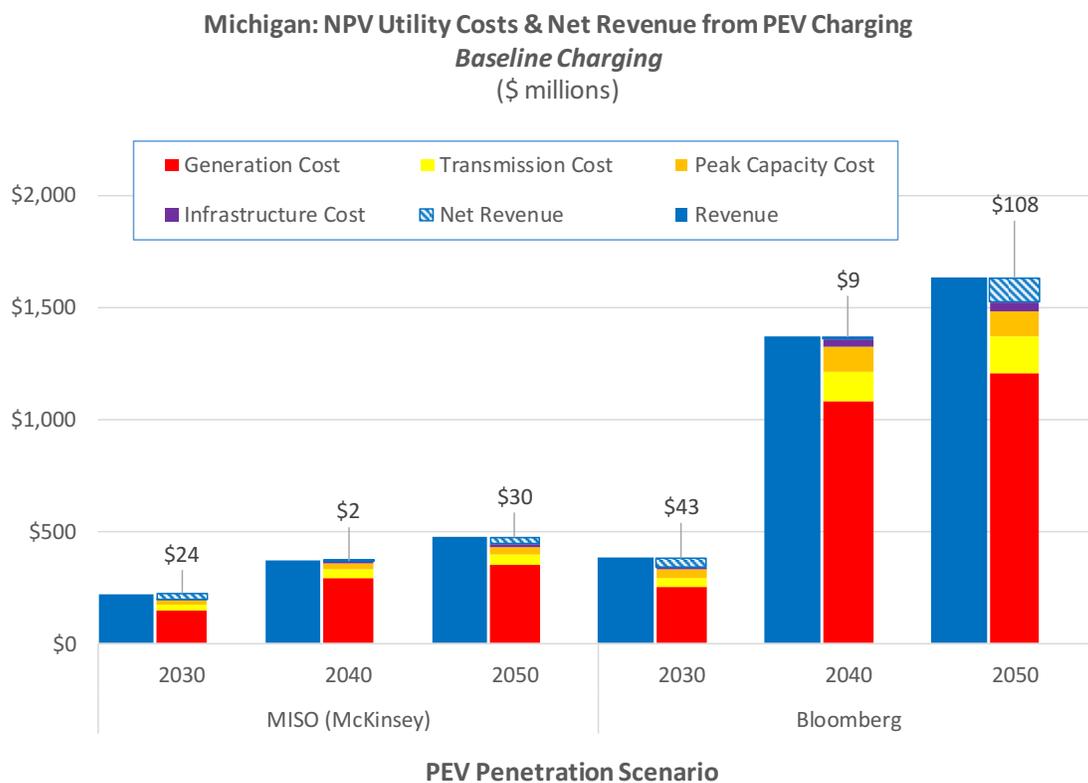
As discussed below, increased peak hour load increases a utility's cost of providing electricity, and may result in the need to upgrade distribution infrastructure. As such, off-peak PEV charging can provide net benefits to all utility customers by bringing in significant new revenue in excess of associated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

Utility Customer Benefits

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

Figure 10

NPV of Projected Utility Revenue and Costs from Baseline PEV Charging



Under the Moderate PEV penetration scenario, the NPV of revenue from electricity sold for PEV charging in Michigan is projected to total \$223 million in 2030, rising to \$475 million in 2050. Under the High PEV (Bloomberg) scenario, the NPV of utility revenue from PEV charging is projected to total \$383 million in 2030, rising to \$1.6 billion in 2050.

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

The striped light blue bars in Figure 10 represent the NPV of projected “net revenue” (revenue minus costs) that utilities would realize from selling additional electricity for PEV charging under each PEV penetration scenario. Under the Moderate PEV penetration scenario, the NPV of net revenue in Michigan is projected to total \$24 million in 2030, rising to \$30 million in 2050. Under the High PEV (Bloomberg) scenario, the NPV of utility net revenue from PEV charging is projected to total \$43 million in 2030, rising to \$108 million in 2050. The NPV of projected annual utility net revenue averages \$42 per PEV in 2030, and \$18 - \$20 per PEV in 2050.

