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# Examining the effects of policy interventions on increasing electric vehicle adoption in California

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This Master's Project

**Examining the effects of policy interventions on increasing electric vehicle adoption in California**

by

**Ethan McDermott**

is submitted in partial fulfillment of the requirements  
for the degree of:

**Master of Science  
in  
Environmental Management**

at the

**University of San Francisco**

Submitted:

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Maggie Winslow, Ph.D.              Date

# Abstract

Any significant effort to reduce global emissions of greenhouse gasses must address the growing concern of the transportation sector's inability to meaningfully reduce its emissions contribution. A major shift in the primary fuel used in the sector away from petroleum-based fuel to electricity is one potential way the sector can lower its emissions and transition into a sustainable future. However, a number of barriers face the electric vehicle market, including competing against an already mature vehicle market, battling consumer preferences, and overcoming technical challenges. This paper examines several policy proposals to combat these barriers and examines the impact similar policies could have on the electric vehicle market in California. California is chosen because of its historical leadership in environmental causes, and for exhibiting cultural values that are in line with increasing the adoption of electric vehicles. It is found that policies that affect the purchase price of the vehicle, and improve access to charging infrastructure are most effective in increasing the number of sales, but that policies aimed at signaling a longstanding commitment to the success of the EV market and reduce GHG emissions are a greater indicator of whether there is sustained growth in the EV market. Recommendations are given based on California's current policy package to strengthen the current EV market, and transition into a self-sustaining market without the need for government intervention.

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# Acronyms

AFV – Alternative Fuel Vehicle

AB32 – Assembly Bill 32

BEV – Battery Electric Vehicle

CAFÉ – Corporate Average Fuel Economy

CARB – California Air Resources Board

DOE – Department of Energy

EIA – Energy Information Administration

EPA – Environmental Protection Agency

EV – Electric Vehicle (Battery Electric and Plug-In Hybrid)

FCV – Fuel Cell Vehicle

GHG – Greenhouse Gas

HEV – Hybrid Electric Vehicle

ICE – Internal Combustion Engine

ICEV – Internal Combustion Engine Vehicle

IEA – International Energy Agency

LEV – Low Emissions Vehicle

MMTCO<sub>2e</sub> – Million Metric Ton of Carbon Dioxide Equivalent

NEV – New Energy Vehicle

OPEC – Organization of the Petroleum Exporting Countries

PEV – Plug-in Electric Vehicle

PHEV – Plug-in Hybrid Electric Vehicle

R&D – Research & Development

RES – Renewable Energy Source

USD – United States Dollar

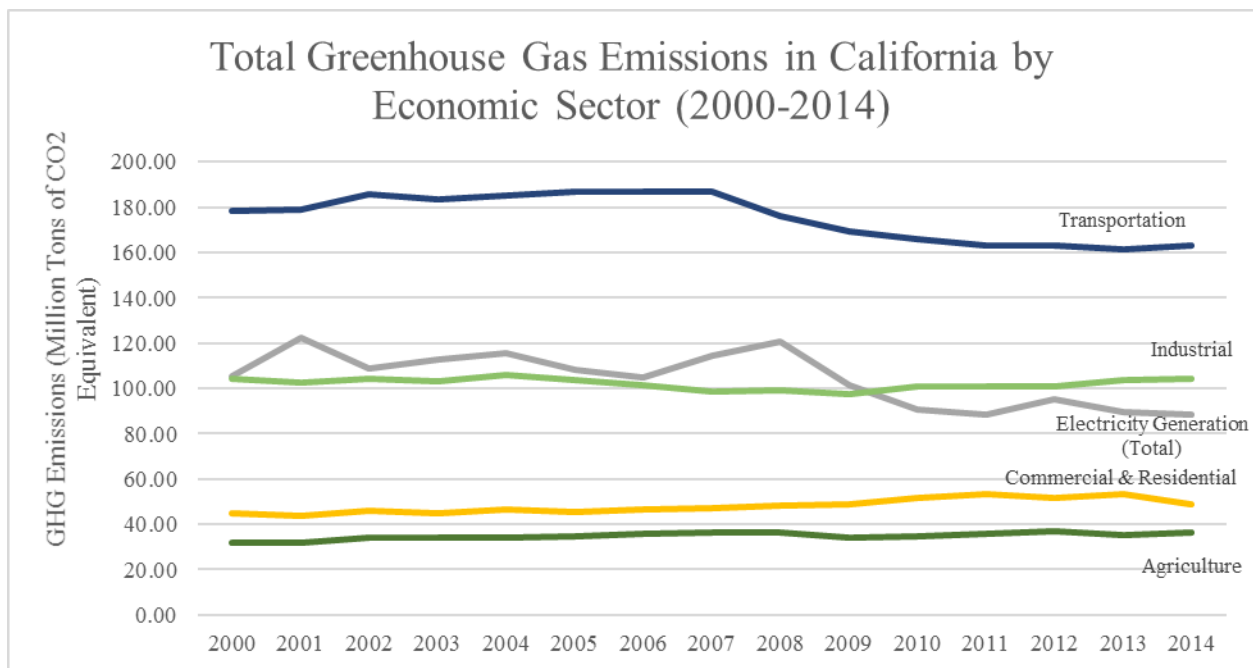
WTP – Willingness-To-Pay

ZEV – Zero Emissions Vehicle

# 1.0 Introduction

## 1.1 Overview of the Transportation Sector

In recent years, there have been significant efforts to reduce global greenhouse gas emissions, brought upon by the threat of anthropogenic climate change. Despite measures to reduce emissions in all economic sectors such as industry and electricity generation, transportation related CO<sub>2</sub> emissions rose by 16 percent from 1990 to 2014 in the United States (EPA, 2016). In California, where a concerted effort has been made to reduce transportation related emissions through an increase in fuel-efficient combustion engines, and a reduction in total consumption of gasoline, emissions from transportation have declined steadily from 2007 into 2014, contrary to the national trend (Fig 1). However, transportation remains the largest contribution to California’s GHG emissions, accounting for up to 37% of GHGs emitted per year, and producing upwards of 160 MMTCO<sub>2</sub> equivalent per year. In comparison, the next largest GHG emitters are the industrial sector, which produced 104.22 MMTCO<sub>2</sub> equivalent in 2014, or 24% of total state emissions. While total electricity generation, which produced 88.37 MMTCO<sub>2</sub> equivalent, accounts for approximately 20% of total state emissions



**Figure 1.** Total greenhouse gas emissions in California by Economic Sector. This graph shows the total GHG emissions per year of each of the 5 major economic sectors in million tons of CO<sub>2</sub> equivalent (MMTCO<sub>2</sub>e). Information obtained from the California Air Resources Board

The large contribution of the transportation sector to GHG emissions may relate to the large amounts of traffic congestion experienced by California's largest metropolitan areas. The San Francisco Bay Area and the Los Angeles metro area are consistently ranked as some of the most congested areas in the country (Schrang et al., 2015), and the excess time in traffic contributes to about 33 gallons of excess fuel used per commuter per year in the Bay Area, and about 25 gallons of excess fuel in the Los Angeles metro area, well above the national average of 19 gallons per commuter per year (Schrang et al., 2015). According to the Energy Information Administration, a gallon of gasoline containing 10% ethanol produces approximately 17.68 pounds of CO<sub>2</sub>, meaning that commuters in the Bay Area release an excess of 583.44 pounds of CO<sub>2</sub> into the atmosphere per year. In 2015, the US Census Bureau estimated through the American Community Survey that there were approximately 2.6 million workers in the Bay Area that commuted by car, truck or van<sup>1</sup>. Therefore, a rough estimate of the total excess CO<sub>2</sub> emitted by commuters in the Bay Area would be approximately 1.5 billion pounds of excess CO<sub>2</sub> per year. This demonstrates an enormous contribution to the total transportation emissions of the state.

The transportation sector includes light-duty and heavy-duty vehicles. Light-duty vehicles include most commercial and passenger vehicles (cars, motorcycle and light duty trucks), while heavy-duty vehicles include heavy freight and mass transportation (heavy-duty trucks, motorhomes, busses). Light-duty vehicles accounted for approximately 70% of California's total transportation emissions, according to the California Air Resources Board (CARB). The vast majority of fuel sources in the transportation sector originate from petroleum-based fuel products (EPA, 2016). Half of the petroleum-based fuel is consumed by passenger vehicles and other highway vehicles, while the remainder of the petroleum is used in diesel fuel and jet fuel (EPA, 2016). Additionally, increasing demand for mobility, and higher levels of motor vehicle adoption throughout the country, exacerbate these issues, and it may be necessary to regulate and carefully manage vehicle demand to mitigate the adverse impacts of transportation related emissions (Liu et al., 2014). In order to make deep cuts into the state's total GHG emissions, it is clearly

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<sup>1</sup> The number of Bay Area commuters was calculated using the American Community Survey's estimate of total commuter population and the percentage of commuters using car, truck, or van in each of the Bay Area's nine counties (Alameda, Contra Costa, Marin, Napa, San Francisco, San Mateo, Santa Clara, Solano, and Sonoma county). This number was then adjusted for the number of commuters per vehicle, to factor in carpools.



necessary to examine strategies to significantly reduce transportation related emissions (Leighty et al., 2012).

Significantly reducing transportation related emissions requires a close examination of three relevant factors: improving vehicle efficiency, reducing carbon intensity of fuels, and reducing the activity of the transportation sector (Leighty et al., 2012). There has been much effort to improve the efficiency of internal combustion engines, and steps have been taken towards reducing the carbon intensity of fuels, but in order to see a large reduction of emissions, large changes in all three of these factors must happen rapidly, especially if California is to meet its GHG reduction targets by 2050 as set by Executive Order S-3-05. A combination of strategies including high efficiency vehicles, electrification of light-duty vehicles, and decarbonizing transportation fuels can achieve these targets, if swift action is taken (Leighty et al., 2012). Because of this, promotion of alternative fuel vehicles, and electrification of the light-duty vehicle market, are seen as major ways to significantly address the greenhouse gas emissions in the transportation sector.

## 1.2 Limitations of Petroleum-Based Fuels

Internal combustion engines using petroleum-based fuels are the predominant power source for vehicle drivetrains globally. This is due to many properties of petroleum-based fuels, such as the ease of transporting these fuels, as well as the high energy density of petroleum and petroleum-based products. This high energy density allows internal combustion engines running on petroleum fuels to have long driving ranges and significant performance advantages, such as faster acceleration or more powerful engines, over other fuel types. However, limitations on petroleum do exist. The main limitations of internal combustion engines involve issues of energy security, the cost of energy, and negative externalities, such as pollution and greenhouse gas emissions.

### 1.2.1 Energy Security

One major limitation of petroleum based fuels is the dependency of the economy and national security on the availability and security of affordable oil. Most energy analysts agree that the US's oil dependence places the nation at risk, and achieving oil independence has been the goal of many of our political leaders (Greene, 2010). Oil prices are often artificially set by the

intergovernmental Organization of Petroleum Exporting Countries (OPEC), and our heavy dependence on imported oil means that any fluctuation in OPEC's oil supply can have severe economic impacts on the US, including production losses (Greene, 2010). Additionally, when concerns of energy security are on the minds of vehicle consumers, they are found to be more likely to favor electric vehicles over internal combustion engine vehicles (Bockarjova and Steg, 2014). Despite this, it has proven near impossible to significantly reduce our reliance on oil imports to any appreciable degree. As of 2016, oil imports from foreign countries account for nearly 1/4<sup>th</sup> of our oil consumption (EIA, 2016), and many claim that oil independence is impossible due to the impracticality of reducing our oil usage to require no imports or no zero oil usage.

However, ensuring energy security is not the same as reducing our imported oil usage to zero. Rather, the goal is to reduce the dependence of oil to the point where any large fluctuations in price do not have severe impacts to the national economy. To this point, reducing our oil dependence is achievable, with alternative fuel vehicles playing a major role in increasing our energy security (Greene, 2010). The continued proliferation of petroleum-based fuels will have severe impacts on our economic future, as the future of the oil market remains relatively uncertain and highly volatile, and investment in alternative fuels and electrification of transportation can reduce these impacts.

### 1.2.2 Cost of Energy

Partially as a result of this oil dependence, gasoline prices are subject to wild variations in price, making the cost of energy for petroleum-based fuels much more uncertain than the relatively stable price of electricity. Internal combustion engines are also much less efficient than electric motors. On average, battery electric vehicles are 2.6 times more efficient than ICE vehicles of similar size and performance (Werber et al., 2009). This efficiency means that much less fuel is needed to drive the same distance in a BEV as compared to an ICEV. The higher efficiency, combined with the on average lower price of electricity as compared to gasoline, means that BEVs see much greater savings per mile as compared to an ICEV.

This increase in efficiency among electricity used as fuel is seen even if the primary energy for the generation of electricity is derived from combustion of fossil fuels. This is because large scale utility power plants are much more energy efficient, and utilize techniques such as

cogeneration to maximize output and minimize energy loss. Small internal combustion engines, as seen in most conventional vehicles, are unable to utilize these techniques to minimize energy loss, and therefore lose a significant amount of energy in the process. Most internal combustion engines are typically 15-20% efficient, so much of that fuel is lost in the exhaust.

The savings in energy and fuel is typically offset by the poor driving range of BEVs, and the high capital cost of purchasing a BEV (Werber et al., 2009). However, the cost of BEVs can be expected to go down as we see improvements in technology and greater efficiency in manufacturing and increased competition between automakers. At the same time, the price of gasoline is highly volatile, due in large part to the lack of substitute goods for gasoline (EIA, 2017). The cost of electricity needed to drive a BEV the same distance as a gallon of gasoline is much more stable and consistently lower than the price of gasoline (DOE, 2013). The lower price of an eGallon lowers the operation costs of driving a BEV as compared to an ICEV, and the stability in price can impact purchase decisions for BEVs. The unique distribution of oil reserves around the globe, and the impossibility of meeting the US's growing petroleum demand through domestic sources means that gasoline is a highly unpredictable fuel source, and a switch to alternative fuels such as electricity can reduce the cost of energy for the transportation sector.

### 1.2.3 Pollution and Greenhouse Gas Emissions

A major drawback of the combustion of fossil fuels for energy is the production of CO<sub>2</sub>, a potent greenhouse gas, as a byproduct. Petroleum is a high-carbon fuel, meaning it has a high carbon-to-hydrogen ratio, and produces large amounts of CO<sub>2</sub> when undergoing combustion. In the United States, combustion of fossil fuels in all sectors of the economy accounted for approximately 94% of the US's CO<sub>2</sub> emissions in 2014, primarily from electricity generation and transportation (EPA, 2016). While in California we see major trends in electricity generation moving towards low carbon fuels and energy sources, such as natural gas, or renewable energy sources, the transportation sector has seen relatively little shift in CO<sub>2</sub> output. The major limitation with petroleum as a fuel source, is that the full cost of the energy is not internalized into the cost at the pump. The external costs of emitting CO<sub>2</sub> and warming up the planet are not seen in any state in the United States, which results in the proliferation of petroleum in the transportation sector as a market failure (Poulson et al., 2006).

