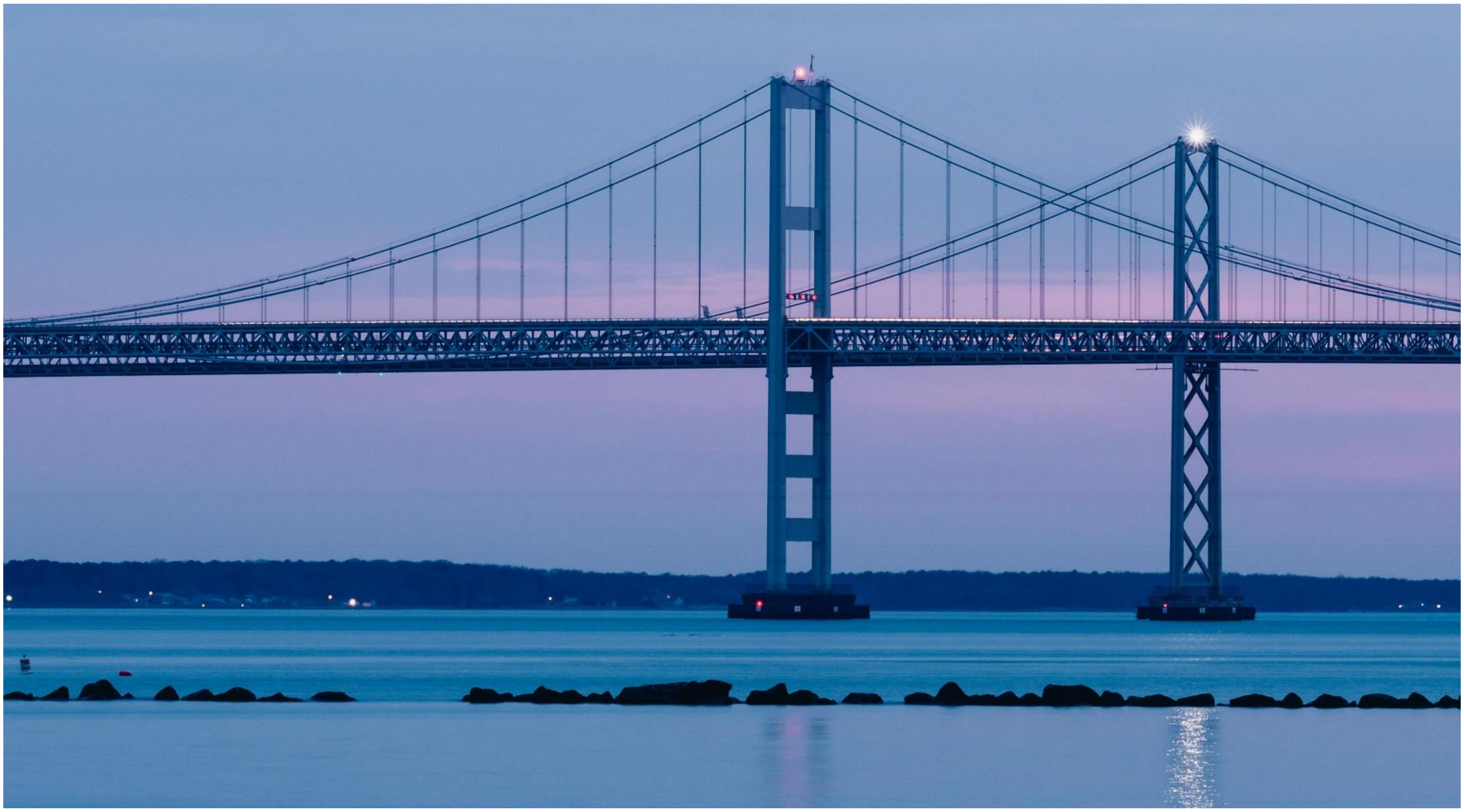

Bay Bridge taken from Sandy Point Beach, Chesapeake Bay, MD. Photo Credit: Mark Tegethoff, https://marktegethoff.com/posts/category/Posts

The Far-reaching Benefits of Electric Vehicles

Ingrid Malmgren

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https://evadc.org/EVInfo

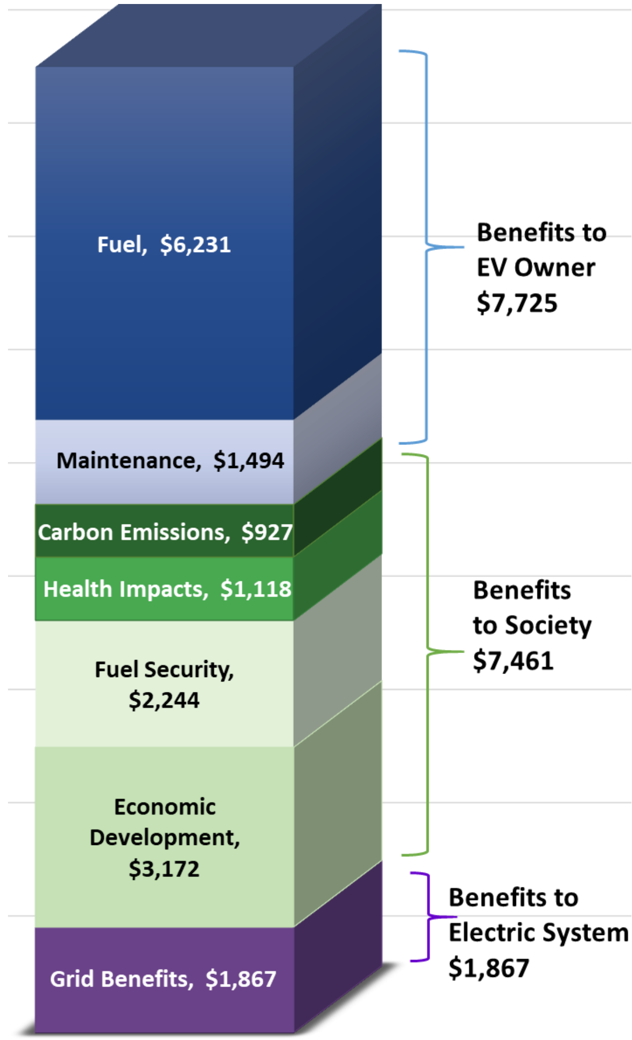
Executive Summary

Can driving an Electric Vehicle (EV) save the world? Perhaps "save the world" is going a bit far, but choosing to buy and drive an EV can have far-reaching effects. When you take into consideration:

- Transportation is the leading cause of greenhouse gas emissions in the United States.[1]
- According to the Environmental Protection Agency (EPA): cars, buses, planes, trucks and trains account for more than half of all the air pollution in the United States. The primary mobile source of air pollution is the automobile.[2]
- Exposure to this pollution leads to health impacts including heart attacks, strokes, and asthma attacks resulting in ER visits, hospitalization, and premature death.[3]
- Dependence on imported fossil fuels for transportation results in significant risk and costs associated with fuel security and national security.
- For most states, gasoline isn't a local commodity, so buying gasoline for fuel means that money spent on gas immediately leaves the local economy.

Electric Vehicles have enormous potential to help address some of the major issues facing our country and the planet today. Electrifying the transportation sector would dramatically reduce greenhouse gas emissions, air pollution, and dependence on fossil fuels. At the same time, EVs could improve domestic fuel security, improve public health, drive economic development, and create a more efficient and resilient electric grid.