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

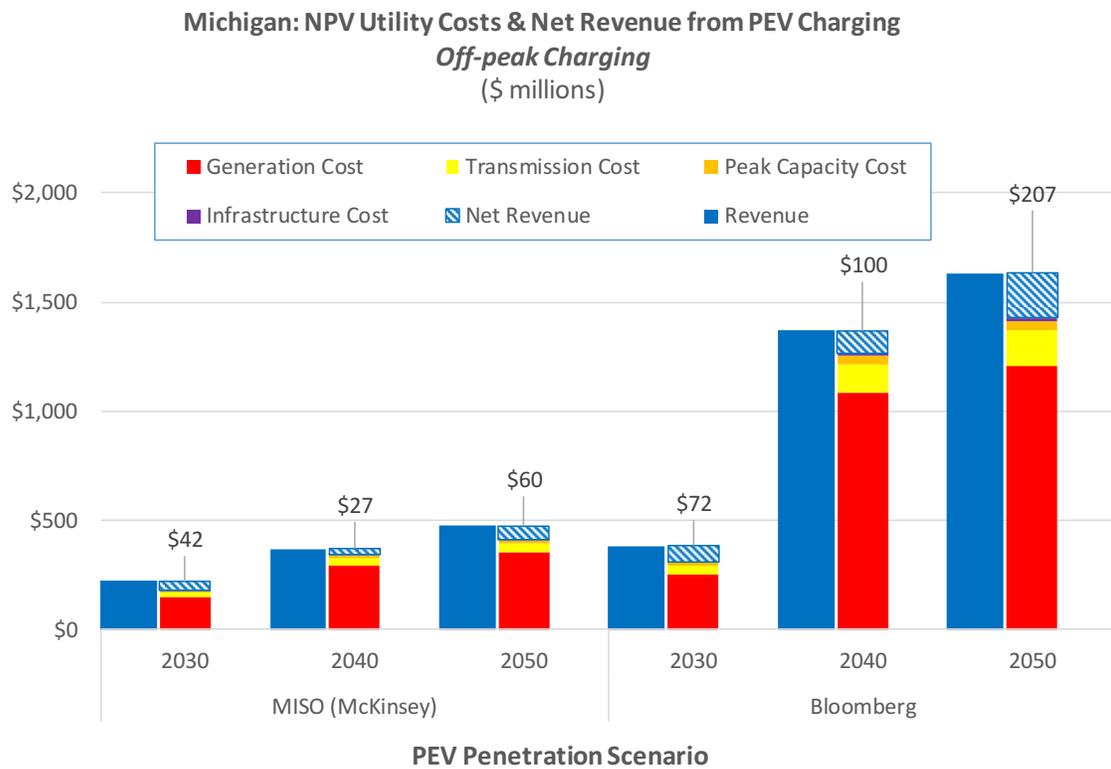
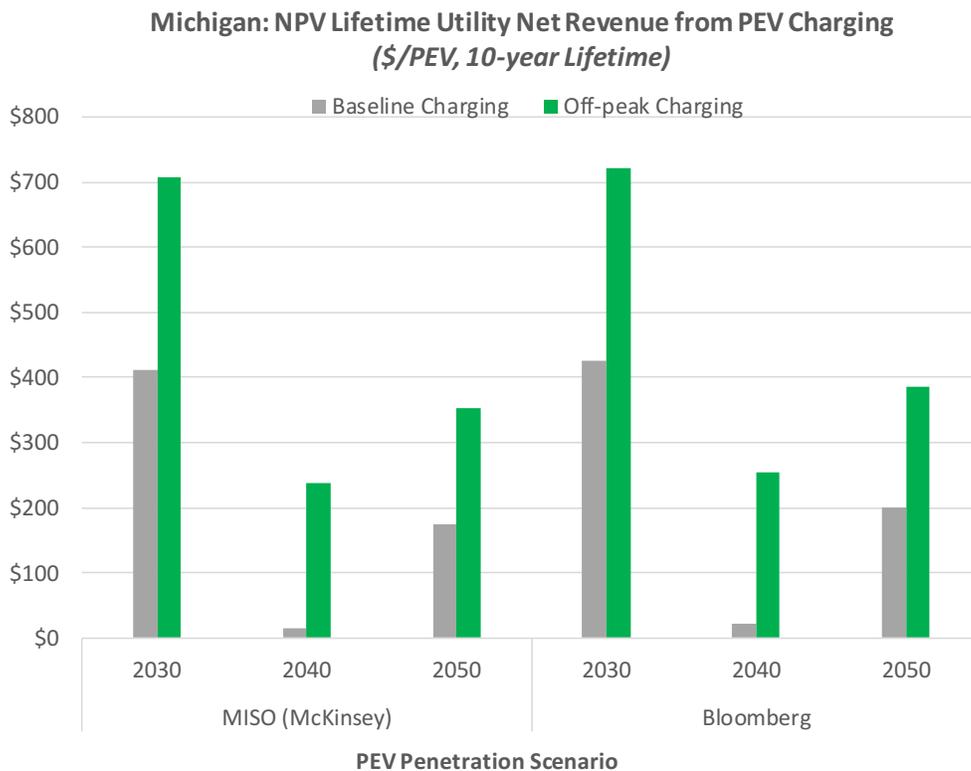


Figure 11 summarizes the NPV of projected utility revenue, costs, and net revenue for off-peak charging under each PEV penetration scenario. Compared to baseline charging (Figure 10) projected revenue, and projected generation and transmission costs are the same, but projected peak capacity and infrastructure costs are lower due to a smaller incremental peak load (see Table 1). Compared to baseline charging, off-peak charging will increase the NPV of annual utility net revenue by \$17 million in 2030 and \$30 million in 2050 under the Moderate PEV

penetration scenario, due to lower costs. Under the High PEV (Bloomberg) scenario, off-peak charging will increase the NPV of annual utility net revenue by \$30 million in 2030 and \$99 million in 2050. This analysis estimates that compared to baseline charging, off-peak charging will increase the NPV of annual utility net revenue by \$30 per PEV in 2030 and \$18 per PEV in 2050.

