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Maximizing societal benefits associated with alternative fuel subsidies: The Case of plug-in hybrid electric vehicles

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Maximizing Societal Benefits Associated With Alternative Fuel Subsidies: The Case of Plug-in Hybrid Electric Vehicles

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*Masters of Science
Science, Technology and Public Policy
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Graduation Requirements for the*

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Abstract

Government seeks to improve the welfare of its citizenry and intervenes in marketplaces to maximize benefits when externalities are not captured. By analyzing how welfare changes from area to area across the country in response to the same intervention informs where government should act. This thesis analyzes the case of plug-in hybrid electric vehicles (PHEVs). PHEVs have many societal benefits, including improving national security, economic, environmental, and health advantages. The magnitude and distribution of these benefits depends on where PHEVs are deployed. This thesis develops and applies a methodology to determine if the benefits from PHEV deployment vary across the country and for ranking regions where positive PHEV consequences are likely to be maximized. The metrics in this method are proxies of key variables which predict the level of benefits in a county from the deployment of a PHEV there; they include population, health benefits from reduced ozone concentration, vehicle miles traveled per capita, existence of non-federal policies, and CO₂ intensity of electricity. By shedding light on how benefits from PHEV deployment vary across counties, this thesis seeks to better inform where to enact government interventions to maximize the benefits of this technology.

Introduction

The federal government enacts policies to benefit the citizenry located across the country. However, it is not certain whether greater benefits resulting from these policies can be attained by accounting for regional and local differences between areas that are all subject to federal policy. The magnitude of these benefits is likely dependent on the issue at hand and how the costs and benefits of any policy accrue. This thesis will analyze the case for plug-in hybrid electric vehicles (PHEVs), which are being promoted as an alternative to the current petroleum-powered internal combustion engine whose usage results in problems such as health incidents, reliance on foreign sources of oil and its associated consequences, and the emission of greenhouse gases (GHG, see section 1.2). President Barack Obama has set a policy goal of deploying one million PHEVs by 2015 (*Barack Obama and Joe Biden: New Energy for America*, 2008).

The American Recovery and Reinvestment Act of 2009 modified the tax credit for qualified PHEVs such that the minimum credit for a vehicle purchase is \$2500 and increases to a maximum of \$7500 with increasing battery capacity (IRS, 2009). President Obama's goal may be more easily achievable if targeted policies were implemented instead of uniform nationwide incentives; these policies would benefit from system effects and could result in optimized benefits (Skerlos & Winebrake, 2010). There are many actions government can take in incentivizing consumers to adopt these vehicles (see section 1.3.2), but this thesis is concerned with tax subsidies offered to retail consumers to help offset the cost difference between PHEVs and conventional vehicles and how the subsidies are best distributed.

The purpose of this thesis is to understand how the societal benefits resulting from the deployment of these vehicles varies geographically across the US. Specifically, the thesis hopes to understand whether the expenditure of one dollar of subsidy results in different levels of benefits in different counties. The goals of encouraging PHEV proliferation include reducing health incidents by improving air quality, displacing petroleum consumption, and reducing GHG emissions. Furthermore, some counties have features that may accelerate PHEV adoption rates like greater accessibility of critical infrastructure to PHEV drivers and the existence of incentives for purchasing PHEVs. These goals and features can be represented by the metrics summarized in Table 1, and these metrics can be used to compare regions with regards to their suitability for PHEV deployment.

