

Electric Vehicle Cost-Effectiveness and its Implications for Utility Program Design

Dr. Nancy E. Ryan¹, Eric Cutter¹, Hilary Staver¹, Ashley Horvat², Brendan O'Donnell³

¹*Energy and Environmental Economics, Inc., 101 Montgomery Street, Suite 1600, San Francisco, CA 94104; for
questions contact eric@ethree.com*

²*Plugshare, 985 East San Carlos Ave, San Carlos, CA 94070*

³*Seattle City Light, 901 5th Ave, 18th Floor, Seattle WA, 98104*

Summary

We quantify the costs and benefits associated with plug-in electric vehicle (PEV) adoption in Seattle, WA under a variety of economic, behavioural, and rate design conditions. We develop a methodology for evaluating net societal and ratepayer benefits from PEV adoption, and find that PEV adoption consistent with Washington's goal of 50,000 PEVs by 2020 produces \$83 million in net ratepayer benefits (in net present value terms) over the lifetime of these vehicles. We demonstrate that PEVs can provide a net benefit to both utility ratepayers and society at large, and that PEV adoption is unlikely to trigger widespread distribution grid upgrades.

Keywords: case-study, cost, incentive, modeling, utility

1 Introduction

Plug-in electric vehicles (PEVs) interact with the electricity system in a way that is unique among distributed energy resources. Unlike other distributed energy resources such as solar and energy efficiency, PEVs add to total electricity load instead of reducing it. Increasing total load distributes utility fixed costs across a greater number of kWh, giving PEVs the potential to reduce electricity rates for all ratepayers regardless of PEV ownership status. For utilities, PEVs represent a new revenue stream that helps counteract the recent stagnation in electricity demand growth [1].

Conversely, PEV charging may require utilities to procure additional generation capacity and upgrade distribution infrastructure sooner than planned. If programs are not put in place to encourage charging in off-peak hours, PEVs can drive up peak demand and its associated costs. In an extreme case, PEV adoption could even increase rates since the cost of new grid infrastructure is charged to all ratepayers.

Utilities across the country have begun developing PEV-related programs that aim to maximize the benefits these vehicles provide while anticipating and minimizing the costs. As of June 2015, 28 utilities in 15 states have established time-of-use (TOU) tariffs specifically for PEVs [2]. Kansas City Power and Light has built a network of over a thousand public EV chargers around Kansas City, and the three investor-owned utilities in California have submitted proposals to the California Public Utilities Commission for similar projects on a larger scale [3,4].

In order for a utility PEV program to be effective, the utility must have access to accurate estimates of the costs and benefits that ratepayers and PEV owners will incur under a given PEV adoption scenario. Energy and Environmental Economics, Inc. (E3) has developed a cost-effectiveness model that quantifies the cost-benefit balance of PEVs from various stakeholder perspectives. Here, we present the lessons for utility

program design that come from applying this model to a case study in Seattle, Washington. Our work focuses on identifying the key determinants of PEV cost-effectiveness and how they can be incorporated into the program design process. Together, they provide insight into three key questions:

1. What are the costs and benefits associated with PEV adoption? Are PEVs cost-effective, and from whose perspective?
2. How much can a utility spend on measures to promote PEV adoption without creating cross-subsidization of PEV owners by ratepayers who do not own PEVs?
3. How robust are these findings to variation in exogenous economic conditions, PEV adoption rates, charging patterns, and rate design?

Our case for this study is Seattle City Light (SCL), a municipal utility serving 415,000 customers in and around Seattle, WA [5]. SCL retained E3 for help in forecasting the grid impacts of future PEV adoption as well as the potential for PEV support programs in its territory. The time period for this study is 2016 through 2030, with costs and benefits accruing out to 2040 when the last cohort of PEVs completes its ten-year lifetime.