According to a recent study of 20,000 global consumers, the single greatest barrier to EV adoption is price.[4] The price of the EV we use in this analysis is $15,090 more than its gasoline-powered counterpart. For most consumers, particularly those who need to finance a new vehicle--and let's face it, most of us fall into that category[5]-- this is a major barrier. While our analysis demonstrates the



Cumulative Benefits, $17,053

widespread value of an EV over its life, if you can't afford one, none of these benefits will be accessed.

Based on our research, a conservative estimate indicates that each EV can provide over $17,000 in benefits over the first eight years of its life. These benefits extend across local communities, states, countries, and globally. Monetizing some of these benefits and incorporating them into EV incentives could make EVs more accessible, improve health, reduce pollution, grow the economy, and--maybe even--help save the world.

Introduction

We conducted this analysis to assess the broader value of each additional Electric Vehicle (EV) on the road. The impacts of choosing to drive electric extend beyond a quiet ride, smooth acceleration, and lower fuel costs. They extend to the local community in the form of economic development and health improvements. They extend to the local electric utility in the form of efficiency and grid resilience. They extend through to the national level in the form of energy security and a reduced need to protect oil interests in volatile regions of the world. They extend globally to lower carbon emissions and costs associated with climate change.

This analysis builds off of an earlier research study *Quantifying the Societal Benefits of Electric Vehicles*[6] which was published for EVS29 in 2016. When the original study was published, there were about 560,000 Electric Vehicles (EVs) that had been sold in the U.S. At the end of 2019, there were over 1.4 million[7] EVs on the road. With the growth in the EV market, numerous additional studies have been undertaken and published identifying both costs and benefits of EVs to vehicle owners, electric utilities, the environment, and society at large. This paper will assess seven values identified in the original study to include new information and additional refinements to the methodology.

Why Offer Incentives for EV purchases?

In spite of robust growth, EVs made up only about 2.5% of the global new car market in 2019.[8] The primary barrier to EV sales is the higher up-front cost of the vehicles.[9] While over the life of the vehicle, an EV is cost competitive with a combustion vehicle, buyers focus heavily on purchase price. The incremental cost of new technology (in this case the battery) adds a lot to the price of the vehicle. In the example we will use in this analysis, the exact same vehicle (a 2020 Hyundai Kona SEL) with an electric drivetrain costs $15,090 more than its internal combustion equivalent. Over time, economies of scale and technological advancements will bring down the incremental cost of the batteries until eventually EVs and Internal Combustion Engine (ICE) vehicles reach cost parity. Until then, financial incentives help make EVs a more attractive and accessible option for those interested in driving electric.

Governments of large economies have supported EV sales through incentives for several reasons including that EVs offer widely-recognized benefits beyond energy savings. These benefits generally align with policy priorities such as climate goals, health improvements, economic development, and fuel security.

EV sales are supported by governments and utilities through a variety of mechanisms including education, outreach, reduced travel tolls, HOV lane access, charging infrastructure, charging rates, and tax credits. Financial incentives have been shown to be a consistent and significant driver in the increase of EV sales.[10]

The choice to drive an EV creates benefits that extend across local communities, states, countries, and globally. Monetizing some of these benefits and incorporating them into EV incentives could save governments money in the long run while helping them meet important policy goals.

Methodology and Assumptions

The original version of this study used cost benefit tests developed for the electric utility industry and applied them to electric vehicles. This updated analysis is based on the original, but uses a broader screen to identify and quantify the value of electric vehicles to drivers, the electric system, and society.

The values calculated for each of these benefits rely on a number of variables, many of which are based on existing research and estimates. Fuel prices, Social Cost of Carbon (SCC), health impact costs, and the other metrics included in this analysis vary significantly based on geography, regional prices, generation mix, and other factors. The results of this analysis are simplified to demonstrate what the benefits of an EV--on average--are in the United States.

While care was taken to find metrics and values that accurately reflect these benefits and a conservative approach was taken to incorporating these values, please keep in mind that this research and the resulting values are intended to be illustrative.

The goal of this analysis is to identify some of the more valuable and measurable benefits of EVs and demonstrate the magnitude of these benefits. Ideally, this updated research will expand the understanding of the range of EV benefits and serve as a tool for policy-makers to use when contemplating EV incentive levels.

Methodology

This analysis quantifies the costs and benefits of two identical vehicles, one with a conventional Internal Combustion Engine (ICE) and one with a battery-powered electric motor (EV) which relies exclusively on electricity for power. We chose the 2020 Hyundai Kona as our reference vehicle because it is manufactured and sold with both an ICE and as an EV. It has been sold in both of these configurations since 2018 and is expected to be sold in both configurations through at least 2021.

This analysis will quantify seven benefits from EVs. They include:

1. Fuel savings
2. Maintenance Savings
3. Environmental Benefits from Reduced Carbon Emissions
4. Health Benefits from Reduced Vehicle Emissions
5. Fuel Security & National Security Benefits
6. Economic Development Benefits
7. Benefits to the Electric Grid

These benefits will flow to different recipients. The fuel savings and operations & maintenance savings will benefit the EV owner or driver. The fuel security, economic development, health, and environmental benefits will affect society as a whole from the local community level through the global level. Additional EV load on the grid during times of low utilization will benefit all electric utility customers, even those customers not driving EVs.

Assumptions

Assumptions used in the valuation and comparison are as follows:

Vehicles are both cash purchases and are sold at sticker price.

This simplifies the analysis. It does however, provide an advantage for the person making an EV purchase. Since EV vehicle purchases require a larger upfront investment, the finance charges for purchasing an EV would be significantly higher if a proportionate portion of the cost of the vehicle was financed. This illustrates the importance of readily available financial incentives at point of sale.

Vehicle lifetime is assumed to be 8 years.

The average new vehicle is kept by the original owner for 6 years.[11] The average age of a vehicle on the road is about 11 years.[12] We chose to assess the costs and benefits of the vehicles over the first 8 years of the vehicle's life. The Hyundai Kona EV comes with a 10-year/100,000 mile battery warranty.[13] The Hyundai Kona SE comes with a 10-year/100,000 mile powertrain warranty. Both vehicles will fall under warranty for the duration of our analysis. Annual mileage is assumed to be 12,000 miles resulting in total vehicle mileage of 96,000 miles.

Another consideration that should be taken into account when purchasing a vehicle is resale value. The average three-year residual value among all new vehicles, according to Kelly Blue Book is 51.7%.[14] While first generation EVs did not fare well in resale value, EVs with over a 200-mile range have resale values on par with comparable ICE vehicles. In fact, the Tesla Model 3 is among the leaders in resale value by a wide margin with a 3-year depreciation of only 10.2% as of July, 2020.[15] With a range of 258 miles, the Kona should have a comparable resale value to conventional vehicles.

Gasoline price is assumed to be \$2.95 a gallon over the life of the vehicle.

Because of the volatility of gasoline prices, to develop a reliable estimate of energy costs to operate the ICE vehicle, we used an average retail gasoline price over the last 10 years from the U.S. Energy Information Administration.[16] It is assumed that gasoline prices for the 8 year life of the vehicle will be within the range of those of the last 10 years, so gasoline prices will be kept constant (at the 10-year average) for the life of the vehicle.

Electricity Costs are assumed to be 12.38¢ per kWh over the life of the vehicle.