Similar to CO<sub>2</sub>, air pollutants are another externality associated with petroleum-based fuels. Air pollutants are a byproduct of the incomplete combustion of gasoline, and are the result of the low efficiency of internal combustion engines. These byproducts can include carbon monoxide, nitrogen oxides (NO<sub>x</sub>), volatile organic compounds (VOCs) and unburnt hydrocarbons, and particulate matter. All are the result of incomplete combustion, and can negatively affect human health. VOCs can react with NO<sub>x</sub> in the air to produce photochemical smog, which has hugely adverse impacts to human health. Because of these negative impacts, California has required all vehicles to have catalytic converters installed, and to be smog tested, to reduce the emissions of these pollutants. However, these pollutants can still have acute health effects on humans, ranging from respiratory irritation to cancer and reduced immune system activity (Kampa and Castanas, 2007).

Particulate matter (PM), particularly particulate matter that is 2.5 micrometers in diameter (PM<sub>2.5</sub>), is generally considered the air quality measure that is most significantly associated with the negative health effects of air pollution (Vimmerstedt et al., 2015). These negative health effects disproportionately affect people living in cities and people living in heavily industrialized areas or areas prone to heavy traffic (Kampa and Castanas, 2007), highlighting another significant social cost to petroleum that is not internalized in the full cost of gasoline. EVs charged using electricity that is primarily generated from fossil fuels such as coal may reduce air pollutants such as VOCs and NO<sub>x</sub>, but may not appreciably decrease PM<sub>2.5</sub> emissions (Vimmerstedt et al, 2015; Wu and Zhang, 2017). This underscores the need to develop clean renewable energy sources in tandem with electric vehicles in order to reduce negative health effects alongside greenhouse gas emissions.

### 1.3 The Future of the Transportation Sector

In order to fully address all of the limitations of petroleum-based fuels, transitioning our motorized transportation from gasoline powered internal combustion engines to zero emissions vehicles is a necessity. However, a large-scale transformation of the transportation sector, with a global vehicle total of almost 2 billion, is likely to be extremely difficult and require large scale changes in public policy (Greene et al., 2014). The future of the transportation sector, and of alternative fuel vehicles, is highly uncertain. Many options in alternative fuel vehicle technology

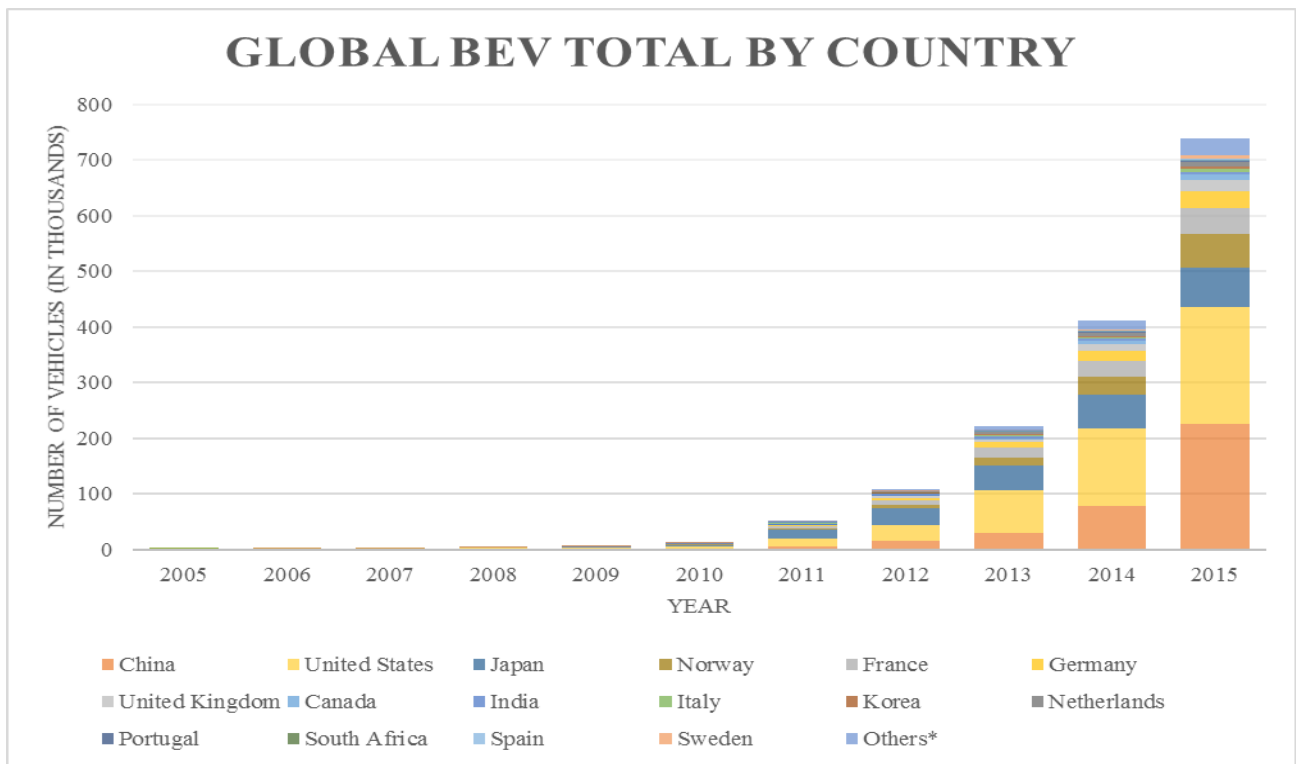
exist, including battery electric, hydrogen fuel cells, compressed natural gas, or a mixed market composed of various shares of all of these technologies (Struben and Sterman, 2008).

The dominance of internal combustion engines in the motor vehicle industry is a major roadblock to successful integration of alternative fuel vehicles, such as battery electric vehicles. The sheer scale of ICEVs creates a number of positive feedback loops that reinforce the dominance of conventional vehicles; repair and fuel services that service internal combustion engines reinforce the desire for ICEVs, and the existing petroleum pipeline infrastructure makes gasoline ubiquitous (Struben and Sterman, 2008). Fuel infrastructure itself offers a disadvantage to alternative fuel vehicles, as new infrastructure would be required for many of these vehicle technologies. Additionally, vehicle choice can be strongly shaped by personal identity, and many may resist alternative fuel vehicle technologies due to their backgrounds, beliefs, biases, and social circles. Technological advances in alternative fuel vehicles can spillover to the ICEV market, and provide performance advantages to the dominant vehicle type (Struben and Sterman, 2008). If the goal is sustainability of transportation, then these barriers must be overcome, through policymaking or through business strategies of electric vehicle automakers.

In 2015, global sales of electric vehicles, including plug-in hybrid electric vehicles, surpassed one million due to a number of national governments imposing greenhouse gas reduction targets and increasing their policy support for the nascent market. Battery electric vehicles are fast approaching the one million benchmark globally, totaling approximately 750,000 vehicles according to cumulative sales data (Fig 2). Compared to 2014, the total number of electric vehicles on the road almost doubled. Despite the small share electric vehicles occupy in the global total of 2 billion vehicles, this growth of the BEV market, along with falling battery costs, offers a glimmer of hope for the future prospects of the EV market (IEA, 2016). However, significant and careful policy support is still necessary for the emerging market to become self-sustaining and competitive in the current vehicle market. Policy measures that are not well thought out have the potential to backfire and destroy the credibility of the electric vehicle market. For example, purchase incentives that fail to capture the full breadth of challenges that the initial players in the electric vehicle market must face may actually create backlash and foster negative perceptions towards electric vehicles (Struben and Sterman, 2008). It is clear that in order to nurture the emerging electric vehicle market, well-thought out policy solutions that fully address the myriad of challenges ahead are necessary.

The electric vehicle market, although growing, is still an incredibly small sector of the overall light-duty vehicle market. Because of the benefits of electric vehicles in comparison to ICEVs, it is prudent to determine policy options to encourage and nurture the EV market. However, policies to encourage electric vehicle adoption can vary widely in cost and effectiveness. In this paper, I will examine the effectiveness of policy options to encourage electric vehicle adoption in order to determine the most effective policies for achieving the stated goal.

The remainder of this paper will be structured as follows: I will first talk about the contextual background of California’s electric vehicle market, including emissions reductions targets, the zero emissions vehicle mandate, and the key players in California’s electric vehicle market. Next I will analyze and discuss the various policy options both in effect worldwide as well as proposed policy options in the literature, and examine their efficacy in achieving the stated purpose of increasing electric vehicle adoption. Lastly, I will discuss the most persistent findings, discuss side effects and rebound effects these policies may have, and formulate policy recommendations to achieve a self-sustaining vehicle market and increase electric vehicle penetration.



**Figure 2.** Global battery electric vehicle total by country. This chart shows the growth of the global BEV market by year. The greatest growth is seen in China, the US, Japan, Norway, France, and Germany. Data obtained from the International Energy Agency’s Global EV Outlook 2016.

## 2.0 Background

The alternative fuel vehicle market is influenced and shaped by a number of factors, including extant policies, attributes of these alternative fuel vehicles, and market forces. In this section I will discuss these factors, in order to provide the context through which various policies are analyzed later in the paper. First I will discuss the Zero Emissions Vehicle Mandate, which is a broad policy that provides the greater context for the development of alternative fuel vehicles such as BEVs. Next I will discuss the attributes of a variety of alternative fuel vehicles, including FCVs, HEVs, PHEVs, and BEVs, to provide context for why the attributes of BEVs make them well suited to achieve specific emissions reductions goals, and to provide a justification as to why BEVs are the major focus of this paper. Next I will describe the policy targets in the BEV market: suppliers and consumers, and how they shape and respond to the EV market. Lastly, I will examine the major barriers in place for the EV market regarding consumer preferences, technological constraints, and infrastructure challenges.

### 2.1 California's Zero Emissions Vehicle Mandate

When discussing policy solutions aimed at increasing electric vehicle adoption in California, it is impossible to ignore the Zero Emissions Vehicle (ZEV) Mandate. The ZEV Mandate, enacted in 1990 as part of the Low Emissions Vehicle (LEV) Program, is one of the most sweeping measures instituted by any state government to address air quality issues and encourage the adoption of battery electric vehicles. Implemented and overseen by the California Air Resources Board (CARB), the ZEV mandate is a technology forcing mandate, intending to create a market for battery electric vehicles in order to overcome the significant obstacles of replacing one technology with another (Bedsworth and Taylor, 2007). Originally born out of discussions on ways to deal with California's increasingly problematic air quality, the ZEV mandate and the LEV program more broadly were seen as necessary steps in order to bring the air quality levels in the state's most polluted areas down to federally acceptable levels (Bedsworth and Taylor, 2007; Collantes and Sperling 2007).

A simplistic overview of the mechanics of the ZEV mandate is as follows: automakers are required to obtain a certain number of ZEV credits as a fixed percentage of their total auto sales. ZEV credits are gained through vehicle sales, through trading with other automakers, or through

simply paying a fine to CARB if unable to comply. Vehicles are valued at a range of credits, taking into account the type of vehicle and the total range. For example, hybrid electric vehicles are not eligible for a full ZEV credit, while fuel cell vehicles, which are a pure ZEV, and have much longer ranges than battery electric vehicles, are eligible for between 1-4 credits, depending on range (UCS, 2016).

The mandate has been described alternately as a policy failure as well as a success. Critics of the mandate point out that ZEV targets often went unmet, as a result of CARB's overestimation of viable vehicle technologies, as well as the pace of technology breakthroughs. This overestimation of the potential of the battery electric vehicle market has led to a reduction of targets, modifications of the regulation, and a "weakened demand signal for zero-emissions vehicles" (Bedsworth and Taylor, 2007). These modifications include provisions for cleaner burning conventional vehicles and plug-in hybrid electric vehicles to gain ZEV credits when sold. Critics claim that the constant need for modification and revision in the ZEV mandate underlines a problematic policy-making process and raises questions of whether the economics behind the mandate are viable. (Duvall et al., 2002). Additionally, many decry the ZEV mandate as unethical, forcing one technology over another and overriding individual choice and preference (Duvall et al., 2002).

Proponents of the ZEV take a different tack, touting the secondary benefits that the mandate has had on a variety of different categories, including patents, economic activity, development of advanced vehicle technologies, fuel and emissions standards in states other than California, non-vehicle applications of battery technologies, among others. Proponents claim that while the primary benefit of the mandate is still relatively uncertain due to the unpredictability of the electric vehicle market, the ZEV mandate is still successful because it sparked development of numerous secondary benefits (Burke and Kurani, 2000). Additionally, proponents claim that a technology forcing mandate is necessary to achieve a transition to sustainable transportation. Greene et al.(2014) used modeling to determine that policies focused solely on valuating negative externalities were likely insufficient to harboring a full transition to electric vehicles, arguing that stronger policies like the ZEV mandate are likely necessary as long as they are well timed, of appropriate intensity, and temporary until the market is able to self-sustain. This also leaves room for policy measures to support the ZEV mandate in its primary goal of a self-



sustaining vehicle market, as mandates are necessarily made in the face of substantial uncertainty (Greene et al.2014).

Because of the significant amendments and reviews the ZEV mandate has undergone in the decades since its implementation, the mechanics of the ZEV mandate are quite complex (Bedsworth and Taylor, 2007). Additionally, the policy goals of the ZEV mandate have changed since the initial implementation. Originally conceived as a measure to address California's significant air quality problems, the goals have slowly changed. In 2006, the California State Legislature passed Assembly Bill (AB) 32, a measure that gave CARB the authority to meet greenhouse gas reduction targets stated in Executive Order S-3-05 that mandated specific reduction targets for all sectors. Since then, the ZEV mandate has been seen as an important tool to reduce greenhouse gas emissions in the transportation sector (Bedsworth and Taylor, 2007; Collantes and Sperling 2007).

## 2.2 Overview of Alternative Fuel Vehicles

While the Zero Emissions Vehicle Mandate at the time of its conception referred, by default, to battery electric vehicles, subsequent amendments included provisions for other advanced alternative fuel vehicle technologies. Additionally, other zero emissions vehicle technologies have since been developed, such as fuel cell vehicles, and also qualify under the ZEV mandate as a zero emissions vehicle. Most of these vehicle technologies are referred to as advanced vehicle technologies, and include fuel cell vehicles, hybrid electric vehicles, plug-in hybrid electric vehicles, and battery electric vehicles.

