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Quantifying the Societal Benefits of Electric Vehicles

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Summary

One of the barriers facing the electric vehicle market is the incremental cost of the vehicles. However, many of the benefits of electric vehicles are not well understood and are omitted from cost-benefit analyses. These benefits relate to human health, air quality and the environment, economic growth, and grid resilience. VEIC conducted a study to identify the broad range of benefits that electric vehicles provide and, where sufficient data exists, developed estimates to quantify these benefits. Assessing the value of these benefits provides guidance for policy-makers to determine incentive and investment levels that accurately reflect the full value of electric vehicles to society.

Keywords: environment, health, policy

1. Background

This study adapts the established framework for assessing the costs and benefits of energy efficiency programs to Electric Vehicles (EVs). Utility programs to reduce consumer demand for electricity have been in operation for decades. Because these programs are operated by regulated utilities and are supported by ratepayer funding, they are subject to rigorous cost-benefit analysis. As shown in Table 1, there are currently five main cost-effectiveness screening tests used to evaluate energy efficiency programs. Each test values certain criteria. The test a state utility commission selects for cost-effectiveness screening is a reflection of the jurisdiction's policy priorities.

Table 1: Energy Efficiency Cost-effectiveness Screening Tests [1]

Test	Perspective	Key Question Answered
Participant Cost Test (PCT)	Program participants	Will program participants benefit over the measure life?
Program Administrator Cost Test (PACT)	Program administrator	Will program administrator costs (and utility bills) increase or decrease?
Ratepayer Impact Measure test (RIM)	Nonparticipating ratepayer	Will utility rates increase?
Total Resource Cost test (TRC)	Stakeholders in service territory	Will the total costs of energy in the utility service territory increase or decrease (regardless of who pays the costs and how receives the benefits)?
Societal Cost Test (SCT)	General public	What are the overall benefits to the community of the energy efficiency program portfolio, including indirect benefits?

With $9.94 billion in efficiency investment budgeted in the U.S. and Canada in 2015 [2], the cost-effectiveness test selected by a jurisdiction can have a significant impact on the design, priorities, and outcome of energy efficiency programs. Some states or jurisdictions use more than one test, often designating a primary test and a secondary test. For the purposes of this analysis, we will focus on the

societal cost test because it incorporates broader impacts and benefits of funding decisions. Billions of dollars of investment decisions are based on the outcome of this test.

The societal cost test is used in six states as the primary cost-effectiveness screening test. While this makes up only about 15 percent of efficiency programs, states that use other tests (including the most popular test, the TRC test) often include environmental impacts as part of their regulatory screening process [3]. In assessing a program's benefits to society, a number of non-energy impacts are taken into consideration, measured and quantified (if possible).

Over the years, researchers have developed a framework for dividing the benefits of these programs into three categories based on the beneficiary: 1) utilities, 2) participants, and 3) society. Examples of utility benefits include reduced terminations, reconnections and arrearages, more stable energy prices, a more resilient and reliable energy system, lower transmission and distribution costs, and utility insurance savings. Participant benefits include increased property value, aesthetics, comfort, safety, and noise reduction. Societal benefits include reduced healthcare costs, job creation benefits, and environmental benefits.

When examined in the context of the societal cost test, electric vehicles offer similar benefits. For utilities, EVs can serve as an additional revenue source that provides flexible and interruptible load. As the EV market expands and as technology advances to include bidirectional charging, EVs could provide valuable grid resources. Participant benefits include reduced energy and maintenance costs for EV operators. Societal benefits are benefits that affect society as a whole, often through the reduction of negative externalities such as environmental or health impacts. They are not paid for by the energy provider or vehicle operator. They are captured from society though socialized costs such as healthcare expenses and taxes. Societal benefits for EVs include national security benefits, better air quality and health, domestic economic development and environmental benefits.