To develop an estimate of the cost of electricity needed to power the EV in a way that is consistent with the methodology we used to estimate gasoline prices, we took the average retail electricity rate in the U.S. over the last 10 years. According to the U.S. Energy Information Administration, average U.S. retail price per kilowatt hour (kWh) for 2010 through 2019 was 12.38¢ per kWh.[17]

Many utilities use rate design to incentivize EV owners to charge at off-peak times such as overnight when rates are much cheaper. Not all utilities offer these discounted rates and the discounts vary widely from utility to utility. For simplicity and consistency, we did not include rate reductions from utilities in this analysis, but it is possible that they could contribute to additional savings. For the purposes of this analysis, it is also assumed that electricity prices will remain stable over the life of the vehicle.

Fuel prices and emissions will be based on national averages.

There exists a great deal of geographic variability related to the values we will assess in this analysis. Fuel prices, electricity prices, emissions from power generation, health impacts-all vary greatly throughout the United States. As a result, we will use national averages for these variables.

The electric vehicle purchase includes level 1 charging equipment which is installed at the EV operator's residence.

This analysis assumes that the EV is charged using the average residential rate. This does not break out workplace charging or public charging which, depending on location, could be subsidized, resulting higher or lower rates. The exception to this is the Total Ownership Cost Analysis (shown in Figure 5). In that section, we will include the cost of an installed Level 2 EVSE.

Both vehicles are driven the same mileage under the same conditions.

The Kona SEL internal combustion vehicle has an EPA rating of 30mpg average city and highway. The Kona EV SEL has an EPA rating of 27 kWh per 100 miles. These are the assumptions used in calculating fuel and energy costs.

All values shown are in 2020 dollars.

The benefits in this analysis are monetized based on existing research and literature. Some of this research is dated, in which case we used the Consumer Price Index inflation calculator[18] to adjust the values into 2020 dollars. We also did not calculate Net Present Value for the values as they tend to be tied to fuel use (or lack thereof) and emissions reduction over the life of the vehicle, so there is not one lump sum value at the beginning of the analysis. Rather, the benefits are accrued over the life of the vehicle based on use.

Value Ranges

Some of the benefits we assessed resulted in a range of values. In these cases we selected mid-range or conservative values within these ranges to present a plausible, balanced analysis.

The Vehicles

	
Hyundai Kona[19]	Hyundai Kona EV SEL[20]
30 mpg EPA	27 kWh/100 miles EPA
10 year/100,000 miles powertrain	10 year/ 100,000 mile battery warranty
3 year free maintenance	258 mile range
$22,100 m.s.r.p.	$37,190 m.s.r.p.

Analysis – Owner Benefits

Fuel Savings $6,231

Using 8-year average costs for both gasoline and electricity in the United States (according to U.S. EIA data) we calculated what it would cost to fuel the two vehicles. As shown in the chart below, the annual fuel cost for the gasoline-powered vehicle would be $1,180 and the fuel cost for the EV would be $401. Fuel savings for the EV driver would amount to $778.89 each year contributing to $6,231 in savings over the eight-year life of the vehicle.

Fuel Costs		
	2020 Hyundai Kona SEL	2020 Hyundai Kona SEL Electric
Annual Mileage	12,000	12,000
Fuel Cost	$2.95/gal	12.38¢ per kWh
Efficiency	30mpg	27kWh/100mi
Annual Fuel $	$1,180	$401.11
Difference	**$778.89**	
Life of vehicle	**$6,231.10**	

Maintenance Savings $1,494

EVs have far fewer moving parts than conventional ICE vehicles. The battery, motor, and electronics associated with the drivetrain require no regular maintenance. EVs feature regenerative braking which uses the motor to slow down. This form of braking system recaptures energy from the momentum of the vehicle and stores it in the battery. While EVs have friction brakes, they are used as supplemental brakes. This creates less wear on the brakes and provides additional stopping power. According to NAPA auto parts, brakes on EVs can last twice as long as brakes on traditional gasoline-powered vehicles.[21]

The America Automobile Association (AAA) has been publishing information about what it costs to maintain and drive vehicles since 1950. In 2017, their publication, *Your Driving Costs*[22] began to include an assessment of Electric Vehicle costs. Their most recent analysis (2019) includes average maintenance and repair costs for both electric and ICE vehicles, including a small SUV with front wheel drive, which we use for the 2020 model year.

Maintenance Costs		
	2020 Hyundai Kona SEL	2020 Hyundai Kona SEL Electric
Annual Mileage	12,000	12,000
Maintenance per mile	9.09¢	6.60¢
Annual Maintenance (first 3 years)	$792	$792
Total Maintenance (first 3 years)	**$2,376**	**$2,376**
Annual Maintenance (next 5 years)	$1090.80	$792
Total Maintenance (next 5 years)	**$5,454**	**$3,960**
Total Maintenance (8 years)	**$7,831**	**$6,336**
Difference Over Life of Vehicle	**$1494.00**	

NOTE: Hyundai offers 3 years of free regular maintenance on ICE vehicles. To adjust for this dealer incentive we calculated 3 years of Maintenance at EV rates and 5 years at ICE rates since some maintenance costs (tire rotation, inspections & registration fees) would still be incurred during the "free maintenance period".

Analysis –Benefits to Society

Carbon Emissions $927

Burning fossil fuels such as gasoline releases carbon dioxide (CO_2) into the atmosphere. CO_2 is a greenhouse gas linked to climate change. To determine the impact of this CO_2 in the atmosphere, the U.S. Environmental Protection Agency (EPA) and

> While the U.S. Social Cost of Carbon is considered to be a low estimate, we will use it in this analysis with the understanding that it is a conservative value.

other federal agencies use the Social Cost of Carbon (SCC) to estimate climate benefits of CO_2 emissions reduction. The SCC value represents an estimate, in dollars, of the economic damages that would result from emitting one additional ton of greenhouse gases into the atmosphere.[23] This value is intended to capture the expense of climate change damages from carbon emissions including changes in net agricultural productivity, human health, property damages from increased flood risk, and changes in energy system costs, such as reduced costs for heating and increased costs for air conditioning.[24]

It is widely accepted by researchers that this value fails to capture all of the economic, ecological, health, and physical damages linked to climate change because some of the damages are difficult to precisely identify and quantify.[25] In addition, models do not incorporate all of the damages identified in the literature. Based on the technical support document prepared by the U.S. government interagency working group on Social Cost of Carbon (SCC), in 2020 dollars, the SCC per ton is $42.00 in 2007 dollars per metric ton using a 3% discount rate.[26] Using the Consumer Price Index to adjust this value to 2020 dollars creates a value of $53.34 per ton. Estimates for the Social Cost of Carbon vary widely both in the U.S. and around the world from a value of near zero to hundreds of dollars. While the U.S. SCC is considered a low estimate, we will use it in this analysis with the understanding that it is a conservative value.

Carbon Emissions		
	2020 Hyundai Kona SEL	2020 Hyundai Kona SEL Electric
Annual Mileage	12,000	12,000
Emissions	20#/gallon[27]	.99#/kWh[28]
Fuel Economy	30 mpg	27kWh/100mi
Energy use/year	400 gal	3240kWh
CO2 emissions/year	8000 lbs.	3240 lbs.
CO2 emissions/year	3.63 metric tons	1.45 metric tons
SCC (2020 dollars) 3% discount rate	$53.34	$53.34
SCC for Annual Emissions	$193.50	$77.59
Difference/year	$115.93	
Life of vehicle	$927.44	

Health Impacts $1,118

In addition to carbon, other emissions such as tiny particulate matter (PM2.5) and ozone precursors from vehicle emissions contribute to serious health impacts including lung cancer, asthma, infection susceptibility, cardiovascular harm, developmental harm, reproductive harm and premature death.[29] In fact, by 2030, EPA air quality emissions standards for vehicles are projected to prevent 40,000 premature deaths, 34,000 avoided hospitalizations, and 4.8 million work days lost each year.[30]

Several researchers have monetized the cost to society of these health damages. Using this data, we have estimated the value of the reduced health damages of driving an electric vehicle rather than driving a gasoline vehicle.

