The Economics and Future of Electric Powered Automobiles

A Cobb-Douglas utility model of electric vehicle consumption and economic cost of electric vehicle adoption in the United States

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BPRO 29000 - Energy and Energy Policy
December 2015
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Executive Summary

Purpose:
We tested the validity of two main findings from current literature on electric vehicles, which state that:

1. Electric vehicles allow consumers to save money by reducing the need for gasoline.
2. Are environmentally beneficial by reducing carbon dioxide emissions.

Our Findings:

1. **On a microeconomic scale**, electric vehicles currently are not feasible to the representative consumer. We included the cost of the electric vehicle itself, which current literature ignored. The three main factors which would cause an arbitrary rational consumer to value the consumption of an electric vehicle over the consumption of other goods in the economy were the real price of electric vehicles, government incentives, and the difference between the price of gasoline and electricity.

2. **On a macroeconomic scale**, with current used car value and the three microeconomic factors mentioned above, switching all consumers to electric vehicles is not the most cost-effective per dollar method for removing carbon dioxide emissions. A filter over a coal plant is significantly cheaper than having 90 million consumers purchase electric vehicles.

Methods:
To test the two main findings of current literature on electric vehicles, we employed the methods below.

1. **Microeconomic Cobb-Douglas Utility model**: In order to quantify and represent a consumer's microeconomic preferences for purchasing an electric vehicle, we built a microeconomic Cobb-Douglas utility model of a representative consumer with the assumption that his or her preferences would depend on the price of an electric vehicle and a beta value to represent extraneous factors they have.

2. **Macroeconomic Cost-Benefit Analysis**: In order to consider the economic cost and environmental benefit of motivating a consumer to switch to an electric vehicle, we investigated the cost efficiency of reducing carbon dioxide emissions by switching all light duty vehicles to electric vehicles. Using a hypothetical case study in which all regularly-used gasoline powered vehicles became electric, we calculated that it would cost $0.12 per kg of carbon dioxide reduced. By comparing this economic cost to existing data, we determined that promoting widespread use of electric vehicles is not a cost effective way to reduce carbon dioxide emissions.
Introduction to the Electric Vehicle Market

Market Drivers and Challenges

We chose to examine the electric vehicle (EV) market since transportation is such a big part of consumers’ lives and constitutes a large portion of the economy in countries across the world. In the United States, 70% of all oil consumed is used for transportation. Passenger vehicles use 70% of transportation oil. Globally, a rising middle class in China and India is causing demand for passenger cars to balloon, and with it, demand for oil. By 2020, there may be as many as 1.5 billion cars on the road, compared to 750 million in 2010.

This high level of demand represents both a challenge and an opportunity to capitalize on new vehicle technologies, and in the process, reap substantial economic development benefits. In a world where oil is a limited resource, an alternate source of transportation fuel – electricity – is not only a smart investment, but as some would say, it is an inevitable one. Further, the switch to electric vehicles will generate economic development opportunities by improving quality of life, reducing energy spending, and decreasing reliance on foreign oil. In addition, the three main technology and demand drives for large batteries and EVs are volatile gas prices which spur demand and promote the market, government policies that promote growth, and consumers driven to reduce carbon emissions.

Like any transformative new technology, electrical vehicles create a variety of potent economic development challenges and opportunities. While the electric vehicle market is still at a relatively early stage of development, it is poised to reshape industries and communities the world over. Table A summarizes the primary hurdles to PEV deployment and as listed, the three main hurdles are: the high cost of PEVs, the limited charging infrastructure currently available, and consumer misperceptions about the operations of PEVs.

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2 Ibid.
In addition, for electric cars to achieve wide scale deployment in the US, new battery service networks must be competitive with the existing gasoline fueling infrastructure in terms of price, range, and reliability. The initial federal government tax credits of $7,500 will both generate initial demand for EV’s while also allowing manufacturers to achieve economies of scale in the product process which will bring down the production costs on subsequent years. However, economic developments can and are taking strides to reduce these barriers.

Table A: Barriers to Development of EVs in the US

<table>
<thead>
<tr>
<th>Hurdles to Development</th>
<th>High Costs of PEVs</th>
<th>Limited Charging Infrastructure</th>
<th>Consumer Adoption/ Misperceptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Demand side strategies</td>
<td>- Provide tax incentives for purchase</td>
<td>- Need innovative business models for batteries</td>
<td>- Lower priced vehicles</td>
</tr>
<tr>
<td></td>
<td>- Alleviate battery ownership risk</td>
<td>- Invest in chargers in public spaces (inexpensive)</td>
<td>- Continued tax incentives</td>
</tr>
<tr>
<td></td>
<td>- Provide non-financial incentives</td>
<td>- Invest in home and fast chargers</td>
<td>- Develop a consumer education plan</td>
</tr>
<tr>
<td></td>
<td>- Encourage utility rate discounts</td>
<td>- Provide incentives for install chargers</td>
<td>- Establish public demonstration of PEVs</td>
</tr>
<tr>
<td></td>
<td>- Transition government fleets to PEVs</td>
<td>- Collaborate with private charging station providers</td>
<td>- Market private sector solutions and advancements</td>
</tr>
<tr>
<td></td>
<td>- Encourage PEV cabs</td>
<td>- Streamline local zoning and permitting</td>
<td></td>
</tr>
<tr>
<td>Supply Side strategies</td>
<td>Make public investments in R&amp;D</td>
<td>- Disseminate information on charger location</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Create tailored workforce training programs</td>
<td>- IT infrastructure to support a range of smart grid applications to ensure reliable service to homes and other charging location</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Provide business financing</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Support supply chain development</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
The United States EV Market

In order to make assumptions in our economic model about how EVs will perform, we conducted market research to gather information on current EV specifications. We found several trends. Although automakers have been experimenting with electric vehicle prototypes for years, they only have recently begun to produce them on a larger scale. The market for purely electric vehicles is in its infancy. The United States currently leads sales of all global EVs and PEVs, selling more than 14,500 of them in the first quarter of 2015 and China with the second largest sales.\(^3\) For our research, we will be mainly focusing on United States electric vehicle market.

The United States EV market grew from 97,000 new vehicles in 2013 to about 119,000 in 2015, an increase of about 23%\(^4\). Nearly every major auto manufacturer now offers at least one plug-in electric vehicle model, including fully electric battery electric vehicles (BEV) and plug-in hybrid electric vehicle models. Consumers in many major U.S. cities can choose from among 5 to 15 electric vehicle models. Chart B displays our research on specific comparisons of the most popular 2015 EV car models on the market. Tesla is currently a top contender within the EV car market players space. Tesla’s latest models have the highest base MSRP price but also most impressive model specifications such as battery size, maximum range, MPGe City and Highway, and horsepower.