2. Methodology and Assumptions

This research study applies this established model for evaluating clean energy programs to the evaluation of electric vehicles using the Societal Cost Test. Seven benefits were quantified in this study to create a more complete picture of the true costs and benefits of an electric vehicle. Instead of simply comparing the sticker prices of an electric vehicle with a conventional gasoline vehicle, this analysis includes fuels savings, maintenance savings, environmental impacts from reduced CO_2 emissions, health impacts from reduced $PM_{2.5}$ and $PM_{2.5}$ precursors in tailpipe emissions, increased national security through reduced reliance on fossil fuel, economic development benefits, and grid resource benefits from transportation electrification.

Although this study estimates the value of EV benefits within the framework of the societal cost test, it is not a fully executed cost-benefit analysis and should not be interpreted as such. The purpose of this analysis is to identify the various benefits of EVs that are not currently captured and accounted for. The goal of this research is not to put an accurate dollar value on these benefits, but rather to identify the benefits of EVs in a broader context and show the overall magnitude of the benefits of EVs. Ideally, this research will expand the understanding of the range of EV benefits and serve as a tool to policy-makers when contemplating and determining EV incentive levels.

To measure EV benefits against those of a traditional gasoline vehicle, a 2016 Nissan Leaf with a 24 kWh battery pack was selected as the representative electric vehicle as it is the world's best-selling all-electric car. A 2016 Honda Civic 4-door vehicle (equipped with a traditional gasoline internal combustion engine) was used as the baseline or comparison vehicle as it is a popular vehicle comparable in size and function to the Nissan Leaf.

The assumptions used in the valuation and comparison are as follows: Vehicles are both cash purchases. Vehicle lifetime is 10 years (most electric vehicles come with a 10-year battery warranty) and annual mileage is 12,000 miles (average vehicle miles travelled for passenger vehicles) [4] resulting in total vehicle mileage of 120,000 miles. Gasoline prices are assumed to be $2.00 a gallon over the life of the vehicle. The electric vehicle is purchased with level 2 charging equipment which is installed at the EV operator's residence. Both vehicles are driven the same mileage under the same conditions. Electricity costs for charging the vehicle will be 12.36 cents per kilowatt hour which is the average price of electricity for

U.S. residential customers in December 2015 [5]. Again, for the purposes of this analysis, it is assumed that electricity prices will remain stable over the life of the vehicle. The electricity for the vehicle will be obtained by 100% clean renewable generation and will not be generated using fossil fuels. While using 100% clean, renewable generation may not be a realistic assumption in many locations, this scenario simplifies the analysis, highlights the potential benefits of electric vehicles, and sets a goal for which to strive in the electrification of transportation.

The benefits in this analysis are monetized based on existing research and literature. The values in this analysis are estimates and are subject to great variability based on inputs such as gasoline prices, electricity prices, vehicle prices, and other variables, all of which are expected to change multiple times over the 10 year life of the vehicle. For this reason, we did not calculate net present value of the investments or adjust for inflation over the life of the vehicle. All values shown are in 2015$ dollars. Some of the benefits we assessed covered a range of values. In these cases we selected mid-range or conservative values within these ranges to present a balanced analysis. While care was taken to find values that accurately reflect the benefits of EVs assessed in this study, the results of this analysis are simplified to expand the understanding of the scope of EV benefits and are for illustrative purposes only.

3. Analysis

3.1 Fuel Savings

Using the NYSERDA Wattplan calculator [6] and based on the assumptions stated earlier in the paper, fuel savings from driving a Nissan Leaf instead of a Honda Civic are estimated to be $688 each year. Residential electricity consumption will increase for the EV operator, whose electric bill will increase by $275 a year from EV charging. As a result, the net energy savings for the electric vehicle will be $413 per year. Over the 10-year life of the vehicle, this will result in a cumulative savings of $4130 on energy costs. Electricity rates will likely be more stable than gasoline prices which are currently at a 10-year low, so it is very possible that fuel savings will be significantly higher than the value presented here over the 10 year life of the vehicle.