We used data from the Bureau of Transportation Statistics (2018) to estimate pollution levels in light duty vehicle emissions.[31] Similarly, we used 2018 eGRID data from the Environmental Protection Agency to estimate the emissions produced from power generation for the EV.[32] We then applied the damage values from the EPA Technical Support Document: *Estimating the Benefit per Ton of Reducing $PM_{2.5}$ Precursors from 17 Sectors* to the emissions from both vehicles.[33] We also adjusted these numbers for inflation using the consumer price index. Based on our calculations, driving an EV in the United States instead of a gasoline-powered vehicle will prevent health impacts valued at about $1,118.

It is important to note that emissions from power plants are valued as being less damaging because vehicle pollution is emitted in much closer proximity to people. This proximity contributes to higher health damages to those in large cities and marginalized socio-economic groups who are more likely to live and work closer to busy roads.[34] [35]

Health Impacts		
	2020 Hyundai Kona SEL	2020 Hyundai Kona SEL Electric
Annual value of health damages from tailpipe emissions	$175.99	$0
Annual value of health damages from elec. generation	$0	$36.28
Difference/year	$139.71	
Life of vehicle	$1117.65	

In addition to providing a greater distance between pollutants to people, U.S. electricity generation is quickly becoming cleaner. As the dirtiest power plants retire and renewables make up a growing percentage of power production, health benefits from EVs will, in fact, grow annually over the 8- year vehicle life. To be conservative, the value was held constant in this analysis.

Fuel Security & National Security $2,244

Oil prices are historically volatile. While the U.S. has decreased oil imports over the last 15 years, in 2019, it still imported 9.1 million barrels of oil a day.[36] This dependence on imported oil creates political complexities and economic costs.

A number of studies and publications have quantified the costs associated with reliance on foreign oil. The study cited in the original publication of this analysis is from 2008 and is from Oak Ridge National Laboratory (ORNL). This study continues to be the go-to reference for assessing costs to the U.S. for fuel security. In fact, a study conducted for NYSERDA recently relied on this study to quantify petroleum displacement benefits from electrification in New York in 2019.[37]

For this analysis, we used the ORNL study (adjusted for inflation) for market effects related to demand and price spikes. Oil is priced globally and is dependent on global supply and demand. Foreign oil has supply security risks. Domestic oil is impacted by economic security risks. Even if a country relies on its own oil, global supply and demand changes make prices very volatile. EVs powered by the U.S. electric grid are not subject to these volatile markets since electricity is regulated and comes from diverse and domestic fuel sources. These values do not include the cost of military policy or operations required to protect access to oil in volatile regions of the world.

For values related to military policy and operations costs, we turned to a 2018 study by Securing America's Energy Future (SAFE) that measured money spent by the U.S. military to protect global oil supplies and calculated this value over the number of barrels of oil imported. They came to a conservative value of 28¢ per gallon of motor gasoline. More comprehensive economic estimates in this study reveal a value of over 70¢ per gallon of motor gasoline.[38]

Consistent with other values in this analysis, we will use the more conservative estimate for military costs and combine them with the costs of market impacts of imported petroleum to quantify the value of reducing reliance on foreign oil by powering vehicles with electricity. There is a very small amount of oil used in generating electricity in the U.S. We accounted for this in the evaluation as seen in the table below.

Fuel Security		
	2020 Hyundai Kona SEL	2020 Hyundai Kona SEL Electric
Military cost of defending oil supply (SAFE)	28¢ per/ gal	0.28¢ per/ gal
Monopsony Component	28¢ per/ gal*	0.64¢ per/ gal
Macroeconomic Disruption/ Adjustment Costs	15¢ per/ gal*	0.34¢ per/ gal
Total Fuel Security	**71¢ per/ gal**	**1.26¢ per/ gal**
Annual Gallons	400	400
Fuel Security Cost per year	$285.51	$5.02
Difference/year	**$280.49**	
Life of vehicle	**$ 2,243.92**	

*Adjusted for portion of oil imported in 2019 (44.5%)[39]

Economic Development $3,172

Every time a driver stops at a gas station and fills up their tank, approximately 80% of the money they spend immediately leaves the local economy.[40] EVs offer two advantages for keeping money in the local economy. The first is that it costs less to power a vehicle with electricity which means that some of the money traditionally spent on gas is kept in

> Using two different methodologies, we estimated that in the U.S. in 2018, approximately $167 Billion was spent on gasoline for cars and immediately left local economies.

consumers' wallets. The second is that electricity is more likely to be generated locally so a greater portion of the money spent on transportation energy will stay local.

A Cal-ETC study estimated that in Florida, households using PEVs would save a net $1,700 per year on fuel and maintenance. It estimated that most of these savings would be spent on food, household furnishings, clothing, and entertainment.[41] Based on typical spending patterns, the same study estimated that this EV-driving household would increase their spending on food byaround $770 each year. This additional spending on food would support local farms, markets and restaurants. Another Cal-ETC study found that for every dollar spent on goods and services in California, 16 more jobs were created than for a dollar spent on gasoline.[42]

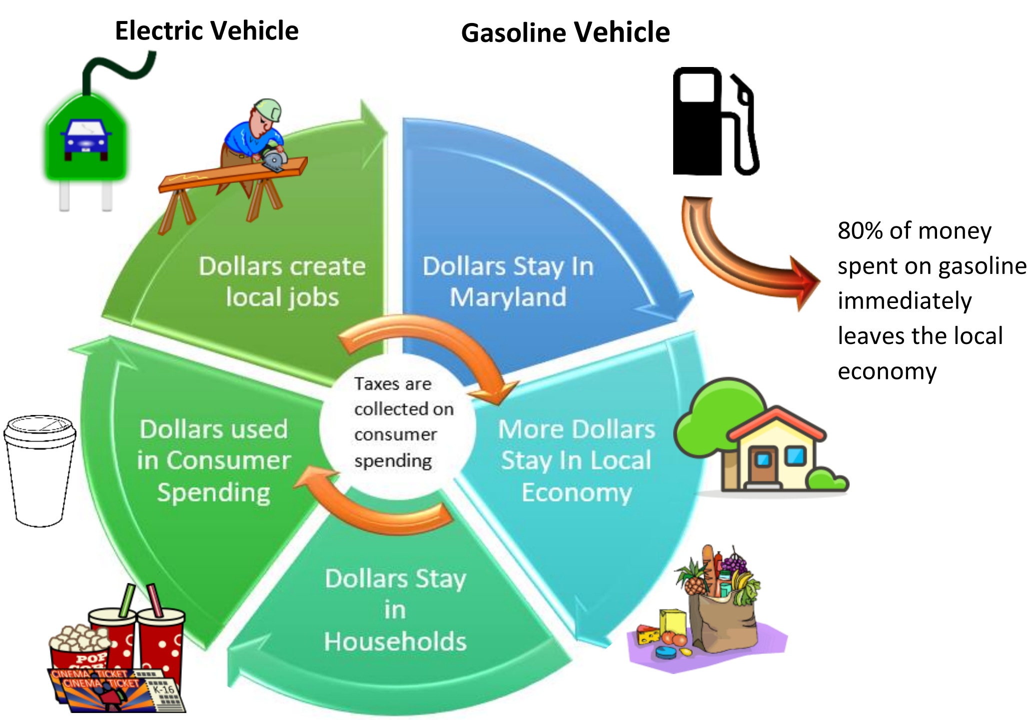
Each step of the Economic Multiplier of Electric Vehicles (shown in **Figure 1**) also has the potential for generating tax revenue which also feeds back into the local economy and creates jobs.

