Measure for Measure: Using the energy utility model to standardize evaluation of transportation efficiency measures

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Justine Sears (corresponding author)
Karen Glitman
Greg Fanslow

jsears@veic.org
Vermont Energy Investment Corporation
128 Lakeside Ave.
Burlington, VT 05401
(802) 658-6060

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ABSTRACT

As the environmental and financial costs of conventional gasoline become more apparent, there is growing interest in the concept of transportation efficiency. Broadly, this concept involves using less energy to meet current travel demand and often employs a systems-level approach. The transportation sector has much to learn from the electric and thermal energy sectors, where demand management strategies have used established screening tools to assess the environmental and financial benefits of efficiency measures for years. Adoption of such screening tools may be ideal for the transportation sector as electric vehicles (EVs) bring these two sectors together. We present an example of how the Vermont State efficiency screening tool can be used to evaluate a transportation measure: a switch from a conventional vehicle to an electric vehicle. The screening tool results demonstrate that the estimated cost benefits of electric vehicles varies from -$15,911 to $24,645, depending on the model of EV, miles driven annually, and externalities considered, among other factors. The cost effectiveness of EVs was improved by including avoided health costs due to reduced tailpipe emissions. More broadly, our results show that cost-effectiveness screening tools used within the electric and thermal energy sectors provide a meaningful way to assess potential gains in transportation efficiency and can be used for evaluation of other transportation efficiency measures (such as bicycle and walking infrastructure, transit, etc.). Use of such screening tools will aid in communication and collaboration between the energy and transportation sectors, while facilitating a systems-based approach to transportation planning and demand management.
INTRODUCTION

Over 70% of energy used in the transportation sector in the U.S. is petroleum-based (1). Amidst concerns about the environmental and financial costs of our heavy reliance on these fuel types, an interest in transportation efficiency and sustainability has emerged within this sector (e.g., 2-5). While the meaning of transportation efficiency is still being debated in the literature, efficiency generally refers to performing the same amount of work (or providing the same level of service) while using less energy. Within transportation, potential efficiency measures include mode shift away from single occupancy vehicles, increased vehicle fuel efficiency, and fuel switch away from conventional fuels to compressed natural gas, electric vehicles, and biofuels. Traditional performance metrics used in transportation have often been limited to congestion, level of service, time of travel and safety (6).

While efficiency is a relatively new topic within transportation, its measurement has long been established within the fields of thermal and electric energy. Within these fields, standardized protocols have been developed to evaluate the potential efficiency gains. Oftentimes, some sort of cost-effectiveness test is used to evaluate the environmental and financial benefits of a measure of interest. In assessing cost-effectiveness, these tests calculate net present value to future energy savings, using forecasted energy costs and inflation, among other factors. Tests vary in scope, with some accounting for externalities and benefits to consumers, while others are limited to the financial costs incurred by utilities. Often, these tests are combined into a screening tool to evaluate the overall financial and environmental benefits of a proposed efficiency measure to consumers, society, and utilities. Widely used screening tools include the National Energy Audit (NEAT) developed by Oak Ridge National Laboratory and used by the U.S. Department of Energy (DOE), and the Building Life Cycle Cost, developed by the National Standards Institute.

Adoption of a cost-effectiveness screening tool may be ideal for the transportation sector as electric vehicles begin to merge the electric and transportation sectors. From a utility perspective, an electric vehicle is just another large appliance. Advantages of utility screening tools include: they are already developed and in use, they are widely known and respected within the utility community, they are somewhat standardized across geographies, and they generally undergo a thorough review process by energy utilities and experts in the field. The Energy Efficiency Guidebook published by the Energy Center of Wisconsin (7) classifies these (not mutually exclusive but often complimentary) tests as: (1) total resource cost test, which includes costs to society and the consumer, (2) the societal cost test, which includes externalities not captured by market prices and non-energy benefits (e.g., avoided health costs), (3) program administrator cost test, which calculates the cost of a utility running an efficiency program, (4) the participant cost test, which estimates long term benefits to the consumer, accounting for lifetime costs, maintenance and installation fees and any available incentives, and (5) the rate impact measure test, which examines lost revenue to the utility from reduced energy consumption achieved through greater efficiency. In efficiency measures that may alter patterns of use of electricity and natural gas, any changes in the timing of demand must be considered (peak vs. off peak).