Public Benefit	Proxy Variable (by County)
<u>Energy security</u> – based on the goal of reducing consumption of petroleum in the transportation sector.	<u>Average vehicle miles traveled per capita</u> – a measure of travel demand and vehicle use for typical consumers.
<u>Climate change</u> – based on the goal of reducing emissions of GHGs.	<u>Carbon intensity of electricity production</u> – a measure of the average carbon dioxide (CO ₂) emissions per megawatt-hour (kg CO ₂ /MWh) generated.
<u>Health effects</u> – based on the goal of reducing local air pollution in order to improve human health.	<u>Health incidence reduction</u> – a measure of health incidences reduced in a county due to a one unit reduction in ozone concentrations.
<u>Market transformation</u> – based on the goal of creating a sustainable market that includes sufficient vehicle and infrastructure market development and which allows for network effects among consumers to be enhanced.	<u>Population density</u> – a measure of capita per area, under the assumption that high density counties allow for stronger network effects among consumers.
<u>Market transformation</u> – based on the goal of creating a sustainable market that facilitates greater PHEV adoption by minimizing vehicle cost to consumers	<u>Existing incentives</u> – a measure of the quantity of non-federal policies incentivizing electric vehicles

Table 1 - Key public benefits of PHEV adoption and proxy variables for ranking system

In this thesis, the counties of the US will be ranked according to metrics which include population density, health benefits from reducing pollutant levels, vehicle miles travelled, existence of non-federal policies supporting PHEV adoption, and carbon dioxide intensity of power generation [used to charge PHEVs]. This thesis seeks to understand which county will derive the greatest benefit from the deployment of a PHEV. This thesis will also investigate the analogous case of hybrid electric vehicles (HEVs) to determine if the counties that may yield the greatest level of benefits from PHEV deployment are where HEVs are currently purchased in the highest densities (assuming the early adopters of HEVs are similar to the early adopters of PHEVs). If there is not alignment between counties that offer the greatest benefits and those that have the highest HEV market penetrations, policy realignment should be considered if maximization of these benefits is the goal. This may also indicate the need to better target the PHEV subsidy scheme (discussed later in detail). The result of this analysis will guide policy makers in targeting policies and incentives towards the areas that offer the greatest benefits from PHEVs.

This thesis will begin by presenting some background information on PHEVs and their potential role in addressing the aforementioned problems of health incidents, reliance on foreign sources of oil, and the emission of GHG. The methodology of how the counties are ranked will then be introduced. How the counties score on these metrics and the final composite scores for the counties will then be presented. Finally, the implications and conclusions of the analysis will be discussed.

1 Background

1.1 PHEVs

PHEVs are hybrid vehicles whose batteries can be recharged by plugging into the electric grid, i.e. electrical energy is stored electrochemically. Like hybrid vehicles, PHEVs combine Internal Combustion Engine (ICE) propulsion with electric propulsion. However, like an electric vehicle it can operate fully from electricity supplied by the grid. Thus, a PHEV can use electricity to displace petroleum consumption. This electric drivetrain is conventionally coupled to an internal combustion drivetrain and both may power the vehicle's wheels. There is no globally optimal configuration of these powertrains at this time. Day to day driving may be powered by the electrical system, while the combustion engine could be utilized for trips longer than forty miles or whatever the range of the vehicle's battery is (Bradley & Frank, 2009).

Since PHEVs have both a battery charger and a fuel tank, they have access to both stored electrical energy from the grid and chemical energy in the form of fuel. Control of the vehicle's energy management modes can be used to manipulate the vehicle's performance, efficiency, environmental impact and cost. PHEVs are generally classified based on their energy management modes and examples of possible modes include (Bradley & Frank, 2009):

- Charge sustaining mode – The battery state-of-charge is maintained within a narrow operating band, resulting in net consumption of liquid fuel.
- Charge-depleting mode – The battery state-of-charge decreases during vehicle operation as electrical energy is consumed.
- Electrical vehicle mode – Operation of the fuel-converting engine is prohibited.
- Engine-only mode – Operation of the electric traction system is severely limited.

Battery development remains a major technological challenge for widespread adoption of PHEVs. Battery technologies considered for PHEV applications generally consist of nickel metal hydride and lithium ion chemistries. The latter is considered the leading candidate for use in PHEV applications because of their higher specific energy and power capabilities. Both chemistries are superior to lead acid batteries employed in conventional vehicles. Cycle life, durability, and cost remain among the prominent challenges preventing widespread adoption of lithium ion technology (Burke, 2007; *Overview Hearing: Gas Prices and Vehicle Technology*, 2008).