The NPV of projected life-time utility net revenue per PEV is shown in Figure 12. Assuming a ten-year life, the average PEV in Michigan in 2030 is projected to increase utility net revenue by over \$700 over its life-time, if charged off-peak. PEVs in service in 2050 are projected to increase utility net revenue by almost \$390 over their life time (NPV) if charged off-peak.

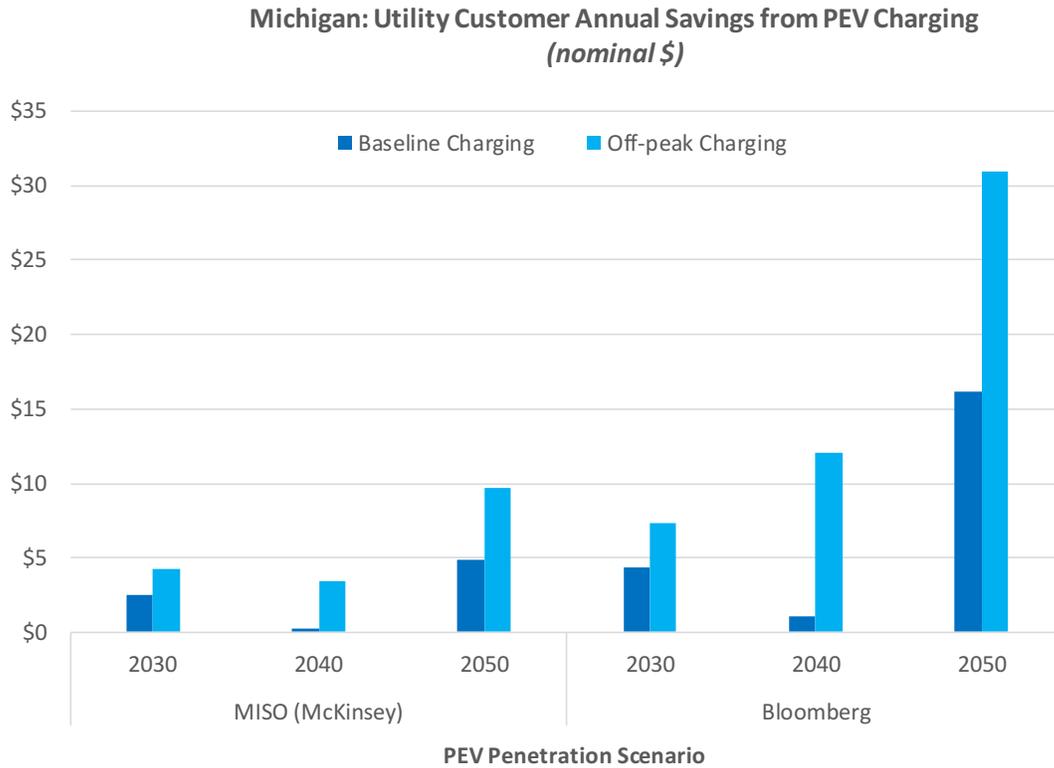
Figure 12 NPV of Projected Life-time Utility Net Revenue per PEV



In general, a utility’s costs to maintain their distribution infrastructure increase each year with inflation, and these costs are passed on to utility customers in accordance with rules established by the state’s Public Utilities Commission (PUC), via periodic increases in residential and commercial electric rates. However, under 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 Michigan, not retained by the utility companies. In effect this net revenue would put downward pressure on future rates, delaying or reducing future rate increases, thereby reducing customer bills.

See Figure 13 for a summary of how the projected utility net revenue from PEV charging might affect average residential electricity bills for all Michigan electric utility customers.⁸ As shown in the figure, under the High PEV (Bloomberg) scenario projected average electric rates in Michigan could be reduced up to 1.1 percent by

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



2050, resulting in an annual savings of approximately \$31 (nominal dollars) per household in Michigan in 2050.