Many states and public energy utilities compile those measures that have been deemed cost effective into an efficiency Technical Resource Manual or TRM (e.g., Pennsylvania Public Utility Commission TRM (8), Efficiency Vermont TRM (9), PepCo TRM (10), Ohio’s Efficiency Smart TRM (11). A TRM can serve as a comprehensive source of approved efficiency measures, providing technicians and analysts...
with estimated savings and relevant calculations. The first efficiency TRM was created in 2000 by the Vermont Energy Investment Corporation, and has since been replicated by energy utilities in multiple states. To date, such manuals only exist for building efficiency measures such as lighting, heating, ventilation, and air conditioning systems and are used by the electric and thermal energy industries and regulators. A transportation TRM would include the results of cost-benefit analyses of those transportation efficiency measures that were deemed cost effective by the appropriate screening tool. Potential measures could include a switch in travel mode, a switch to a more efficient vehicle, a switch in fuel type, or analysis of transportation demand measures such as car share and bike share programs, public transit, walking and biking infrastructure, telecommuting programs, and improved timing of intersection signalization.

In our analysis for this paper, we used the screening tool currently in use by the state of Vermont Public Service Board and the state’s electric utilities, to assess the costs and benefits of a switch from a conventional vehicle to an EV. This screening tool was developed in 2000 and has been used to evaluate the merits of hundreds of proposed efficiency measures in that time. This particular screening tool performs a total resource cost test: it accounts for some costs to the consumer, although the focus of the tool is on societal costs (and benefits).

In recent years there have been a number of papers evaluating the environmental and economic value of electric and hybrid electric vehicles (e.g.,12-15). Results of these analyses have varied, depending on the type of vehicle examined (battery electric vehicle, plug-in hybrid electric vehicle, and hybrid electric vehicle) and the assumed fuel mix of electric power generation (coal, hydropower, nuclear, etc.). While the environmental benefits of EVs have been recognized by multiple studies (16-18), the economic competitiveness and potential societal benefits of this new technology is still unclear. Paul et al. (19) predict that higher gas prices will result in higher penetration rates of EVs and greater reductions in GHG emissions from PHEVs. Crist (12) estimates that while battery electric vehicles would achieve some environmental benefits, in France, overall lifetime costs of EVs remain higher than conventional vehicles, for both consumers and society. Although EVs were estimated to emit fewer greenhouse gas emissions over vehicle lifetime, in most scenarios these environmental benefits were not found to outweigh the higher financial costs required to achieve a fuel switch to electric power. Delucchi and Lipman (18) found that EV battery costs will need to be substantially reduced before these vehicles are economically competitive with conventional vehicles for consumers, specifically, they predict that battery costs will need to be reduced to ~$100/kWh. Recent Department of Energy estimates predict that by 2014, battery costs will drop from current prices of $600+/kWh to $300 kWh (20).

While this research has added greatly to our understanding of the impacts that these new vehicles may have on our society and electrical infrastructure, the preponderance of papers with varying assumptions and estimates can be overwhelming to some of the most important end users, namely policy makers, utilities and transportation planners, regulators, as well as potential EV customers. In this paper we demonstrate how a standardized means of evaluating transportation efficiency measures can bring clarity to end users of the data. Our analysis is limited to pure electric vehicles and does not include plug-in hybrid electric vehicles, such as the Chevrolet Volt and Plug-in Toyota Prius.
METHODS

We used the Vermont state screening tool to compare the lifetime ownership costs of four electric vehicles to comparable models of conventional vehicles. We used both annualized costs of ownership and upfront costs (home charging station installation, vehicle purchase price) to estimate the value of one vehicle model relative to another. This estimated Net Present Value (NPV) in 2012 dollars represents the overall value of one vehicle relative to another, over the course of the vehicle’s lifetime. Avoided costs achieved through future savings (e.g., avoided fuel costs) were discounted at an annual rate of inflation of 3.6%. We assumed vehicle lifetime to be 12 years. We did not take into account the resale potential of vehicles. In our calculations, we included estimated maintenance costs of conventional and electric vehicles, purchase price, current and projected fuel costs (of electricity and gasoline), avoided emissions, costs of home vehicle charging station installation, and increased peak electricity demand (see Table 12 for a more complete list of assumptions). We assumed that travel patterns (captured by annual VMT) would not change with fuel type. We also assumed that the majority of EV charging would occur at off-peak hours and assigned an electricity load profile consistent with residential outdoor lighting (primarily night time charging).