PHEVs have a parallel configuration that can operate by battery charged from the electric grid or as a traditional hybrid vehicle that burns liquid fuel, traditionally petroleum (Samaras & Meisterling, 2008). The latter gives them the same range as standard ICE vehicles; however, sixty percent of US vehicle trips could be covered by the vehicle running entirely off its battery (Samaras & Meisterling, 2008). Running the vehicle entirely off electricity would have the secondary desired consequence of displacing the consumption of gasoline. Studies indicate that 34-73% of light duty vehicles (LDVs) could be supported as PHEVs from the current power infrastructure (Kintner-Meyer, Schneider, & Pratt, 2006; Stephan & Sullivan, 2008). Although these vehicles can be charged with the standard 120 volt electrical outlets, most households may not have the

capability to charge PHEVs (especially those that live in houses without garages or in apartments). Using 240 volt outlets would significantly reduce charging times, but this would require consumers incurring additional costs in installing or upgrading existing outlets (Langfitt, 2009; Samaras, 2008).

1.2 Potential Benefits of PHEVs

1.2.1 Reduced Health Impacts/Ozone

The use of PHEVs results in reduced emissions of air pollutants and improved local air quality as a result compared to conventional ICEs (Skerlos & Winebrake, 2010).

Utilization of PHEVs has the potential to reduce ozone, particulate matter concentrations (except in areas near polluting power plants), and volatile organic compounds and nitrogen oxides (reductions of both result in less secondary particulate matter) (EPRI & NRDC, 2007). The Environmental Protection Agency (EPA) defines an incident as an adverse health effect resulting from exposure to a pollutant

(<http://www.epa.gov/oaqps001/benmap/models/BenMapManualSept08.pdf>). Human exposure to sufficiently high levels of these pollutants may result in increased rates of health incidences. The effect on incidence rate due to a decrease in a unit of emissions is a function of overall pollutant levels and the size of the population and population exposed to the pollutant (Skerlos & Winebrake, 2010).

1.2.2 Increased Energy Security

By charging vehicles from the grid instead of fueling vehicles with petroleum, utilization of PHEVs results in reduced petroleum consumption. The transportation sector accounts for 70% of petroleum consumption and the US imports approximately 66% of its petroleum consumption (EIA, 2009). These imports contribute to the United States' growing trade deficit. As a result of this dependency on imported oil, the US is in relations with politically unstable nations and is competing with many emerging oil-consuming countries in the search for new resources (Deutch & Schlesinger, 2006). Furthermore, the US is confronted with the risk of economic fallout that would occur if the petroleum supplying nations, especially OPEC, significantly decreased or halted exports. This dramatic fall in oil supply would considerably increase oil prices and disrupt economic activity throughout the US (Crane et al., 2009). Since the US imports the majority of its petroleum, reduced consumption would result in increased energy security; this benefit would be shared nationally (Skerlos & Winebrake, 2010). Furthermore, the fueling cost per mile of PHEVs are a third of the cost of fueling a standard gasoline vehicle (Romm, 2006).

1.2.3 Reduced GHG Emissions

The UN Intergovernmental Panel on Climate Change (IPCC) warns that global temperature increases of more than one to five degrees Celsius from 1990 due to anthropogenic GHG emissions increase the risk of extreme climate events and their negative consequences (Bernstein et al., 2007; McCarthy, Canziani, Leary, Dokken, & White, 2001). According to the IPCC, GHG emissions must be reduced to 50-85% of 2000 levels by 2050 to stabilize temperatures (Bernstein, et al., 2007). LDVs account for

60% of transportation emissions and 17% of US emissions overall (Samaras & Meisterling, 2008). In the US, petroleum fueled 94% of the transportation sector (EIA, 2010). This sector saw the fastest growth of any in CO₂ emissions (EPA, 2010; Romm, 2006).