Recent studies conducted by the National Renewable Energy Laboratory (NREL) and Energy & Environmental Economics have shown that reduced gasoline spending associated with owning and operating an EV yields roughly $4000 in regional economic development over the life of the vehicle.[43] One challenge with these analyses is that they include the value of the federal tax credit.

Without this initial economic incentive, local spending in the economy would be much lower until fuel savings catch up with the incremental cost of the vehicle. This is one reason why EV incentives are still an important market driver and readily contribute to local and regional economies cost of the vehicle.

Economic Development		
	2020 Hyundai Kona SEL	2020 Hyundai Kona SEL Electric
Per EV Regional Economic Development[44]		$4,100* *over life of vehicle
National Average per EV per year[45]		$362 to $431
Average Value/year	**$396.50**	
Life of vehicle	**$3,172.00**	

Figure 1: Economic Multiplier of Electric Vehicles



Grid Benefits $1,867

The U.S. electric grid is made up of generation facilities, transmission lines, and distribution lines that generate and deliver energy necessary to meet consumer electric demand. It has extremely limited storage capacity and must constantly adjust to provide sufficient power in real time. As demand for power grows during different times of the day, the grid must respond immediately. As more renewables contribute power to the grid, overgeneration can occur. Depending on how EVs are integrated with the grid, their impact can range from costing utilities and transmission operators a great deal of money to providing tens of thousands of dollars in grid benefits per vehicle.

In an ideal world, a graph of electricity usage would be flat with steady electricity generation and steady electricity use. In reality, people use more electricity during different times of day and under different weather conditions.

Figure 2: Incorporating Daily EV Load

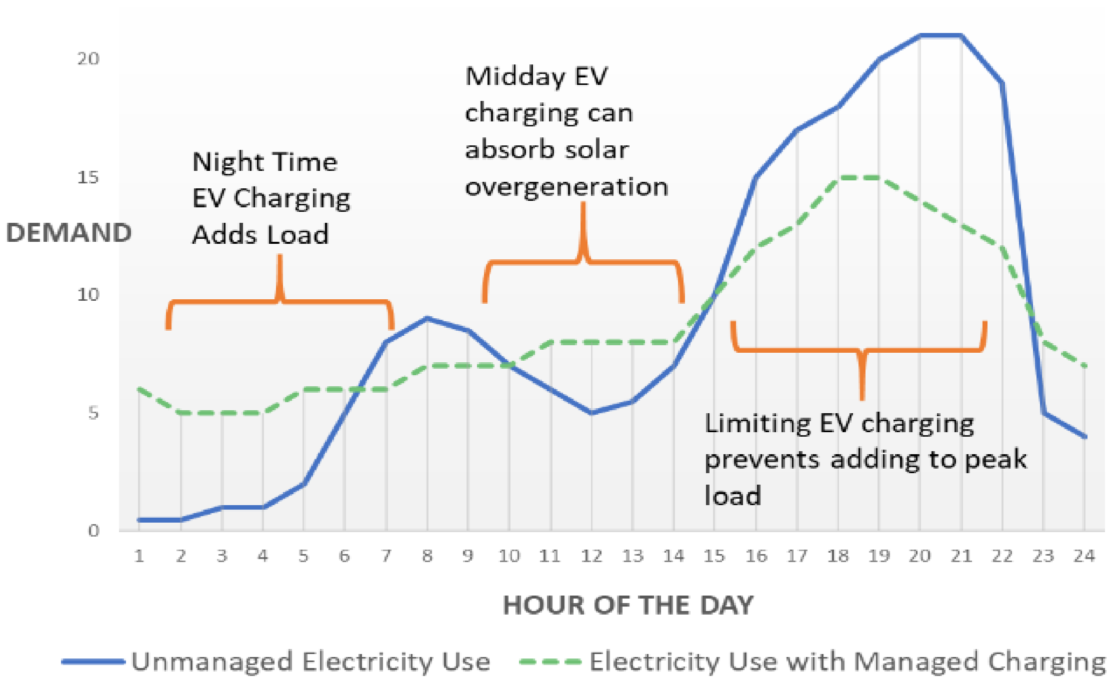


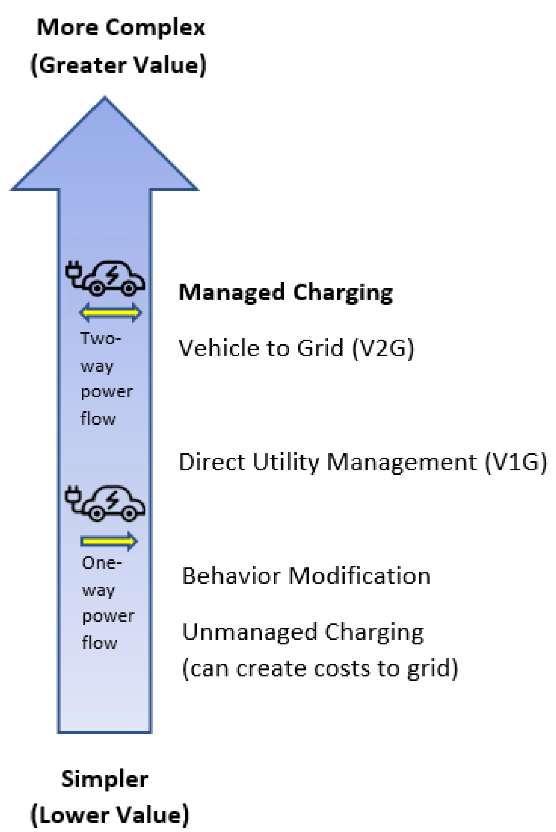
Figure 2 illustrates a simplified day of grid demand and the potential positive impact of EVs on this demand. Simply by charging EVs during times of low power demand (valleys), and curtailing (or stopping) charging during times of high demand (peaks), the vehicles can help flatten electric load which can save utilities and transmission operators a great deal of money. Conversely, if EVs charge during times of heavy power use (peak load) the costs to utilities and transmission operators could be enormous.

Utilities employ several "tools" to help keep electricity supply and demand aligned. Some utilities use rate design (such as time-of-use rates) to offer lower electricity prices to encourage EV owners to charge during times of low demand (typically at night). Another tool utilities use is "Demand Response." As demand for power increases, electricity prices rise exponentially. Demand response techniques involve notifying and encouraging electric customers to reduce their use during times of high demand for a financial incentive.

If utility customers adjust their behavior, it allows utilities to reduce capital investments to keep up with demand. Increased revenue from massive off-peak charging will put downward pressure on rates, since it utilizes currently under-utilized assets. Not all utilities offer rate design and/or demand response options to residential customers, but these tools are expected to become widespread over the next several years and will be valuable for both EV customers and utilities.

The next level of complexity and value as seen in **Figure 3** is managed charging which allows the utility to control vehicle charging directly. Using charging equipment, the utility can slow or curtail charging as necessary to regulate power demand. This could be as simple as slowing or turning off charging during peak events, or as complicated as controlling small fluctuations in charging for frequency regulation. Managed charging is a nascent technology and has not yet been integrated or perfected. It is not available to retail utility customers and may take a while to become widespread.