2 Methodology

2.1 Overview of Model Structure

This analysis was performed using the E3 PEV cost-effectiveness model, a deterministic stock rollover model written in Python and Excel that estimates PEV cost-effectiveness and grid impacts. Figure 1, below, shows the basic structure of the model. The model takes as inputs a PEV adoption trajectory as well as data describing relevant environmental and PEV-associated marginal costs. For each year of the study period, the model calculates annual PEV costs and benefits while adding and retiring PEVs according to the adoption trajectory and vehicle lifetime. These annual numbers are combined into a single present value output for each cost and benefit component over the lifetime of all vehicles added during the study period.

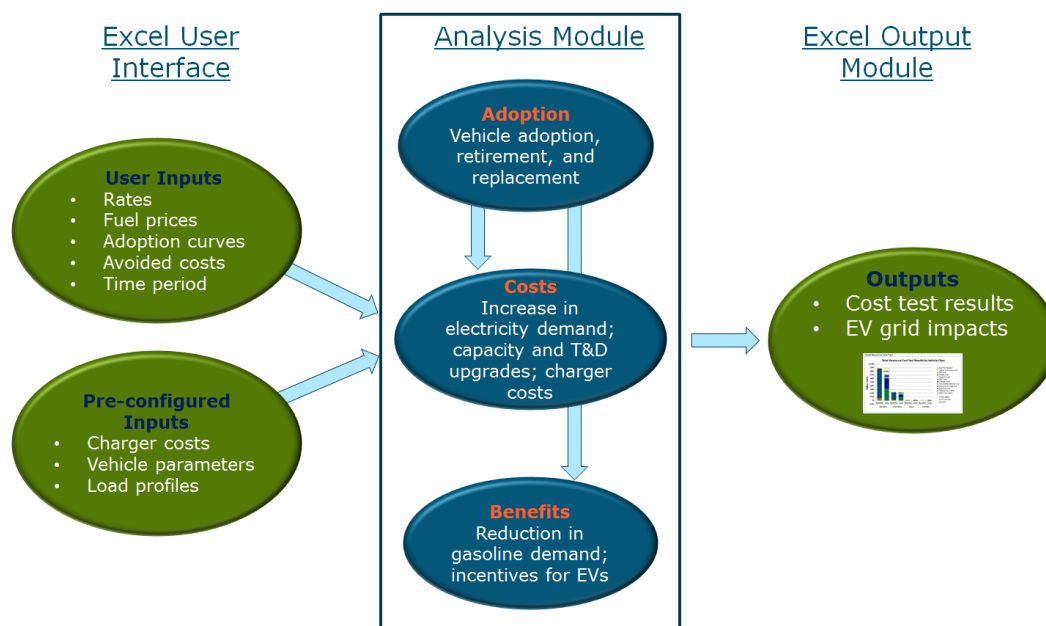


Figure 1: Basic structure of the E3 EV Dashboard model

2.2 Cost-Effectiveness Tests

We use the present value outputs to evaluate net cost-effectiveness from two different stakeholder perspectives.¹

¹ For readers familiar with the California Standard Practice Manual (SPM) cost tests and/or previous E3 PEV studies, the “societal test” we discuss in this paper is the Total Resource Cost Test and the “ratepayer test” is the Ratepayer Impact Measure. We have given them generic names designed to be more intuitive to readers outside California, but the tests themselves are unchanged.

The “societal test” measures costs and benefits accrued across the entire economy. The societal test therefore includes costs paid by the utility as well as those borne by PEV adopters. Note that because the societal test covers the entire economy, net cost-effectiveness results will not change if a cost is shifted from one party to another within the economy. For example, state tax credits are not included as a societal benefit in this study because we define our system as the state of Washington. State tax credits therefore only redistribute money that is already in the Washington economy rather than adding to or subtracting from total economic value. Conversely, federal tax credits are included as a benefit because they bring new value in from outside the region.