Charging PHEVs from the electric grid displaces GHG emissions from the vehicle engine to the grid. If PHEVs charge from generating plants that have an expected portfolio of energy sources, including coal, there is the potential to reduce emissions by 25% in the short term and over 50% in the long term compared to conventional hybrid vehicles; however, these emissions reductions are conditional upon the carbon intensity of future electricity generation portfolios and the efficiency of the vehicles being replaced (Samaras & Meisterling, 2008; Stephan & Sullivan, 2008). Hybrid vehicles reduce GHG emissions 30 – 50% compared to conventional vehicles (Romm, 2006).

1.3 The Science, Technology, and Policy Issue

1.3.1 Intersection of technology, business, the economy, the environment, and government

Reducing petroleum consumption by utilizing PHEVs is at the intersection of technology, business, the economy, the environment, and government. The mass commercialization of PHEVs is contingent upon advances in technology, especially in battery storage of power. Energy density needs to increase and cost needs to decrease to meet long-term goals for PHEV development. As mentioned earlier, cycle life and durability are anticipated challenges for battery technology. Automotive manufacturing competitiveness hinges on battery manufacturing capability and US companies have not focused on this front as have manufacturers in Japan, China, Korea, and Germany. To minimize the time required to recover the cost of a more expensive battery through fuel cost savings, battery costs will need to come down; this can be accelerated through government policies and government-supported research (Burke, 2007; *Overview Hearing: Gas Prices and Vehicle Technology*, 2008). As mentioned previously, many households do not have the infrastructure necessary to charge these vehicles (Langfitt, 2009; Samaras, 2008).

Fostering a climate conducive to the adoption of a new generation of vehicle requires the proper combination of market and policy conditions. The government's role entails protecting the health of its populace and the environment, since the marketplace is not wholly incentivized to do this. Government thus has a role to play in mitigating the effects of global warming. As PHEVs could play a role in reducing GHG emissions, government actions to curtail these emissions would effectively promote sales of PHEVs.

Aside from the environmental reasons, government has other motivations to reduce the technological and market hurdles to PHEV adoption. These include seeking energy independence and reducing the trade deficit resulting from importing petroleum, increasing national security, counteracting the effects of the credit crunch/financial crisis on investment monies to develop/deploy new technologies, and stimulating the economy by creating jobs and laying infrastructure to reduce business' costs.

1.3.2 Possible policy approaches

The government can take several courses of action to spur adoption of PHEVs by addressing the barriers that limit consumer adoption. Government can purchase fleets of vehicles to give companies a steady customer base as they increase economies of scale and lower costs; open new market directions (i.e. PHEV vans); collaborate with the private sector in conducting technology research; provide tax breaks/subsidies/rebates to incentivize PHEV production and/or consumption; and develop regulatory schemes – cap and trade, carbon tax, fuel initiatives, etc. to discourage petroleum consumption.

Government can also take action on increasing charging capabilities for consumers. As Langfitt points out, not all households have garages and charging capabilities (Langfitt, 2009). Without this necessary infrastructure, a large segment of the population will not be able to take advantage of the low operating costs of driving PHEVs in all-electric mode. Government could invest in the electric grid and in building electric outlets at buildings and complexes that do not have charging capabilities.

Table 2 below summarizes the major barriers to market share for PHEVs and possible policy actions to address them. The list is not all-inclusive.

Table 2 - Barriers to widespread consumer adoption of PHEVs

Barrier	Policy action
Battery capacity and performance	Increased federal R&D Increased research grants for non-federal entities
Cost of battery/vehicle	Increased consumer tax rebate/subsidy Increased carbon/fuel tax Cap and trade scheme that attributes cost to GHG emissions
Lack of charging infrastructure	Tax rebates/subsidies for consumer installation Phased in government mandate for installation of charging infrastructure

1.3.3 Policy goals

Many justifications exist for government action/inaction: equity, efficiency, security, liberty, and community (Stone, 2002). The reasons for justifying the proliferation of PHEVs may best fall under “security”, be it protecting citizens’ health, protecting the environment, maintaining economic stability, or maintaining national security. The aforementioned goals may also form the basis of judging enacted policies.