### 2.2.1 Fuel Cell Vehicles

Fuel cell vehicles (FCVs) are a type of electric vehicle motor that use oxygen and compressed hydrogen to generate electricity to power the motor, emitting only heat and water vapor as byproducts. Theoretically, FCVs have a high maximum conversion efficiency of energy generation, however in practice that efficiency is much lower, with some studies estimating the practical conversion efficiency at around 55% (van Vliet et al., 2010). This places FCVs as being more efficient than a conventional internal combustion engine, but still less efficient than batteries (Myers, 2008). FCVs generally have a longer driving range than other zero emissions vehicles, however their usefulness is limited by the lack of hydrogen infrastructure, as well as the

difficulties of actually storing hydrogen in vehicles for use in a fuel cell engine (Ross, 2006; van Vliet et al., 2010). Additionally, there are numerous challenges to widespread penetration of hydrogen fuel cells, mainly regarding unacceptably high production and ownership costs that make FCVs uncompetitive in the vehicle market, even compared with BEVs, but also with regard to the durability of the proton exchange membrane (PEM) of FCVs (Edwards, et al.2008; van Vliet et al.2010; Chalk and Miller, 2006). These technical challenges have led to FCVs to represent a relatively small share of the ZEV market, although in recent years select regions in California have seen FCVs become available, particularly in areas that have access to hydrogen stations.

### 2.2.2 Hybrid Electric Vehicles

Hybrid electric vehicles (HEVs) are perhaps one of the most well-known alternatives to the internal combustion engine to consumers, and occupy the largest niche in the alternative fuel vehicle market. Hybrid electric vehicles, in the broadest sense, refer to vehicles that use both gasoline fuel and electricity to power the motor and move the vehicle. HEVs differ from plug-in hybrids in that the electricity stored in the battery is generated from the activities of the internal combustion engine, as well as energy recuperated from activities such as braking (Adnan et al., 2016). Examples of HEVs that are currently on the market include the Toyota Prius, and many automakers provide hybrid versions of their popular models, such as the Honda Accord, Chevrolet Malibu, and Ford Escape. Because this type of vehicle cannot run without an internal combustion engine, and must rely on gasoline fuel for its primary power, this type of vehicle is considered a fuel-saving vehicle that increases the efficiency of the internal combustion engine (Adnan et al., 2016; Tie and Tan, 2013). HEVs are still eligible for partial credit under the ZEV mandate, however a dedicated portion of vehicles sold to meet the ZEV mandate must be pure ZEVs (Bedsworth and Taylor, 2007).

### 2.2.3 Plug-in Hybrid Electric Vehicles

Plug-in hybrid electric vehicles (PHEVs) are a subtype of hybrid electric vehicles that differ from prominent HEV models in that they are powered by both electricity obtained from the grid as well as by gasoline fuel (Adnan et al.2016). PHEVs and BEVs comprise a subset of AFVs termed PEVs (Plug-in electric vehicles). PHEVs are not strictly zero emissions vehicles, as they retain an internal combustion engine after the battery's charge is depleted in order to extend the

driving range, but they have significantly reduced air and greenhouse gas emissions as compared to HEVs and ICEVs. Because PHEVs operate very similarly to battery electric vehicles (BEVs), in that consumers must charge the battery using a plug-in outlet, while also extending the functional range with an internal combustion engine, many people argue that PHEVs can be used as a bridge to get consumers who are worried about the performance limitations of BEVs more comfortable with the concept, without having to sacrifice too much in terms of vehicle performance. Additionally, increasing PHEV use will necessitate enhancement of grid infrastructure by utilities to support the increased demand of electricity (Hadley and Svetkova, 2008). PHEV batteries generally have less range and less capacity than pure BEV batteries (Adnan et al., 2016), so PHEVs could also serve as a bridge for electrical utilities to enhance the grid infrastructure in preparation for larger scale penetration of BEVs.

#### 2.2.4 Battery Electric Vehicles

Battery electric vehicles (BEVs) are vehicles that are powered solely from electricity obtained from the grid and stored in batteries. BEVs are the main focus of this paper, both because the ZEV mandate that provides much of the background context for this paper has a heavy focus on BEVs, and because BEVs occupy the largest share of pure ZEVs in California. For these reasons, BEVs are likely to become the main agent by which air pollutant and greenhouse gas emissions are reduced in the transportation sector (Nealer et. al, 2015). Battery electric vehicles differ greatly from ICE vehicles, with substantial decreases in performance as measured by engine power and acceleration, and driving range (Liao et al, 2016; Rasouli and Timmermans 2016). Additionally, they require large adjustments to consumer behavior, as they must be charged for long periods of time, as opposed to ICE vehicles, which take minutes to refuel (Liao et al., 2016). These challenges, alongside cost and technical limitations, have proved to be difficult challenges for the BEV market to overcome. However, because of the ZEV mandate and supporting policies, BEV technology has overcome many of its initial limitations, such as the high cost of batteries (Vimmerstedt et al., 2015). Nevertheless, there are still concerns about high costs and technical challenges, such as the limited driving range of most commercially available BEVs (Silva and Krause, 2016).

## 2.3 Benefits of Battery Electric Vehicles

BEVs are the main focus of this paper for their unique benefits in relation to other alternative fuel vehicles. Unlike HEVs and PHEVs, BEVs produce no emissions at the tailpipe and do the most to reduce the reliance of petroleum on the transportation sector. Other pure ZEVs, like FCVs, are much more expensive than BEVs, making them less cost competitive and less likely to receive widespread market penetration. In addition, the electric grid infrastructure is quite robust and already exists in most areas, unlike hydrogen infrastructure. These qualities make BEVs uniquely poised to overcome the petroleum dominance of the transportation sector.

Because BEVs do not produce any emissions at the tailpipe, they have a lower global warming potential than similarly sized ICEVs (Brennan and Barder, 2016). However, it is false to assume that a BEV produces no emissions throughout its life cycle. Indeed, BEVs are shown to produce more emissions through vehicle and battery production than ICEVs, however this increase in emissions is quickly offset by an enormous reduction in emissions through operation (Nealer et al., 2015). In one study, it would take 4,900 miles of driving a midsize BEV to offset the extra production emissions, and 19,000 miles of driving a full-size BEV to achieve the same (Nealer et al., 2015) and in both cases, both vehicles continue to produce zero tailpipe emissions over the entire course of their operational lives.

Emissions through recharging are highly dependent on the generation mix of electricity in the region (Vimmerstedt et al., 2015), as well as the time of day BEV charging occurs. However, with California's renewable portfolio standards and increasingly robust renewable energy market, the emissions are likely to stay much lower over the course of the life cycle of the BEV (Nealer et al., 2015; Joseck and Ward, 2014), making BEVs the likely vehicle type by which California is able to achieve the massive GHG reduction targets mandated by Executive Order S-3-05. It is important, however, to continue to promote renewable energy sources in tandem with policies aimed at promoting BEVs. As the demand in the transportation sector shifts from petroleum towards electricity generation, it is important to ramp up our renewable energy generation, otherwise the GHG emissions savings, and air pollution reduction, will be minimal (Vimmerstedt et al., 2015).

Additionally, BEVs do not contribute to ambient air pollution, especially in crowded cities, where the high density of vehicles causes significant declines in air quality. Ambient air

pollution has been implicated in a number of poor health outcomes, ranging from asthma to lung cancer (OECD, 2014). These negative health effects lead to negative economic outcomes, illustrating the impact on both public health and the economy of environmental externalities associated with fossil fuel combustion. The economic loss based on the value of a statistical life in the United States from negative health effects associated with ambient air pollution was 4.4 million USD in 2010 (OECD, 2014). BEVs producing no tailpipe emissions, and deriving electricity from clean renewable resources, could prove an important step to improving ambient air quality and reducing this economic and social loss.

Another major benefit of BEVs is the potential to address oil dependence in the transportation sector. Petroleum-based fuels dominate the transportation sector, accounting for over to 90% of energy usage (EPA, 2016). The US produces large amounts of this petroleum, but about 1/4<sup>th</sup> of petroleum consumed by Americans is imported from foreign countries. (EIA, 2016). Because BEVs operate on electricity that is produced locally from a variety of primary fuel sources, this reduces the reliance on both petroleum as a fuel source, as well as reducing the reliance of obtaining those fuel sources from foreign countries.

Partially as a result from overreliance on one fuel source, and partially as a result of the reliance on often erratic international markets, petroleum prices have undergone major price spikes over the years, while electricity prices remain, on the whole, relatively stable (DOE, 2013). In addition to being much more price stable, the electricity price equivalent to a gallon of gasoline is, on average, much lower than the price of gasoline. At current electricity prices, the cost of refueling an electric vehicle in California is \$1.63/eGallon, according to the most recent Department of Energy eGallon calculator. This price stability could be seen as another benefit of BEVs, as it reduces the uncertainty for a consumer of future fuel prices, which could impact future purchase decisions.

Lastly, BEVs have lower operational costs due to the need for fewer fluids, fewer maintenance costs and thus lower maintenance costs than similarly sized luxury vehicles (Alexander and Davis, 2013). Electric drive powertrains are generally more free of maintenance than those of internal combustion powertrains, and electric vehicles generally have regenerative braking, reducing the need to replace brake pads (Alexander and Davis, 2013). The low cost-per-mile of BEVs as compared to ICEVs and the lower operational costs of BEVs as compared to similar

luxury ICEVs means the cost of ownership for a BEV may be cheaper than similarly sized ICEVs, despite the higher initial purchase price.

## 2.4 Policy Targets

It is important when discussing the role of government policy to determine who is affected and to what degree these policy measures are effective at influencing behavior. Policy measures that are aimed to directly impact the BEV market, such as purchase subsidies, or tax credits for BEV purchases can be effective at promoting the BEV market, but may be derided by critics for being unethical, and can form the perception that the government is picking winners and losers in the marketplace (Duvall et al., 2002). Other policies, that instead attempt to correct market failures by including network externalities into the cost of things like gasoline fuel prices via a carbon tax may work to make BEVs more cost competitive, but it is questionable whether or not these measures are strong enough to facilitate a wholesale conversion to a self-sustaining BEV market, especially in the relatively short time frame many scientists believe that we must reduce our greenhouse gas emissions in to prevent the most severe effects of global warming (Greene et al., 2014). Therefore, it is important that government agencies, ruling bodies, and political leaders balance the political impact of policy decisions with the potential benefit of these policies, especially if the overriding goal is to achieve massive greenhouse gas reduction targets in a rapid time frame.

The two major groups affected by policy to impact EV adoption are vehicle consumers and vehicle suppliers. Vehicle consumers can be individuals, employers, or government agencies, who may all value different attributes when considering purchase decisions, so policies may impact these groups differently. Suppliers manufacture EVs and the response of manufacturers and suppliers to government policy is important in fostering fair and realistic policy goals. This section will examine the relationships of suppliers and consumers to government policy in order to facilitate an understanding of what effective policy may look like.

### 2.4.1 Suppliers

Manufacturers and automakers supply the BEV market in California, and have complex and, at times, adversarial relationships with policy makers that implement regulations and mandates that may constrain or force manufacturers to adopt different strategies (Wesseling et al., 2015).

Particularly in the context of California's ZEV mandate, manufacturers have taken various strategies to combat, comply with, or influence the technology-forcing regulation. Manufacturer responses to the ZEV mandate have evolved over time. Many car manufacturers employed oppositional strategies, wielding political influence and utilizing lawsuits to adapt or loosen regulations surrounding ZEVs in the early stages of the mandate. However, later strategies tilted towards car manufacturers exploring innovative strategies, and ways to gain market share over competitors (Wesseling et al., 2015). This shows a marked shift in the perception of the viability of the BEV market by automakers, indicating that suppliers find value in the BEV market, and therefore are aiming to capture a greater market share. This change in attitude is also apparent with the founding of electric car manufacturer Tesla, which manufactures only electric cars, in contrast to all other BEV manufacturers.

Manufacturers may also respond to other public policy options, such as subsidies, that allow what may initially be seen as a high-risk low-reward market to become more attractive to suppliers. Indeed, many manufacturers see subsidies as reducing the burden and risk on producing BEVs, and have a positive effect on growth in the market (Greene et al., 2014). Additionally, as manufacturers have a direct stake in the financial success of their venture, many car manufacturers may be inclined to partner with employers or governments on programs to increase electric vehicle adoption, such as offering discounts to employees if they choose to finance a BEV, or through providing vehicle fleets to government agencies at discount rates (Tomic and Bloch-rubin, 2014).

#### 2.4.2 Consumers

Consumers can take the form of individual consumers, employers who facilitate the purchase of an EV for employees, and government agencies who procure EVs for government use.

Individual consumers are the primary drivers of demand in the EV market, and as such, much research has been done on the main factors that drive consumer preference towards or away from EVs. Formulating policy to maximize consumer preferences towards EVs is therefore important in increasing consumer demand for EVs. These preferences will be discussed in more detail in the following section.

One factor of consumer behavior is that consumers are hesitant to employ new technology until a certain level of familiarity is gained with the technology. The neighbor effect suggests that the

importance of certain vehicle attributes may change as the market share of those vehicles increases, and consumers become more familiar and comfortable with the new technology (Mau et al., 2008). This suggests that as EVs gain a greater share of the vehicle market, attributes such as driving range may become less important as consumers become more familiar and comfortable with these limitations, and as the world becomes more adapted to these conditions. Indeed, agent-based modelling using the diffusion of innovations theory of consumer behavior shows that the single factor that had the greatest impact of getting later adopters of technology to purchase EVs was exposure to the new technology (Silvia and Krause, 2016).

Employers play an important role in the EV market, as an employer's attitude towards electric vehicles may affect their employee's vehicle purchase decisions. Because many consumers use vehicles to commute to work, the lack of available charging infrastructure at the destination may discourage potential consumers from purchasing an EV. As a result, many employers offer free electric vehicle charging as a non-monetary incentive to purchasing an electric vehicle (Tomic and Bloch-rubin, 2014). These and other policies, such as preferential parking or car sharing programs, can facilitate or encourage a prospective EV owner's final purchase decision. Additionally, as the market share of EVs increases, employers may use their electric vehicle policies to attract current owners of EVs as an added incentive of employment. Other potential ways employers can encourage EV adoption include incentives for commuting with an EV, purchase options for employees looking to finance an EV, and offering fee-based charging services for EVs (Tomic and Bloch-rubin, 2014). Policy that requires employers to reduce the GHG emissions of the commuting behavior of their employees may spur the adoption of these types of employer policies.