Currently in September 2015, Tesla leads the market, with sales over 20,000 units, or about 35% of the plug in EV market in 2015. Seven models (the Nissan Leaf, Chevrolet Volt, Tesla Model S, Toyota Prius Plug-in, Ford Fusion Energi, Ford C-Max Energi, and BMW i3) made up 88% of total U.S. electric vehicle sales in 2014. Chart A below shows the breakdown of EV battery cars in the United States in September 2015 by car manufacturers. According to a recommendation by the Electrification Coalition, a nonpartisan, not-for-profit group of business leaders committed to promoting policies and actions that facilitate the deployment of electric vehicles on a mass scale, by 2040, 75% of the vehicle miles traveled in the U.S. should be electric miles.


Expansion of the US EV Market

Baum and Associates projects a 65% increase in EV sales by 2017 in the United States, demonstrating the increasing relevance of electric vehicles in the discussion of environmental concerns. According to Baum and Associates, a firm which provides forecasting and market research of the automotive and related industries including the growing electric vehicle segment, sales of electric vehicles in the United States will increase to over 1 million per year in 2017.  

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5 "Projected Plug-in Electric Vehicle Sales in the U.S. from 2014 to 2018 (in 1,000 Units)." Statista.
Because of these projections for the increase in electric vehicles in the US, we considered the source of the electricity used to power the electric vehicles and the environmental impact. Our cost-benefit analysis demonstrated that incentivizing consumption of EVs is a cost-ineffective way to reduce CO₂ emissions.
Literature Review

Electric vehicles’ impact on the environment has been explored many times. Our economic model is original because it hopes to examine rational consumers’ choice between switching to electric vehicles (EVs) and purchasing all other goods. We were able to find many studies exploring the environmental impact of switching to EVs, which will supplement our argument for whether or not pushing for consumers to switch to EVs is a good choice.

Overall, the literature we found stated that:

- As the electric sector evolves to become more green and more drivers switch to EVs, greenhouse gas emissions will decrease;
- Switching to EVs saves drivers money in the long term since they do not have to pay for gasoline.

Environmental Assessment of Plug-in Hybrid Vehicles

An extremely comprehensive study published in 2007 by the Electric Power Research Institute demonstrated the different levels of greenhouse gases (GHG) that would be emitted in the future with varying levels of Plug-In Hybrid Electric Vehicle (PHEV) fleet penetration and electric sector improvement.6 Hybrid cars still use gasoline and are less environmentally clean as pure EVs.7 This implies that if the study were done with EVs, there would be even more reductions in greenhouse gas emissions. The study assumes different levels of energy sector improvement, with improvement defined as shifts toward sustainable energy sources such as wind and solar power. The studies found that, in general, with increasing fleet penetration and improvements in the electric sector toward renewable energy, greenhouse gas emissions will reduce dramatically.

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6 "Environmental Assessment of Plug-In Hybrid Electric Vehicles.” Electric Power Research Institute.
7 "How Do Hybrid Cars and Trucks Work?” Union of Concerned Scientists.
Table B: The evolution of the electric sector determines what power sources electric vehicles draw from.

<table>
<thead>
<tr>
<th>PHEV Fleet Penetration</th>
<th>2050 Annual GHG Reduction (million metric tons)</th>
<th>Electric Sector CO₂ Intensity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>High</td>
</tr>
<tr>
<td>Low</td>
<td>2050 Annual GHG Reduction (million metric tons)</td>
<td>163</td>
</tr>
<tr>
<td>Medium</td>
<td></td>
<td>394</td>
</tr>
<tr>
<td>High</td>
<td></td>
<td>474</td>
</tr>
</tbody>
</table>

Source: Electric Power Research Institute

Below is a graph documenting the key parameters the study used to describe varying levels of electric sector improvement, as defined by carbon dioxide emission intensity as a metric.
Electric Vehicles’ Fuel Cost Savings across the United States

A report published by the Union of Concerned Scientists in 2012, State of Charge, explores electric vehicles’ global warming emissions and fuel-cost savings across the United States. They found that EVs consume no gasoline and contribute very little to oil consumption.8 EVs also save drivers money since drivers do not have to pay money for gasoline. However, a key factor that the current literature excludes in their analysis of consumers’ microeconomic decision to purchase an EV versus a traditional gasoline is the price of the electric vehicle itself.

![Electric vehicles slash oil consumption and cost thousands of dollars less to fuel compared with gasoline vehicles.](image)

*Electric vehicles consume no gasoline and contribute very little to oil consumption, since less than 1 percent of U.S. electricity is generated with petroleum. Note: Assumptions include gasoline cost of $3.50 per gallon, a national average electricity price of 11 cents/kWh, a discount rate of 3 percent applied to future savings, cumulative lifetime mileage of 186,000 miles, and annual travel that starts at 15,000 miles per year and declines 4.5 percent per year over 15 years. Electric-drive efficiency is that of the Nissan LEAF (0.34 kWh/mile) and is representative of today’s small to midsize EVs. Greater annual mileage or higher electric efficiency would result in increased cost savings estimates.*

*Source: Union of Concerned Scientists*

Overall, the literature we found concluded that as the electric sector evolves it becomes possible to sustain EVs while reducing greenhouse gas emissions. Moreover, from the consumer’s standpoint, we find that switching to EVs or PHEVs save drivers money in the long term by reducing the amount of money they have to pay for gasoline. However, the analysis excludes the cost of the electric vehicle itself.

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Cobb-Douglas Utility Model

We modeled the preferences of a representative consumer with Cobb-Douglas Utility Preferences for an Electric Vehicle, and all other goods in the economy. Our model assumes that the consumers preferences depend entirely on the price of the electric vehicle. This is to give micro-economic mathematical perspective into incentive to purchasing / using an electric vehicle.

We have consumer utility function represented as:

\[ U(C, V) = C^\gamma(P_{EV})V^{1-\gamma(P_{EV})} \]  \hspace{1cm} (1)

s.t: \( m = P_C C + P_{EV} V \)

Where:
- \( C \) = Units of all other goods consumed
- \( V \) = Units of Electric Vehicle consumed
- \( P_C \) is the price of all other goods consumed
- \( \gamma(P_{EV}) \) is the price of the Electric Vehicle (defined below)
- \( P_{EV} = P_{vehicle} - (GovtIncentives + FuelSavings) \)
- \( \max(P_{EV}) = x \)

For \( \gamma < \frac{1}{2} \) the consumer values 'utils' gained from their electric vehicle more than from consuming other goods.
For $\gamma = \frac{1}{2}$ the consumer is indifferent to consuming equal amounts of other goods compared to their electric vehicle.

For $\gamma > \frac{1}{2}$ the consumer would prefer consumption of other goods to consumption of their electric vehicle.

The $P_{\text{vehicle}}$ is the amortized price of the electric vehicle over its useful (to the consumer) life so that it can be valued evenly over time periods.