In contrast, the “ratepayer test” evaluates how the technology in question affects utility rates and ratepayers. From the ratepayer perspective, the benefit is the revenue the utility brings in from PEV charging, while the only costs that are considered are those that fall on the utility and must be recovered through rates. A technology with a positive net result is beneficial to ratepayers, because the technology generates more revenue than costs. Conversely, a technology with a negative net result is a net cost and may require raising electricity rates for all ratepayers.

Figure 2 shows which costs and benefits are included in the societal and ratepayer tests. A third perspective not covered in this paper is that of the PEV owner. Also, note that the societal test we present in this study includes only explicitly monetized costs and benefits. It is possible to expand the test to include non-monetized benefits such as health and energy security improvements from reducing fossil fuel use; this would increase net PEV cost-effectiveness.

	Component	PEV Owner	Ratepayer	Society
PEV Customer costs and benefits				
	Incremental Vehicle Costs	-		-
	Gasoline Savings	+		+
	Utility Bills	-	+	
	Federal Tax Credits	+		+
	State Tax credits	+		
PEV Charger Cost				
	Utility Asset		-	-
	Customer Assets	-		-
Admin Costs				
	Utility Program Administration		-	-
Electricity Supply Costs				
	Energy Cost		-	-
	Losses Cost		-	-
	A/S Cost		-	-
	Capacity Cost		-	-
	Transmission and Distribution Cost		-	-
	RPS Cost		-	-
	Utility GHG Allowance Cost		-	-
Societal Benefits				
	Transportation GHG Allowance Cost			+
	“Societal” value for CO2			+
	Health benefits			+
	Decreased Petroleum Use			+

Figure 2: Cost test components (“+” = benefit, “—” = cost)

2.3 Spatial Distribution of Vehicles

A key concern for utilities and regulators is whether significant PEV adoption will overload the distribution grid and trigger rate increases as utilities upgrade or add feeders and substations.

The answer to this question depends to a large extent on how PEV load is distributed geographically. In order to produce a realistic pattern of PEV adoption, our model distributes different types of PEV charging load across the grid proportionally to the distribution of the rate class that load is associated with. Table 1 shows the proxies used for each type of PEV load in the model.

Table 1: Proxy loads used for spatial distribution of PEVs

Type of PEV Charging Load	Proxy Load
Light-Duty Vehicle Home Charging Load	Residential Load
Light-Duty Vehicle Workplace Charging Load	Commercial Load
Buses Charging Load	Commercial Load
Forklifts Charging Load	Industrial Load

We calculated the percentage of total annual energy load from each ratepayer class on each of SCL's 178 distribution feeders. The PEV load associated with that ratepayer class was then distributed across the feeders using the same percentage breakdown. For example, if a particular feeder served 2% of the total annual residential load, our model allocated 2% of the light-duty vehicle (LDV) home charging load to that feeder.

In each year the model determines which feeders have reached full capacity and need an upgrade. It also tracks baseline, non-PEV load growth. Upgrades triggered by baseline load growth are not included in the transmission and distribution (T&D) costs shown in our results, because they are necessary even with zero PEV adoption.

This approach models PEV load distribution effectively on a system-wide basis, such that the load for each type of PEV is distributed proportionally to the total load of the ratepayer classes associated with that type of PEV. However, with additional data it would be possible to approximate PEV distribution with even higher granularity. Research has shown that the adoption of PEVs and other conspicuous "green" products such as solar panels tends to exhibit a clustered pattern at the zipcode and even street level. This clustering is attributable both to demographic differences and to early adopters influencing neighbours to adopt the same technologies ("peer effects") [6,7]. E3 has examined the impact of this high-granularity PEV clustering in California and found minimal incremental grid impacts [8].

2.4 Scenarios

This analysis consists of a baseline scenario ("**Base Case**") accompanied by six sensitivity analyses. The Base Case is based on achieving Washington State's current goal of 50,000 PEVs on the road by 2020. We prorate Washington's statewide PEV goal for SCL's service territory based on the percentage of total state population living in the service territory.

The six sensitivities (shown in Table 2) fall into three broad categories: sensitivities related to potential utility actions, sensitivities to account for local cost variation, and sensitivities to account for exogenous variation in large system variables.