Michigan 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 Michigan by 2030, 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. [13]

Based on these battery cost projections, this analysis projects that the average annual cost of owning a PEV in Michigan will fall below the average cost of owning a gasoline vehicle by 2030, even without government

⁸ Based on 2015 average electricity use of 7,728 kWh per housing unit in Michigan.

purchase subsidies.⁹ See Table 2 which summarizes the average projected annual cost of Michigan PEVs and gasoline vehicles under each penetration scenario. All costs in Table 2 are in nominal dollars, which is the primary reason why costs for both gasoline vehicles and PEVs are higher in 2040 and 2050 than in 2030 (due to inflation). In addition, the penetration scenarios assume that the relative number of PEV cars and higher cost

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

GASOLINE VEHICLE		MISO (McKinsey)			Bloomberg		
		2030	2040	2050	2030	2040	2050
Vehicle Purchase	\$/yr	\$4,281	\$5,470	\$6,963	\$4,398	\$6,198	\$8,018
Gasoline	\$/yr	\$1,233	\$1,603	\$2,065	\$1,254	\$1,759	\$2,320
Maintenance	\$/yr	\$261	\$326	\$400	\$262	\$337	\$415
TOTAL ANNUAL COST	\$/yr	\$5,775	\$7,400	\$9,428	\$5,914	\$8,293	\$10,753

PEV		MISO (McKinsey)			Bloomberg		
		2030	2040	2050	2030	2040	2050
Vehicle Purchase	\$/yr	\$4,505	\$5,676	\$7,117	\$4,622	\$6,391	\$8,263
Electricity	\$/yr	\$576	\$671	\$772	\$585	\$715	\$837
Gasoline	\$/yr	\$232	\$259	\$314	\$236	\$282	\$348
Personal Charger	\$/yr	\$81	\$101	\$122	\$81	\$101	\$122
Maintenance	\$/yr	\$146	\$192	\$239	\$147	\$197	\$245
TOTAL ANNUAL COST	\$/yr	\$5,540	\$6,899	\$8,564	\$5,671	\$7,685	\$9,815

Savings per PEV		2030	2040	2050	2030	2040	2050
	\$/yr	\$234	\$501	\$864	\$244	\$608	\$937

PEV light trucks will change over time; in particular the High PEV (Bloomberg) scenario assumes that there will be a significantly higher percentage of PEV light trucks in the fleet in 2050 than in 2030, which further increases the average PEV purchase cost in 2050 compared to 2030.

As shown in Table 2, even in 2050 average PEV purchase costs are projected to be higher than average purchase costs for gasoline vehicles (with no government subsidies), but the annualized effect of this incremental purchase cost is outweighed by significant fuel cost savings, as well as savings in scheduled maintenance costs. In 2030, the average Michigan driver is projected to save \$234 – \$244 per year compared to the average gasoline vehicle owner, without government subsidies. These annual PEV savings are projected to increase to an average of \$501 - \$608 per PEV in 2040, and \$864 - \$937 per PEV in 2050, as relative PEV purchase costs continue to fall, and the projected price of gasoline continues to increase faster than projected electricity prices. The NPV of annual savings for the average PEV owner in Michigan is projected to be \$153 in 2030, rising to \$320 in 2050.

The NPV of total annual cost savings to Michigan drivers from greater PEV ownership are projected to be \$89 million in 2030 under the Moderate PEV penetration scenario, rising to \$271 million in 2040 and \$521 million in 2050. Under the High PEV (Bloomberg) scenario, the NPV of total annual cost savings to Michigan drivers from greater PEV ownership are projected to be \$156 million in 2030, rising to \$1.1 billion in 2040 and \$1.8 billion in 2050.

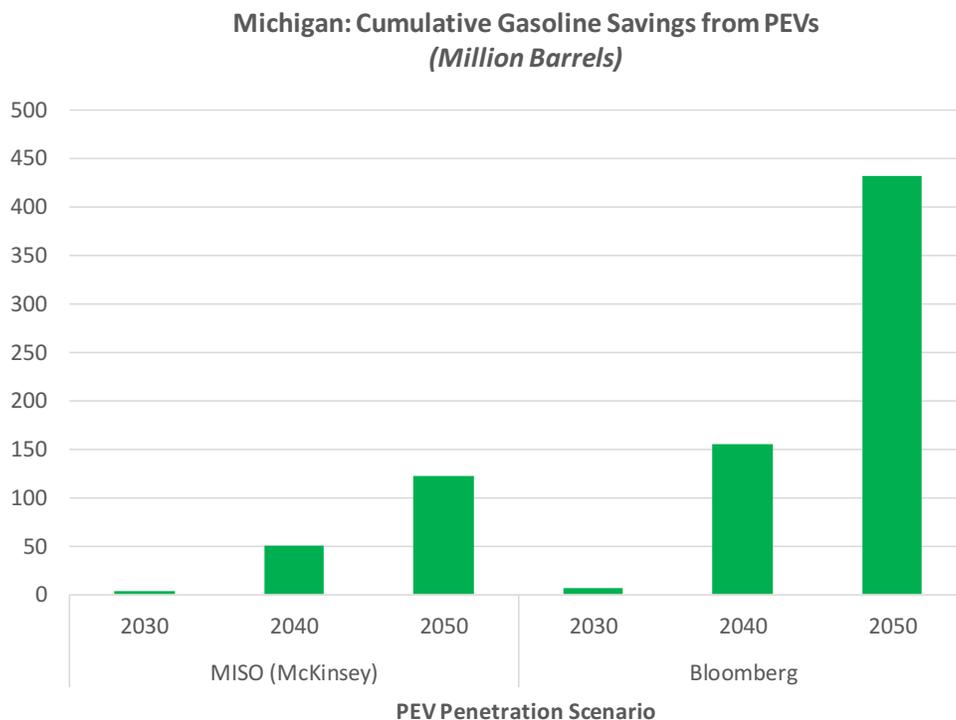
⁹ The analysis assumes that all battery electric vehicles in-use after 2030 will have 200-mile range per charge and that all plug-in hybrid vehicles will have 50 mile all-electric range.