Government agencies may find greater utility out of attributes of EVs that consumers do not gain utility from. One example is GHG reduction capability. Governments may find greater utility out of the GHG reduction capability of EV vehicles than the average consumer, meaning they may be willing to pay the higher purchase prices of these vehicles in order to obtain that utility (Rijnsoever et al., 2013). This attribute of governments as consumers may provide a unique opportunity for EV manufacturers to have an assured market in order to help provide research and development to lower costs and improve vehicle performance for consumers who value financial and technical attributes more highly.



## 2.5 Barriers to Electric Vehicle Adoption

BEVs face a number of challenges and barriers to entering the consumer market. Many of these barriers are structural; a result of the dominance of ICEVs in the market. Examples of these structural barriers are the pervasive nature of ICEV infrastructure, including service stations, and refueling stations. BEVs also face technological barriers, including the limitations of current technology to address consumer needs. An example of this barrier is the capacity of modern batteries, which limits driving range. Lastly, consumer behavior and preferences are potentially a major barrier to electric vehicle adoption. These consumer preferences have been studied several times using stated preference surveys to determine what consumers believe are the major reasons they would or would not purchase a BEV. Key among these findings are that BEVs are believed to be too expensive, have insufficient driving ranges, and take too long to charge (Liao et al., 2016). Conversely, consumers derive utility from the reduced emissions, and the perception that BEVs contribute to a positive social image (Silvia and Krause, 2016).

### 2.5.1 Consumer Perception and Behavior

Consumer perception of electric vehicle technology is important because consumers are the main drivers in stimulating and maintaining demand in the electric vehicle market. Without consumer demand, the EV market would be unable to sustain itself, even despite government intervention. Therefore, it is important to know what consumers think of electric vehicles and what their vehicle preferences are. Most consumer concerns for BEVs are related to the cost of purchasing the vehicle. While consumers do value attributes such as emissions savings and sustainability, purchase price and vehicle performance tend to outweigh the environmental benefits of BEVs for most consumers (Egbue and Long, 2012). This is unsurprising, as the cost of current BEVs are still significantly higher than similarly sized ICEVs, especially as compared to more economical models (Brennan and Barder, 2016). Many commercially available electric vehicles are often \$10,000 to \$20,000 more expensive than similarly sized ICEVs while being unable to provide an advantage in attributes that consumers value (Silvia and Krause, 2016).

The operational costs of driving an EV are generally lower than driving an ICEV, in part due to lower maintenance costs and the lower costs of recharging. However, consumers primarily focus on the high upfront purchase costs of EVs, and are much worse at valuing the operational costs

of running an EV as opposed to an ICEV. Beeton and Budde (2013) held a workshop to determine the most salient barriers to EV adoption for consumers and found that high initial purchase costs ranked first, while the ability to value lower operational costs ranked fourth, indicating that consumers considered the purchase price of EVs to be prohibitive, even if they were able to save money overall over the lifespan of the vehicle.

According to a study by Egbue and Long (2012), consumer attitudes towards BEVs are neither completely positive nor completely negative, even though most consumers recognize the importance of sustainability as a concept, and recognize EVs as a mechanism that is discussed to achieve this sustainability. This finding is interesting, as it suggests that consumer attitudes and perceptions of EV technology are important to the likelihood of adoption. Reasons for this include a number of unaddressed concerns many consumers have with BEV technology. Many are skeptical that EVs are more cost effective than ICEVs, or that they provide enough emissions savings to be worth the high cost. Concerns with methods of charging, and other unfamiliar aspects of BEVs also contribute to this ambivalent view of EVs. Charging time is shown to be a significant factor for most consumers, suggesting that this unfamiliarity may negatively affect consumer perceptions of electric vehicles (Liao et al., 2016). This is important, because policies to lower costs or make EVs more attractive to use may be ineffective if consumers are unconvinced that these technologies are worthwhile.

The most consistent barrier to EV adoption cited in the literature is the high initial purchase price of EVs (Beeton and Budde, 2013; Liao et al, 2016). This barrier is highly significant and negatively impacts consumer perceptions of EVs, despite the lower operational costs of driving an electric vehicle (Beeton and Budde, 2013). This indicates that EVs will likely not see widespread adoption until they become more cost comparable to ICEVs, either through government policy or technological innovations to drive down costs. Additionally, communication of the environmental benefits of EVs is important to address consumer concerns with unfamiliar technology and encourage EV adoption (Egbue and Long, 2012). Because consumers are the driving force behind the mass adoption of new technology, it is important to address these concerns in order to see any significant increase in EV market share.

## 2.5.2 Technology

One major area in which ICEVs have an advantage over BEVs is driving range. “Range anxiety”, or the fear that the driving range of an EV is insufficient for a consumer’s driving needs, is commonly cited as a major reason why BEVs may have a low likelihood of penetrating the market. Consumers often have a high willingness to pay for increased driving range, and one study showed that consumers value the driving range of an electric vehicle at up to \$75 per mile (Hidrué et al., 2011). The high willingness-to-pay for an increase in driving range suggests that the short driving range of most commercially available BEVs is too high a cost to pay for most consumers (Silva and Krause, 2016). The low driving range of BEVs as compared to ICEVs is due to the capacity of the battery, and current battery capacity is insufficient to sustain mileages of greater than 200 miles while simultaneously keeping costs down.

Additionally, BEV charging is time consuming, with most standard charging ports requiring upwards of 8 hours to fully charge (Hackbarth and Madlener, 2013). Recent technological advancements have allowed for specific charging ports that may fast charge a vehicle in up to 30 minutes, however competing standards in fast charge design ports may bog down the electric vehicle market, and compound the problem. Moreover, 30 minutes is still a much longer time to refuel a vehicle than many consumers are used to. This requires changes in consumer behavior which, as discussed previously, is a major barrier to electric vehicle adoption. These barriers can be addressed with breakthroughs in battery and charging station technology, as well as market-based innovations. One potential solution to reducing charging time is through using exchangeable battery stations, where a depleted battery can be exchanged for a fully charged one for a fee. This would reduce the recharging time, and increase the utility of EVs for consumers (Ito et al., 2013).

Additionally, because of the limited range most BEVs experience, BEVs have to refuel more commonly, and consumers may worry that the current density of charging stations is insufficient to justify purchasing a BEV (Hackbarth and Madlener, 2013). For many people, the short range of the BEV and the long charging times may make BEVs unsuitable for their lifestyles, especially if longer car trips are required or desired. Advances in technology to make batteries more efficient, or more lightweight are necessary in order to achieve an acceptable range for consumers while keeping costs low.

### 2.5.3 Infrastructure

One major obstacle for the BEV market is related to infrastructure, particularly how to overcome the positive feedback effects associated with ICEVs. One reason why ICEVs are much more attractive than other AFVs is because of the ubiquitous nature of refueling infrastructure for ICEVs. Consumers find ICEVs attractive because they are easy to refuel, which in turn incentivizes more refueling stations. This positive feedback loop is difficult for new technologies to overcome, as even with a dramatic increase in EV charging infrastructure, ICEV refueling infrastructure would remain dominant until EVs reach some critical threshold (Struben and Sterman, 2008). This effect extends to other vehicle services, such as repair and maintenance services. Parking structures that do not provide electric vehicle charging could also be considered an infrastructure challenge, as it disincentivizes the use of EVs in favor of ICEVs.

Another obstacle for the BEV market is increasing demand from the grid, and the increasing necessity of sophisticated grid-to-vehicle communication technologies. The carbon intensity of BEVs is highly dependent on both the generation mix that utilities utilize in powering the grid, as well as the time of day BEV charging occurs. BEV charging has the greatest environmental impact when charged during the night time. This is because of low demand at night, prompting utilities to use smaller power plants at their least efficient generating state (Weldon et al., 2016). This finding may prove particularly problematic, as nighttime charging is the preferred charging method for BEV owners, particularly given the relatively long length of charging as compared to refueling an ICEV. However, because wind generation is generally highest at night, investments in wind power could reduce the carbon intensity of night time BEV charging (Weldon et al.2016).

Additionally, while BEV charging reduces greenhouse gas emissions as compared to ICEV emissions, there are potential negative effects, including an increase in emissions of air pollutants in regions where the generation mix is dominated by coal (Huo et al., 2015). This increase in urban air pollution is not expected to be seen in California where coal generated electricity occupies a relatively low share of the generation mix, however (Huo et al., 2015). This spatial and temporal variability of the effects of charging on the environment may require consumers to significantly adjust their behavior to extract the maximum potential benefit from BEV ownership.

## 3.0 Analysis

In order to analyze policies aimed at increasing electric vehicle adoption and their effectiveness, multiple studies detailing the outcomes of a number of different policies were gathered and summarized to detail the expected effects of policies that are currently considered when looking at increasing EV adoption. Next, the effects of a number of policies in a variety of different countries were examined, and then compared to the levels of EV adoption in those countries. These studies examine the different types of policy incentives that each country offers, as well as historical context and background necessary to examine the true effects of these policies. I will compare this to the level of PEV (BEV and PHEV) penetration in these select countries to determine what has been effective in encouraging PEV adoption, and then examine the suitability of these policies for California. The findings are summarized in Tables 1 and 2.

### 3.1 Types of Policies to Encourage EV Adoption

When discussing policies aimed at increasing the adoption of a certain type of technology, it is necessary to identify these policies by type. Purchase-based policies, or fiscal incentives, attempt to discount the actual financial cost of the electric vehicle in the form of subsidies or tax credits to consumers for the cost of the vehicle. Because of the high costs of most EVs currently on market, this type of intervention acts to expand the size of the market for EVs, making them more likely to be adopted. Additionally, because the most important barrier to consumers is the high purchase price of the vehicle, subsidies work to address this highly salient barrier. Other fiscal incentives include exempting EV owners from taxes associated with owning a vehicle, such as registration taxes or value-added taxes. Because purchase-based policies require governments to cover a portion of the cost of the vehicle, they are naturally very expensive policies. Use-based policies, conversely, are low cost policies that require significantly less tax revenue to fund. These types of policies attempt to influence consumer behavior by providing incentives to driving BEVs, and by reducing the marginal costs of driving an EV. Technology forcing regulations are another type of policy that is used to stimulate the development of advanced technology in order to achieve or meet a specific performance standard or reduction target that is unachievable with current technology. These regulations can be technology specific, mandating developments in a specific technology (such as BEVs), or they can be technology

neutral, setting a specific goal and allowing the free market to determine the ideal technology to achieve this goal. All of these policies, effects, and other factors to consider are summarized in Table 1 at the end of this section.

### 3.1.1 Purchase-Based Policies

One major barrier to mass adoption of EVs is the high purchase price relative to ICEVs. Currently, EVs are not cost competitive with similarly sized ICEVs, and as such fiscal incentives are required in order to overcome this barrier (Lévy et al., 2017). Subsidies can also be directed towards manufacturers as R&D subsidies, or funds provided to facilitate technological breakthroughs and drive costs down (Fox et al., 2017). Tax credits function as a subsidy when provided to customers who purchase an electric vehicle, refunding a portion of taxable income if an electric vehicle was purchased in the same tax year. There are few differences between a tax credit and subsidy, as they function similarly. The major difference is when the money is received, subsidies can be received at the time of vehicle purchase, while tax credits are obtained when taxes are filed. Additionally, subsidies are collected either as a rebate or as a direct discount off of the vehicle purchase, while tax credits reduce the amount of tax liability borne by consumers. This key difference comes into play when analyzing who is purchasing electric vehicles, as many low-income earners bear no tax liability, and thus would gain no benefit from the tax credit given to EV consumers.

As expected, the magnitude of the financial incentives play a role in how effective they are in promoting EV adoption. Countries with financial incentives of \$2,000 or less almost uniformly have lower market shares of electric vehicles than countries with more generous incentives (Sierzchula et al., 2014). This implies that it may be more effective to implement larger financial incentives in order to see significant gains in market share. Additionally, financial incentives are shown to have a positive, significant correlation with increased EV adoption, meaning that strong financial incentives are a strong predictor of the amount of EVs purchased (Sierzchula et al., 2014).

#### 3.1.1.1 Direct Subsidies

The nature of subsidies can differ depending on the country, or in the case of the United States, the state that implements the subsidy. In France, for example, subsidies are given as a percentage of the purchase price, depending on the level of CO<sub>2</sub> emitted by the vehicle. In the case of a zero

emissions BEV, the subsidy covers up to 27% of the purchase price of the vehicle, up to €6,300 or approximately \$6,900 USD (Lévy et al., 2017). The UK similarly offers a direct subsidy on purchase, up to 35% of the cost of the car, to a maximum of £4,500, or approximately \$5,800 USD, depending on the characteristics of the vehicle. In both cases the cost of the vehicle is discounted for the consumer upon purchase, providing an immediate reduction in cost. Other subsidy models follow the structure of a rebate, where a portion of the vehicle sale is refunded after the full vehicle cost. California's Clean Energy Vehicle rebate follows this model, in which EV purchasers can apply for a rebate within 18 months of purchase.

Regardless of the form a subsidy takes, the basic goal of a direct subsidy is to increase the number of BEVs sold while minimizing the cost to the government. California currently implements a PEV rebate program of \$2,500, with an extra \$2,000 rebate for consumers with a household income below 300% of the poverty line. Additionally, California implements an income cap, excluding consumers with an individual income of \$150,000, or household income of \$300,000. This reformulation of the clean vehicle rebate is a recent development for low and moderate income consumers attempts to provide a greater incentive to consumers with a lower willingness-to-pay (WTP) for an electric vehicle. A major concern with utilizing subsidies to increase market penetration, is the idea that the bulk of government revenue would be spent on consumers with an already high WTP for an electric vehicle and its attributes (Silvia and Krause, 2016; DeShazo et al., 2017).

A major consideration in formulating policies with the aim of increasing BEV adoption is to assess what the overall goal is. In California, an aggressive increase in the amount of the rebate would have the effect of increasing the number of BEVs sold, with the trade-off being a much higher cost to the government. While this particular scenario may accomplish the desired goal of increasing the number of BEVs sold, it is important to consider the cost effectiveness of such a scenario. DeShazo et al.(2017) examined a number of policy scenarios modeled off of California's current rebate program, including more aggressive rebates structures, price caps, and income caps. They found that policy scenarios that implement a progressive rebate scheme with lower income caps than the current rebate program would save millions of dollars in costs to the government without sacrificing a significant number of PEVs adopted. The effect of this policy structure is targeting fiscal incentives to people with a considerably lower WTP for an electric vehicle. This ensures access to new vehicle technology across income levels, and increases the

allocative efficiency of the electric vehicle market, improving the overall cost-effectiveness of the policy (DeShazo et al., 2017).