We assume that Govt Incentives are positive and Fuel Savings are positive since it is cheaper to operate an electric vehicle per unit of distance than it is to operate a gasoline vehicle per unit of distance. Govt Incentives are also amortized in the same way as $P_{\text{vehicle}}$ for the same reason. Fuel savings is valued evenly over time periods, and is calculated in terms of price difference of electricity and gasoline.

Our $\gamma(P_{\text{EV}})$ function is designed so that the consumer’s preference between $C$ and $V$ are a function
of the price of the electric vehicle and $\beta$ which represents the unknown factors a consumer would weigh in determining his own consumption preferences, to account for the fact that his preferences are not based entirely on the price of the electric vehicle.

\[ \gamma(P_{EV}) = \frac{P_{EV}}{x} + \beta s, \ \gamma(P_{EV}) \leq 1 \quad (2) \]

Since $P_{EV} > 0$, $\frac{P_{EV}}{x} \in (0, 1]$
Then $\beta \in [0, 1)$ s.t $\gamma(P_{EV}) \leq 1$

**First Order Partial Derivatives**

The Marginal Utility of the electric vehicle is given by the equation:

\[ \frac{\partial U}{\partial V} = (1 - \gamma(P_{EV}))V^{-\gamma(P_{EV})}C^{\gamma(P_{EV})} \]

\[ \frac{\partial U}{\partial V} = (1 - \frac{P_{EV}}{x} + \beta))V^{-\frac{P_{EV}}{x} - \beta}C^{\gamma(P_{EV})} \quad (3) \]

Which is positive.

The Marginal Utility of all other goods in the economy is given by the equation:

\[ \frac{\partial U}{\partial C} = (\gamma(P_{EV}))V^{1-\gamma(P_{EV})}C^{\gamma(P_{EV})-1} \]

\[ \frac{\partial U}{\partial C} = (\frac{P_{EV}}{x} + \beta)V^{1-\frac{P_{EV}}{x} + \beta}C^{\frac{P_{EV}}{x} + \beta - 1} \quad (4) \]

which is also positive.

Because the partial derivatives of a Cobb-Douglas Utility Function are both positive, we know that his preferences are monotonic.

Next when we solve for the Marginal Rate of Substitution (MRS), by dividing The Marginal Utility of all other goods in the economy by The Marginal Utility of his electric vehicle:

\[ \frac{\gamma(P_{EV}))V^{1-\gamma(P_{EV})}C^{\gamma(P_{EV})-1}}{(1-\gamma(P_{EV}))V^{-\gamma(P_{EV})}C^{\gamma(P_{EV})}} = \frac{\gamma(P_{EV}))V^{1-\gamma(P_{EV})}C^{\gamma(P_{EV})-1}}{1-\gamma(P_{EV})}V^{-\gamma(P_{EV})}C^{\gamma(P_{EV})} \]

\[ MRS = \frac{\frac{P_{EV}}{x} + \beta}{1 - \frac{P_{EV}}{x} - \beta} \quad (5) \]

we obtain that the consumer has convex preferences, since the absolute value of MRS decreases as C increases and V decreases.

**MRS Solution**

From the MRS we can obtain the optimal amounts for both C and V:

\[ V^* = \frac{1-\gamma(P_{EV})}{\gamma(P_{EV})} \frac{P_C}{P_{EV}} C^* \]

We can then substitute this into m:

\[ m = P_C C^* + P_{EV} \frac{1-\gamma(P_{EV})}{\gamma(P_{EV})} \frac{P_C}{P_{EV}} C^* \]

\[ m = \frac{P_{EV}}{\gamma(P_{EV})} \]

\[ \implies C^* = \frac{m\gamma(P_{EV})}{P_C} \quad (6) \]
We substitute this back into the MRS:

\[ V^* = \frac{m(1 - \gamma(P_{EV}))}{P_{EV}} \]  

(7)

Therefore we have that the optimal choice is:
\[(C^*, V^*) = \left( \frac{m \gamma(P_{EV})}{P_C}, \frac{m(1 - \gamma(P_{EV}))}{P_{EV}} \right)\]

If the consumer were indifferent, and based on arbitrary prices (simply for visualization):

\[\text{Consumption Indifferent (}\gamma = \frac{1}{2}\)]

And if the prices changed, which would affect the MRS, it would cause MRS to either increase in slope, or decrease, leading to different optimal choices for the consumer:

\[\text{Different MRS cases when } \gamma = \frac{1}{2}\]
Second Order Partial Derivatives

When we evaluate the second order partial derivatives, we see that the economic implications depend on our value of gamma.

Given that $C > 0$ and $V > 0$, for the Utility Function, taking the second order partial derivative with respect to $V$ yields:

$$
\frac{\partial^2 U}{\partial V^2} = (1 - \gamma(P_{EV}))(-\gamma(P_{EV}))V^{-\gamma(P_{EV})-1}C^{\gamma(P_{EV})}
$$

This equation is negative, meaning that the marginal utility of the EV decreases as he consumes more units of EV.

Taking the second order partial derivative with respect to $C$ yields:

$$
\frac{\partial^2 U}{\partial C^2} = (1 - P_{EV})^2 - \beta)(-\gamma(P_{EV})^{\gamma(P_{EV})})V^{P_{EV}}C^{\gamma(P_{EV})+\beta}
$$

This equation is negative, meaning that the marginal utility of all other goods in the economy decreases as he consumes more units of all other goods.

Now, we assume that our agent will maximize his utility function with respect to his budget constraint.

$$
\max_{\{C,V\}} C^{\gamma(P_{EV})}V^{1-\gamma(P_{EV})}
$$

such that $m = P_{C}C + P_{EV}V$

Next, we used the Lagrangian to solve for the consumers optimal bundle: $(C^*, V^*)$

$$
\mathcal{L}(C,V,\lambda) = C^{\gamma(P_{EV})}V^{1-\gamma(P_{EV})} + \lambda(m - P_{C}C - P_{EV}V)
$$

Solving for $\lambda$ in [C]:

$$
\lambda = \frac{2C^{\gamma-1}}{P_{C}}
$$

Substituting into [V]:

$$
(1 - \gamma)V^{-\gamma} = P_{EV}P_{C}^{-\gamma}C^{\gamma-1}
$$

$$
\frac{1}{V^{\gamma}} = V^{-\gamma} = \frac{1}{\gamma}P_{EV}^{\gamma}C^{\gamma-1}
$$

$$
V^{\gamma} = \frac{P_{C}^{1-\gamma}}{P_{EV}^{\gamma-1}}
$$

$$
\Rightarrow \quad V^* = \left[\frac{P_{C}}{P_{EV}^{\frac{1-\gamma}{\gamma}}C^{\gamma-1}}\right]^{\frac{1}{\gamma}}
$$
Combining \([C]\) and \([V]\) we get:

\[
\frac{P_C}{P_{EV}} = \frac{\gamma}{1-\gamma} \frac{C^{\gamma-1}}{V^{-\gamma}}
\]