Other Benefits

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

The estimated cumulative fuel savings (barrels of gasoline¹⁰) from PEV use in Michigan under each penetration scenario are shown in Figure 14. Annual fuel savings under the Moderate PEV penetration scenario are projected to total 3.3 million barrels in 2030, with cumulative savings of more than 122 million barrels by 2050. For the High PEV (Bloomberg) scenario, annual fuel savings in 2030 are projected to be 5.8 million barrels, and by 2050 cumulative savings will exceed 432 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

Figure 14 Cumulative Gasoline Savings from PEVs in Michigan



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. [14]

The projected annual greenhouse gas (GHG) emissions (million metric tons carbon-dioxide equivalent, CO₂-e million tons) from the Michigan light duty fleet under each PEV penetration scenario are shown in Figure 15. In this figure, projected baseline emissions from a gasoline fleet with few PEVs are shown in red for each year, and 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

¹⁰ One barrel of gasoline equals 42 US gallons

charging are based on EIA projections of average carbon intensity for the East North Central (ENC) electricity generation region, which includes Michigan.

As shown in Figure 15, GHG emissions from the light duty fleet in Michigan were approximately 49 million tons in 2015. Absent significant PEV penetration, baseline annual fleet emissions are projected to fall to 29.9 million tons by 2050, a reduction of 39 percent from current levels. This projected reduction is based on turnover of the existing vehicle fleet to more efficient vehicles that meet more stringent fuel economy and GHG standards. Compared to baseline emissions in 2050, GHG emissions are projected to be reduced by up to 1.9 million tons under the Moderate PEV penetration scenario and as much as 7.7 million tons under the High PEV (Bloomberg) scenario. Through 2050, cumulative net GHG emissions are projected to be reduced by 26 million tons under the Moderate PEV penetration scenario and 99 million metric tons under the High PEV (Bloomberg) scenario.