Estimated Fuel Savings Value over Life of Vehicle……..…$4130

3.2 Operations and Maintenance:

Electric vehicles have far fewer moving parts than conventional internal combustion engine vehicles. The battery, motor, and electronics associated with the drive train require no regular maintenance. Oil changes become obsolete and there are no other fluids to change aside from brake fluid. Brakes on an electric vehicle require less maintenance than brakes on a conventional car since wear on the brakes of an EV is significantly reduced due to regenerative braking [7].Table 2 summarizes an article published by *Inside EVs* that itemized the maintenance cost savings of owning and operating an EV [8].

Table 2: Maintenance Costs over First 100,000 miles

Service/Maintenance	Traditional Vehicle	Electric Vehicle
Tires	$700	$700
Oil Change (every 5,000 miles)	$600	0
Automatic Transmission Fluid	$ 60	0
Spark Plugs and Wires	$200	0
Muffler	$180	0
Brakes	$400	$200
Total	$2140	$900

Based on **Table 2**, maintenance savings for an EV in the first 100,000 miles would be $1240. This number is adjusted using a multiplier of 120% to account for the additional 20,000 miles needed to reach the 120,000 miles used in the assumption for the mileage over life of the vehicle, yielding a value of $1488.

Estimated Maintenance Savings over Life of Vehicle…….……..…..$1488

3.3 Impact of Carbon Emissions on the Environment

Burning gasoline produces carbon dioxide (CO_2) which is a greenhouse gas linked to climate change. The U.S. Environmental Protection Agency (EPA) and other federal agencies use the Social Cost of Carbon (SCC) to estimate climate benefits of CO_2 emissions reduction. The value of the SCC is intended to capture the expense of climate change damages from carbon emissions including changes in net agricultural productivity, human health, property damages from increased flood risk, and changes in energy system costs, such as reduced costs for heating and increased costs for air conditioning [9]. It is widely accepted by researchers that this value fails to capture all of the economic, ecological, health, and physical damages linked to climate change because some of the damages are difficult to precisely identify and quantify [10]. In addition, models do not incorporate all of the damages identified in the literature. Based on the technical support document prepared by the U.S. government interagency working group on Social Cost of Carbon, in 2015$, the SCC per ton is $42.30 [11].

A wide range exists in valuation of the estimated social cost of carbon. While it is accepted that the EPA number omits certain damages, researchers continue to try to ascertain a more comprehensive value. Researchers at Stanford recently modified an Integrated Assessment Model (IAM) to account for substantially slower economic growth rates associated with climate change, which impact poor countries most profoundly. They came up with a new estimate for the social cost of carbon at $220 per ton [12]. The findings of this study support increased investment in carbon reduction, according to study co-author Delavane Diaz, "If the social cost of carbon is higher, many more mitigation measures will pass a cost-benefit analysis. Because carbon emissions are so harmful to society, even costly means of reducing emissions would be worthwhile [13]."

Choosing to drive an electric vehicle (Nissan Leaf) instead of driving a comparable gasoline powered vehicle (Honda Civic) will result in a carbon emissions reduction of about 4,096 pounds per year [14]. Based on the Stanford estimate for the social cost of carbon, the value of reduced carbon emissions over the 10 year life of the vehicle would equate to roughly $4506. While there are compelling arguments supporting higher estimates for the social cost of carbon, in this assessment of the value of reduced carbon emissions from operating an electric vehicle, we have chosen to use the conservative EPA value. Over the 10 year life of the vehicle, this results in savings of a little over 20 tons of carbon which translates into avoided costs of $866 using the EPA social cost of carbon value.