Now solving for optimal consumption of \(C\):

First solve for \(\lambda\) in \([V]\):

\[
\lambda = \frac{(1-\gamma)V^{-\gamma}}{P_{EV}}
\]

And substitute into \([C]\):

\[
\gamma C^{\gamma-1} = \frac{P_C (1-\gamma)V^{-\gamma}}{P_{EV}}
\]

\[
\implies C^* = \left[\frac{P_C}{P_{EV}} \frac{1-\gamma}{\gamma} \frac{1}{V^{\gamma}}\right]^{\frac{1}{\gamma-1}} \tag{13}
\]

And now we have the optimal consumption bundle between units of \(EV\) and units of other consumption (this conclusion is different from the MRS solution because it gives optimal amount of a good relative to the other good without income factored in):

\[
(C^*, V^*) = \left(\left[\frac{P_C}{P_{EV}} \frac{1-\gamma}{\gamma} \frac{1}{V^{\gamma}}\right]^{\frac{1}{\gamma-1}}, \left[\frac{P_C}{P_{EV}} \frac{1}{\gamma} C^{1-\gamma}\right]^{\frac{1}{\gamma}}\right) \tag{14}
\]
Cost-Benefit Summary

Introduction

In order to assess the economic feasibility and benefits of electric vehicles, we considered a hypothetical case in which all gasoline light duty vehicles in the United States became electric. Our case assumes that gasoline light duty vehicles will be run until the end of their useful life and then be replaced with electric light duty vehicles. We first calculated the change in yearly electricity demand and the net decrease in national CO₂ emissions, and then analyzed the economic cost of this carbon dioxide emissions change. We decided to omit diesel powered vehicles from our calculations because the majority of diesel powered vehicles in the United States are heavy duty, and battery-electric heavy duty vehicles are not a practical option in the foreseeable future.

Our calculations showed that this change would lead to 11.294% increase in yearly electricity demand and a net decrease in national CO₂ emissions of 6.64%. Following these calculations, shown and explained below, we calculate the cost per kg of decreased CO₂ emissions. We consider different cases for the economic cost of changing these gasoline powered vehicles to electric vehicles.

The initial case calculated total economic costs without including the cost of a government incentive, and calculated it would cost $0.12 per kg of CO₂ emissions. The second case included the tax rebate incentive, and showed there would be an approximate savings of $3.5 per kg of CO₂, however this value does not seem feasible because the average cost of a vehicle on the road is significantly smaller than the average cost of a new vehicle.

Data has demonstrated that investments in sources of renewable energy can reduce CO₂ for as low as $0.04 per kg of CO₂ such as in coal plants. Electric vehicles, then, are an economically expensive way of decreasing CO₂ emissions with current incentives and prices. We conclude, then, that policy makers should invest in renewable energy sources rather than incentivize consumers to purchase electric vehicles or offer higher incentives on new electric vehicles.
Initial Calculations and Data

Please note that for conciseness we have included abridged calculations in this section; you may find the complete calculations for several of the figures in the Appendix.

To begin our cost benefit analysis, we first calculated the total number of gasoline cars on the road, the total gallons of gas consumed annually, and total PWh of gasoline used to power gasoline cars presently.

In 2013, there were 116 million employed workers that commuted to work.\(^9\) 76.4% (88.9 million) drove alone and 9.4% (10.9 million) carpooled.\(^{10}\) It’s reasonable to assume every worker that drove alone has a car to drive in, meaning there are at least 88 million cars on the road for every business day in the US. For carpoolers, there are anywhere between (2.19 million and 5.47 million cars) for between 2 to 5 people in a car. We can assume at least 90 million cars travel per day.

The average American drove 21,687.52 km annually.\(^{11}\) The average gasoline fuel economy is 27.7 km per gallon (US).\(^{12}\) If all 90 million consumer cars (light-duty) drove 21,687.52 km annually at an economy of 27.68 km per gallon, the total gallons of gas consumed is 70.5 gallons.

In each gallon of gasoline there are approximately 33.4 kWh.\(^{13}\) Then this calculates to 2.36 PWh of thermal energy used by 90 million gasoline powered road vehicles in 2013 (from only commuting workers).

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9 Statista, “Number of Full-time Employees in the U.S. 1990-2014 | Timeline.”
11 LoveToKnow, “How Many Miles Do Americans Drive Per Year?”
12 United States Department of Transportation, "Table 4-23: Average Fuel Efficiency of U.S. Light Duty Vehicles | Bureau of Transportation Statistics."
Total Increase in Demand for Electricity

From the range of EVs currently available in the US (see the Current Market section), we can build a model EV between the best and the worst (in terms of km per kWh). We choose a model EV with range of 240 km and capacity of 60 kWh giving us 4 km per kWh charge.

If all 90 million cars in 2013 were all our model EVs, then the total US consumption of electricity would have risen by 11.3%.

Total Change in CO₂ Emissions

We want to calculate how this change from gasoline-powered vehicles to electric vehicles would change CO₂ emissions in the United States. First, we calculated the total reduction due to the lack of burning gasoline in the engines of all consumer vehicles. We then added the increase in CO₂ emission due to the increase demand in electricity. From here, we found the net change in total CO₂ emission to be a 6.64% reduction.

Reduction (no more gas burning):

Each gallon of gasoline contains 8.88 kg of CO₂. If 90 million cars were instead our model EV, there would be a 626 billion kg reduction in CO₂ from gasoline emissions.

Gain (more power for charging):

With the US’s current mix of energy sources (non-renewables and renewables), there are 0.62 kg of CO₂ per kWh generated in 2007. With 0.49 PWh, this would create 301 billion kg of CO₂. This is 48% less, or a 326 billion kg of CO₂ reduction than if all cars were gasoline powered.

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15 "State Electricity and Emissions Rates." MiloSlick Scientific.
Total Change in CO$_2$ emissions:

In US in 2014, the total change would be 4.9 trillion kg.$^{16}$ If all cars became our model EVs, then we would see a (4.9 trillion - 325 billion) / 4.9 trillion = 6.64% reduction in total US CO$_2$ emissions.

**Net Economic Cost of CO$_2$ Reduction ($)**

Here, we first calculate the total cost to power all gasoline powered vehicles. We then calculate the cost to power the equivalent number of electric vehicles.

**Total economic cost to power gasoline vehicles:**
The average cost of regular gasoline per gallon in 2013 was $3.44.$^{17}$ Therefore, from these 90 million cars in 2013, approximately $243 billion was spent on gasoline.

**Total economic cost to power electric vehicles:**
The average cost of household electricity in the US is $0.121 per kWh.$^{18}$ 0.488 PWh therefore costs $59.2 billion. The cost of charging 90 million model EVs is 24.4% of the cost of gasoline for 90 million vehicles.