Figure 15

Projected GHG Emissions from the Light Duty Fleet in Michigan

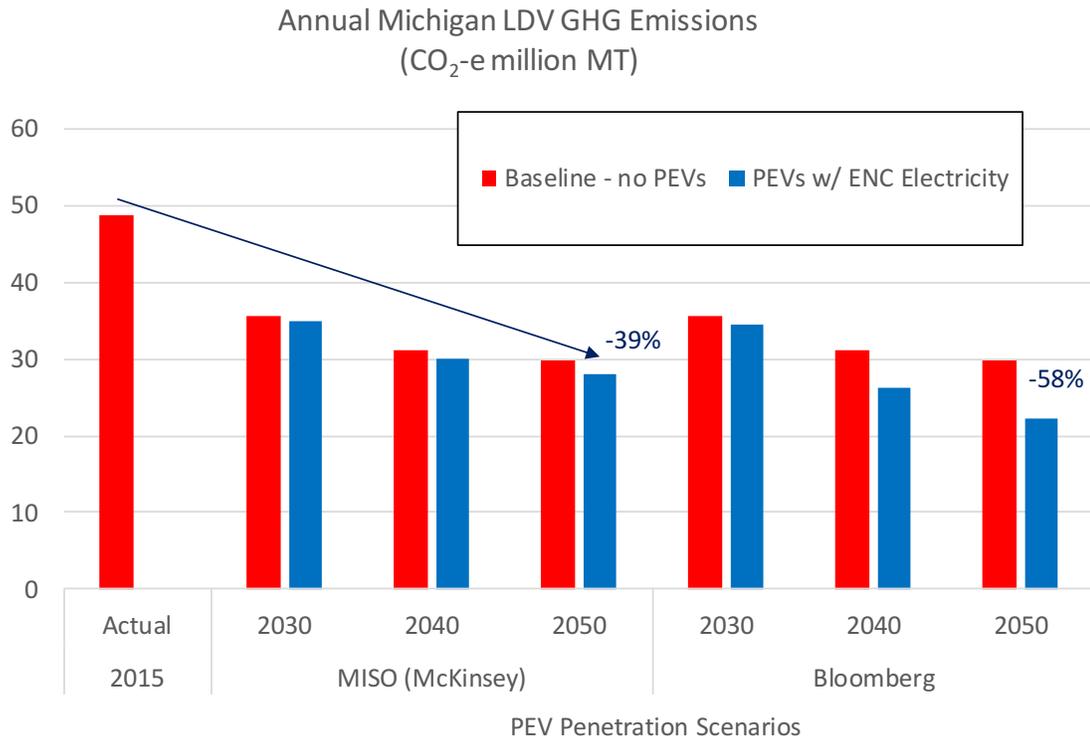


Figure 16

NPV of Projected Social Value of PEV GHG Reductions

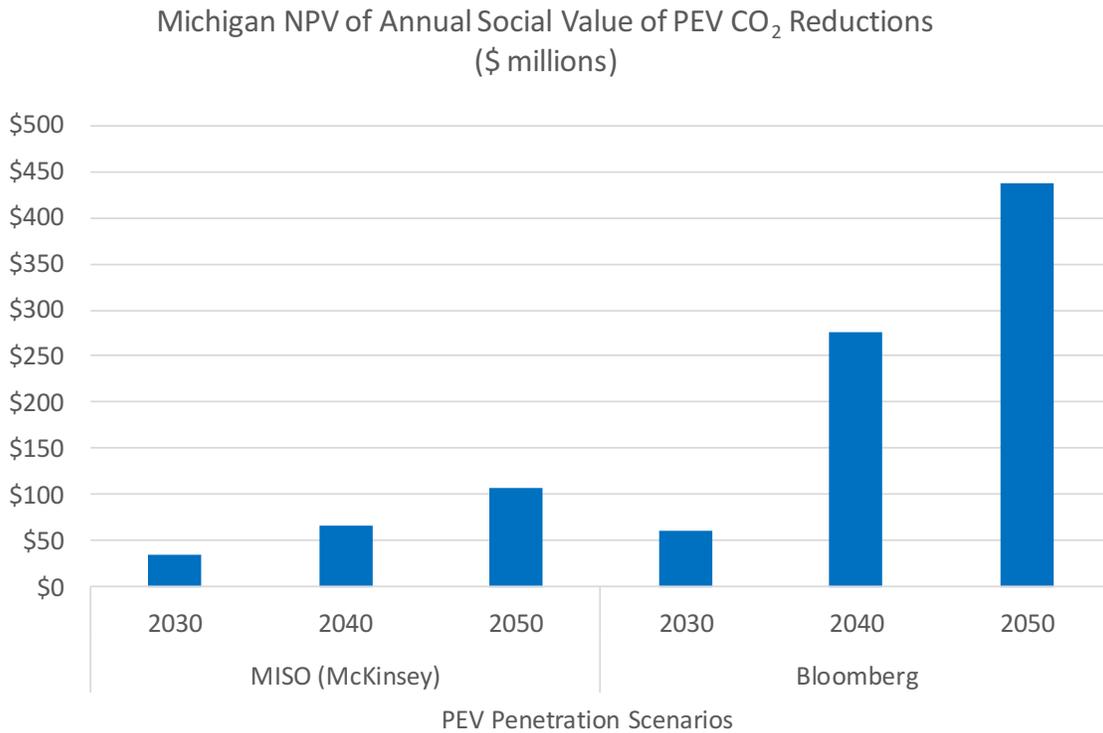


Figure 16 summarizes the estimated NPV of the monetized “social value” of GHG reductions that will result from greater PEV use in Michigan. The social value of GHG reductions represents potential societal cost savings from avoiding the negative effects of climate change, if GHG emissions are reduced enough to keep long term warming below two degrees Celsius from pre-industrial levels. The values summarized in Figure 16 were developed using the Social Cost of CO₂ (\$/MT) as calculated by the U.S. government’s Interagency Working Group on Social Cost of Greenhouse Gases [15].

The NPV of the monetized social value of GHG reductions resulting from greater PEV use is projected to total \$35 million per year in 2030 under the Moderate PEV penetration scenario, rising to as much as \$108 million per year in 2050. Under the High PEV (Bloomberg) scenario the NPV of the monetized social value of GHG reductions from greater PEV is projected to be \$62 million per year in 2030, rising to as much as \$438 million per year in 2050.

The NPV of the projected monetized social value of annual GHG reductions averages \$61 per PEV in 2030, and \$63 - \$81 per PEV in 2050.

Total Societal Benefits

The NPV of total estimated societal benefits from increased PEV use in Michigan under each PEV penetration scenario are summarized in Figures 17 and 18. These benefits include cost savings to Michigan drivers, utility customer savings from reduced electric bills, and the monetized benefit of reduced GHG emissions. Figure 17 shows the NPV of projected societal benefits if Michigan drivers charge in accordance with the baseline charging scenario. Figure 18 shows the NPV of projected societal benefits if Michigan drivers charge off-peak. Both figures assume that GHG emissions from electricity production follow EIA’s current projections for future carbon intensity of the regional electric grid.