The action-based sensitivities are the **High Adoption Case** and the **Rate Base Case**. The High Adoption Case is identical to the Base Case except for a 25% increase in the number of PEVs on the road in 2020, which produces corresponding increases in adoption rate during the interim and subsequent years. This case explores the impacts of a hypothetical SCL program designed to accelerate PEV adoption. Since the study

period extends out to 2030 but the extra 25% adoption target is in 2020, some benefits and costs will increase by more than 25%. The Rate Base Case looks at the implications of SCL paying for 50% of the total cost of charging infrastructure, both public and private, needed to support the base case adoption scenario.

We show two sensitivities that account for local variation in charger installation costs. While charger costs have been declining, installation costs vary significantly from site to site and are difficult to predict. The **High Charger Cost Case** assumes charger installation costs are three times higher than those included in the Base Case. Another uncertainty is the extent to which PEV drivers will rely on public charging infrastructure. In the base case we assume most PEV drivers will charge predominately at home. The **More Public Charging Case** includes additional public charging infrastructure.

The **Conservative Case** and **High Gas and Carbon Case** examine the impacts of exogenous factors. These two scenarios test the effects of low and high gasoline prices respectively. The Conservative Case also slows the price drop of PEVs themselves, a variable that depends on sales of PEVs nationwide. Similarly, carbon price, as tested in the High Gas and Carbon Case, is determined by state and federal policy.

Table 2: Scenario Definitions

	Base Case	High Adoption Case	High Charger Cost Case	Conservative Case	High Gas and Carbon Case	More Public Charging Case	Rate Base Case
Gas Price (\$/gallon of gasoline)	EIA (Reference Gasoline Price Case, AEO 2015)	-	-	10% less than base case	EIA (High Gasoline Price Case, AEO 2015)	-	-
Carbon Price (\$/metric ton CO ₂)	35% less than SCL 2016 IRP forecast	-	-	-	SCL 2016 IRP Carbon Price	-	-
Adoption Curve	50,000 LDVs by 2020	62,500 LDVs by 2020; 25% increase from base case	-	-	-	-	-
Charger Costs	Res. L1: \$500; Res.L2: \$2,500; Commercial: \$12,500	-	3x base case for commercial chargers; +\$1000 for residential L1 and L2 chargers	-	-	-	-
Vehicle costs	EV vehicle prices decline 9% annually	-	-	EV vehicle prices decline at 4.5% annually, 1/2 the base case rate	-	-	-
Charging Pattern	54% of PEVs charge only at home; 46% charge at both home and workplace	-	-	-	-	All PEVs charge both at home and at the workplace	-
Rate Base	SCL pays no charger costs	-	-	-	-	-	50% of charger costs (public and private) added to SCL rate base

3 Major Findings

3.1 PEV adoption yields net societal benefits under most scenarios

Our analysis shows PEVs produce net societal benefits under all but one of the scenarios tested. Figure 3 shows the societal results for the entire fleet of plug-in light-duty vehicles (LDVs) adopted in SCL's territory through 2030. We assume a time-of-use (TOU) rate schedule in which the on-peak rate is double the off-peak rate. The **Base Case**, at the far left, shows a net benefit of \$374 million in present value over the lifetimes of the light-duty PEVs adopted through 2030. Benefits are dominated by savings on gasoline expenditures, while costs consist mostly of charger and incremental vehicle costs. Energy, capacity, and T&D costs are relatively minor in comparison.

The **High Adoption Case** increases the quantity of PEVs on the road in 2020 by 25% and then continues this adoption trajectory out to 2030. Since we present our results in the form of total present value across the light-duty PEV fleet, increasing fleet size increases all cost and benefit totals even though the per-vehicle values have not changed. The total net benefit under the High Adoption Case is 79% higher than the Base Case net benefit. The difference in net benefits is higher than 25% because our adoption targets are based on Washington's 2020 PEV adoption goal but we model vehicles adopted through 2030.