1.3.3.1 Maximizing social benefits

Regardless of where social benefits occur, the magnitude of total social benefits from PHEV usage is a function of where the PHEVs are used (Skerlos & Winebrake, 2010). The regional factors that impact the magnitude of PHEV benefits include:

1. population and population distribution
2. response of local population to changes in air quality

3. the location and amount of vehicle miles traveled (VMT)
4. synergies arising from complementary PHEV incentives
5. the efficiency, emissions, and accessibility of the of the electricity used for PHEV charging

As these factors are sufficiently heterogeneous across the country, targeting PHEV subsidies to consumers in locations where they are most favorable can significantly increase social benefits for the entire nation (Skerlos & Winebrake, 2010) while using public monies in a more efficient manner.

An alternative to the existing tax credit that *every US consumer has the equal opportunity to take advantage of* may include offering significantly larger credits to areas featuring higher net benefits of PHEV usage and reduced credits in regions of low net benefits. This tax credit reformulation considering regional heterogeneity could increase the net social benefits of PHEV adoption; furthermore, the effectiveness of subsidies aimed to accelerate PHEV diffusion will vary based on heterogeneity in consumer preference, demographics, network effects, and complementary policies at the state and local level (Skerlos & Winebrake, 2010).

1.3.3.2 Equity versus maximum welfare

Transportation and energy are certainly not the first fields where budget constraints have affected the provision of services. In health care, cost-effectiveness analysis is suggested to demonstrate how to maximize benefits attainable within a defined budget (Ubel, DeKay, Baron, & Asch, 1996). However, cost-effectiveness analysis has been criticized for resulting in policies that violate people's values as equity is not considered in these analyses. To continue with a health care example, suppose that there are two tests to screen a population for cancer. Test 1 can screen an entire population and prevent 1000 deaths; however, Test 2 can screen only half the population at the same total cost but result in preventing 1100 deaths. If there was enough money to screen the entire population with Test 2, 2200 deaths would be prevented. Even though Test 2 would result with a greater health benefit even with screening only half the population, it is considered less equitable because every member of the population cannot be screened.

The challenge is weighing the social equity of the current system against the greater benefits of a targeted approach. Some argue that equity is the greater good. For example, noted political philosopher John Rawls (1971) once stated that "[e]ach person possesses an inviolability founded on justice that even the welfare of society as a whole cannot override. For this reason justice denies that the loss of freedom for some is made right by a greater good shared by others." In "classical welfare theory", maximal social welfare is a function of equitable distribution of benefits as well as efficiency (Birdsall & James, 1993). However, according to "public choice theory", government "agents" seek to maximize individual utility over social welfare (Birdsall & James, 1993).

However, targeting PHEV subsidies may result in much greater social benefits and higher adoption rates of these vehicles compared to the existing subsidy regime (Skerlos & Winebrake, 2010). In the concept of Pareto efficiency, the welfare of an individual is improved without compromising the welfare of another. However, Skerlos and

Winebrake argue that although PHEV subsidies would be limited to certain geographic areas, social benefits would accrue to society at large. Thus, everyone's welfare is improved and a targeted subsidy regime achieves some measure of equity and efficient distribution of benefits.

In any situation where the distribution of resources is at stake, different stakeholders have different visions of what is equitable (Stone, 2002). Any distributions have three dimensions to be defined: the recipients, the item to be distributed, and the distributor/process for determining and executing the distribution. In the case of the recipients, this thesis defines them as citizens of a county. In the case of the distribution process, every US citizen has access to the vehicle subsidy which is distributed by the government. Even though the end distribution is not uniform, the process itself could be considered equitable. Furthermore, considering local/regional characteristics that maximize social benefits may be considered without contradicting equity, since the goal of equity is not necessarily absolute equity.