As shown in Figure 17, the NPV of annual societal benefits are projected to be a minimum of \$659 million per year in 2050 under the Moderate PEV penetration scenario and \$2.3 billion per year in 2050 under the High PEV (Bloomberg) scenario. Approximately 78 percent of these annual benefits will accrue to Michigan drivers as a cash savings in vehicle operating costs, 5 percent will accrue to electric utility customers as a reduction in annual electricity bills, and 17 percent will accrue to society at large in the form of climate change mitigation due to reduced GHG emissions.

As shown in Figure 18, the NPV of annual societal benefits in 2050 will increase by \$30 million under the Moderate PEV penetration scenario, and \$99 million under the High PEV (Bloomberg) scenario if Michigan drivers charge off-peak. Of these increased benefits, all will accrue to electric utility customers as an additional reduction in their electricity bills.

Figure 17

Projected NPV of Total Societal Benefits from Greater PEV use in MI – Baseline Charging

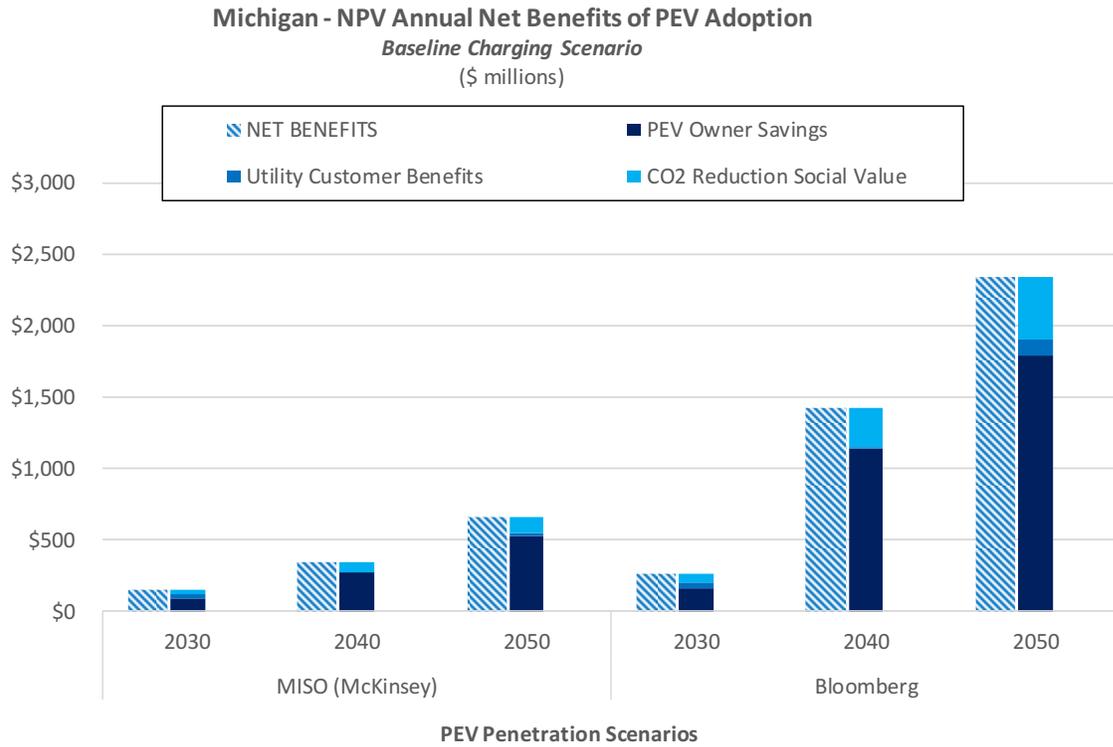
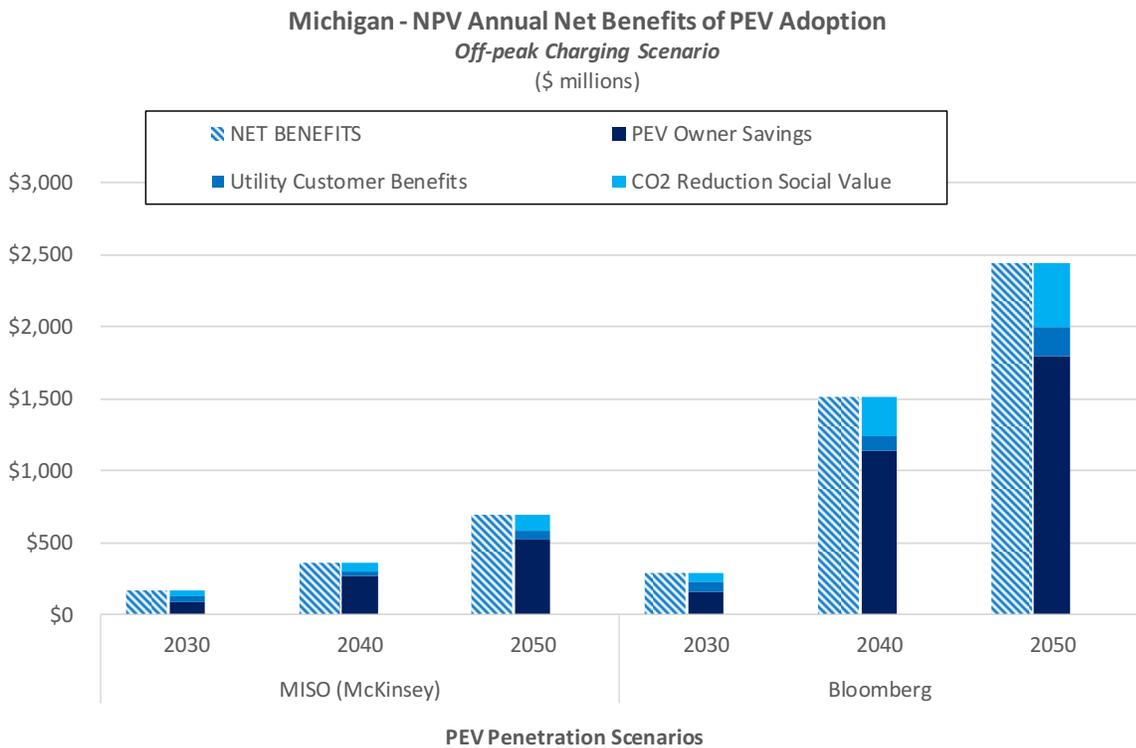