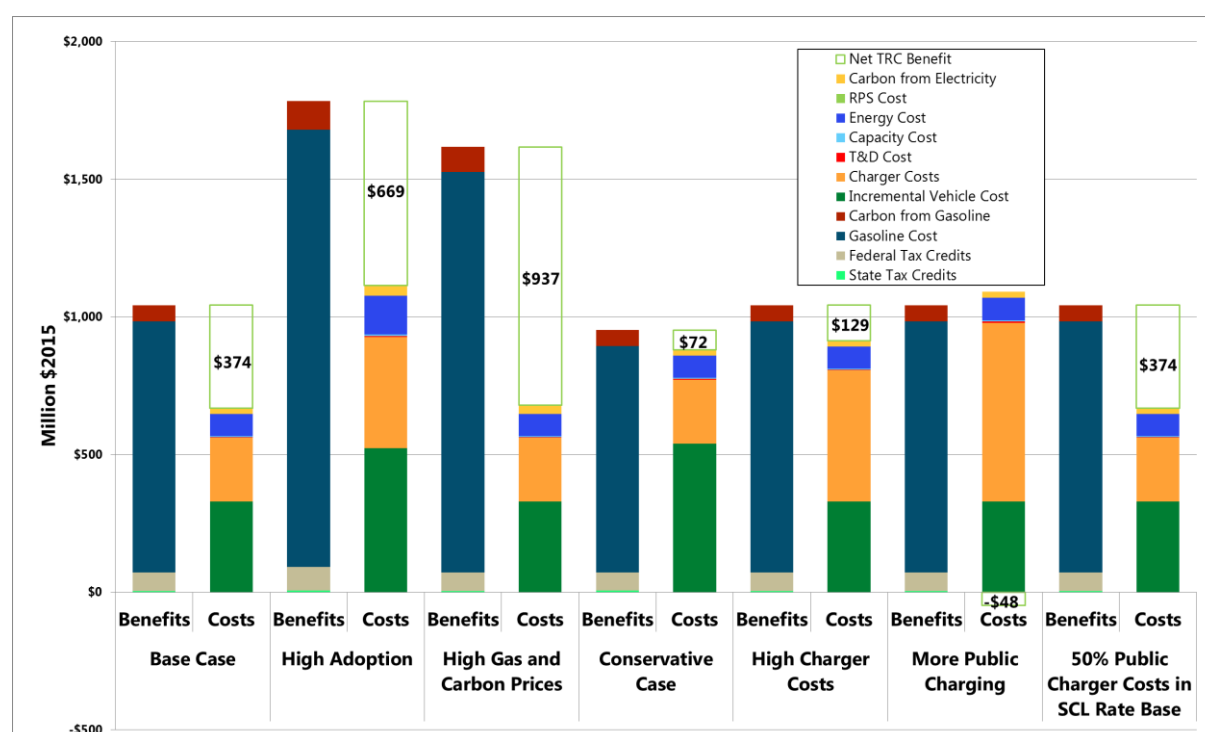


Figure 3. Light-duty PEV societal cost and benefit results by scenario

The **High Gas and Carbon Case** increases gas and carbon prices, which increases the fuel savings benefit for the same number of vehicle miles driven. Since the quantity of carbon saved by reducing gasoline consumption is greater than the quantity emitted by generating more electricity, the increase in carbon prices further increases the net benefit.

The **Conservative Case** reduces the net benefit because higher vehicle purchase prices more than offset the reduced savings from cheaper gasoline.

The **High Charger Cost Case** is identical to the Base Case except for increasing the cost per charger, so net benefits are accordingly reduced in this scenario. The **More Public Charging Case** has the same effect but for a different reason. Instead of increasing the price of an individual charger, this case assumes more public charging stations are built to enable more PEV owners to charge at work.