**Difference in Total Economic Cost:**

($242,785,831,734$ gasoline) – ($59,190,663,960 electricity) = $183.6 billion

More money per driving American worker: 183,595,167,774/90000000 = $2,040 amount saved annually

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$^{16}$ "Total U.S. Carbon Dioxide Emissions from Energy Consumption between 1975 and 2014 (in Million Metric Tons of Carbon Dioxide)." Statista.

$^{17}$ "Weekly Retail Gasoline and Diesel Prices." U.S. Energy Information Administration.

$^{18}$ "Average Monthly Electrical Bill by State – Updated Data." Eye On Housing.
Cost of Vehicle (1 – No Incentives)

So far, we have calculated the economic cost of charging and gasoline expenditures due to a consumer switching from a gasoline-powered vehicle to an EV. Now, we will calculate the economic cost incurred due to the higher price of an EV compared to the price of a gasoline vehicle.

$31,252 is the average cost of a new gasoline vehicle in August 2015.\textsuperscript{19} Tesla’s CEO Elon Musk estimates the Model 3 is priced at $35,000 in 2017.\textsuperscript{20} However, the Tesla Model 3 performs significantly better than our model EV in terms of km/kWh, and since the current most basic Tesla Model S has around 5.57 km per kWh,\textsuperscript{21} we can assume that the Model 3 will be the same or better.

For the 90 million commuter light-duty vehicles, with the assumption that they were all new gasoline vehicles, then the cost of the switch would be precisely $337 billion. With that there is also an additional total economic cost of $183 billion from the fact that 90 million cars would be charging instead of filling up with gasoline. This brings the total economic cost to around $521 billion.

As aforementioned, we see a net reduction of 326 billion kg of CO\textsubscript{2} emissions if 90 million gasoline cars became EVs for one year.

Furthermore, the price reduction per vehicle is only around $1.6 per KG of CO\textsubscript{2}. Amortized over 8 years, this becomes $0.20 per kg. Of course, this is if we assume the value of every one of the 90 million vehicles are new and valued above $31,000. This is quite impractical, since it exceeds the average price of most vehicles on the road in the US. This means the price reduction per kg of CO\textsubscript{2} is significantly higher because vehicles are worth less than average of a new vehicle.

\textsuperscript{19} Janet, Loehrke, and Carey Anne. "Report: Average Price of New Car Hits Record in August." USA Today.


\textsuperscript{21} "Model S Specifications." Tesla.
Current industry estimates put the cost of coal power plant and carbon capture and sequestration at $80/ton CO$_2$ or $0.08$ per kg of CO$_2$, and given that the CO$_2$ has an economic value of $40$ per ton, or $0.04$ per kg of CO$_2$, the net economic cost of Carbon Capture and Sequestration is $0.04$ per kg.\textsuperscript{22}

**Cost of Vehicle (2 – Incentives)**

The US Government offers up to $7,500 tax credit on purchasing a new EV dependent on size of battery.\textsuperscript{23} For our model EV it would be $7,500 by today’s standards. Also it was calculated earlier that an EV would save the average person approximately $2,000 annually due to not buying gasoline. Some US states also offer further incentives (e.g. Louisiana $6,900 - $9,500). For simplicity we assume there are no further incentives.

This would bring the hypothesized price of a new Tesla Model 3 to $27,500.

For the 90 million commuter light-duty vehicles, with the assumption that they were all new gasoline vehicles, then there would be $337.7$ billion in total savings from a new EV.

Therefore, if every person switched to EVs there would be an approximate (((337,680,000,000 +183,595,167,774)/ 325,645,540,462.189 kg) = $338$ billion, i.e. $3.5$ per kg of CO$_2$ saved, or - $3.5$ per kg of CO$_2$ in price reduction. This figure shows that with current incentives and estimated cost saved per customer, then there would be very significant gain from 90 million cars switching to EVs now.

However this number is unrealistic because not all 90 million cars are worth $31,252 on average, or even $25,500 on average. Used cars sell for less most of the time; the average cost of a used car was $18,800 in 2015.\textsuperscript{24}

\textsuperscript{22} “Carbon Dioxide: From Industry to Oil Fields.” Pinnacle.
\textsuperscript{24} “Used Car Prices Increase Nearly 8 Percent to Hit Record High in Q2 2015, Says Edmunds.com.” Edmunds.
Therefore we can conclude that given the current US energy profile, mass adoption of electric vehicles would be a cost ineffective way of reducing carbon emissions. At the same cost, fitting coal plants with carbon capture systems would decrease carbon emissions by three times the amount of a complete switch to electric vehicles. Not to mention even better alternatives like replacing coal plants altogether with nuclear, wind, or combined-cycle gas plants. In order for a mass switch to EVs to be even feasible, either price of electricity per kWh would have to decrease (hence reduction in average amount of CO₂ produced, thus investment in renewable energy), price of a new EV would have to decrease, and/or the amount of government incentives would have to increase.²⁵

²⁵ **Disclaimers:** The figures that were calculated only account for 90 million gasoline vehicles estimated from workers who commute to work every day. The true number for total gasoline vehicles in the US used every day is substantially larger and would greatly affect our values, for example, if calculations were done with 150 million vehicles which more resembles the amount driven by Americans annually. Many other assumptions were made as well, such as no effect on supply/demand markets for gasoline and electricity (hence constant or stagnated, which is more realistic, price).
Public Policy Overview

Introduction to Policy Instruments

Our primary objective in this section is to complement the economic model of the consumer’s choice between electric vehicles and consumption developed at the beginning of this paper. In our model, the utility-maximizing agent weights consumption of the two goods $C$ and $V$ by the parameter $\gamma$, which is a function of the relative price of an electric vehicle model.

The overall price of an electric vehicle model is itself determined by the price of an EV less government incentives and the cost savings from switching to electric energy from gasoline. Thus, any government subsidies/incentives that reduce the face value consumers pay for a car and/or increase the cost savings from switching to electricity from gasoline will thus decrease both $P(EV)$ and the parameter $\gamma$. Therefore, such government subsidies/incentives will increase the weight the consumer allocates to spending on EVs, thus driving a resulting increase in aggregate demand for (and purchasing of) EVs.

We will provide a brief overview of major current governmental EV incentives in place at the federal, state and local levels. Additionally, we will conduct a simplified economic analysis of the main types of price and quantity instruments currently being implemented both in the US and other countries with major investments in renewable energy. In doing so, we believe this analysis will help policymakers assess current best practices in incentivizing renewable energy development and production.

In addition, we have included a feasibility study in the Appendix that details the costs and benefits of converting all gasoline vehicles to electric. Based on the results of our feasibility study, given the current US power mix, EVs are not the most cost-efficient option of reducing greenhouse gas emissions. Increased battery life, improved charging efficiency and lower overall cost per vehicle are barriers to the long-term sustainability of the EV model. Hence, the US government could more efficiently allocate its funding in areas other than EV purchase and
development incentives, assuming a primary goal of reducing greenhouse gas emissions over time through a mixture of price and quantity policy instruments.