Figure 3: Continuum of EV-Grid Interaction



The options discussed so far only require one-way power flow from the grid to the vehicle (V1G). Services that EVs could provide to the grid that offer the highest value include bidirectional charging or power flow that goes back and forth between the vehicle and the grid (V2G). These services are not widely available through utilities thus far but are expected to become widespread in the years ahead. In addition, most mass-market EVs[46] are not currently equipped with bidirectional chargers thus cannot serve in these roles.

There are significant benefits (and potentially costs) to the grid from EV charging. To determine a reasonable estimate of the value to the grid that EVs are likely to provide in the present or near future, we chose to focus on the value of benefits that EVs can contribute to the grid in the current technological and regulatory environment.

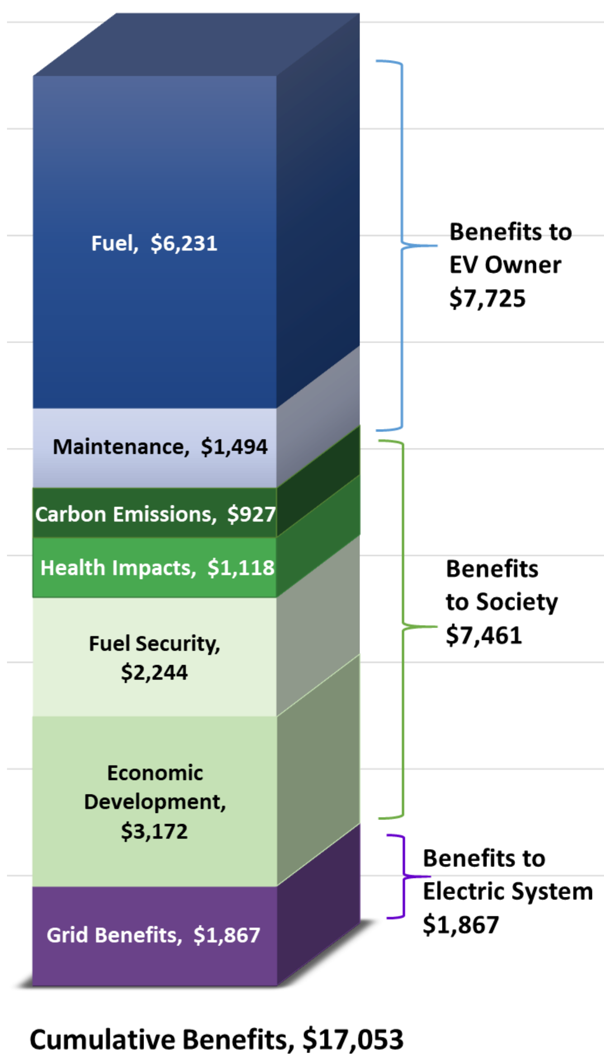
We selected ratepayer benefits as our value of EVs to the grid since they are well-documented and readily available. After examining current literature, we included ranges from a cross section of scenarios and studies. We selected a mid-range value from the literature as a conservative value for this analysis. It is important to keep in mind that there is great potential for EVs to provide much greater value to the grid in the future, but if EV charging is unmanaged, there is also potential for EVs to create significant costs to the grid as well.

EV Benefits to the Grid		
Study	Scenario	Value
Cal-ETC[47]	Low	$2,788
	High	$9,607
MJ Bradley[48]	Low	$744
	High	$1,692
Bonneville[49]	Low-Unmanaged	$300
	High-Unmanaged	$800
	Low-Managed	$830
	High-Managed	$1,000
MJ Bradley[50]	NY-NYC	$2,258
	NY-Long Island	$1,087
	NY-Upstate	$(569)
Average		$1,867

Conclusions and Next Steps

Electric Vehicles create broad benefits that extend beyond gas savings. **Figure 4** illustrates the compiled value of EV benefits over the course of its first 8 years on the road. Based on the average fuel and electricity prices over the last ten years, a single EV will save its **owner $7,725** in gasoline and maintenance savings. This is the average savings, which may be lower or higher depending on local gas prices, electricity prices, and where you live.

Figure 4: Compiled EV Benefits over 8 Years & 96,000 miles



Conservative estimates demonstrate that the same EV will yield climate benefits, health benefits, fuel security & national security benefits, and economic development benefits of about $7,461. These benefits help **society**. Over the life of the same vehicle, this vehicle could provide benefits to make the **electric grid** more efficient and resilient which we conservatively estimate could yield **ratepayer benefits** of $1,867. With the exception of fuel and maintenance savings, the EV owner creates these benefits by driving an EV *but does not receive monetary compensation for these benefits*. Over the life of the EV, the benefits from this vehicle will likely be over $17,000.

As Figure 5 illustrates, even without EV incentives, when considering the broader benefits an EV provides, the cost of a traditional gasoline powered vehicle (to the consumer and society) will be greater over the first 8 years than the cost of a comparable Electric Vehicle. Since these savings accrue over time and EVs have a significantly higher up-front cost, EV incentives are an important tool to change consumer behavior and access these benefits from EVs.

Figure 5: Total Ownership Cost

Vehicle	Hyundai Kona SEL	Hyundai Kona EV SEL
Vehicle Cost	$22,100	$37,190
Level 2 Charging Station (Including installation)	$0	$1,000
Energy Costs	$9,440	$3,209
Maintenance Costs	$7,830	$6,336
Social Cost of Carbon	$1548	$621
Health Costs of Pollution	$1,408	$290
Economic Development Benefit	$0	-$3,172
National Security Costs	$2,284	$40
Grid Benefit	$0	-$1,867
Total 8-year Cost to Owner and Society	$44,610	$43,647

This analysis provides a tool for policymakers to identify and capture the broader benefits of EVs and facilitate appropriate incentive values to reflect a more accurate value of EVs. Policymakers can leverage that value to reduce the incremental cost of EVs in the marketplace which will help meet policy goals and support job creation, economic development, national security, public health improvement, climate goals, and a more efficient electric grid.

Next Steps

An economic analysis such as this one can always continue to benefit from refinements in methodology, expansion of the literature review to incorporate new publications as they become available, and incorporation of additional benefits as they are identified. This study is not designed to accurately capture every dollar of benefit from EVs, but rather to provide a framework of thinking more broadly about the far-reaching implications of the decision to purchase an EV and how it can support policy goals like public health, energy security, economic development, and climate change.

Next steps that emerged in the course of this research include:

1. Conduct additional research on local and regional economic development benefits. There is a significant amount of literature that identifies economic development benefits that EVs can contribute to states and regions, but they are often presented in large scale job creation, and billions of dollars of economic development associated with multiple scenarios of EV adoption. This information may be more

2. Because the variables used in these analyses fluctuate based on geography, fuel prices, generation mix, labor rates, and many other inputs, it would be useful to develop an online tool or calculator that is maintained to update inputs based on current values. It could also be linked to geographic data to incorporate regional or local fuel/electricity costs, labor rates, generation mix and healthcare costs to provide more regionally accurate and up-to-date values.

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[1] **United States Environmental Protection Agency:** *Fast Facts on Transportation Greenhouse gas Emissions.* 2018. https://www.epa.gov/greenvehicles/fast-facts-transportation-greenhouse-gas-emissions

[2] **National Park Service:** *Where does air pollution come from?* January 17, 2018. https://www.nps.gov/subjects/air/sources.htm#:~:text=Mobile%2C%20stationary%2C%20area%2C%20and,to%20the%20Environmental%20Protection%20Agency.