Finally, the **Rate Base Case** produces results identical to those of the Base Case. This is because it changes who pays for some of the chargers but not the total amount of the charger costs. Since this cost test is looking across the whole economy, shifting a cost between parties does not affect net economic benefit. The difference between these scenarios is reflected in the ratepayer test results.

One result that was consistent across all scenarios is that T&D upgrade costs are very small compared to the other cost components. E3's previous PEV research in California found similarly small T&D results [8]. The T&D costs incurred by any particular utility will depend on the amount of capacity available on its distribution grid. Distribution-constrained utilities will likely see higher T&D costs than utilities with a substantial amount of unused capacity.

One factor that boosts PEV cost-effectiveness in Seattle is the relative cost of gasoline and electricity. SCL's electricity mix is over 90% hydropower, a source of electricity that is both low-carbon and very low-cost compared to most other generation sources [5]. Being able to replace gasoline expenditures with unusually low-cost electricity gives PEVs a cost-effectiveness boost in SCL's territory that would not occur in areas that rely on more expensive generation sources for their electricity.

3.2 PEV adoption benefits the general body of utility ratepayers

While the societal test demonstrates that PEVs can produce net economic benefit, a net economic benefit does not say anything about the impact that PEVs will have on utility rates and ratepayers. We therefore test cost-effectiveness from the ratepayer perspective as well. Figure 4 (see next page) shows the ratepayer results for the same seven light-duty PEV scenarios, again using a TOU rate.

All scenarios except for the Rate Base Case show a net ratepayer benefit, meaning that they bring in more revenue for utility than they incur costs. The **Base Case**, **Conservative Case**, **High Charger Cost Case** and **More Public Charging Case** produce identical ratepayer results. This is because the differentiating factors between these cases are cost components such as fuel and vehicle costs that are borne by the PEV owners rather than the utility, and are thus not included in the ratepayer test.

The net ratepayer benefit shows us how much a utility can invest in a revenue-neutral PEV program. For example, in the **Base Case**, the net ratepayer benefit means that over the lifetimes of all PEVs adopted through 2030, PEV owners are paying a present value of \$83 million more in electricity bills than SCL is spending on producing electricity to serve the PEV load. SCL can therefore invest up to present value \$83 million in incentivizing PEVs without imposing any cost on ratepayers who do not own PEVs.

The **Rate Base Case** is the only scenario in Figure 4 that produces a net ratepayer cost. Covering 50% of all charger costs would not be a revenue-neutral strategy for SCL. We found that revenue neutrality could be preserved if Seattle City Light paid approximately a third of the cost of total charger needs.

Revenue neutrality may not be an appropriate criterion when considering utility investment to promote electrification. There are cases, such as energy efficiency programs and incentives for distributed energy resources, in which regulators have allowed utilities to institute programs that are a net cost to ratepayers. Market transformation is the usual rationale for such ratepayer subsidies. However, even if a utility is planning a program that will not be revenue-neutral, the net ratepayer cost/benefit can help them forecast how much must be charged to the general ratepayer population and how much rates must increase.

Table 3 presents the net present value of ratepayer benefit on a per-vehicle basis. The per-vehicle net benefit is the maximum amount a utility can invest per vehicle while maintaining revenue neutrality. Potential utility programs include direct vehicle purchase incentives, consumer education and outreach, public charging stations, and upgrades to customer premises to accommodate charging equipment [9]. Though buses and forklifts are not included in the results shown in Figures 3 and 4, we performed a separate analysis for these vehicles that produced the results in Table 3.