Estimated Environmental Benefit over Life of Vehicle…….……...$866

3.4 Health Impacts

According to the EPA, fine particle pollution such as that found in vehicle tailpipe emissions [15]:

- Causes early death (both short-term and long-term exposure)
- Causes cardiovascular harm (e.g. heart attacks, strokes, heart disease, congestive heart failure)
- Is likely to cause respiratory harm (e.g. worsened asthma, worsened Chronic Obstructive Pulmonary Disease (COPD), inflammation)
- May cause cancer
- May cause reproductive and developmental harm

In addition, autism spectrum disorder (ASD) and low birthweight of infants have been linked with fossil fuel emissions [16]. Those *most* susceptible to health risks from fine particle pollution include infants, children and teens [17][18]. Children are more vulnerable to health impacts from emissions because of their physiology, because they are growing, and because they have higher breathing rates [19]. These source-

based emissions can be reduced entirely by transitioning to an electric vehicle powered by clean renewable energy.

To determine an estimate of the avoided health costs of switching to an electric vehicle, two separate methodologies were employed. The first methodology used data from a National Academy of Sciences publication, *Hidden Costs of Energy: Unpriced Consequences of Energy Production and Use* [20]. The estimates in this study relied on the GREET model developed by Argonne National Laboratory and sponsored by the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy. The National Academy of Sciences study employed this model to estimate emissions per vehicle mile travelled and determine health damages from non-greenhouse gas emissions. The study estimated non-climate damages to be 1.38 cents per vehicle mile travelled (VMT). This value was multiplied by the 120,000 miles over the life of the vehicle and adjusted to 2015$. The health impacts over the 10 year life of a conventional light-duty automobile amounted to $1893.01.

The other methodology employed to determine the value of health impacts of internal combustion engine vehicles used EPA passenger car emissions averages for NO_X and $PM_{2.5}$ and multiplied the quantity of these emissions from each vehicle by dollar values determined in other studies to account for morbidity and mortality associated with directly emitted $PM_{2.5}$ and $PM_{2.5}$ precursors from on- road mobile sources [21]. A mid-range value of 1.48 cents/VMT was used from this technical support document, and over the course of 120,000 miles, resulted in a socialized cost of $1,477.61.

Due to the varied sources for the data and different methodologies for calculating the results, a mid-range estimate of $1686.00 is used to monetize the health benefits of driving an electric vehicle fuelled by clean energy over the course of 10 years and 120,000 miles.

Estimated Health Value over Life of Vehicle……...$1686

3.5 National Security

Again, a wide range of estimates exist regarding the impact of gasoline and oil dependence on U.S. national security. Estimates of national security externalities associated with acquiring a gallon of gasoline range from approximately 95 cents/gallon [22] to nearly $4.00/gallon [23]. In 2014, 35% of U.S. petroleum imports were purchased from OPEC countries and 20% were purchased from Persian Gulf countries. Overall, 27% of the petroleum consumed in U.S. came from foreign sources [24]. The National Defense Council Foundation estimated that in 2006, oil-related security externalities cost $825 billion per year adding $8.35 per gallon to oil refined in Persian Gulf [25]. In 2010, U.S. spending on military operations in the Persian Gulf to secure the safe delivery of oil cost the equivalent of an extra $1.17 per gallon of gasoline from that region [26]. The Institute for the Analysis of Global Security estimates that $50 billion is spent each year to support military operations to protect access to Middle East oil [27].

In addition to the costs of military operations necessary to secure this energy source, costs that are incurred, but are not accounted for in the price of gasoline include the higher cost of oil that results from the U.S. demand on world oil price and on OPEC market power (demand) as well as costs incurred from the disruption of the U.S. economy from oil price and supply volatility (macroeconomic disruption and adjustment costs) [28]. Other costs associated with foreign oil supply include vulnerabilities in supply, regional instability and military conflict resulting from dramatic wealth disparities resulting from oil distribution and control, and lack of accountability, free-markets and democratic reform in oil wealthy governments.

The most conservative study reviewed in this analysis was the joint technical support document for the final rulemaking for 2017-2025 Light-Duty Vehicle Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standards developed by the U.S. Environmental Protection Agency Office of Transportation and Air Quality and the National Highway Traffic Safety Administration of the U.S. Department of Transportation published in 2012. This study established energy security premiums per barrel of oil of about $18 [29], since each barrel of oil yields about 19 gallons of gasoline, these premiums equate to 95 cents per gallon of gasoline. Based on the Wattplan Calculator [30], driving an EV will save about 344 gallons of gas a year, which is 3440 gallons over the life of the vehicle. When this 3440 gallons is multiplied by the 95 cents per gallon national security premium, the national security savings from owning an EV is $3268.