In the case of PHEV incentives, the item to be distributed is total subsidy dollars in the form of tax rebates. Thus, the government distributes tax rebates to purchasers of PHEVs wherever they live in the country. This is analogous to the distribution of tax rebates to the purchasers of HEVs. Some parts of the country have higher rate of HEV purchase than others and receive more tax rebates than areas where less HEVs are purchased. Thus, even though all taxpayers across the country are contributing to the pool of money used to pay out tax rebates, only purchasers of HEVs receive these rebates. The rate of HEV ownership per 10,000 people is illustrated in Figure 1. This map illustrates how the distribution of hybrid electric, and by extension their subsidies, are not distributed uniformly across the US. There are many states that have no HEVs (colored white in Figure 1) although their citizens pay the same tax rates as citizens of states with higher concentrations of HEV ownership; see below:

Figure 1 - HEV density across the Lower 48

Contrast the goal of equity with efficiency. Skerlos and Winebrake (2010) posit that the social benefits of PHEV deployment could be maximized if the subsidy regimes are more targeted to the areas that yield the greatest social benefit. Efficiency can loosely be defined as “getting the most output for a given input” (Stone, 2002). Regions that grade highest in the metrics described in the subsequent methodology section would yield the greatest social benefit. Many of these benefits would be shared by everyone, including people that do not purchase PHEVs; thus, maximizing these benefits is considered the greater good. The goal of this thesis is not to develop a new formulation of PHEV subsidy regimes, i.e. to scrap an “equitable” scheme to one that is maximally efficient, as such a regime would likely not pass political muster. However, it may be worthwhile to compare the value of incremental efficiency versus the value of incremental equity in the context of societal benefits. An incremental increase in efficiency does not violate the principle of Pareto optimality (policies cannot leave anyone worse off) and is in line with the notion of utilitarianism (maximizing overall utility) (Nagel, 1984). In the context of Pareto optimality, an area that has subsidies diverted away from it may end up having fewer or no PHEVs at some point in the future under a more targeted policy regime than under the current policy scheme. One hand, that area is still no worse off than in its current situation since policy that moves already deployed PHEVs to other areas that may yield greater social benefits is not under consideration. On the other hand, an area that

has subsidies diverted from it still is paying the same amount in taxes and will not realize the local (especially health) benefits that would have resulted from PHEV deployment.

1.3.4 Use of policy to solve a problem

1.3.4.1 Tax rebates and hybrid vehicles

The Energy Policy Act of 2005 offered a credit to taxpayers who purchased “Qualified Hybrid vehicles” (IRS, 2007). These credits would be phased out after a manufacturer sold 60,000 qualifying vehicles. Numerous studies have been conducted on the effect of tax incentives on HEV sales. Beresteanu and Li (2009) report that the tax credit explains 20% of hybrid vehicle sales in 2006 and that consumers capture the majority of the benefit from the tax rebate. Using new vehicle sales data that includes model and city sales data, the authors of this study develop a logit model whose purpose is to simulate the effect of changing various variables on the sales of individual vehicle models. The authors find that gas price has a large effect on HEV sales and that federal tax incentives also significantly affect HEV adoption. They find that the size of the incentive matters and that the tax rebate is much more effective at stimulating sales than the tax deductions the rebates replaced.

In another study, Boyle and Matheson (2008) come to a different conclusion; they find that manufacturers accrue the majority of the benefit of the tax credit as a subsidy and that early adoption of HEVs is due primarily to non-economic reasons. The authors acknowledge that the average HEV subsidy does result in 27-32% greater sales. The authors develop a regression model to determine the impact of tax credits on HEV prices. They conclude that despite the manufacturers capturing the majority of the benefit from tax credits, the credits still spur HEV sales.

Sallee (2008) studies the incidence of federal and state tax incentives on Toyota Prius sales. He analyzes sales trends versus changes in incentives (and versus incentive non-events) to determine whether the consumer or the producer captures the benefit. He concludes that consumers capture all the benefit of these incentives and that state tax incentives have little or no effect on transaction prices. Sallee observes that the federal tax credit introduced sharp changes in the value of a subsidy whose dates were announced in advance, inducing a timing response in consumers. He also notes that sales volume is affected by seasonal variations, gas prices, and dealer incentives. Sallee concludes that he cannot distinguish between total sales effects and incentive timing effects.