#### 3.1.1.2 Tax Credits

Another mechanism of subsidy used in many countries worldwide to attempt to spur the purchase and market penetration of electric vehicles are tax credits. Tax credits functionally provide the same benefit as a direct subsidy or rebate, in that they effectively reduce the cost of vehicle purchase, however mechanistically they are distinct. A tax credit works by reducing the amount of taxable income a consumer is liable to pay, and in the United States the Plug-in Electric Drive Motor Vehicle Credit (PEDVC) is structured this way. In the United States, a consumer that purchases an electric vehicle is eligible for a tax credit of up to \$7,500, with amounts varying based on the capacity of the battery. In California, a consumer would be eligible for both the federal incentive as well as the clean energy vehicle rebate provided by the state, for a combined savings of up to \$10,000. However, one major limitation of the PEDVC is that it takes the form of a non-refundable tax credit. A non-refundable tax credit does not reduce the amount of tax owed to below zero, meaning the tax credit does not affect consumers who do not owe income taxes, which is up to 35.7% of tax filers (Borenstein and Davis, 2016).

The nature of a tax credit incentive requires the full cost of the vehicle to be borne by the consumer at time of purchase with the benefits being withheld until taxes are filed. Consumers tend to value financial incentives that occur immediately or close to time of purchase more heavily than incentives that are obtained into the future (DeShazo et al., 2017). This further disincentivizes middle and low income consumers from considering an electric vehicle purchase (Borenstein and Davis, 2016), making the fiscal incentive more likely to be claimed by consumers who likely would be able and willing to purchase an EV without the tax credit.

#### 3.1.1.3 Vehicle Purchase Tax Exemptions

One interesting policy that is seen in many European countries is a vehicle purchase or registration tax that is based on the CO<sub>2</sub> emissions of the vehicle. Many of the European countries that implement these vehicle purchase taxes exempt zero emissions vehicles as part of their EV incentive programs to much greater success. Additionally, many countries have value-added taxes (VAT) on all consumer goods and services, including vehicles. Exemptions from the



VAT, which can be quite high in some countries, can also serve as a fiscal incentive for EV purchase and function as a sort of subsidy

As discussed in a later section, Norway provides exemptions from the vehicle registration tax that is imposed on all ICEVs, as well as the 25% value-added tax, making BEVs much cheaper in comparison to an ICEV. Many European countries follow a similar scheme, where high registration fees and taxes are waived for EVs and other clean vehicle technologies (Lévay et al., 2016). Norway's incentives are the most generous of all European countries, particularly because of the high registration tax and VAT that is imposed on ICEVs. In this case, the vehicle registration tax and value added taxes work to make BEV's much more cost competitive with ICEVs (Fridstrøm and Østli, 2017), which is not the case for the US market, even taking into account fiscal incentives. Because Norway's vehicle registration tax is calculated using a number of vehicle attributes, including CO<sub>2</sub> and NO<sub>x</sub> emissions, ICE power, and curb weight, it would likely remain close to zero for BEVs even without the exemption, due to the lack of tailpipe emissions and an ICE (Fridstrøm and Østli, 2017). In this case then, the incentive policy is the vehicle registration tax itself, rather than the tax exemption, though exemption from the VAT and other incentives do provide additional value to consumers in Norway.

A similar mechanism that is seen in a few countries is a feebate system. The feebate system works via a tax imposed on polluting vehicles, while a subsidy is given to purchasers of EVs or other ZEVs. The intended effect is similar to many of the vehicle registration taxes that are levied in certain European countries, which is to lessen the gap in price between more expensive EVs and less expensive ICEVs. The challenges to this system include the need to carefully design policy such that the feebate incentive does not significantly lower tax revenue (Lindberg and Fridstrøm, 2015). The current research on the effectiveness of such a program in California suggests that a feebate program may be effective in lowering the average emissions rates based on European case studies and modeling, but also notes that because of the differences politically and culturally between the United States and Europe, these findings may need to be assessed with some caution (Bunch et al, 2011).

### 3.1.2 Use-Based Policies

In contrast to purchase-based, or fiscal policies to encourage EV adoption, which reduces the fixed cost of EV purchase, use-based policies work by decreasing the marginal costs of driving

an EV (Langbroek et al., 2016). Additionally, use-based policies are largely context dependent, and provide benefits based on what consumers in a certain area would derive benefits from. For example, a driver in Los Angeles would derive greater benefit from HOV lane access than a driver in the Central Valley due to the greater density of traffic in the Los Angeles metropolitan area. Because of this context-dependency, many use-based policies are local in scope.

Other use-based policies can have a broader scope while still reducing the marginal costs of driving an EV. Providing discounted electricity rates when charging an electric vehicle, or financing publicly available charging stations, or providing free public charging all decrease the marginal costs of driving an EV, but aren't necessarily local in scope. These types of policies can have secondary benefits as well. Time-of-use charging rates could help alleviate issues of overgeneration of renewable energy sources, and rarely used or idle electric vehicles could be used as much more efficient electricity storage than current methods of storage (Kordkheili et al., 2015; Martinot, 2016). This would require a heavy interaction between the grid owner and consumer to realize the full benefit, but this level of interactivity demonstrates how policy can be used to incentivize EV ownership as a broader GHG abatement strategy (Tuttle and Baldick, 2012).

Use-based policies are generally low-cost in comparison to fiscal incentives; it does not cost governments much to allow solo drivers use of HOV lanes. However, this is not to say that all use-based policies are low cost. Providing discounted electricity rates based on time-of-use charging requires expensive smart meters to be installed, which given the low numbers of electric vehicles currently in circulation, may not provide enough savings to the utility to be economical (Lyon et al., 2012). Financing the construction of charging stations, or providing free charging, is similarly expensive, yet research shows that EV consumers gain a significant amount of utility out of public charging stations (Ito et al., 2013).

Use-based incentives may also increase the visibility and familiarity with EVs. An increase in charging stations may make consumers more aware of EVs, and more familiar with the idea of EV charging, and other use-based incentives may make the idea of owning an EV more attractive to the everyday consumer. According to numerous theories of consumer behavior including the Transtheoretical Model of Change and the Diffusion of Innovations Theory, exposure to, and familiarity with, electric vehicles may move consumers who are initially skeptical of electric

vehicle technology (those in an early stage-of-change) to consumers who are more willing to embrace electric vehicle technology (those in a late stage-of-change) (Langbroek et al., 2016; Silvia and Krause, 2016).

Common use-based incentives discussed in the literature are discounted electricity rates for EV charging, building and installing public EV charging stations, with or without free charging, free public parking for EVs, free toll roads and HOV lane access for single occupants, and public procurement of BEV fleets. All three of the major utilities in California provide discounted electricity rates based on the time of charging, usually starting at 9 PM or later. Many localities also offer free public parking and charging in certain parking structures and parking lots.

California also offers free HOV lane access to EV drivers.

#### 3.1.2.1 Public Procurement

One potential policy to explore is public procurement of electric vehicles by local governments. Most EV policies are targeted towards a mainstream market, which some argue is inefficient, as money could be better spent targeting niche markets, such as early adopters of technology who already heavily favor BEV attributes (Green et al., 2014). A study of Dutch local governments showed that government agencies value lower emissions, and gain utility from vehicles with lower or nonexistent carbon emissions (Rijnsoever et al., 2013). Public procurement of BEVs could have the effect of increasing visibility and familiarity with BEV technology, which in turn could make consumers more comfortable with BEV technology through the neighbor effect (Mau et al., 2008). This could influence consumer preferences for vehicle attributes, which in turn could lead to greater consumer demand.

Additionally, public procurement of BEVs could provide an assured market for the technology, incentivizing automakers to invest in R&D and providing economies of scale. The assured market would allow for automakers to become more efficient at producing and developing EVs for the mass market. This learning by doing is a positive feedback effect that could lower production costs as manufacturers gain experience with new vehicle technology. Replacing large fleets such as the United States Postal Service vehicle fleet could provide a large enough market to see significant positive feedback effects benefit EV manufacturers (Green et al., 2014).

### 3.1.2.2 Charging Infrastructure

One interesting finding is that the number of charging stations seems to have a stronger predictive effect on a country's EV market share, more than financial incentives offered (Sierzchula et al., 2014). A campaign to install numerous public charging stations could prove more effective overall in encouraging EV adoption, however it is also likely that charging stations and financial incentives are complimentary policies, so by investing in both you see greater returns. California's ZEV action plan includes an executive order to install enough charging infrastructure to support 1 million ZEVs by 2020, which if achieved could greatly impact California's BEV market.

The biggest challenges facing a large-scale campaign to support the installation of public charging stations is that the demand for charging infrastructure remains low as long as there is low market penetration of electric vehicles (Zhang et al., 2014). Therefore, it is important that governments invest in charging infrastructure in order to overcome this chicken and egg problem and reduce the range anxiety that acts as a barrier for many would-be EV consumers. The United States has some policies to promote alternative fuel infrastructure through public-private partnerships. However, because of the strong predictive effect of EV charging stations on EV market share, it may be necessary to consider more aggressive policy approaches.

### 3.1.3 Technology Forcing Regulations

Technology forcing regulations, or technology forcing climate policies, are policies typically enacted to achieve some level of technological breakthrough, by setting or mandating a specific target that is currently unachievable with the goal of achieving these targets through technological advancements. An example of this can be seen in the ZEV mandate, where the State of California mandates that a certain percentage of an automaker's vehicle sales must be a qualified zero emissions vehicle. This encourages automakers to lower costs to be able to sell more ZEVs, and obtain a profit. Ideally, this would incentivize automakers to invest in research and development in order to drive down costs, which would spill over to the mass market. This example is an illustration of a technology neutral regulation, which is a regulation that merely sets a target and delegates the task of determining the most likely technology to achieve that target to free market forces (Fox et al., 2017).

In contrast, a technology specific regulation is a regulation that supports and promotes a specific technology type. In the context of the passenger vehicle market, this would be a policy that mandates the production of BEVs, or the construction of BEV related infrastructure, such as charging stations. With considerable uncertainty, it can be politically dangerous to promote a specific technology using public policy, as the costs of backing so called “loser” technologies, or technologies that fail to deliver cost-effective solutions, can be steep and consequential (Jaffe et al., 2004). However, technology specific policies are more cost effective than technology neutral ones when a “winner” technology is promoted (Fox et al., 2017). This risk-reward trade-off between technology specific and technology neutral policies is emblematic of the dilemma that faces policymakers when evaluating climate policy. Studies show that while technology neutral policies are less risky, they may be less cost effective, and may not send a strong enough signal to firms and consumers about the direction of technology development, leading to underinvestment in what may potentially be a “winner” technology (Fox et al., 2017). Additionally, changes must come rapidly and decisively to see significant GHG reductions, due to the long turnaround time of the passenger vehicle stock, and time investments for the implementation of new infrastructure (Leighty et al., 2012).

Regardless of the specific type of technology forcing regulation, they play an important role in addressing major market failures associated with environmental pollution while also addressing market failures in the diffusion of technology (Jaffe et al., 2004). Environmental policy typically attempts to address the market failure associated with environmental pollution, by implementing solutions to internalize the costs to polluting firms. However, in the realm of the passenger vehicle market, where significant technological breakthroughs are necessary to overcome the externalities associated with environmental pollution, there is another market failure in the diffusion of technology. Technological diffusion may be hampered in the market since the value of a specific technology may vary depending on the level of current adoption, commonly called returns to adoption. Consumers may be reluctant to adopt a new technology that is rarely used, but be more willing to accept it as it becomes more widespread. Manufacturers tend to see lower production costs as they gain experience in production. Additionally, network externalities tend to halt major innovations in the passenger vehicle market. Many ICEV owners derive value from owning an ICEV because of the ubiquitous nature of refueling stations, service stations, and other network incentives (Jaffe et al., 2004; Fox et al.2017). While typically technology forcing

regulations such as carbon taxes are viewed as ways to correct the market failure of environmental pollution, they can serve equally as well in addressing the market failure of network externalities.

#### 3.1.3.1 Zero Emissions Vehicle Mandate

The mechanics and politics behind the ZEV mandate have been discussed previously in this paper; instead this section will focus on the role of the ZEV mandate as a policy to encourage EV adoption and an evaluation of the policy in terms of effectiveness and opportunities for improvement. The ZEV mandate is considered a technology forcing mandate, as it mandates a certain portion of automakers sales are from advanced vehicle technologies. Because the mandate does not specify a certain type of vehicle technology, it can be considered a technology-neutral regulation. Because ZEV credits are allocated according to vehicle type and range, purchase price is not the only factor in meeting these requirements. HEVs and PHEVs are much lower cost, but are only eligible for partial ZEV credit. Additionally, in 2018 partial credits for non-ZEV technologies will be slowly phased out due to a tightening of the mandate's rules. FCVs are eligible for many more credits than a BEV, due to the much longer vehicle driving range, but are significantly more expensive and hydrogen refueling infrastructure is sparse, meaning that BEVs emerge as the dominant technology under this mandate, even though the regulation itself does not favor BEVs.

While it currently appears that BEV technology is emerging as the technological “winner” in reducing emissions in the transportation sector and achieving the GHG reduction targets set by Executive Order S-3-05, it's important to note that due to the long temporal scope, technological uncertainty, network externalities, and other effects, it is almost impossible to predict the mechanism through which California will achieve its GHG reduction goals (Greene et al., 2014). There is significant research that suggests that BEV technology is likely a “winner” technology, or a technology that produces a desired outcome while remaining economically viable (Greene et al., 2014; Fox et al., 2017), however it is important to note that many of these findings are based on models that incorporate several assumptions. However, the ZEV mandate and CARB have shown remarkable flexibility in adjusting with the demands of market forces, loosening targets among challenges from automakers, and tightening targets when it is deemed appropriate to achieve the goal of emissions reductions in the transportation sector (Wesseling et al., 2015).

This flexibility is important to the success of a regulation with such a long time scale, as the uncertainty of the future market necessitates policy change (Greene et al., 2014).

Because the ZEV mandate will phase out partial credits for advanced vehicle technologies that produce tailpipe emissions, the mandate will start favoring BEV and FCV technologies. This change will transition the mandate towards a technology-specific direction. Technology-specific regulations have the benefit of being more cost effective than technology-neutral regulations if they promote a “winner” technology. Because of significant research that shows that BEV technology demonstrates increasing returns to adoption, and decreasing battery costs year after year, there seems to be good reason to shift towards a more BEV-specific technology. This change could prove more cost-effective in the long run, though with the potentially significant drawback of manufacturers being forced to sell more high cost vehicles (Fox et al., 2017). Without careful attention, this could prove problematic as automakers are less incentivized to sell and manufacture lower cost HEVs and PHEVs, while consumers interested in GHG abating vehicle technologies may be unwilling to purchase higher cost BEVs.