Figure 18

Projected NPV of Total Societal Benefits from Greater PEV use in MI – Off-peak



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).¹¹ 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 Michigan between 2030 and 2050, based on the range of publicly available PEV adoption estimates from various analysts.

Moderate PEV Scenario – MISO (McKinsey): Penetration of PEVs modeled by MISO Energy – the regional transmission organization that covers Michigan - during on-going MISO Transmission Expansion Planning (MTEP) efforts; this PEV penetration scenario was produced for MISO by McKinsey & Company [16]. Under this scenario approximately 6 percent of in-use light duty vehicles in Michigan will be PEV in 2030, rising to 12 percent in 2040, and 17.6 percent in 2050.

High PEV Scenario - Bloomberg: The estimated level of PEV penetration each year, based on Bloomberg New Energy Finance’s (Bloomberg) July 2017 estimate of annual U.S. PEV sales through 2040, conservatively extended through 2050. [17] For this scenario the estimate of total in-use PEVs each year is based on cumulative PEV sales over the preceding thirteen years (average in-service life for light duty vehicles), and assuming that PEV sales in Michigan will be proportional to total vehicle sales. Under this scenario 10.8 percent of in-use vehicles will be PEV in 2030, rising to 41.5 percent in 2040 and 55.7 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 Michigan Department of Transportation.

Based on assumed future PEV characteristics and usage, the analysis projects annual electricity use for PEV charging at each level of penetration, as well as the average load from PEV charging by time of day. The analysis then projects the total revenue that Michigan’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) an off-peak 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

¹¹ 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.

peak demand.¹² However, if given a “nudge” - in the form of a properly designed and marketed financial incentive - many Michigan drivers will choose to delay the start of charging until off-peak times, thus reducing the effect of PEV charging on evening peak electricity demand (scenario 2). [18] As noted above, most Michigan utilities offer special rate plans for EV owners intended to incentivize off-peak charging.

For each PEV penetration scenario, this analysis also calculates the total incremental annual cost of purchase and operation for all PEVs in the state, compared to “baseline” purchase and operation of gasoline cars and light trucks. For both PEVs and baseline vehicles annual costs include the amortized cost of purchasing the vehicle, annual costs for gasoline and electricity, and annual maintenance costs. For PEVs it also includes the amortized annual cost of the necessary home charger. This analysis is used to estimate average annual financial benefits to Michigan 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 (CO₂-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 average grid emissions in Michigan.

Net annual GHG reductions from the use of PEVs are calculated as baseline GHG emissions (emitted by gasoline vehicles) minus GHG emissions from each PEV penetration scenario. The monetized “social value” of these GHG reductions from PEV use are calculated using the Social Cost of Carbon (\$/MT), as calculated by the U.S. government’s Interagency Working Group on Social Cost of Greenhouse Gases. [19]

¹² 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.

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Acknowledgements

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[Charge Up Midwest](#) is a partnership of environmental and clean energy organizations actively working to increase electric vehicle deployment throughout the region in Illinois, Missouri, Michigan, Minnesota, and Ohio. Partner organizations include the Natural Resources Defense Council, Ecology Center, Sierra Club, Great Plains Institute, Environmental Law and Policy Center, Clean Fuels Ohio, and Fresh Energy. Through ChargeUp Midwest these organizations seek to engage with a broad range of stakeholders to support actions that increase investment in electric vehicle infrastructure, create a more resilient and low-carbon grid, expand education of the public and policymakers about the benefits of electric vehicles, and otherwise accelerate the production, sales, and access to electric vehicles in the region for all Midwest residents.

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