This number does not include costs associated with U.S. military operations to secure stable oil supplies from volatile regions of the world. Neither does this estimate take into account the human cost of U.S. military operations protecting oil imports. Therefore this is a very conservative estimate and does not capture the entire value of reducing oil dependency through the use of an electric vehicle.

Estimated National Security Value over Life of Vehicle……...$3268

3.6 Economic Development

A number of studies have been conducted to examine the economic impacts of the electric vehicle industry. As with any change, the transition to a transportation sector powered by electricity will have both winners and losers. Widespread adoption of EVs will result in job losses in the oil industry, at gas stations, and possibly in the auto maintenance and mechanic industry (EVs need far less maintenance than conventional gasoline and diesel vehicles). However, direct jobs will be created in the auto industry in manufacturing, research and development, and battery manufacturing. Indirect jobs will result from installation and maintenance of electric vehicle supply equipment (EVSE).

In addition to direct and indirect job creation, electric vehicles cost less to maintain and operate. Every dollar not spent on gasoline, or oil changes, or transmission fluid has the potential to go back into the local economy. According to the U.S. Energy Information Administration, over 80 percent of the cost of a gallon of gas immediately leaves the local economy [31]. By reducing gasoline expenditures, more money will stay local and boost the local economy. A study by the California Electric Transportation Coalition found that each dollar saved from gas spending and used to purchase other household goods and services generates 16 jobs in the state [32]. New Yorkers City residents drive much less than the average U.S. metro resident, which keeps $19 billion each year flowing within the local economy [33].

A study in Oregon conducted an analysis (performed by the Northwest Economic Research Center) and found that, "…Every time an Oregon driver purchases an EV rather than a gasoline or diesel-powered vehicle, that driver is pumping more money back into Oregon's economy, creating jobs and increasing state and local tax revenue. We estimate impacts for several common scenarios, concluding that each such vehicle decision can increase state and local tax revenue between $426 and $1,503 over a ten-year period, under today's conditions [34]." There are limited analyses that estimate a per vehicle economic benefit of driving an EV. For the purposes of this research we will adopt a mid-range value of $965 from this study to represent the economic development benefit on the local economy of driving an electric vehicle.

Estimated Economic Development Value over Life of Vehicle……...$965

3.7 Electric Vehicles as a Grid Resource

Electric vehicles serve an important transportation function, but, they are typically in use for mobility less than 5% of the time [35][36]. This limited use, coupled with the storage capability of EV batteries means that EV load on the grid can be flexible and also serve as a storage or regulation resource for the grid. The U.S. electric grid has extremely limited storage capacity. Thus every time electricity demand increases, generation must immediately increase to meet this demand. Because of their batteries, electric vehicles can store small amounts of electricity in their batteries and effectively decouple electricity generation from demand. This could benefit vehicle owners, distribution utilities, and regional transmission operators in a number of ways.

At the most basic level, electric vehicle charging can be managed so that the impact on the grid is minimal. Charging can be managed either through voluntary adoption of utility-offered time-of-use rates that reward off-peak charging (indirect control) or it can be managed through utility-controlled charging signals (direct control). This type of management would result in minimized additional load and grid impact from EVs as well as greater energy cost savings for EV owners and operators. Demand response programs are another area in which EVs can bring value to the electric grid. An aggregated group of EVs can respond to a signal from utilities or regional transmission operators to curtail charging at critical times to avoid high power prices or grid reliability issues. Participants in demand response programs can receive compensation from the regional transmission operator or distribution utilities that offer Demand Response programs.