**Key Current EV Incentive Policies and Measures in the US**

As mentioned in the introduction, our model indicates that government policymakers can implement subsidies to decrease the overall cost of an EV paid by consumers, thus shifting the utility-maximizing agent’s consumption choice towards EVs. While many individual states and cities have also implemented unique policy incentives, the list is extensive and we will limit our scope to several major key initiatives below.

<table>
<thead>
<tr>
<th>Policy</th>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Income Tax Credit</td>
<td>Federal</td>
<td>Range from $2,500 to $7,500 per EV; phases out after a given automaker sells 200,000 units that are eligible for the credit.</td>
</tr>
<tr>
<td>American Recovery and Investment Act (2009)</td>
<td>Federal</td>
<td>Provided $400 million in grant funding for the deployment of electric charging infrastructure.</td>
</tr>
<tr>
<td>Zero Emission Vehicle Program</td>
<td>State</td>
<td>California requires that 15% of new automobile sales in the state are EVs by 2025. Similar programs have been implemented in nine other states with varying levels of stringency.</td>
</tr>
<tr>
<td>EV Purchase Subsidies</td>
<td>State and City</td>
<td>Many states offer purchase subsidies for some or all types of electric vehicles. Amounts vary based on type of vehicle and cost; subsidy types are primarily tax credits and rebates. In addition, several cities including Riverside and San Francisco (CA) have offered additional subsidies.</td>
</tr>
<tr>
<td>Preferential Charging Rates</td>
<td>City</td>
<td>Some utilities offer discounted electricity rates for EV charging, and many offer time-of-use (TOU) rates that lower the cost of charging during non-peak hours.</td>
</tr>
<tr>
<td>Home Charger Support</td>
<td>City</td>
<td>Utilities in several major metropolitan areas offer cost-sharing for EV charger installation.</td>
</tr>
</tbody>
</table>

*Source: The Int’l Council on Clean Transportation*²⁶

²⁶ Ibid.
Types of Policy Instruments

Renewable energy technologies are not yet mature enough to be sufficiently competitive with conventional technologies on the energy market. Hence, in addition to the specific incentives and policies listed in the previous section, there are a range of economic policy instruments being deployed to encourage investment in renewable energy, both in the United States and globally.

One of the most economically efficient solutions to promote usage and development of renewable energy over conventional, fossil-fuel based energy sources would be to tax fossil fuel prices to internalize the negative externalities associated with their use. However, because of uncertainty regarding the exact shape of the social damage cost function due to fossil fuel use, it would be extremely difficult to determine the optimal level of taxation. Hence, a subsidy-based approach to promoting RES use and development would be more effective. These constitute two main forms - price and quantity instruments.

Note: Source for all graphs in this section: Menanteau, Philippe. The Static and Dynamic Efficiency of Instruments of Promotion of Renewables. University of Grenoble, France.

Price Instruments

Feed-in Tariffs

Feed-in tariff policies guarantee a certain price for a certain period of time for electricity produced from renewable energy sources (RES). Utilities are mandated to purchase electricity from energy producers at the level of the tariff, which is typically set by public authorities, for a set length of time.

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27 Menanteau, Philippe. The Static and Dynamic Efficiency of Instruments of Promotion of Renewables. University of Grenoble, France.

28 Ibid.
Hence, feed-in tariffs create a subsidy for producers of renewable electricity. Producers will generate electricity up to the point where the marginal cost of producing renewable electricity equals the level of the feed-in tariff, at \( X \), and produce the amount \( Q_{out} \). The overall cost of the subsidy is given by the area \( P(in) \times Q(out) \).

Some governments, such as Spain and Italy, cover the cost of subsidizing renewable electricity producers through cross-subsidies across all consumers. In other countries, the cost of the subsidy is covered by the customers of the utility under regulation, by all taxpayers, or through a combination of the two, as is the case in Denmark.²⁹ FITs are popular among governments, owing to their efficiency. According to the European Commission’s update on renewable energy policies within the European Union, “well adapted feed in tariff regimes are generally the most efficient and effective support schemes for promoting renewable electricity.”³⁰

**Competitive Bidding System**

Under a competitive bidding system policy, renewable energy producers compete to supply a given amount of RES that is defined by the regulator. Electric utilities are then required to purchase electricity from the respective power producers. France adopted this system under its Eole 2005 program, developed in 1996, to promote wind energy.³¹

Parties compete on the price per kWh proposed during bidding, and each renewable energy supplier is then given a contract to produce electricity at the bidded price. The marginal cost, \( P(out) \), is the price paid for the last project selected, which enables the quantity \( Q(in) \) to be obtained. The area under the marginal cost curve yields the total cost of reaching the target quantity of electricity.

²⁹ Ibid.
³¹ Menanteau, Philippe. *The Static and Dynamic Efficiency of Instruments of Promotion of Renewables*. University of Grenoble, France.
Quantity Instruments

Renewable Energy Certificates

Under this scheme, a fixed quota of electricity for sale must be generated using renewable energy sources. In order to meet his requirement, operators have the option to generate the required amount of electricity themselves, purchase the energy through another renewable energy producer, or buy certificates from other operators to meet the quota. RECs incentive the production of carbon-neutral renewable energy by subsidizing the production of electricity generated from renewable sources.

RECs offer a more market-driven alternative to promote renewable energy development than feed-in tariffs or government investment support. One REC typically represents 1 MwH of electricity, and can be sold, traded, or bartered. The price of a certificate depends on several factors, including the year the certificate was generated, type of power created, geographical location, and supply/demand, among various other factors.

For example, assume that there are two operators A and B, both assigned to produce \( q \) units of electricity. Operator A produces less efficiently than B, and experiences higher marginal production costs \( MC(A) \). However, since the operator is able to trade RECs, they can limit production to \( Q(A) \) and buy certificates at price \( p \) to reach the assigned quota \( q \). Operator B will increase production to \( QB \) and sell surplus certificates for price \( p \).

Hence, the certificates lower the cost of achieving the policy objective (\( Q \frac{1}{4} Q(A) \| Q(B) \frac{1}{4} 2q \)), as indicated by the shaded regions, versus a system where operators are inflexibly assigned the
constraints QA and QB. While it would also be possible to achieve such results by assigning each operator a designated production level, in situations where the government (or other relevant authority) has only incomplete information it is much more difficult to allocate efficient quantities, where marginal costs are equalized (MC(A) = MC(B)).

The green certificate system allows the public authority to assign specific quantity goals (Q(A) and Q(B)) to operators, while simultaneously reducing the total cost of attaining the production target. While a feed-in tariff could also yield efficient allocation of production, it would not necessarily be capable of reaching the desired total amount, because the shape of the marginal production cost curves is not fully known to the public authority.