We included one lease option in the analysis: the Honda Fit EV is currently only available for a three year lease, not purchase. Our analysis thus compared the monthly lease rates for the conventional Honda Fit (only estimates for the 2012 model were available) and the Honda Fit EV (model year 2013). In addition, the Honda Fit EV is only available for a 12,000 annual VMT (maximum) lease. Each additional mile driven above 12,000 results in a fee of $0.20. The conventional Fit is available for a 15,000 annual VMT lease for a slightly higher monthly fee. We compared the conventional and EV Fits at 8,000, 12,000 and 15,000 annual VMT, including a $3,000 penalty in the 15,000 mile scenario for the EV model (all other vehicles were compared at 8,000, 12,000 and 16,000 levels of annual VMT).

The screening tool also accounts for greenhouse gas (GHG) emissions of measures under evaluation and assigns a cost to carbon of $80/ton (thus, measures achieving avoided GHG emissions are credited $80/ton while measures increasing such emissions are penalized). Although greenhouse gases are not currently regulated at the federal level and no compliance carbon market exists nationally, this price is meant to account for the externalities associated with global climate change and was derived by estimating the cost of reducing emissions to “sustainability levels” (21).

We modified the Efficiency Vermont screening tool to include estimated health costs associated with the local air pollution of conventional vehicle tailpipe emissions as well as health costs of electricity generation. Traditionally, screening tools have not considered health costs in their calculations, although research suggests that these costs are substantial (e.g., 22-24). Estimates of health costs ranged from $0.01 per mile (23) to $0.69 per mile (24). In our calculations we use the estimate of $0.11 per mile, a midrange cost estimated by McCubbin and Delucchi (22) and adjusted for inflation to 2012 dollars using the Bureau of Labor Statistics Consumer Price Index (the 1990 estimate of health costs reported by McCubbin and Delucchi was $0.067). These estimated costs include health care costs of diseases and health problems aggravated and caused by local motor vehicle tailpipe emissions, including NOx, SOx, and CO.

Based on the mix of electricity used in Vermont, we estimated non-climate air pollution costs associated with the generation of electricity to be 0.025¢ per kWh. This value is a weighted average derived from the
National Research Council (25) and is based on their estimates of non-climate air pollution costs of electricity generation from natural gas ($0.002/kWh) and coal ($0.032/kWh). We weighted these costs in accordance to estimates from the Vermont Electric Power Company (26) and the utility ISO-New England (27) energy sources: approximately 5% of the electricity used in Vermont comes from natural gas and <1% from coal. In contrast, nationally, approximately 23% of electricity comes from natural gas and 45% from coal, resulting in estimated health costs of 1.5 ¢ per kWh.

The U.S. Department of Energy Alternative Fuels and Advanced Vehicles Data Center (AFDC; 28) recently released their own screening tool, called a ‘cost calculator’, that helps consumers compare the purchase and long term ownership costs of both conventional and electric vehicles (including hybrid electric, plug-in electric and pure electric vehicles; collectively we will refer to these vehicles types as EVs). While we used this tool as a guide in our development of a screening tool, a major shortcoming of this tool is that it does not include the estimated cost of a new battery, nor does it have the track record and widespread acceptance of the utility screening tools. Because the battery replacement amount is expected to be substantial (ranging from $5,000-$12,000), we chose to include it in our screening tool. Although battery costs are considered proprietary information by manufacturers and reliable estimates are difficult to obtain, we used an estimate of $300/kWh, based on recent DOE price projections (21). Nissan, the manufacturer of the all-electric model the Leaf has stated that most likely the battery would not need to be replaced all at once, rather components would require replacement gradually, thus the cost to the vehicle owner may be considerably less than the projected amount. However, in our tool we assumed a one-time battery replacement cost after 100,000 miles or 8-10 years, in accordance with manufacturer warranties.