Electric vehicles can also be used for energy arbitrage. By storing energy purchased during off-peak times and selling it back to the grid or using it to power home energy use (behind-the-meter) during peak load, EV owners or operators can save money, or even make money by storing energy. The storage capabilities of EVs also make them candidates for renewable load following, which means that they can capture and store excess solar or wind power at the time of generation and make it available for use during times of high demand.

The most advanced form of vehicle-to-grid integration involves wholesale market opportunities. EVs equipped with bidirectional chargers could best serve in the ancillary services markets of the regional transmission operator. EVs have the potential to provide Regulation, Operating Reserves, Energy Imbalance and Voltage Control [37]. All of these services require small amounts of storage, but near-instantaneous response to grid signals. They also require bidirectional chargers, which are not installed in EVs on the market today.

Studies and demonstration projects at the University of Delaware provide the most comprehensive accounting of the value an EV providing wholesale grid services might have. A 2001 study by Kempton et al. calculated the vehicle owner's annual net profit from Vehicle-to-Grid (V2G). Table 3 shows representative midrange figures extracted from the full analysis in the report [38].

Table 3: Vehicle owner's annual net profits from Vehicle-to-Grid (V2G). Key: $net (revenue-cost)

	Peak Power	Spinning reserves	Regulation Services
Battery full function	$267 (510 – 243)	$720 (775 – 55)	$3,162 (4479 – 1317)

A number of studies have developed estimates of the income an EV can produce for its owner when serving as a grid resource. Initial studies estimate that electric vehicle owners can make $300 to $500 per year through V2G. The most lucrative wholesale market (and perhaps the best fit for EV batteries) is the frequency regulation market. According to an article by Ferber, it is possible that electric vehicles can earn up to $5,000 a year in frequency regulation markets [39]. Ferber goes on to point to the example of the Nuuve Corporation, a leading V2G pilot program, is currently testing 30 electric vehicles for the frequency regulation market in Denmark and expects to pay electric vehicle owners up to $10,000 over the lifetime of the car.

There are a few barriers to widespread integration of EVs in wholesale electricity markets. As mentioned earlier in this section, EVs do not come equipped with bidirectional chargers. This means that in order to enable an EV to serve in a capacity that requires bidirectional charging, the EV must be retrofitted with a bidirectional charger. Under current manufacturer's warranties, this will void the warranty on the battery. The other challenge with wholesale market opportunities is that they require a minimum resource size. In some ISOs this resource is 1 MW. This would require at least 300 electric vehicles to be aggregated into one resource. Electric vehicle adoption in most places has not reached the point where this is feasible. With these barriers in mind and for the purposes of our analysis, we will adopt a mid-range estimate of $4000 over the life of the vehicle to identify this potential revenue source and include it in Figure 1, but represented in a grey pattern to indicate that the market is not yet mature enough for widespread participation of EVs in wholesale electricity markets.

Estimated Grid Resource Value over Life of Vehicle……...$4000

3.8 Difficult to Quantify Costs and Benefits

The research determined that not all identified benefits of electric vehicles are quantifiable, but many provide value in marketing electric vehicles and in contributing to a broader understanding of the benefits of transportation electrification. For example, quieter operation and increased driving performance associated with electric drive vehicles is difficult to quantify, but does have some value. Other benefits, like avoiding 400 trips to the gas station [40], are difficult to quantify, but may help inform a buyer's decision to purchase an EV. In addition to the value of serving as a grid resource, EVs could be used to improve grid resilience by creating microgrids and grid islands that could be relied upon in emergencies and weather disasters. This value is also not included in this analysis, but should be recognized as having value.

Also not included in the estimates are insurance costs. The research provided mixed results on insurance costs of electric vehicles versus comparable gasoline vehicles. A 2014 study released by *Coverhound* indicated that on average it cost $200 less a year to insure an electric car than a comparable internal combustion engine (ICE) vehicle. The article attributes this difference to the concept that insurance companies may view electric vehicle drivers as more responsible and less likely to make traffic violations or get into accidents [41]. However, independent research conducted by myself, determined that quotes provided from an insurance agent on a Nissan Leaf and Honda Civic were nearly identical. Depending on the vehicle model and driver information, it may cost less to insure an electric vehicle.