#### 3.1.3.2 Carbon Taxes

Carbon taxes are one of the most discussed policy instruments when discussing GHG abatement in a number of economic sectors. The reason for this is the generalized nature of a carbon taxation scheme. A carbon tax would naturally affect the prices of a broad variety of goods and services, due to the prevalent nature of fossil fuel combustion in the modern economy. The price of the carbon tax would reflect the external costs to society from fossil fuel combustion, including negative health outcomes, greenhouse gas emissions, and other negative effects that are currently not accounted for in the costs of fossil fuel combustion. The higher costs for energy would therefore stimulate abatement strategies, including the research and development of advanced vehicle technologies, as well as consumer preferences for fuel efficient vehicles. Research shows that as gasoline prices rise, automakers respond to these price increases by increasing the costs of fuel efficient vehicles, which is consistent with the idea that consumers value fuel efficient vehicles when gasoline prices are high (Langer and Miller, 2008). The implication of this finding is that a carbon tax would affect consumer preferences for fuel efficient and alternative fuel vehicles.

One attractive prospect of using carbon or gasoline taxes as a policy to increase electric vehicle adoption is that carbon taxes spur a variety of GHG abatement strategies, including behavior changes among consumers such as adopting less carbon intensive transportation strategies (Fox et al. 2017). Because many policies to encourage EV adoption increase the total number of vehicles, and do not reduce or lower total travel demand, a carbon tax could be a useful tool to combat the potential rebound effects of other policies. For example, financial incentives may have the unintended effect of increasing the total number of vehicles on the road, worsening issues such as congestion and total energy demand (Rudolph, 2016), however a carbon tax could have the opposite effect, even amongst those who do not purchase an EV, reducing total vehicle miles traveled and lessening traffic congestion and total energy demand.

Carbon taxes are generally seen in the literature to be a regressive policy, disproportionately affecting the poor over the wealthy. This is because carbon taxes would increase the price of goods and services and low income households generally have less ability to pay for this price increase. The regressive nature of this policy can be combated through efficient use of the tax revenue. Williams et al. (2014) shows that with a \$30/ton tax on CO<sub>2</sub>, an equal, annual lump-sum rebate to all individuals would provide a positive increase in welfare for earners in the bottom three income quintiles. This finding makes intuitive sense, as high income households tend to consume more energy than low income households, while energy expenditures are typically a higher fraction of total expenditures in low income households. A lump-sum rebate would then allow the costs of a carbon tax to fall more heavily on high income households, without sacrificing the environmental benefits (Borenstein and Davis, 2015).

However, it is important to be aware of the limitations of carbon taxes and other similar technology-neutral approaches such as cap-and-trade programs. Simply valuating the social cost of carbon into the price of carbon may provide the initial motivation to invest in new vehicle technologies, however technology spillover effects lead to firms underinvesting in research and development for fear of being unable to reap the full benefits (Azar and Sandén, 2011). In this way, governments may need to adopt technology specific policies such as research and development grants in order to realize the full benefits of new vehicle technologies. Additionally, carbon taxes are unable to send a strong signal towards a potential winner technology, leading to relatively inefficient abatement costs, especially at the stringency levels that are likely to be deemed acceptable by the public (Fox et al., 2017). It is likely that strong, technology specific



policies will be required as complements to carbon pricing schemes in order to successfully achieve a full transition to electrification (Greene et al., 2014).

Type of Policy	Policy Effects	Other Factors to Consider
Direct Subsidies	Provide a greater incentive to consumers with a lower WTP for EV attributes	Provides a more immediate form of financial assistance as compared to a tax credit
Tax Credits	Provide a greater incentive to consumers with a lower WTP for EV attributes	The structure of the tax credit impacts who reaps financial benefits. Non-refundable credits do not benefit consumers who do not owe a tax liability
Vehicle Purchase Tax Exemptions and Feebates	Lowers the gap in price between expensive EVs and economical ICEVs. If registration taxes are based on CO <sub>2</sub> emissions, this serves as a way to internalize the cost of carbon	The strength of this policy is dependent on the strength of the negative economic incentives for ICEVs
Use-Based Incentives	Decreases the marginal cost of using an EV	May have secondary effects on traffic congestion and demand on infrastructure
Public Procurement	Provides an assured market for EV manufacturers, and increases public familiarity with EV attributes	
Installation of Charging Stations	Removes range anxiety, increase familiarity with EV charging infrastructure	High numbers of charging stations helps to remove network externalities favoring ICEVs
Vehicle Mandates	Provides a strong signal for an energy transition in the vehicle market, requires automakers to invest in EV technology	By design, this policy is far-reaching and made in the face of much uncertainty, therefore it must be continually monitored and updated in the face of new information
Carbon Taxes	Stimulates a number of abatement strategies, internalizes the social cost of carbon, increases the value of low carbon technologies to consumers	Carbon taxes may disproportionately impact the poor over the wealthy. Proper use of tax revenue may be needed to overcome this barrier. Carbon taxes may not be a strong enough signal to achieve a full energy transition on their own

**Table 1.** A list of the types of policies discussed in section 3.1, along with the expected policy effects, and other factors to consider

## 3.2 Comparison of Policies with BEV Penetration in Select Countries

In this section the types of policies implemented by each of the five countries listed will be examined in detail, as well as other contextual factors such as the historical context for certain policies, cultural attitudes, or other relevant factors. In addition, the market share for each country as determined by the International Energy Agency's Global EV Outlook 2016 will be discussed in the context of the policy framework of each specific country. Table 2 at the end of this section lists every country discussed, along with policies implemented and the PEV market share. Countries were selected for their relevance to the vehicle market, the diversity of policies implemented, and share of global emissions.

### 3.2.1 United States

Until recently, the United States was the largest vehicle market in the world, having only recently been overtaken by China. Following the oil crisis in the 70s, various efforts have been taken to reduce the dependency of the US's transportation system on foreign oil, including the implementation of the Corporate Average Fuel Economy (CAFÉ) standards in 1975. Following increased research and development into improving the fuel economy of automobiles, breakthroughs in electric vehicle technologies occurred, as automakers attempted to increase their average fuel economy by pushing sales of hybrid and pure electric vehicles (Jun, et al., 2016). As gasoline prices stabilized following the oil crisis, the investment in fuel efficient vehicles and AFVs had dwindled until the Energy Independence and Security Act of 2009, which raised the CAFÉ standards to 54.5 mpg by 2025 (Zhou et al., 2014). This reinvigorated the AFV market in the United States, spurring investments in hybrid and pure electric vehicles.

The United States offers few federal incentives, and many of the EV incentives offered are at the state level, reflecting the country's vast differences in suitability for EV penetration (Onat et al., 2017). These differences range from attitudes towards EVs, to the electrical generation mix of certain states, often requiring state specific policies in order to maximize the benefits received from BEV adoption. For example, a BEV purchased in Wyoming or Kansas will not have the same emissions savings as a BEV purchased in California or Vermont, due to the differences in the generation fuel between states. Thus, policies in Wyoming or Kansas should aim for encouraging a cleaner grid, rather than for greater electric vehicle adoption (Onat et al., 2017).

The federal incentives offered include a non-refundable income tax credit (PEDVC) of up to \$7,500, based on the power of the battery, for a plug-in electric vehicle purchased on or after 2010, as well as a tax credit of up to 30% of the cost of any installed alternative fuel infrastructure, including electric vehicle charging stations (Zhou et al., 2014). However, the vehicle purchase incentive will phase down to 50% after an auto manufacturer has sold 200,000 EVs. Additionally, the alternative fuel infrastructure incentive expired as of December 31, 2016, marking this current tax year as the last year for any owner of electric vehicle charging infrastructure to claim these benefits.

One effect of the non-refundability of the PEDVC incentive is that, distributionally, the credit benefits high-income earners. In 2014, 90% of the credits were claimed by those in the top quintile in adjusted gross income (Borenstein and Davis, 2016). This demonstrates a similar problem that we see in electric vehicle subsidies, which is that consumers with higher incomes and a higher WTP for an electric vehicle are able to reap the majority of the benefit, leading to relatively inefficient policy incentives.

State-level incentives are often more robust, reflecting the focus of state governments on fostering the EV market for the state, depending on the state's suitability for large scale EV penetration. As discussed previously, California offers a rebate incentive along with an income cap and an extra subsidy for low income earners. Additionally, various use-based policies exist, including HOV lane access, free or preferential parking in many municipalities, and discounts such as lowered insurance rates, or lowered electricity rates for EV charging on off-peak hours. California has also adopted the already discussed ZEV mandate, which requires auto manufacturers to dedicate a portion of their sales to zero emissions vehicles, such as BEVs. California's long history of leadership in environmental protection is one explanation for its robust incentives for encouraging EV adoption, and as a result, California accounts for 40% of EVs sold in the United States (Zhou et al., 2014), while EV sales for the United States as a whole accounted for only 0.7% of total vehicle sales (IEA, 2016). The United States is also one of only two countries tracked by the IEA that did not experience sustained growth of its EV market, perhaps due to weakened signal on the national level of the importance of promoting EVs.

The large nature of the United States transportation network and vehicle market likely requires a more localized approach in encouraging EV adoption, as the large diversity between states in

factors such as wealth, population, electrical generation mix, and cultural attitudes towards EVs requires a more tailored approach. However, signaling from the federal government is important as well, as the increased CAFÉ standards starting in 2009 and federal incentives for EVs have spurred innovations in the EV market in the past few years. Therefore, in order for the EV market to succeed in the US, both state governments and the federal government should work together to provide consistent messaging regarding the importance of reducing our dependence on petroleum-based fuels and reducing our greenhouse gas emissions.

### 3.2.2 China

China is the world's fastest growing economy, and they have largely overtaken the United States as the largest vehicle market in the world. As a result, oil demand in China has skyrocketed, and air quality has plummeted in the region. These factors have motivated the government of China to embrace policies that aim to electrify the transportation sector, and reduce the air quality issues and extreme oil dependence that plague the most densely populated regions of the country. Since 2011, China has signaled the desire to transition to pure electric drive technology, and they have instituted a number of policies to achieve that goal. China's EV policies can be divided into three categories: financial policies, infrastructure promoting policies, and R&D investment policies (Zhang et al., 2017). Since 2015, China is now leading in electric vehicle adoption, largely due to the country's policy approach (Zhang and Bai, 2017).

China's financial policies mainly involve the use of tax exemptions and direct purchase subsidies offered on both the national level as well as the regional level. Tax exemptions are offered to ZEV's, there called New Energy Vehicles (NEV), including waiving purchase taxes and vehicle taxes for PHEVs, BEVs, and FCVs. Subsidies for NEVs started in 2009, and were given directly to auto manufacturers, to drive down the stated purchase price of the vehicles. Local governments contribute their own subsidies, very often at a 1:1 match with the national government covering up to 60% of total vehicle cost. These subsidies are intended to phase out and increasingly favor NEVs with greater mileage and range, decreasing by 20% in 2017, 40% in 2019, and with a gradual phase out after 2020 (Zhang and Bai, 2017). This reflects China's reliance on the ability of auto manufacturers to lower EV costs as sales increase. Careful examination of the potential of China's EV market to become self-sustaining are necessary in order to prevent the collapse of the EV market. Conversely, continuing subsidies longer than

necessary can increase the reliance of the EV market on government funds, reduce the rate of R&D breakthrough technologies and weaken the EV market (Zhang and Bai, 2017).

Infrastructure promotion policies China is pursuing include interface standardizing and setting charging prices. In addition, in 2015, the government of China described their plans to construct large amounts of EV charging infrastructure according to demand projections by 2020. However, the number of charging stations is woefully insufficient to match the increase in EVs, and the standards for EV charging ports are well behind other countries, with aspects such as voltage not having a uniform standard between EVs. These issues present major problems for China's goals of increasing EV penetration in the vehicle market, as the lack of standardized charging equipment, and insufficient charging infrastructure disincentivizes consumers to purchase an electric vehicle (Zhang et al., 2017).

It is uncertain whether protecting the environment is a major concern for China when developing policies to encourage EV adoption. Policies promoting renewable energy generation are not aggressive enough to reduce China's reliance on coal generation to an appreciable degree, due in part to the large quantity of power that China must produce (Wu and Zhang, 2017). To this end, policies to promote electric vehicles in China may not actually reduce pollution or greenhouse gas emissions, instead emissions would simply shift to power plants. In fact, HEVs utilizing gasoline may actually provide more emissions savings and reduce air pollution in China if there is no substantial change in the generation mix, due to the capability of HEVs to increase the efficiency of gasoline combustion by storing some of the energy as electricity (Wu and Zhang, 2017). This would suggest that for China, the promotion of EVs is more related to issues of energy security and local air quality than broader environmental protection (Wu and Zhang, 2017).

While the total number of EVs, including PHEVs purchased tripled between 2014 and 2015 in China, from 104,000 to 312,000, due mostly to the policy support and strong messaging in favor of electric vehicles, the policy support in China needs to be retooled in order to achieve maximum effectiveness. EVs as a percentage of market share remain low, with EV's comprising about 1% of new vehicle sales in China (IEA, 2016). The major reasons for this include the lack of support infrastructure for EVs in China, as there is not enough charging infrastructure for the current number of EVs on the road. The subsidies phasing out may also cripple the EV market in

its infancy, which could provide public backlash if EV's become unsustainable as reliable method of transportation. While China is currently second in the world in terms of the number of EV sales, much of that could be attributable to its large population, as the market share of EVs remains fairly average in comparison to other nations (IEA, 2016).

### 3.2.3 Japan

Japan's vehicle market is notable for being the leading EV market for more than a decade, having achieved great strides in EV and HEV technology. Japanese HEVs comprise the vast majority of the global HEV sales, with Toyota comprising 80% of the HEVs sold in 2008 due to the success of the Prius (Pohl and Yarime, 2012). Additionally, Japanese automakers invested in BEV technologies very early on, in response to the oil crisis in the 1970s. Japan's comparative advantage in fuel efficient cars as compared to the U.S. made Japan a net exporter of fuel efficient vehicles during the oil crisis, and as a result, many policies in the U.S. affected Japanese automakers. For example, the ZEV mandate introduced in 1990 spurred a large increase in HEVs from Japanese automakers, including Toyota and Nissan, as at the time the regulation allowed HEVs to obtain ZEV credits. However, much of the Japanese government's policies were directed towards pure electric vehicles, raising questions on whether Japan's public policy had a significant impact on the development of EV technologies, or whether market forces spurred on much of the research and development of EV technologies (Pohl and Yarime, 2012).

Japan's policies to increase electric vehicle adoption include subsidies and tax credits for environmentally friendly vehicles, including BEVs, but also including HEVs, natural gas vehicles, and other low emissions vehicles. Japan also has a trade in program for old ICEVs, which allow for subsidies 2.5 times greater when trading in an ICEV that is older than 13 years. These purchase incentives have weakened after 2013, with subsidies dropping from up to \$1000 USD to up to \$850 USD currently. There are several tax exemptions as well, including the vehicle purchase tax and tonnage tax, and many local governments have incentives as well, including reduced tolls and preferential parking (Zhou et al., 2014). Additionally, Japan's Ministry of International Industry and Trade (MITI) has launched programs since the 1970s aimed at increasing R&D for BEV technologies, providing government funding to companies and universities aimed to increase the number of technological breakthroughs in BEV technology (Ahman, 2006).