Our analysis did not account for potential reductions in fuel efficiency of EVs during winter months when the battery may be relied upon heavily for heat generation, particularly in northern climates. In contrast to conventional vehicles, EVs do not have large amounts of waste heat to access for heating drivers and passengers. To date, there are few reliable estimates of what this additional energy requirement may be, but it should be considered in future analysis as use of EVs becomes more widespread and more detailed data is available.

Vehicles compared

In our analysis we tried to pair comparable vehicles as much as possible. See Table 1 for a list of vehicles used in our analysis. In some cases this was not always possible, for instance, while the Fit is among the most compact cars on the market, it is larger and more powerful than the iMiEV (the Fit features a 117 horsepower engine and 90.8 cubic feet of interior vs. 66 horsepower and 85 cubic feet of interior space in the iMiEV). The Nissan Leaf, while all electric, similar to the iMiEV, has a larger battery (and more power), in addition to more interior space. Thus, we thought it more appropriate to compare the Leaf to a midsize vehicle, such as the Nissan Versa, rather than compact vehicle. We also include a comparison between the Kia Rio and the all-electric Coda, both sedans with relatively few luxury options. All electric vehicles used in our analysis are eligible for the federal incentive of $7,500, although this was not deducted from the purchase price used in our modeling.

We used the screening tool to run a total of 16 scenarios. We made four vehicle comparisons, including one lease option. Within each comparison of vehicles, we ran four separate scenarios, each of which estimated the cost-benefit of EV purchase (or lease, in the case of the Honda Fit EV) coupled with: (1)
installation of a Level 1 110v home charger; (2) installation of a Level 2 220v home charger; (3) Level 1
installation plus avoided health costs achieved through reduced tailpipe emissions and (4) Level 2
installation plus avoided health costs achieved through reduced tailpipe emissions.

TABLE 1. Vehicle Comparisons used in analysis

<table>
<thead>
<tr>
<th>Conventional Vehicles (MSRP)</th>
<th>Electric Vehicles (MSRP)</th>
<th>Electric Vehicle Battery Size (kWh)</th>
<th>Electric Vehicle Range (miles)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2012 Honda Fit ($15,325) vs. 2012 Mitsubishi i-car (iMiEV) ($29,975)</td>
<td>16</td>
<td>62</td>
<td></td>
</tr>
<tr>
<td>2012 Nissan Versa ($14,670) vs. 2012 Nissan Leaf ($35,200)</td>
<td>24</td>
<td>73</td>
<td></td>
</tr>
<tr>
<td>2012 Kia Rio ($13,600) vs. 2012 Coda ($38,145)</td>
<td>31</td>
<td>88</td>
<td></td>
</tr>
<tr>
<td>2012 Honda Fit ($313-$322/month lease) vs. 2013 Honda Fit EV ($389/month lease)</td>
<td>20</td>
<td>82</td>
<td></td>
</tr>
</tbody>
</table>

TABLE 2. Estimates used to derive lifetime costs and benefits of EV and conventional vehicle use.

<table>
<thead>
<tr>
<th>Input</th>
<th>Estimate</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>MSRP (not including purchase and use taxes)</td>
<td>Varied with model</td>
<td>Manufacturer websites</td>
</tr>
<tr>
<td>Annual Vehicle Miles Traveled</td>
<td>8k,12k, and 16k</td>
<td>2009 National Household Travel Survey (29)</td>
</tr>
<tr>
<td>Cost of level 1 home charging installation</td>
<td>$500</td>
<td>Personal comm. with electricians</td>
</tr>
<tr>
<td>Cost of level 2 home charging installation</td>
<td>$2,200</td>
<td>EV Manufacturer websites</td>
</tr>
<tr>
<td>Cost of battery replacement</td>
<td>$300/kWh</td>
<td>U.S. Department of Energy (20)</td>
</tr>
<tr>
<td>Life of battery</td>
<td>8 years/100,000 miles</td>
<td>Manufacturer battery warranties</td>
</tr>
<tr>
<td>Annual maintenance costs, conventional vehicle</td>
<td>$0.054/mile</td>
<td>American Automobile Association (30)</td>
</tr>
<tr>
<td>Annual maintenance costs, EV</td>
<td>$0.041/mile</td>
<td>Alternative Fuel Data Center (28)</td>
</tr>
<tr>
<td>Health costs of conventional vehicle use/mile (2011 $)</td>
<td>$0.11/mile</td>
<td>McCubbin and DeLucchi (22)</td>
</tr>
<tr>
<td>Societal benefits of reduced fossil fuel emissions</td>
<td>$80/ton CO2eq.</td>
<td>Vermont state screening tool (31)</td>
</tr>
<tr>
<td>Health costs of generating electricity used in Vermont</td>
<td>0.025¢/kWh</td>
<td>National Research Council (25)</td>
</tr>
<tr>
<td>2012 price of electricity</td>
<td>12.8¢/kWh</td>
<td>Vermont state screening tool (31)</td>
</tr>
<tr>
<td>2012 price of gasoline</td>
<td>$26.62/MMBtu</td>
<td>Vermont state screening tool (31)</td>
</tr>
<tr>
<td>EV fuel efficiency</td>
<td>Varied with model</td>
<td>U.S. Environmental Protection Agency (32)</td>
</tr>
<tr>
<td>Gasoline fuel density</td>
<td>0.114 MMBtu/gallon</td>
<td>Argonne National Lab. GREET model (33)</td>
</tr>
<tr>
<td>Conventional vehicle miles/gallon</td>
<td>Varied with model</td>
<td>Manufacturer websites</td>
</tr>
</tbody>
</table>
RESULTS