Table 3: Ratepayer benefit on a per-vehicle basis

Vehicle	Maximum per-Vehicle Incentive (net ratepayer benefit)
LDV BEV	\$1,250
LDV PHEV	\$1,177
Bus	\$120,505
Forklift	\$14,668

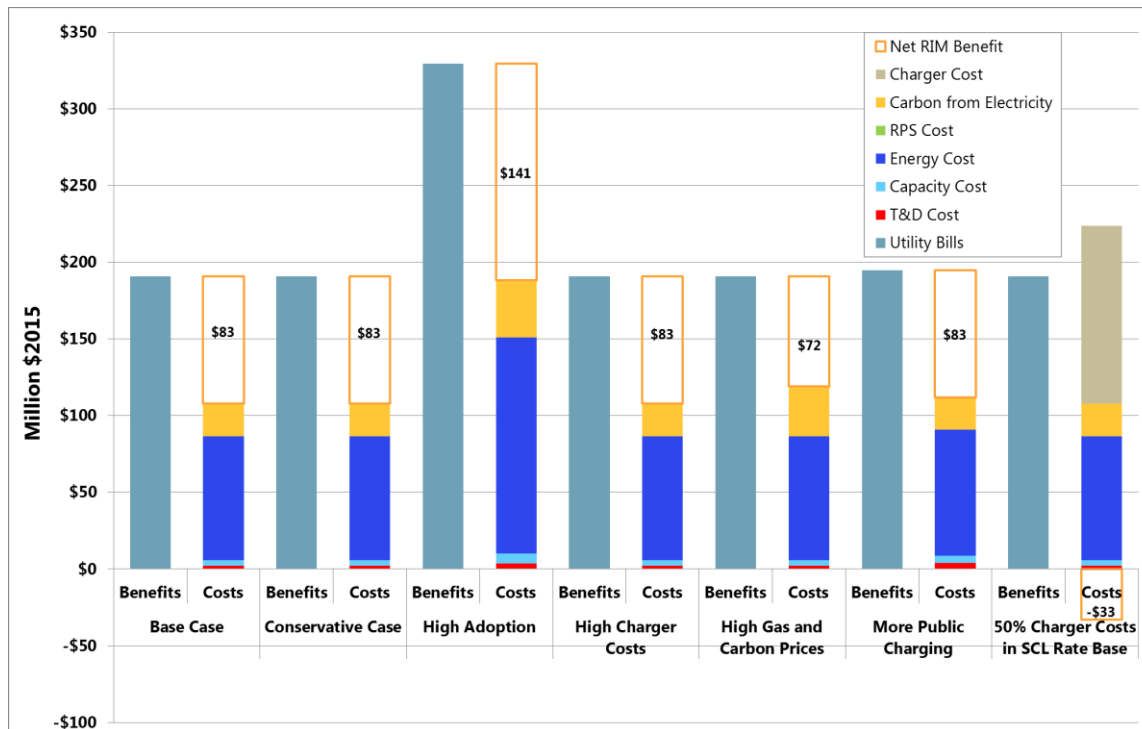


Figure 4: RIM results for Seattle City Light under all scenarios

3.3 Sensitivities and Robustness of Findings

As Figures 3 and 4 demonstrate, PEVs can provide both societal and ratepayer benefits under a variety of conditions. However, both individual cost components and net cost/benefit are more sensitive to some variables than others.

Our results suggest that PEV-related T&D upgrades are relatively small, consistent with E3's previous PEV studies in California. Table 4 shows that for both adoption scenarios, T&D costs account for 2-3% of total utility costs from the ratepayer test under the TOU rate and 9% under the flat rate. The new energy and capacity costs the utility will incur to serve future PEV load will be much larger than the T&D costs.

However, for distribution-constrained utilities concerned with minimizing upgrades, our findings show that T&D costs are more sensitive to rate schedule than to adoption trajectory. For a given adoption scenario, T&D costs are 300-400% higher under the flat rate as compared the TOU rate. By contrast, moving from the base case to the high adoption case while holding the rate schedule constant increases T&D costs by only 40-65%. If minimizing T&D costs are a priority, developing EV-specific TOU rates may be a worthwhile investment. An important caveat on these findings is that we are assuming full participation in the TOU rate schedule, ie a mandatory TOU structure. While many utilities' TOU programs are still voluntary, studies have shown substantial participation in voluntary TOU programs among the PEV owners, both in terms of joining the program and modifying their consumption behaviour [10].