Japan has had relatively low levels of EV market share, seeing only 0.6% of PEVs as new car sales, and is one of two countries tracked by the IEA that did not experience sustained growth in the EV market in 2015 (IEA, 2016). While Japan had an early focus on advanced vehicle technology, with the Japanese government signaling the importance of developing the BEV market in the 1970s, much of this research and development has had spillover effects into the HEV market. It is not clear whether this is due to the relative weakness of Japan's policies promoting BEVs, or due to overwhelmingly strong market forces promoting the production of HEVs, as demand for Japanese HEVs increased in the United States for several reasons, including the oil crisis in the 70s, and California's ZEV mandate in the 90s.

### 3.2.4 Norway

Norway is an interesting case because it is the country with the highest level of PEV penetration in the world, with approximately 23.3% of all new vehicle sales being EVs, including PHEVs (IEA 2016). Additionally, Norway is the first country in the world to have 1 BEV for every 100 ICEVs on the road (Zhang et al., 2016). For comparison, the United States has achieved only 1% of EVs as new vehicle sales, and most developed countries have similar levels of market penetration. Another remarkable facet of Norway's BEV market is the fact that this level of market penetration was achieved rapidly, with sales of BEVs relatively modest until 2010, when BEV sales started to rapidly rise. The situation in Norway can be explained by a variety of policy successes, however the case in Norway also demonstrates a remarkable dedication to the success of the EV industry despite numerous policy failures.

Norway has a significant number of policies and incentives aimed specifically at increasing the adoption of BEVs only (as opposed to BEVs and PHEVs). These policies include waiving the registration tax (worth up to \$11,000), exemption from the value-added tax, free parking, usage of bus lanes, waiving toll fees, and promoting a dense network of charging stations (Zhang et al., 2016). Many of these policies and incentives have been in place for a long period of time, as early as the 1990s for many of the tax exemptions and usage based policies. While many of these incentives, such as the waiving of toll fees or access to bus lanes did not seem to have any significant impact on the growth of BEV sales (Mersky et al., 2016, Zhang et al., 2016), it signaled the importance that the Norwegian government placed on the success of the EV market. These incentives are set to end in 2017. Many are concerned that the discontinuation of these

policies and incentives would hamper the EV market, and there is a lively debate on how much the success of the EV market will suffer with the discontinuation of these incentives. There is potential that consumers will react negatively to the removal of these incentives, and go back to purchasing an ICEV (Figenbaum and Kolbenstvedt, 2013).

Another major factor in Norway's EV success is the internalization of carbon's social cost into the price that consumers pay. Norway pays one of the highest carbon taxes in the world, and Norwegians have paid this carbon tax for over two decades, with carbon taxes being implemented in 1991. Gasoline faces the highest tax rate in the country, with a tax of \$51 USD per ton of CO<sub>2</sub> produced (Bruvoll and Larsen, 2004). This carbon tax means that consumers in Norway pay some of the highest fuel prices in the world. In 2014, fuel prices reached upwards of \$9 USD per gallon in Oslo (NPR, 2014), and 11% of the purchase price of gasoline is due to the tax on carbon implemented by the government of Norway (Bruvoll and Larsen, 2004).

However, Norway's EV market has also hit a number of stumbling blocks. During the early 2000s, the EV market in Norway was dominated by one electric car company named Think Global. The company suffered numerous setbacks, but received heavy backing from the government, being bailed out of bankruptcies several times until its final collapse in 2011 (Røstvik, 2014). Afterwards, the EV market in Norway quickly diversified, with many EV manufacturers entering the market, including Tesla and Nissan, coinciding with the rapid growth of Norway's EV sales. The fact that perception of EVs did not suffer among Norwegian consumers despite the litany of failed promises from Think Global shows that the chief reason for Norway's EV success is the commitment to environmental causes.

Norway's longstanding commitment to environmental causes, leading them to adopt aggressive climate policies and policies to electrify the transportation sector, is likely the main reason that Norway's EV market has seen considerable success in the past few years. Despite policy setbacks, perceptions of EVs have not suffered. Policies to tax carbon, subsidize electric vehicles, and provide use-based incentives have remained in place for multiple decades, showing a remarkable stability and consistency in Norway's goals and messaging regarding the importance of climate change and greenhouse gas emissions reduction. While it may be tempting to isolate one variable as the reason for Norway's interesting success, it is likely a combination of policy measures and attitudes that contributed to the growth of Norway's EV sales. Norway



provides an interesting case study in the importance of cultural values and attitudes in electrifying the transportation sector.

### 3.2.5 The Netherlands

The Netherlands is another country that has managed to achieve a high level of EV penetration. In the Netherlands in 2015, 9.7% of all new vehicle sales were PEVs, with 2,540 BEVs sold and 41,230 PHEVs sold between 2010 and 2015 (IEA, 2016). The Netherlands is an interesting case because the majority of PEV penetration is attributed to the sale of PHEVs, which is unlike Norway, where the majority of EV sales were BEVs. The Netherlands, like Norway, has a robust policy network to encourage the adoption of EVs, featuring strong tax exemptions on the national level. Additionally, many municipalities in the Netherlands complement these tax incentives with many use-based policies such as free charging, and allocation of parking spots to EV drivers.

The major fiscal policy enacted at the national level in the Netherlands is the exemption of EVs from several taxes that are imposed on all vehicles. The Vehicle Purchase Tax (VPT) is a registration tax that is collected when the vehicle is registered. As of 2013, the VPT is 100% based on the NEDC CO<sub>2</sub> emissions rating of the vehicle and follows a continuous function, meaning that vehicles with lower emissions pay a lower tax (Kok, 2015). At higher levels of CO<sub>2</sub> emissions, this VPT can reach amounts greater than €10,000, or approximately \$11,000 USD (Tietge et al., 2016). BEVs and PHEVs are exempt from this registration tax due to their lower emissions ratings. Additionally, the Netherlands imposes an Annual Road Tax (ART) for the use of public roads. The ART is based on the mass of the vehicle as well as the fuel type, and exemptions from this tax exist for BEVs and PHEVs (Kok, 2015). Lastly, the Netherlands has a Company Car Tax (CCT) for company cars that are driven for private use. The CCT is calculated as a percentage of the value of the vehicle including the VPT, so CO<sub>2</sub> emissions are valued twice in the CCT. BEVs and PHEVs are exempt from the CCT, providing incentives to both employers and employees who pay the CCT to adopt an EV. The CCT tax exemption lasts for up to 5 years after the car is registered (Kok, 2015). Because 92% of PEVs purchased are registered to companies, this makes the CCT exemption a particularly important policy tool to increase EV adoption (Tietge et al., 2016).

One important aspect of the Netherlands fiscal policies to increase EV adoption is that these incentives were highly publicized and very salient to consumers. Many car models were promoted as VPT, ART, and CCT free to consumers and employers (Kok, 2015). This salience increases the likelihood that these incentives affected consumer purchase behavior, and the strength of many of these incentives, particularly the VPT and CCT exemption, signaled a commitment to increasing EV adoption

Many municipalities have incentives to adopt EVs as well. In Amsterdam, there is a €5,000 (~\$5,500 USD) subsidy for fully electric vehicles that are registered by companies. Additionally, EV owners are given priority when applying for parking permits. The wait time for these parking permits otherwise can reach up to ten years. Additionally, owners of EVs can request public charging stations to be installed if they do not have access to private charging at no cost to the requester (Tietge et al., 2016). Other major municipalities in the Netherlands have similar incentives.

The differentiation of financial incentives between PHEVs and BEVs are not distinct as compared to incentives offered in Norway. This lack of policy distinction has caused consumers in the Netherlands to adopt many more PHEVs than BEVs, likely because costs for PHEVs are lower, and the vehicle attributes are more similar to ICEVs, offering greater flexibility (IEA, 2016). Because the emissions of a PHEV are related to the number of electric miles driven vs. the number of gasoline miles driven, efforts to increase electric miles driven need to be robust to realize the pollution and emission savings benefits of financial incentives that do not differentiate between PHEV and BEVs (Kok, 2015).

Country	EV Policies in Place	PEV Market Share in 2015 <sup>2</sup>
China	Vehicle Tax Exemptions, Direct Purchase Subsidies	1.00%
Japan	Tax Credits for EV Purchase, Vehicle Tax Exemptions, Some localities have reduced tolls and preferential parking	0.60%
Netherlands	Vehicle Tax Exemptions, Some localities offer subsidies, free parking, free charging, installation of public charging stations	9.70%
Norway	Vehicle Tax Exemptions, Value Added Tax Exemption, Free Parking, Use of Bus Lanes, Toll Waivers, Carbon Tax on Gasoline	23.30%
United States	Tax Credits for EV Purchase and Installation of Alternative Fuel Refueling Stations. Some states offer additional fiscal incentives and use-based policies	0.70%

**Table 2.** EV policies by country examined in section 3.2. PEV market share in 2015 is given as well, to provide a comparison between policies in effect and market share of PEVs.

## 4.0 Discussion

### 4.1 Major Findings

Because most countries have low levels of market penetration of electric vehicles, it is difficult to definitively say which policies work and which policies do not work in electrifying the transportation sector. However, exhaustive literature review of the effects of many different policies on increasing vehicle electrification have demonstrated several findings. Firstly, financial incentives, if correctly structured, provide the greatest gains to electric vehicle adoption. The two countries with the greatest EV market shares in 2015 are countries that offer some of the strongest fiscal incentives in the form of indirect subsidies that are valued at over \$10,000 USD. Secondly, use-based policies are positively correlated with increased EV adoption, but the effectiveness of these policies are context dependent, and likely correspond to commuter concerns in specific localities. Lastly, technology forcing regulations are likely necessary to send a strong enough demand signal to automakers, and carbon taxes could provide

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<sup>2</sup> Market share is determined by the International Energy Agency's Global EV Outlook 2016 and includes BEV and PHEVs. Market share in 2015 is taken directly from Table 11 Electric cars market share by country 2005-15

a way to promote changes in consumer behavior, while also alleviating some of the problematic side effects of other EV policies.

Subsidies and financial incentives have a strong predictive effect on BEV adoption, particularly when the incentives are generous (Sierzchula et al., 2014). This is because generous financial incentives reduce the effective purchase price of BEVs, which tend to be more expensive, to values that match greater numbers of consumer WTP for BEV attributes, which often include shorter ranges, longer refueling times, and other undesirable attributes as compared to an ICEV. Rebates and direct subsidies upon purchase tend to be valued more highly by consumers over tax credits, and tax credits that are non-refundable do not benefit a significant portion of earners in the United States.

One interesting observation is that the two countries with the highest EV penetration, The Netherlands and Norway, both have high vehicle registration taxes that are based either partially or in whole on CO<sub>2</sub> emissions, and do not offer direct subsidies for EVs, at least on the national level (Kok, 2015; Zhang et al., 2016). Instead, exemption from these taxes acts as a form of indirect subsidy for EVs, creating a strong disincentive for ICEVs and a strong incentive for PEVs. There are very few studies that examine whether a similar vehicle registration tax based on CO<sub>2</sub> emissions would be effective in California, or what the distributional effects of such a policy would be. Both the Netherlands and Norway implemented high vehicle registration taxes and value added taxes before the advent of the EV market. For example, the Netherlands only transitioned the VPT to be based on CO<sub>2</sub> emissions relatively recently, in 2013.

Use-based policies is a broad term to encompass any policy that attempts to reduce the marginal costs of driving an EV. This can range from relatively minor policies, such as allowing EV drivers access to HOV lanes, to much more extensive policies, such as installation of electric vehicle charging infrastructure, and free public charging stations. Because these policies attempt to lower the marginal costs of driving and EV, they are by nature dependent on local context. The marginal cost of driving an EV in a congested area is much higher than driving an EV in a less congested area, therefore, HOV lane access may be an effective policy tool in some of California's congested cities.

Use-based policies to encourage EV adoption can signal a commitment to clean vehicle technologies which is important to automakers and consumers. In the case of Norway, there are a

large number of financial and use-based incentives, many of which were in place before Norway had a large market share of EVs. This consistency and stability is likely a major reason why perception of EVs in Norway never suffered. Low-cost use-based incentives can then be used to signal to consumers and automakers a commitment to promoting ZEV technology, making consumers more likely to become receptive to these technologies. In the Netherlands, city governments offer many cost-saving use-based policies as well, such as free public charging, and prioritized parking permits. The ability of policies to save on the everyday costs of using an EV is a common theme in these two successful markets.

A policy instrument currently not in effect in California or anywhere in the United States is a carbon tax. Internalizing the social cost of carbon into the price consumers pay is commonly cited as a cost-effective way to stimulate GHG abatement strategies using the free market. As previously discussed, Norway has some of the highest fuel prices in the world as a result of aggressive carbon taxation. These fuel prices increase the total cost of ownership of an ICEV, and consumers in Norway are highly motivated by economic factors to consider the adoption of an electric vehicle (Zelenkova, 2013). Additionally, carbon emissions are essentially taxed again through the vehicle registration tax, of which a portion is calculated through CO<sub>2</sub> emissions. Avoiding these extra costs is a major motivation to Norwegian consumers to adopt an EV, indicating that carbon taxes could be an important policy measure to shape consumer behavior.

Modeling using high fuel costs due to carbon taxation has been shown to increase the probability of adopting a BEV by 19% (Rudolph, 2016). Additionally, carbon taxes can stimulate a wide variety of abatement strategies, many of which would have beneficial outcomes, such as a reduction of vehicle miles traveled overall. Carbon taxes are politically unpopular, particularly in North America. No state in the union currently enforces a carbon taxation scheme. A price-per-ton on CO<sub>2</sub> emissions could stimulate market demand for EVs and other ZEV technologies. Usage of tax revenue could offset the potential regressive effects on lower income households.

## 4.2 Limitations of the Analysis

Because the PEV market is very new in many of the countries studied, the data is very preliminary. Norway and the Netherlands did not see meaningful increases in PEV adoption until after 2010 (IEA, 2016). It is possible that the time frame is simply too short to fully examine the effects of certain policies on BEV market penetration. Additionally, many of the policy

outcomes discussed are based on stated preference data. There may be differences between the stated preferences and actual purchase behavior, which could impact the effect of these policies (Liao et al., 2016). For example, many studies conclude that subsidies increase consumer willingness-to-pay for electric vehicle attributes, but because many of these studies are based on stated preference surveys and not market purchase data, the magnitude of the effect may not reflect real-life purchase behavior. Because of this limitation, policy outcomes were framed in terms of the overall expected impact on the EV market, rather than attempting to quantify the effects of any given policy.