[3] **United States Environmental Protection Agency:** *Our Nation's Air.* 2018. https://gispub.epa.gov/air/trendsreport/2018/#effects

[4] **Ipsos.** *What Will it Take to Put Consumers in the Driver's Seat of Battery Electric Vehicles?* January 23, 2020. https://www.ipsos.com/en-us/news-polls/Battery-Electric-Vehicles

[5] **Experian.** *Auto Loan Debt Sets Record Highs*. July 18, 2019. https://www.experian.com/blogs/ask-experian/research/auto-loan-debt-study/#:~:text=Of%20the%20new%20passenger%20vehicles,increase%20over%20Q1%202018%20figures.

[6] Malmgren, Ingrid. *Quantifying the Societal Benefits of Electric Vehicles*. **World Electric Vehicle Journal** 8(4):986-997. DOI: 10.3390/wevj8040996. December 2016. https://www.researchgate.net/publication/316579570_Quantifying_the_Societal_Benefits_of_Electric_Vehicles

[7] Alternative Fuels Data Center from Transportation Research Center at Argonne National Laboratory. U.S. Plug-In Electric Vehicle Sales by Model. 2019.

(includes Plug-In Hybrid Electric vehicles): https://afdc.energy.gov/data/10567

[8] McKinsey & Company: *McKinsey Electric Vehicle Index: Europe cushions a global plunge in EV sales.* July 17, 2020. https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/mckinsey-electric-vehicle-index-europe-cushions-a-global-plunge-in-ev-sales#

[9] **Ipsos.** *What Will it Take to Put Consumers in the Driver's Seat of Battery Electric Vehicles?* January 23, 2020. https://www.ipsos.com/en-us/news-polls/Battery-Electric-Vehicles

[10] Zifei Yang, Peter Slowik, Nic Lutsey, Stephanie Searle. **International Council on Clean Transportation.** *Principles for Effective Electric Vehicle Incentive Design*. June, 2016. https://theicct.org/sites/default/files/publications/ICCT_IZEV-incentives-comp_201606.pdf

[11] Doug Demuro. **Auto Trader**. *Buying a Car: How Long Can You Expect a Car to Last?* June 30, 2019 https://www.autotrader.com/car-shopping/buying-car-how-long-can-you-expect-car-last-240725

[12] Bomey, Nathan. **USA TODAY**. *Old cars everywhere: Average vehicle age hits all-time high*. June 28, 2019. https://www.usatoday.com/story/money/cars/2019/06/28/average-vehicle-age-ihs-markit/1593764001/

[13] HYUNDAI USA. Kona Electric. 2021. https://www.hyundaiusa.com/us/en/vehicles/kona-electric/compare-specs

[14] Jim Gorzelany, Senior Contributor. **Forbes**. *Here's Why Electric-Car Resale Values Are Rising, With Tesla Leading The Segment*. March 25, 2019. https://www.forbes.com/sites/jimgorzelany/2019/03/25/heres-why-electric-car-resale-values-are-on-the-upswing/#1f9ffcdb6af3

[15] **Autoblog.** *Electric cars ranked by resale value.* July 23, 2020. https://www.autoblog.com/photos/electric-cars-ranked-by-resale-value/

[16] **U.S. Energy Information Administration**. U.S. All Grades, All Formulations Retail Gasoline Prices. November 30, 2020. https://www.eia.gov/dnav/pet/hist/LeafHandler.ashx?n=pet&s=emm_epm0_pte_nus_dpg&f=a

[17] **U.S. Energy Information Administration.** Table 5.6.A. Average Price of Electricity to Ultimate Customers by End-Use Sector, by State, September 2020 and 2019 (Cents per Kilowatthour). https://www.eia.gov/electricity/monthly/epm_table_grapher.php?t=epmt_5_6_a

[18] **U.S. Bureau of Labor Statistics**. Consumer Price Index Inflation Calculator. https://www.bls.gov/data/inflation_calculator.htm

[19] Google Search Page. 2020 Hyundai Kona. https://www.google.com/search?sa=X&rlz=1C1CHBF_enUS817US817&q=2020+Hyundai+Kona&stick=H4sIAAAAAAAAAOPgE-LVT9c3NMyoyssoNspNV4Jw03IL89Kr8iy0NLOTrfQTS0vyc_NLMstS9XPzU1Jz4itTE4viS4oyc63AfAUQfxGroJGBkYGCR2VpXkpipoJ3fl7iDlZGAE_13atiAAAA&ved=2ahUKEwi4g6KllZztAhXjm-AKHWZWBFMQmxMoATAeegQIIBAD&biw=1536&bih=722

[20] Google Search Page. 2020 Hyundai Kona Electric. https://www.google.com/search?sa=X&rlz=1C1CHBF_enUS817US817&q=2020+Hyundai+Kona+EV+SEL&stick=H4sIAAAAAAAAAONgFmJQ4tVP1zc0zLCwLEkrq8zWUs9OttJPLC3Jz80vySxL1c_NT0nNia9MTSyKLynKzLXKzcxTyC0uKnjE-J2NW-Dlj3vCUm_ZJq05eY3xGRsXsZqFzrJysbnmlWSWVAodYhXaz8rF5-sS5hyUWpyfU1qSmZ8nZMHF5Zyfk5OaDOZpcYlICegnwwX0kxOLijUYpIS4MESFglB0unApSskiq4G4LikzJzU-qTQzJwVkjDwXfiVCMShm-nGpSSnh0IDwMchgFS4i1AlloJgexaUjpUFQV3xxSWVOKsgOLS6iVQuloNgUxqUlpUZYLyjmgPZocBGpViiUi92_ILUoMS9FyEvIg0sMFLW-qblJqUXF_mkemUCZouSMSiE9eBJQ4RKUgiTDlLSSpPL0jCygffxcqEJCPghjHYXsuXghKSYnsSQ1JSQfq2lJ5uYpxtmVGUimwYTIMC3ZODs5K6nIAMk0mJBStlH8rkvTzrFFCk4o-_-_n8HPQUpTS4iL3bPYJz85MUfQ8el5-Zf_39trCXNxhCRW5Ofl51YKPnxvcZDv3Vt7JUXOrZY37pv6P7IXPK_0f7_ZBl8HCRYFBg0Gw54mRobrySYOWgxN-1YcYmPhYBRg4FnEKmFkYGSg4FFZmpeSmKngnZ-XqOAaphDs6gMAbspHmdIDAAA&ved=2ahUKEwi4g6KllZztAhXjm-AKHWZWBFMQri4wKHoECAwQOg

[21] Fields, Cecelia. **Electric Car Maintenance: What You Need to Know.** October 2, 2019. https://www.motorbiscuit.com/electric-car-maintenance-what-you-need-to-know-about-maintaining-your-ev/

[22] **American Automobile Association** (AAA). *YOUR DRIVING COSTS How Much Are You Really Paying to Drive?* 2019. https://www.aaa.com/AAA/common/AAR/files/AAA-Your-Driving-Costs.pdf

[23] Kevin Rennert, Kevin and Kingdon, Cora. **Resources for the Future**. *Social Cost of Carbon 101: A review of the social cost of carbon, from a basic definition*

to the history of its use in policy analysis. August 1, 2019. https://www.rff.org/publications/explainers/social-cost-carbon-101/#:~:text=The%20social%20cost%20of%20carbon%20(SCC)%20is%20an%20estimate%2C,greenhouse%20gases%20into%20the%20atmosphere.