Just as there are benefits that are difficult to quantify, there are some negative implications of EV ownership that should be noted to present a balanced analysis. Range limitations are a significant deterrent to EV adoption. For many households, especially rural households without access to public transportation, the purchase of an EV means that a gasoline vehicle would need to be purchased, rented, or retained for long trips or commutes. EV charging infrastructure is still not robust enough to entirely alleviate range anxiety in most regions. In addition, not all vehicle types come in electric models. The most popular vehicle type in the United States is the pickup truck [42]. There is currently no all-electric pickup truck available on the market. Again, while it is difficult to quantify these "costs", they exist and affect consumer decisions about vehicle purchases.

4. Conclusions and Next Steps

4.1 Conclusions

Figure 1: Compiled EV Benefits over 10 Years & 120,000 miles

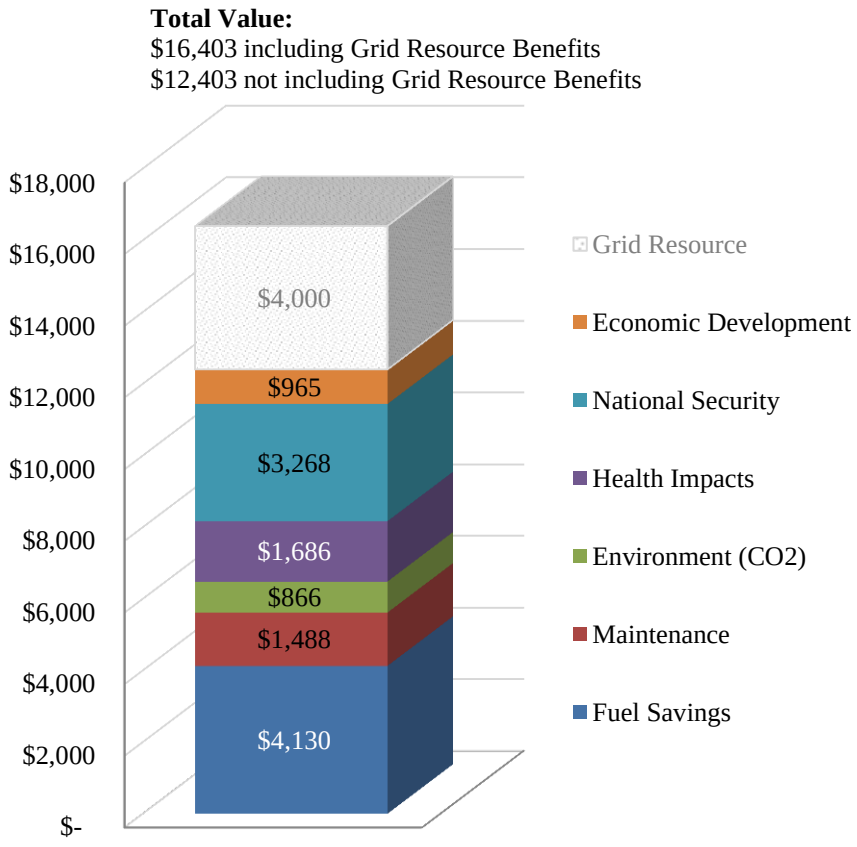

Figure 1 illustrates the aggregated benefits of an electric vehicle over its life. The maintenance and fuel savings of the EV (totalling $5,618) are participant benefits and are realized by the vehicle owner. The environment, health, national security and economic development benefits (totalling $6,785) are societal benefits which are dispersed throughout society and not currently captured and realized directly by any single party. The EV owner creates this value to society by choosing and driving an EV, but does not receive compensation for this value. For this reason, this analysis provides a useful tool for policymakers to identify and capture the broader benefits of EVs and facilitate the appropriate incentive values to reflect a more accurate value of EVs and leverage that value to reduce the incremental cost of EVs in the marketplace.