Table 4: Comparison of T&D impacts of changing adoption versus changing rate schedule

Scenario	Rate Schedule	Transmission and Distribution Costs (\$ million present value)	Percent of Utility Costs
Base Case	TOU	\$3,404,856	2.7%
Base Case	Flat	\$14,658,792	8.9%
High Adoption	TOU	\$4,768,691	2.3%
High Adoption	Flat	\$24,157,165	8.8%

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Authors

Dr. Nancy E. Ryan, Partner, E3. Dr. Ryan is a partner at Energy and Environmental Economics (E3), where she leads the electric transportation practice area. She is an economist with over two decades of experience in energy and environmental policy. Prior to joining E3, Dr. Ryan held several high-level appointed positions at the California Public Utilities Commission including Deputy Executive Director for Policy and External Relations (2011-2013), Commissioner (2010-2011), and Chief of Staff to President Michael R. Peevey (2007-2009). During her tenure at the CPUC, Dr. Ryan guided development of California's policies in electric transportation, renewable energy, smart grid, energy storage, and long term planning and procurement. She also worked closely with senior officials from the California Air Resources Board, the California Energy Commission, the California ISO and the Governor's Office to devise strategies to achieve California's ambitious Greenhouse Gas reduction targets and develop regulations implementing California's cap and trade program for the electric sector. Dr. Ryan's career path has also included positions in environmental advocacy and academia. She was a Senior Economist at the Environmental Defense Fund from 2001-2005 and taught applied economics at UC Berkeley's Richard and Rhoda Goldman School of Public Policy from 1996-2007. Dr. Ryan received her Ph.D. in Economics from the University of California at Berkeley and a BA in Economics from Yale University.



Mr. Eric Cutter, Director, E3. Mr. Cutter is a lead analyst at E3 on the costs and benefits of energy storage, distributed generation, and customer load management, working with the Electric Power Research Institute (EPRI), utilities, regulators and technology companies to assess their value for the integration of renewable and distributed generation. Mr. Cutter's prior experience includes 5 year as independent consultant working on energy and water resources and 10 years at Pacific Gas and Electric Company. Mr. Cutter earned a B.A. in Economics and German from Tufts University and an M.B.A. and an M.S. in Energy and Resources from the University of California, Berkeley.





Ms. Hilary Staver, Associate, E3. Ms. Staver joined E3 in 2014 after completing her Master of Environmental Science degree at Yale University. Her work at E3 focuses on distributed energy resource valuation, retail rate design, and energy policy analysis. She has significant experience in the field of transportation electrification, including cost-benefit analysis of emerging technologies, grid impact modeling, and incentive program design. She is a major contributor to Phase 3 of the California Electric Transportation Coalition's Transportation Electrification Assessment. In addition, she has worked with Seattle City Light, the Energy Foundation, the Electric Power Research Institute, and other clients to help utilities predict and prepare for the impacts of widespread adoption of electric vehicles.



Mrs. Ashley Horvat, VP Strategic Initiatives, Plugshare. Mrs. Horvat joined PlugShare in April 2015 to launch PlugShare Guide, a new PlugShare consulting division. Prior to joining PlugShare, she served as the State of Oregon Chief EV Officer and designed and implemented the West Coast Electric Highway program in Oregon. She has worked extensively over her tenure working with other states to develop DCFC implementation strategies and fundamentally understands what it takes to translate a vision into a reality by tapping into her core competencies such as managing large and diverse teams, strategic acumen, big picture thinking with detail-oriented comprehension, and connecting the user needs and experiences with technical, practical requirements and data.



Mr. Brendan O'Donnell, Energy Planning Supervisor, Seattle City Light. Mr. O'Donnell is an energy planner with the newly-formed Customer Energy Solutions team at Seattle City Light. He is responsible for resource planning, analysis, and strategy for the utility's energy efficiency, distributed renewables, and electric transportation programs. Prior to joining City Light, Brendan held positions at Rocky Mountain Institute and EES Consulting.