**Compliance vs. Voluntary REC Markets**

There are two types of markets for RECs in the United States - compliance markets and voluntary markets. In states with compliance markets, electric utilities are required to supply a predetermined percentage of electricity from renewable suppliers each year. In California, the requirement is 33% renewable by 2020. Compliance markets currently exist in 29 U.S. states (plus D.C. and Puerto Rico) under the Renewable Portfolio Standard. Electric utilities prove compliance with state requirements by purchasing RECs. Under voluntary markets, buyers of energy may opt to purchase renewable power voluntarily.

**Evaluating Policy Instruments**

Given the diverse array of price and quantity instruments available for governments to incentivize investment in renewable energy sources and the limited funds available for public authorities to do so, it is crucial for policymakers to also evaluate the associated costs and benefits of each approach before deciding to pursue implementation. However, this question is outside the scope of our analysis and therefore we have decided not to include an in-depth cost-benefit analysis of the various policy schema outlined above.

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32 "Database of State Incentives for Renewables & Efficiency® - DSIRE." DSIRE.
33 "Mandatory & Voluntary Offset Markets." CORE: Mandatory vs Voluntary Markets.
Current State of Renewable Energy

United States renewable energy (Hydro, Biomass, Geothermal, Solar, Wind and Others) accounted for 12.87% of total United States Energy Production in 2013:

<table>
<thead>
<tr>
<th>Year</th>
<th>Hydro (Billion kWh)</th>
<th>Geothermal (Billion kWh)</th>
<th>Waste (Billion kWh)</th>
<th>Wood (Billion kWh)</th>
<th>CSP (Billion kWh)</th>
<th>Utility PV (Billion kWh)</th>
<th>Rooftop PV (Billion kWh)</th>
<th>Onshore Wind (Billion kWh)</th>
<th>Offshore Wind (Billion kWh)</th>
<th>Renewable Total (Billion kWh)</th>
<th>U.S. Total (Billion kWh)</th>
<th>% Renewable</th>
</tr>
</thead>
<tbody>
<tr>
<td>2002</td>
<td>264.33</td>
<td>14.49</td>
<td>15.04</td>
<td>38.66</td>
<td>0.555</td>
<td>10.34</td>
<td>0</td>
<td>0</td>
<td></td>
<td>343.44</td>
<td>3858.45</td>
<td>8.90%</td>
</tr>
<tr>
<td>2003</td>
<td>275.81</td>
<td>14.24</td>
<td>15.81</td>
<td>37.53</td>
<td>0.534</td>
<td>11.19</td>
<td>0</td>
<td>0</td>
<td></td>
<td>355.29</td>
<td>3883.18</td>
<td>9.15%</td>
</tr>
<tr>
<td>2004</td>
<td>268.42</td>
<td>14.81</td>
<td>15.42</td>
<td>38.12</td>
<td>0.575</td>
<td>14.14</td>
<td>0</td>
<td>0</td>
<td></td>
<td>351.48</td>
<td>3970.56</td>
<td>8.85%</td>
</tr>
<tr>
<td>2005</td>
<td>270.32</td>
<td>14.69</td>
<td>15.42</td>
<td>38.86</td>
<td>0.550</td>
<td>17.81</td>
<td>0</td>
<td>0</td>
<td></td>
<td>357.66</td>
<td>4055.42</td>
<td>8.82%</td>
</tr>
<tr>
<td>2006</td>
<td>289.25</td>
<td>14.57</td>
<td>16.10</td>
<td>38.76</td>
<td>0.508</td>
<td>26.59</td>
<td>0</td>
<td>0</td>
<td></td>
<td>385.77</td>
<td>4064.70</td>
<td>9.49%</td>
</tr>
<tr>
<td>2007</td>
<td>247.51</td>
<td>14.64</td>
<td>16.52</td>
<td>39.01</td>
<td>0.612</td>
<td>34.46</td>
<td>0</td>
<td>0</td>
<td></td>
<td>352.76</td>
<td>4156.74</td>
<td>8.49%</td>
</tr>
<tr>
<td>2008</td>
<td>254.83</td>
<td>14.84</td>
<td>17.73</td>
<td>37.30</td>
<td>0.864</td>
<td>55.36</td>
<td>0</td>
<td>0</td>
<td></td>
<td>417.72</td>
<td>4119.39</td>
<td>10.14%</td>
</tr>
<tr>
<td>2009</td>
<td>273.44</td>
<td>15.01</td>
<td>18.16</td>
<td>36.05</td>
<td>0.74</td>
<td>0.16</td>
<td>1.93</td>
<td>0</td>
<td></td>
<td>419.59</td>
<td>3950.31</td>
<td>10.62%</td>
</tr>
<tr>
<td>2010</td>
<td>257.08</td>
<td>15.67</td>
<td>18.59</td>
<td>37.61</td>
<td>0.82</td>
<td>0.46</td>
<td>3.21</td>
<td>0</td>
<td></td>
<td>428.38</td>
<td>4125.06</td>
<td>10.38%</td>
</tr>
<tr>
<td>2011</td>
<td>325.07</td>
<td>18.70</td>
<td>19.79</td>
<td>36.95</td>
<td>1.82</td>
<td>5.64</td>
<td>119.75</td>
<td>0</td>
<td></td>
<td>520.07</td>
<td>4105.73</td>
<td>12.67%</td>
</tr>
<tr>
<td>2012</td>
<td>276.24</td>
<td>15.56</td>
<td>19.82</td>
<td>37.8</td>
<td>4.33</td>
<td>8.45</td>
<td>140.82</td>
<td>0</td>
<td></td>
<td>513.4</td>
<td>4047.76</td>
<td>12.22%</td>
</tr>
<tr>
<td>2013</td>
<td>269.14</td>
<td>18.52</td>
<td>19.96</td>
<td>39.94</td>
<td>9.25</td>
<td>167.66</td>
<td>0</td>
<td>0</td>
<td></td>
<td>522.46</td>
<td>4058.21</td>
<td>12.87%</td>
</tr>
</tbody>
</table>


Hydropower remain the largest source of electricity in the United States where it had produced 51% of the total renewable electricity in the US in 2013, and 6.8% of total US electricity[^36], followed by biomass, combined wind, geothermal, then solar.