We were able to adapt the state screening tool to determine the long-term financial and energy efficiency benefits of a transportation efficiency measure: a switch from a conventional vehicle to comparable electric vehicle. The EV models were deemed cost effective by the screening tool in approximately half of the scenarios examined (Figure 1). The Mitsubishi iMiEV, Nissan Leaf, and Honda Fit EV performed consistently well as long as avoided health costs were included in the screening tool criteria. The Coda however was not as competitive, due mostly to this vehicle’s larger batteries and thus higher estimated cost of battery replacement. At present, the screening tool does not account for the added convenience achieved through a larger battery and greater range (a benefit), only the increased price of replacement (a cost). The iMiEV, Leaf, and Honda Fit EV all provided some, albeit small, overall financial benefit over the time periods examined, even without the incorporation of avoided health costs. For the iMiEV and the Leaf these benefits occurred (or increased) with higher annual miles driven. In the case of the Fit EV, there was no benefit above 12,000 miles due to the $0.20 fee assigned to each mile above this VMT level, in accordance with the lease agreement.

Overall estimated benefits varied widely, even within the same vehicle model. The iMiEV at its least cost effective (level 2 home charging, 8,000 annual VMT, and no accounting for avoided health costs) provided negative financial benefits of -$3,546, and its most cost effective (level 1 home charging, 16,000 annual VMT, and avoided health costs included) $24,645, the maximum amount of benefit achieved by any of the EV scenarios considered in our analysis. Similarly, estimated benefits of the Leaf varied widely, from -$8,556 (level 2 home charging, 8,000 annual VMT, and no accounting for avoided health costs) to $22,620 (level 1 home charging, 16,000 annual VMT, and avoided health costs included).

Comparisons of the Coda and the Kia Rio resulted in the greatest negative cost-benefit estimates. Without the inclusion of avoided health costs, benefit estimates ranged from -$11,556 to -$15,911. The Coda did not achieve positive benefits until avoided health costs were included and annual VMT reached 16,000.

Estimated benefits of the Honda Fit EV were much less variable due to the smaller temporal window considered: 3 years vs. 12. Estimates for the Fit ranged from -$4,047 (level 2 home charging, 16,000 annual VMT) and $6,044 (level 1 home charging, 12,000 annual VMT and avoided health costs included).