In addition, the countries examined are a small sample size, and many other factors aside from policy effects may factor into EV purchase decisions. For example, both Norway and the Netherlands have high levels of EV adoption, but both countries are smaller both in total area and in population than California. Because they are much smaller countries, range anxiety is less salient (Kok, 2015). Additionally, cultural attitudes, pro-environmental, and pro-government attitudes may be factors in responding favorably to policies favoring EVs and other clean vehicles (Agrawal et al., 2010). The policies themselves should not be assumed to be the only mechanisms affecting the market share of EVs in each respective country.

As the EV market grows, and as more countries focus their efforts on reducing emissions in the transportation sector, we may see the emergence of purchase data in response to government policy that could give rise to more sophisticated comparative analyses and help inform policy decisions. Additionally, we may see the emergence of new market strategies to increase EV adoption as an increasingly mature market attempts to gain even more market share. With the announcement of Tesla's new Model 3 scheduled to begin production later this year, marketed as an affordable, long range electric vehicle, we may be at the cusp of exciting future research into the developing EV market.

### 4.3 Challenges to Expanding California's EV Market

California's electric vehicle market will experience several challenges, and will require government support to overcome many of these challenges. Energy transitions are inherently difficult, and even if EVs were identical to ICEVs in all attributes, EVs would still face substantial challenges due to positive feedback effects reinforcing ICEV dominance (Struben and Sterman, 2008). The reality is however, EVs are not identical to ICEVs in all attributes, and face

many technical challenges as well. Issues of battery capacity, battery cost and driving range all top the list of consumer concerns (Liao et al., 2016). Additionally, technology spillover effects lead to firms underinvesting in R&D technologies to improve these attributes (Struben and Serman, 2008; Azar and Sandén, 2011). For example, lightweight battery technologies would have applications in the ICEV market as well, lightening the curb weight and improving vehicle performance. There are numerous policy challenges as well, policy can affect the purchase price of vehicle, and provide other non-economic incentives for the use of electric vehicles, but policy alone cannot change consumer behavior or preferences. Policy to increase EV adoption, or make EVs more attractive to drive may have the unintended effect of reducing the number of people utilizing non-vehicle modes of transport (Langbroek et al., 2016). These challenges will need to be addressed as the EV market continues to grow.

#### 4.3.1 Technical Challenges

Many of the technical challenges facing the EV market are obvious and salient to most consumers. BEVs simply do not have enough range to be widely acceptable to the mainstream market. Because vehicle range is determined by the capacity of the battery, there is a tradeoff between increased range and vehicle cost. This means that until battery costs fall dramatically, the driving range of passenger EVs will remain much lower in comparison to an ICEV. Policy cannot directly affect the driving range of electric vehicles, however R&D subsidies could overcome the underinvestment due to technology spillover effects, and high charging station density and quick charging times may alleviate consumer concerns about range (Dimitropoulos et al., 2013)

An additional challenge to a growing EV market is the integration between electric vehicles and the grid. There is a growing body of literature examining grid interactions with electric vehicles as part of a distributed grid, acting as storage for renewable energy sources (Kempton and Letendre, 1997; Tuttle and Baldick, 2012; Kordkheili et al., 2015; Martinot, 2016). Future interactions with the grid are seen as an evolution from simple grid-to-vehicle interactions in the first generation of PEVs, to complex grid-to-vehicle and vehicle-to-grid interactions guided by advanced charging communications technology that allows for automatic charging based on factors such as CO<sub>2</sub> emissions, real-time price information and RES generation (Tuttle and Baldick, 2012). The reality is, this sort of advanced grid-vehicle interaction is likely necessary to

take full advantage of the GHG emissions savings potential of BEVs, particularly as market share increases and electricity demand increases as well. RES generation is intermittent, and electricity storage is required to realize the full benefit of RES generation. Electric vehicles are seen as one potential method of distributed storage, becoming an integral part of the electrical grid, charging in response to high RES generation and discharging in response to high electrical demand (Kordkheili et al., 2015; Martinot, 2016). This comes with a number of challenges however, as technological advances in vehicle-to-grid communication need to be achieved for this to be fully realized. Less sophisticated methods such as time-of-use pricing, providing low electricity rates during late night hours when wind generation is highest, can be a low-cost method of achieving the same goal. However, the full advantages of using EVs as grid storage can only be realized utilizing sophisticated grid-vehicle communications.

### 4.3.2 Policy Challenges

Many of the policies proposed have unintended side effects or rebound effects that may necessitate further policy response. Policies to promote BEV adoption could have the unintended effect of persuading consumers who already engage in low-carbon modes of transportation (walking, biking, public transportation) to purchase a BEV. A total increase in the number of vehicles on the road could also provide greater constraints to cities and localities who must deal with greater traffic, and more demand for parking (Rudolph, 2016). Additionally, policies aimed to benefit one specific type of technology necessarily have winners and losers. Because of the nature of the transportation sector being strongly path dependent, and vulnerable to strong network externalities, a successful transition will likely be achieved using one vehicle technology, rather than a heterogenous mix of alternative fuel vehicle types (Struben and Sterman 2008).

#### 4.3.2.1 Rebound Effects and Unintended Consequences

Policy proposals to increase BEV adoption could have unintended consequences that policymakers must deal with. If BEV policies cause a shift in modes of transport from already zero-carbon sources such as walking or bicycling, then this would have the opposite intended effect. Models have shown that BEV policies can have the effect of vehicle adoption in consumer groups who may not own a vehicle (Rudolph, 2016). Depending on the generation mix of electricity, emissions could also increase due to the worsening energy ratio for consumers who



switched from bicycling to driving. Therefore, in order to counteract this effect, electrical generation must come from renewable sources, particularly during times of high EV charging demand.

Alongside this rebound effect, an increase in total number of vehicles on the road could worsen many currently existing problems such as traffic congestion, and limited parking in large cities. Instead of substituting ICEVs with an EV, households may instead increase the number of cars (Liao et al., 2016). More vehicles on the road and greater vehicle miles traveled can exacerbate many of these problems. Traffic congestion already contributes a large amount of excess CO<sub>2</sub> emissions in the state of California, and the addition of large numbers of new drivers on the road could worsen this problem. Additionally, as cities lower the marginal cost of using an EV by providing free parking, free charging, bus lane access, and other incentives, the strain on the city infrastructure would increase. More parking facilities may be needed as the number of vehicles on the road increase, and this could prove to be problematic for already overcrowded and congested cities.

#### 4.3.2.2 Winners and Losers from BEV Policies

Achieving a successful energy transition in the transportation sector is likely to be strongly path-dependent, meaning that the composition of the sector in the future will depend highly on decisions made today (Struben and Sterman, 2008). There are many AFVs types that are considered when determining GHG abatement strategies, however positive feedback effects such as network externalities likely mean that a heterogenous transportation mix is unlikely, and therefore focus should be on promoting technologies that achieve desirable environmental effects in order to overcome these positive feedback effects. Bakker and van der Vooren (2012) argue that despite the risks inherent in governments choosing winners, promoting electric vehicle technologies is important because of the inherent inefficiencies of ICEs, the negative health effects of fuel combustion, and because increasing renewable generation means that vehicle electrification may provide true zero emissions transportation.

This path dependency necessarily means that other competing technologies are likely to be losers in a world where electric vehicles reach critical mass. AFVs that are fueled by natural gas or biofuels would lose out in an electrified transportation system, as the lack of refueling infrastructure would be difficult to overcome, and the comparative benefits of these vehicles

would likely be insufficient to overtake these network externalities (Bakker and van der Vooren, 2012). Because of this, policies and other positive signals towards the development of BEVs should be as strong as possible, and implemented for an appropriate period of time to prevent collapse and to ensure that BEVs do emerge as a winner technology in reducing GHG emissions in the transportation sector (Struben and Sterman, 2008).

## 5.0 Conclusions and Recommendations

### 5.1 Policy Conclusions

Many of California's current EV incentives are in line with much of the research regarding the effectiveness of such policies. California's longstanding commitment to ZEVs is demonstrated by the ZEV mandate and aggressive companion climate policies. This commitment to ZEVs has changed automaker behavior and strategies, as many car manufacturers currently offer commercially available BEV and PHEVs. In addition, the ZEV mandate has been revisited a number of times in the face of concerns about the pace of technological breakthroughs, in order to keep the demand signal realistic and achievable. For a policy with significant uncertainty, it is important that it remain flexible and malleable in the face of new information in order to successfully achieve its goals, and the ZEV mandate has shown this flexibility.

California's financial incentives for EVs are similarly in line with the findings of current research. California has implemented an income cap on eligibility for the clean vehicle rebate; individuals with an income of less than \$150,000, and households with incomes of less than \$300,000 are eligible for a rebate of up to \$2,500 after purchase of a BEV. This is in line with research that suggests that it is more effective for financial policies to target consumers with a lower willingness-to-pay for electric vehicle attributes, in order to increase both the efficiency of the policy, as well as increase the total number of EVs adopted. Additionally, California provides an increased rebate of up to \$4,500 for households that are under 300% of the poverty line which allows low and moderate income households who may value EV attributes the opportunity to purchase one.

Federal incentives are conversely fairly weak and inefficient. While the federal incentive is relatively generous in dollar amount, offering up to \$7,500 in tax credit, it is an inefficient

incentive in terms of affecting EV adoption. The tax credit is non-refundable, meaning it targets high-income earners who are more likely to owe income tax, and these high-income earners have a higher WTP for electric vehicle attributes, indicating that many do not need financial incentives in order to purchase an electric vehicle. For consumers who are eligible for both the state and federal incentives, this can offer significant savings on an electric vehicle purchase, however because of how the incentives are structured, the number of people who would be eligible for both is minimal.

California's use-based incentives are similarly strong and signal a commitment to ZEV technology. BEVs and PHEVs are allowed HOV lane access, the three major utilities serving California offer discount electricity rates for EV charging based on time of charging, and many local city governments allow free parking or free charging in some parking structures and parking lots. As the market share of EVs increases, it may be necessary to revisit these policies or examine other policies to counteract potential rebound effects such as increased vehicle miles traveled, greater traffic congestion, and other effects that could reduce the effectiveness of these incentives.

The two countries studied with the highest EV penetration both implement high vehicle registration taxes, allowing EVs to be exempted from these high costs. Because California does not already experience these high extra costs for registration or purchase, this mechanism may not be particularly achievable for California (Fridstrøm and Østli, 2017). One study concluded that a majority of Californians support an increase in registration fees and taxes for polluting vehicles and lower registration fees and taxes for clean vehicles (Agrawal et al., 2010). However, the highest tax proposed in that survey was as part of a feebate system \$2,000 USD for heavily polluting vehicles, while zero emissions vehicles would get up to a \$1,000 USD subsidy which is weaker than the savings of up to \$11,000 USD that EV owners receive in tax exemptions in Norway and the Netherlands. It is possible that a feebate system may have the same effect as a vehicle registration tax (Lindberg and Fridstrøm, 2015; Bunch et al., 2011), however the research is thin, and more research is needed before determining whether heavy vehicle registration taxes for polluting vehicles, or a steep feebate system for electric vehicles would be suitable for California, or meaningfully increase PEV adoption.

## 5.2 Policy Recommendations

Although California's EV incentives tend to align with much of the research regarding the effectiveness of policies to increase EV adoption, improvements can still be made. The ZEV mandate should be made stronger as automakers become less resistant to the production of BEVs and PHEVs. This strong demand signal is necessary in order to overcome the significant positive feedback effects and network externalities that currently benefit ICEV transport, and achieve a full transition to electrification. The mandate should be changed to promote pure ZEVs as part of this stronger mandate, such that economies of scale for BEV technology can be achieved.

Additionally, the federal incentive for plug-in vehicles should be retooled. As it stands, much of the federal subsidy for plug-in vehicles goes to high-income earners, which represents an inefficient use of government money (Borenstein and Davis, 2015). Because high-income earners tend to value electric vehicle attributes higher than lower-income earners, they are more willing to pay for more expensive BEVs. While efforts to retool this subsidy with an income cap and a progressive rate structure could provide greater efficiency, simply changing the tax credit from a non-refundable credit to a refundable credit could provide many low-to-moderate income earners the opportunity to take advantage of both state and federal incentives, which could greatly increase the number of EVs adopted. Absent a significant change to, or elimination of, the federal incentive for plug-in vehicles, California should investigate the potential benefits of providing a more generous rebate, perhaps with a progressive tiered structure. DeShazo et al.(2017) introduce a number of rebate structures which would have the effect of lowering the cost of the policy to the government, without a significant decrease in number of vehicle adopted. Policy 5 shown in Table 9 of DeShazo et al. (2017), shows that an aggressive increase of California's BEV rebate to \$5000 to all consumers who have a household income of \$100,000 or less, with an income cap of \$100,000 would have the effect of increasing BEV adoption without significantly increasing the cost of the program.

More research into the effects on steep feebates on California's vehicle market should be done in order to determine whether this would be an effective policy to encourage EV adoption. Feebates can decrease the gap in price between ICEVs and EVs by imposing a fee on ICEVs and a subsidy for EVs, but the research on the policy outcomes is currently thin, and an attempt to implement a feebate system in California previously failed to pass. The available research on

feebates is promising, and the effect achieved with such a system would be similar to many of the vehicle registration fees seen in many other European countries.

California should also pursue an aggressive campaign to finance and install electric vehicle charging stations throughout the state, and the target of 1 million recharging stations by 2020 should be met. The density of electric vehicle charging stations has as much of an impact on purchase decisions as purchase price, and having a robust charging station network could help to overcome the network advantage that ICEVs have. Additionally, visibility of these charging stations should be increased in order to familiarize consumers with EV charging technology, and increase the salience of EV technology in consumers' minds. Familiarity with EVs and associated technology can move consumers to a later stage-of-change, which makes them more likely to adopt new vehicle technologies.

Lastly, California should consider adopting programs to increase public procurement of EVs. Public procurement can increase consumer contact with EVs, and can be part of a program to enhance familiarity with electric vehicles and their attributes. These programs could also develop economies of scale as EV manufacturers gain an assured market in the public sector, increasing their ability to learn by doing.

California is the largest EV market in the United States, and contains the largest share of EVs of any state. Despite this, the EV market faces many challenges and will require significant government support in order to become a fully mature market in the face of positive feedback effects. California has a long-standing commitment to the success of the ZEV market, and as battery costs continue to fall and adoption continues to increase, California should take advantage of this renewed interest in EV technology by promoting policies that send a strong signal to the success and growth of the EV market.

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