Grid resource benefits are estimated and included in this analysis, but are not currently available to utilities and EV owners through bidirectional charging. They are explained in the text, and are shown in figure 1, but should not yet be taken into consideration when weighing the costs and benefits of purchasing an EV. As a result, one should conclude that the cumulative benefits of owning and operating an EV for 10 years are estimated at roughly $12,403 without taking into account government incentives.

When comparing the cost of purchasing an electric vehicle to a traditional gasoline vehicle, one would also want to consider additional costs on the electric vehicle side (an installed level 2 charging station - roughly $1000) as well as additional benefits (federal incentives -$7500). As Table 4 illustrates, while the cost of our sample gasoline-powered vehicle may initially appear to be less due to a lower purchase price ($18,640 for the Civic vs. $29,010 for the Leaf.), accounting for the operation and maintenance savings as well as the socialized costs of a traditional gasoline vehicle results in the 10 year cost of the Nissan Leaf as being $8,533 less than the Honda Civic. This number is based on current benefits and excludes benefits that may be available in the future such as grid resource benefits. It is important to note that these benefits are not all returned to the vehicle purchaser. The societal benefits in particular are spread out over a broad population and are more difficult to capture.

This exercise of applying the Societal Cost Test framework to an electric vehicle as an investment has helped us develop a better understanding of, 1) the full suite of electric vehicle benefits, 2) the extent to which these benefits have been quantified in the literature, and 3) gaps in quantifying these benefits. Results from this study should provide a tool for policymakers to use in determining appropriate investment and incentive levels for electric vehicles. Appropriate investment and incentive levels for electric vehicles, in turn, will promote market transformation and facilitate the electrification of the transportation sector.

Table 4: Total Ownership Cost over Life of Vehicle

	Nissan Leaf	Honda Civic
Vehicle Cost	$ 29,010	$18,640
Charging Station Cost (including installation)	$ 1,000	0
Federal Incentive (U.S.)	-$ 7,500	0
Energy Costs	$ 2,750	$ 6,880
Socialized Environmental Costs (CO2)	0	$ 866
Socialized Health Costs	0	$ 1686
Economic Development Benefit	-$ 965	0
National Security Costs	0	$ 3,268
Maintenance	$ 1080	$ 2,568
Total 10 Year Cost to Owner and Society	**$25,375**	**$33,908**

4.2 Next Steps

The numbers in this analysis will be subject to constant change due to fluctuations in gas prices, electricity generation mix, international political environment, market fluctuations and battery and vehicle technology

improvements. In addition to updating this analysis as these variables change and as more EVs enter the marketplace and obtain greater market share in the transportation sector, there are a couple of projects and analyses that could provide additional information to support this analysis and contribute to future research endeavours.

1. A geographic analysis that incorporates electricity generation mix into the study (as well as their associated health and environmental impacts) to provide net benefits should be layered onto this analysis to provide a more realistic assessment of the environmental and health benefits of EVs in different regions of North America. As written, this study over-simplifies the analysis by assuming that the electricity is generated by clean, renewable resources with no fossil fuel emissions. This is currently not a very realistic scenario in much of North America. In Vermont or Quebec, electricity generation produces almost no harmful air pollution, whereas in some mid-Atlantic and mid-western states, where coal is the predominant fuel used in electricity generation, health impacts are estimated to be as high as 71 cents/kWh [43]. A study conducted by the Union of Concerned Scientists found that electric vehicles in tandem with a progressively cleaner electric grid are an important element in addressing climate change. They found that even in areas where electricity generation is coal intensive (resulting in high in CO_2 and $PM_{2.5}$ emissions), electric vehicles still result in at least a 34 mpg fuel economy equivalent [44]. Providing net benefits as part of this accounting would present a more complete analysis and should be considered as a next step.
2. Another useful analysis based on this work would be to better represent the range of values within each estimate by providing high-case scenarios and low-case scenarios. This would help demonstrate the significant range in quantified benefits.

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