While incorporation of avoided health costs from tailpipe emissions greatly improved the cost effectiveness of EVs, the air pollution and health costs associated with the generation of electricity used in Vermont were found to be negligible. At 0.025¢ per kWh, these costs amounted to $8-16 over the course of vehicle lifetime, depending on annual VMT. Generally, cost effectiveness of EVs increased with annual vehicle mileage, although the inclusion of avoided health costs had a larger overall effect on cost-effectiveness. Similarly, the type of home charging equipment installed (Level 1 vs. Level 2) had a relatively small effect on overall cost-effectiveness.
FIGURE 1. Screening tool estimated net present value of 12 years of electric vehicle (EV) ownership relative to ownership of a comparable conventional vehicle, and estimated net present value of a three year lease term for the Honda Fit EV relative to a conventional Fit. (A) compares ownership costs of a Mitsubishi iMiEV to those of a Honda Fit; (B) compares ownership costs of a Nissan Leaf to a Nissan Versa; (C) compares ownership costs of a Coda to a Kia Rio; and (D) compares ownership costs of a Honda Fit EV vs. a conventional Honda Fit over the course of a three year lease (Honda Fit EVs are not currently available for purchase). Costs of a residential level 1 (L1) or level 2 (L2) home charging (EVSE) are included in all estimates. Some estimates also include avoided health costs that would be achieved through reduced tailpipe emissions and improved local air quality.
Although there is variation in the financial benefits of EV purchase and use, because these vehicles are more efficient than conventional vehicles, the EV used less energy on an annual basis than the conventional vehicle to which it was compared (Figure 2). In all cases, as annual VMT increased, energy saved increased. We estimate that the greatest gains would be achieved from the Leaf over the Versa, due largely to the fact that the Versa was the least fuel efficient model examined in this study (27 mpg for the Versa vs. 31 mpg for the Honda Fit and 33 mpg for the Kia Rio). The Coda did not achieve the large energy savings seen in other models as annual VMT increased, due to its lower fuel efficiency: 0.46 kWh/mile vs. ~0.3 -0.34 in the Focus, iMiEV, and Leaf.

FIGURE 2. Screening tool estimated energy saved annually by use of electric vehicles instead of an equivalent conventional vehicle. *Honda Fit comparison was done at 8,000, 12,000 and 15,000 annual VMT due to lease stipulations.

DISCUSSION

We found the Efficiency Vermont screening tool to be amenable to evaluating transportation efficiency measures. The economic and environmental benefits of a switch to an EV will vary with the miles driven annually, the type of home charging installed, the externalities included in the analysis, and the mix of electricity used to power the vehicle. A screening tool similar to the one we used in this analysis would be helpful to transportation planning agencies to establish a standardized protocol for evaluation of transportation efficiency measures. In its current form, the screening tool includes costs both to the consumer directly (MSRP, installation costs of home charging stations, maintenance costs), but also externalities, such as air quality and greenhouse gas emissions. The mitigation of such externalities is generally considered to be beneficial to society at large. However consumers may not be inclined to personally pay for such mitigation. Inclusion of such externalities was much of what made the EVs in this study cost effective. In particular, the estimated health costs of tailpipe emissions were sizable ($0.11/mile), adding up to +/- $1,000 annually, depending on the number of miles driven. Consideration of these societal benefits may be useful as a basis for incentive programs to promote EV ownership and use. This method is often used by energy utilities to establish incentives leading to market transformation through more rapid adoption of a new technology with demonstrated long-term efficiency or environmental benefits.
A shortcoming of this particular screening tool is that it does not account for the increased convenience and reduced range anxiety (substantial benefits to many consumers) that accompany larger batteries, only the large financial cost of replacement (estimated to be $9,300 for the Coda). Given the uncertainty surrounding battery cost, it is unclear at present how quickly this assumption may change making these vehicles more economically competitive. Future transportation screening tools should include some mechanism to credit vehicles for this added convenience or include some optional measure of individual travel patterns that may require such an extended range for the vehicle to meet consumer needs. It is important to note that although the Coda did not perform as well as other EVs in our analysis, this vehicle offers a lower sticker price and considerably longer range than that of the Nissan Leaf (73 miles for the Leaf vs. 88 for the Coda).

For many of the scenarios examined, inclusion of avoided health costs made the difference between these electric models result in net benefit instead of cost under higher mileage scenarios. Our results demonstrate that there are substantial gains for society from such a fuel switch away from conventional gasoline and to electricity, including, but not limited to reduced energy use overall, improved local air quality, and reduced greenhouse gas emissions. We conducted preliminary calculations that suggest the purchase of an EV is not yet financially beneficial to consumers, even with current federal incentives in some cases (these incentives of up to $7,500, were not included in the primary cost-benefit analysis conducted for this paper). Although fuel costs are considerably cheaper over the long term (assuming current prices), the initial purchase price, cost of home charging station installation, and possible battery replacement after ~8 years combine to makes lifetime ownership costs of an EV ultimately more expensive by $5,000+ after accounting for the federal incentive, depending on the model and annual miles driven. An exception to this trend was the Honda Fit EV lease option, which we estimated to ultimately be cheaper for the consumer, after accounting for avoided fuel and maintenance costs. Much of the additional cost of EV ownership is driven by presumed battery replacement and new lease options that allow consumers to avoid this cost and permit the federal incentive to be used as a down payment, may make EVs more affordable.