**Cost of Energy Production**

<table>
<thead>
<tr>
<th>Power Plant Type</th>
<th>Cost $/kW hr</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal</td>
<td>$0.10-0.14</td>
</tr>
<tr>
<td>Natural Gas</td>
<td>$0.07-0.13</td>
</tr>
<tr>
<td>Nuclear</td>
<td>$0.10</td>
</tr>
<tr>
<td>Wind</td>
<td>$0.08-0.20</td>
</tr>
<tr>
<td>Solar PV</td>
<td>$0.13</td>
</tr>
<tr>
<td>Solar Thermal</td>
<td>$0.24</td>
</tr>
<tr>
<td>Geothermal</td>
<td>$0.05</td>
</tr>
<tr>
<td>Biomass</td>
<td>$0.10</td>
</tr>
<tr>
<td>Hydro</td>
<td>$0.08</td>
</tr>
</tbody>
</table>

Adapted from US DOE

---

Conclusion

Current literature showed us that as the energy sector evolves, the incremental shift from gasoline powered vehicles to electric vehicles further reduces carbon dioxide emissions. From a micro-economic perspective, consumers save money by switching to electric vehicles because they pay significantly less for electricity per mile in an electric vehicle than gasoline per mile in a gasoline vehicle. The same results were found in our cost-benefit analysis. A Cobb Douglas model of a representative consumer was used to provide a generalized view on how one would choose consumption of an electric vehicle based on the price of an electric vehicle, which is affected by the actual price of the vehicle, incentives, and savings on fuel (gasoline vs electricity) costs. The representative consumer’s optimal choice would be decided mostly by the price of an electric vehicle, and complemented by various external factors represented by beta.

Our Cobb Douglas Microeconomic Model showed that that three main factors will drive a consumer to value the consumption of an electric vehicle more than consumption of other goods, by driving down the value of gamma to less than one half:

1. More government incentives
2. Lower price of electric vehicles
3. Greater absolute difference in price of gasoline vs. price of electricity (both in units of price per kilometer). In our current cost-benefit, we found that a switch to electric vehicles would save approximately $2,000 annually from fuel consumption alone.

Our hypothetical cost-benefit case study in which 90 million gasoline light-duty vehicles were instantaneously replaced by electric vehicles demonstrated that promoting use of electric vehicles is a cost inefficient way of reducing carbon emissions. Combined cost of new electric vehicles would cost more than $0.12 per kg of carbon dioxide per year (amortized over eight years), while a simple filter over a coal plant would cost $0.04 per kg. We then considered government incentives currently being implemented to promote development of and investment in renewable energy sources, leading to the result that there could be a cost of -$3.50, or a benefit
of $3.50 per kg of carbon dioxide removed. However this figure was unreasonable due to our assumption that every car was new (thus valued at its highest).

Without considering costs, however, a change from 90 million gasoline vehicles burning fossil fuels to 90 million electric vehicles charging in households with the current US energy profile would lead to an overall reduction of approximately 325 billion kg of carbon dioxide, or around 6.64% of annual US carbon dioxide emissions.

Finally, Renewable Energy Production in the United States would have to improve significantly in order to strengthen the previous figures because it would reduce the amount of carbon dioxide produced per kWh thus reducing the cost to remove a kg of carbon dioxide. The current energy profile is mostly non-renewable energy now such as fossil fuels, so that when renewables expand to a larger percentage of the profile, it will lower the average amount of carbon dioxide produced per kWh, and also potentially affect the price of electricity as renewable energy is practically infinite. Moreover, in conjunction with our research on public policy, we found that subsidizing electric vehicles isn’t the most cost-effective way to reduce greenhouse gas emissions. Instead, government money would be better spent on subsidies for Renewable Energy through tariffs.
Appendix

A - Calculations

Hypothetical Case Study

Citation 12: \[90,000,000 \text{ cars} \times 21,687.52\text{km}] / 27.68 \text{ km per gal} = 70,515,780,346.82 \text{ gallons}

Total Change in CO$_2$ Emissions

Reduction (no more gas burning): Each gallon of gasoline contains 8.887kg of CO$_2$. If 90 million cars were instead our model EV, there would be a \((70,515,780,346.82 \text{ gallons} \times 8.887\text{kg CO}_2) = 626,673,739,942.189 \text{ kg reduction in CO}_2\) from gasoline emissions.

Cost of Vehicle - 1:

For the 90 million commuter light-duty vehicles, with the assumption that they were all new gasoline vehicles, then there would be \((35,000 – 31,252) \times 90,000,000 = $337,320,000,000 \text{ total cost for the switch.}\)

Furthermore, the price reduction per vehicle is only around \((520,915,167,774 / 325,645,540,462.189 \text{ kg of CO}_2) = $1.5996 \text{ per KG of CO}_2\).

Cost of Vehicle - 2:

This would bring the hypothesized price of a new Tesla Model 3 to \$35,000 - $7,500 = $27,500.\)

For the 90 million commuter light-duty vehicles, with the assumption that they were all new gasoline vehicles, then there would be \((27,500 – 31,252) \times 90,000,000 = -337,680,000,000 \text{ total cost, or rather around }$337.68 \text{ billion total savings from a new EV.}\)

Total Increase in Demand for Electricity:

If all 90 million cars in 2013 were all our model EVs:

\((90,000,000 \text{ cars}) \times (21,687.52\text{km driven annually}) = 195,187,680,000,000 \text{ km driven annually}\)

Since our model EV drives 4km on one kWh, we divide this by 4 producing the result of 0.4879 PWh used to drive that many km annually. The total US Electricity Consumption in 2013 was 3.832 PWh. If 90 million cars became EVs on Jan 1 2013, then the total rise in total US consumption of electricity due to switch from conventional to EVs: \(1 - (3.832) / (3.832 + 0.4879) = 11.294\%\). Thus the total US consumption of electricity would rise by 11.294\%.
## B – Specifications of Existing Electric Vehicles in the United States

<table>
<thead>
<tr>
<th>Model</th>
<th>Year</th>
<th>Base MSRP</th>
<th>Battery Size</th>
<th>Max Range</th>
<th>MPGe City</th>
<th>MPGe Hwy</th>
<th>Horsepower</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tesla Model S</td>
<td>2015</td>
<td>$59,900</td>
<td>85 kWh</td>
<td>245 mi</td>
<td>33 mi</td>
<td>119</td>
<td>N/A</td>
</tr>
<tr>
<td>Tesla Model S P85D</td>
<td>2015</td>
<td>$105,000</td>
<td>85 kWh</td>
<td>245 mi</td>
<td>33 mi</td>
<td>98</td>
<td>N/A</td>
</tr>
<tr>
<td>Tesla Roadster</td>
<td>2011</td>
<td>$68,950</td>
<td>96 kWh</td>
<td>224 mi</td>
<td>31 mi</td>
<td>116</td>
<td>N/A</td>
</tr>
<tr>
<td>Nissan Leaf S</td>
<td>2015</td>
<td>$29,010</td>
<td>96 kWh</td>
<td>100 mi</td>
<td>40 mi</td>
<td>122</td>
<td>288</td>
</tr>
<tr>
<td>Chevrolet Volt LT</td>
<td>2016</td>
<td>$33,170</td>
<td>96 kWh</td>
<td>245 mi</td>
<td>33 mi</td>
<td>116</td>
<td>N/A</td>
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<td>$25,120</td>
<td>96 kWh</td>
<td>245 mi</td>
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<td>98</td>
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<td>Honda Fit EV</td>
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<td>245 mi</td>
<td>33 mi</td>
<td>98</td>
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**Note:** Horsepower values for some models are not available (N/A).
Bibliography