[24] U.S. Environmental Protection Agency. *The Social Cost of Carbon: Estimating the Benefits of Reducing Greenhouse Gas Emissions.* January 19, 2017. Accessed 10/20/20. https://19january2017snapshot.epa.gov/climatechange/social-cost-carbon_.html

[25] Ibid.

[26] US EPA, *Technical Support Document: Technical Update of the Social Cost of Carbon for Regulatory Impact Analysis - Under Executive Order 12866 - Interagency Working Group on the Social Cost of Carbon, United States Government (original values in 2007$ per metric ton)*, August 2016. https://www.epa.gov/sites/production/files/2016-12/documents/sc_co2_tsd_august_2016.pdf

[27] Department of Energy (DOE), Alternative Fuels Data Center (AFDC), Physical and chemical properties of gasoline. *How Can a Gallon of Gasoline Produce 20 Pounds of Carbon Dioxide?* https://www.fueleconomy.gov/feg/contentincludes/co2_inc.htm

[28] This value accounts for the carbon emissions generated from the electricity needed to power the EV. This is based on the average carbon emissions of all U.S. electricity generation in 2018. The carbon intensity of electricity generation in the U.S. goes down every year and the emissions generated to power an EV are already lower than this value.
U.S. Energy Information Administration (EIA). FREQUENTLY ASKED QUESTIONS (FAQS) *How much carbon dioxide is produced per kilowatthour of U.S. electricity generation?* https://www.eia.gov/tools/faqs/faq.php?id=74&t=11#:~:text=In%202018%2C%20total%20U.S.%20electricity,of%20CO2%20emissions%20per%20kWh

[29] American Lung Association. *The Road to Clean Air: Benefits of a Nationwide Transition to Electric Vehicles.* 2020. https://www.lung.org/getmedia/99cc945c-47f2-4ba9-ba59-14c311ca332a/electric-vehicle-report.pdf

[30] U.S. EPA. *Smog, Soot, and Other Air Pollution from Transportation*. From 2018 National Emissions Inventory. https://www.epa.gov/transportation-air-pollution-and-climate-change/smog-soot-and-local-air-pollution

[31] U.S. EPA. Office of Transportation and Air Quality, Bureau of Transportation Statistics. *Estimated U.S. Average Vehicle Emissions Rates per Vehicle by Vehicle Type Using Gasoline and Diesel*. Apr. 6, 2018. https://www.bts.gov/content/estimated-national-average-vehicle-emissions-rates-vehicle-vehicle-type-using-gasoline-and

[32] U.S. EIA. *Electricity emissions by plant and by region*. Final annual data for 2019. Release date: October 22, 2020 https://www.eia.gov/electricity/data/emissions/

[33] U.S. EPA. (BenMAP) *Estimating the Benefit per Ton of Reducing PM2.5 Precursors from 17 Sectors*. February, 2018. https://www.epa.gov/benmap/estimating-benefit-ton-reducing-pm25-precursors-17-sectors

[34] Shekarrizfard, Maryam et al. *Influence of travel behaviour and daily mobility on exposure to traffic-related air pollution*, Environmental Research. Vol 184 (May 2020), https://doi.org/10.1016/j.envres.2020.109326.

[35] Environmental Defence, Ontario Public Health Association. *CLEARING THE AIR How Electric Vehicles And Cleaner Trucks Can Reduce Pollution, Improve Health And Save Lives In The Greater Toronto And Hamilton Area*. JUNE 2020. https://clearingtheair.ca/

[36] U.S. EIA. *Oil and petroleum products explained*. April 27, 2020. https://www.eia.gov/energyexplained/oil-and-petroleum-products/imports-and-exports.php

[37] MJ Bradley for NYSERDA. *Benefit-Cost Analysis of Electric Vehicle Deployment in New York State Final Report.* Report Number 19-07. February 2019. https://www.mjbradley.com/news-events/nyserda-releases-new-york-electric-vehicle-benefit-cost-analysis

[38] Securing America's Energy Future. *The Military Cost of Defending the Global Oil Supply*. 2018. http://secureenergy.org/wp-content/uploads/2020/03/Military-Cost-of-Defending-the-Global-Oil-Supply.-Sep.-18.-2018.pdf

[39] U.S. EIA. *Oil and petroleum products explained*. April 27, 2020. https://www.eia.gov/energyexplained/oil-and-petroleum-products/imports-and-exports.php

[40] **U.S. EIA**. *Gasoline and Diesel Fuel Update.* November 30,2020. https://www.eia.gov/petroleum/gasdiesel/

[41] **Energy and Environmental Research Associates,** LLC. James J. Winebrake, Erin H. Green, and Edward Carr. *Plug-In Electric Vehicles: Economic Impacts and Employment Growth*, PRELIMINARY FINAL REPORT. October 2017 https://caletc.com/assets/files/EERA-PEV-Economic-Impacts-and-Employment-Growth.pdf

[42] Roland-Holst, David. *Plug-in Electric Vehicle Deployment in California: An Economic Assessment* September 2012. https://caletc.com/assets/files/ETC_PEV_RH_Final120920.pdf

[43] Results across multiple PEV market success scenarios suggest average net private benefits ranging from $255 to $791. The range of $362 to $431 per PEV per year for the national average falls more or less in the middle of these higher and lower division ranges. https://www.nrel.gov/docs/fy17osti/66980.pdf
E3 found that EVs are a form of economic stimulus to the region since drivers purchase locally-produced clean electric fuel. On average, EVs adopted through 2030 are estimated to add $4,100 per vehicle to the local economy. http://www.b-e-f.org/wp-content/uploads/2020/06/BEF_EV-cost-benefit-study_2020.pdf

[44] **Bonneville Environmental Foundation** (BEF). *EV cost benefit study summary: Electric Vehicle Costs and Benefits for BPA Full Requirements Customers*. April 2020 http://www.b-e-f.org/wp-content/uploads/2020/06/BEF_EV-cost-benefit-study_2020.pdf

[45] **National Renewable Energy Laboratory**. Marc Melaina, Brian Bush, Joshua Eichman, Eric Wood, Dana Stright, Venkat Krishnan, David Keyser, Trieu Mai, and Joyce McLaren. *National Economic Value Assessment of Plug-In Electric Vehicles Volume I*. December 2016. https://www.nrel.gov/docs/fy17osti/66980.pdf

[46] With the exception of a few manufacturers including Tesla, who introduced bidirectional charging capability in 2020 but is not advertising the capability. Also, Nissan and Kia which have CHAdeMO chargers which are bidirectional. https://electrek.co/2020/05/19/tesla-bidirectional-charging-ready-game-changing-features/

[47] Garrett Fitzgerald, Chris Nelder, **Rocky Mountain Institute**. 2017. *From Gas to Grid: Building Charging Infrastructure to Power Electric Vehicle Demand.* Table 7, page 78. https://rmi.org/wp-content/uploads/2017/10/RMI-From-Gas-To-Grid.pdf

[48] Ibid.

[49] **Bonneville Environmental Foundation** (BEF). *EV cost benefit study summary: Electric Vehicle Costs and Benefits for BPA Full Requirements Customers*. April 2020 http://www.b-e-f.org/wp-content/uploads/2020/06/BEF_EV-cost-benefit-study_2020.pdf

[50] **MJ Bradley for NYSERDA**. *Benefit-Cost Analysis of Electric Vehicle Deployment in New York State Final Report.* Report Number 19-07. February 2019. https://www.mjbradley.com/news-events/nyserda-releases-new-york-electric-vehicle-benefit-cost-analysis