In addition, Level 2 home charging station installation was another aspect that contributed to the relatively high cost of EV ownership. Although many EV manufacturers are recommending that EV owners install Level 2 charging in their homes, prevailing travel patterns revealed by the 2009 National Household Travel Survey suggest that Level 1 charging will meet the needs of most vehicle owners. Average daily VMT per driver is less than 30 miles (Santos et al. 2011), well below the range on any of the vehicles examined in this study, suggesting that people would generally not be plugging in completely depleted batteries and that 8 hours of Level 1 charging would be enough to fully charge their vehicle for the following morning. For those who already have an outlet available, this would bring home charging station installation costs down to essentially zero and substantially reduce it for others, relative to the cost of installing Level 2 supply equipment.

We found that although the health costs associated with local air pollution (tailpipe emissions) were sizable, the health costs associated with the generation of electricity were negligible in our screening of EVs. The mix of electricity used in Vermont is comprised primarily of hydropower, nuclear power, and other renewable sources, all of which produce a relatively small amount of air pollution. In regions with a greater dependence on coal and natural gas, the health costs associated with electricity generation (and thus EV use) will be higher but would most likely remain below estimated health costs of conventional...
vehicle tailpipe emissions. Similarly, Witt et al. (34) project that in California, reductions in tailpipe emissions achieved by EVs and PHEVs will outweigh any additional power plant emissions resulting from increased electrical demand. Much of what is so damaging about conventional vehicle tailpipe emissions is that they often occur in densely populated areas, resulting in high levels of exposure.

The VMT thresholds that we found can be used to develop criteria to identify ideal EV owners (those that will benefit most) and the level of government incentives necessary to make EVs competitive in the market place until manufacturers are able to reduce prices through economies of scale achieved through increased production. The difference between the benefit to society and the true, upfront cost paid by the consumer provides a potential starting point for an incentive program, or at least an indication of how sizable incentives will need to be in order for EVs to be competitive with conventional vehicles.

Our results show the screening tools used by energy utilities can provide a clear and meaningful way for transportation professionals to evaluate potential efficiency measures. Such a screening tool could be modified to provide a standardized means of cost-benefit analysis for any number of transportation efficiency measures, including a comparison of vehicles and fuel types, as in this example, or an analysis of transportation demand measures such as car share and bike share programs, public transit, walking and biking infrastructure, telecommuting programs, and improved signalization. As mentioned earlier, within the electric power industry, the results of screening tools are often complied into Technical Resource Manuals that provide of a comprehensive list of approved measures, demonstrated to be cost effective and provide efficiency gains. This model can be extended to transportation, where a transportation TRM could be used by state DOTs and other agencies that want to evaluate the costs and benefits of transportation efficiency and transportation demand management measures. Our results show that EVs can be cost effective relative to conventional vehicles under some circumstances but also that there is a role for standardized screening tools with the transportation field. Use of these tools will facilitate collaboration and communication between the transportation and energy sectors.

This research suggests that further exploration of utility screening tools for the transportation sector is merited. The Vermont State screening tool, for example can be further tailored to effectively assess transportation efficiency measures, for example the combining and bundling of measures may be especially relevant for transportation. There are a variety of different factors to consider when estimating cost effectiveness: the ratio of cost to benefit, but also the potential for widespread implementation and overall feasibility of a given efficiency measure. For instance, some measures may be deemed cost effective by a given tool or test, but require such large capital investment that they are rendered politically impossible (conversely, if the tool demonstrates substantial return on investment over time, this may provide a strong basis for data-driven decision making and planning). Screening tools provide a reliable means of testing cost effectiveness but not feasibility of implementation, nor estimates of large scale energy and financial savings. In combination with more traditional transportation planning techniques, these tools offer a powerful means of assessing potential efficiency gains.

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Efficiency Vermont Cost-Effectiveness Screening Tool