In another study, Diamond (2009) discusses the limits of using a national time series in analyzing HEV sales and isolates all the variables. He employs a cross-sectional analysis of hybrid registration data over time from US states to test how several socioeconomic and policy variables affect hybrid vehicle adoption rates. This allows Diamond to examine how differences in incentive schemes influence their efficacy. Literature he examines notes that cost savings and the “green image” of a vehicle influence purchase decisions. Diamond also found that HEV purchasers have higher incomes and are more sensitive to gas prices than environmental benefits. He notes that it is difficult to isolate

the effect of government incentives as the market share of HEVs have increased over time before and after the introduction of tax credits. Diamond concludes that gas price, vehicle miles travelled (VMT) for a jurisdiction, and state environmentalism (measured by the Green Planning Capacity Index) had the largest effect on market share. He also concludes that producers reap the benefits of tax incentives, not the consumer.

1.3.4.2 Fleet adoption of alternative fuel vehicles

The Energy Policy Act of 1992 (EPA 1992) requires 75% of all Federal fleet light duty vehicle (LDV) acquisitions capable of being centrally fueled and primarily operated in a metropolitan statistical area (MSA) be alternative fuel vehicles (AFVs) (USDA, 2009). Exemptions exist under certain conditions and “Biodiesel credits” may partially fulfill an agency’s EPA requirements. The Energy Policy Act of 2005 (EPA 2005) requires that all AFVs actually be fueled with alternative fuel.

Executive Order 13423, Strengthening Federal Environmental, Energy, and Transportation Management, seeks to reduce petroleum consumption in fleet vehicles by 2% annually through 2015 and increase alternative fuel consumption at least 10% annually. Executive Order 13423 also directs agencies to begin purchasing plug-in hybrids once they are reasonably comparable on a life-cycle economic cost basis with conventional vehicles (GAO, June 9, 2009).

The General Services Administration (GSA) will buy and deliver \$300 million worth of energy-efficient and alternative fuel vehicles using funds from the American Recovery and Reinvestment Act (ARRA) (GSA, 2009). GSA will spend about \$285 million for 17,600 commercially available fuel-efficient vehicles, which includes 2,500 hybrid sedans. GSA will also dedicate \$15 million to pilot advanced technology vehicles in their fleet. Pilot programs will focus on commercially available compressed natural gas and hybrid buses and all-electric vehicles.

Lin, et al, (2008) examine the long term emissions reductions of a vehicle fleet replacement plan in Illinois. They note that government fleets are ideal for upgrading to alternative fuel technologies since they have on average higher annual mileage than household vehicles and they operate one third of the truck population, which has even higher annual mileage. Compared to privately owned vehicles, government fleets are more politically compliant, and emissions savings are more easily harnessed since fuel efficiency is a function of maintenance and driving habits. Thus, targeting this group of vehicles may prove more cost-effective than household vehicles.

Haller, et al, (May 2007) found that although a Forest Preserve program has been able to convert 50% of their fleet to bi-fuel vehicles, it has been more difficult to attain cost savings and emissions reductions. Much of this can be attributed to the elimination or significant delay of anticipated grant programs for installing fueling stations and other related infrastructure. Inconvenient refueling processes may substantially reduce driver use of the bi-fuel, and use of gasoline reduces cost effectiveness and emission reductions.

The GAO (GAO, June 9, 2009) found that agencies must meet a number of requirements covering energy use and vehicle acquisition that sometimes conflict with one another, like reducing facility energy consumption and using electricity to charge an electric vehicle. Furthermore, the GAO notes that data from 2006 indicate that agencies primarily fueled their AFVs with gasoline, not alternative fuel, and GAO analysis found no evidence that this changed in 2007. Agencies will likely find it more difficult to meet both the requirement to fuel AFVs only with alternative fuel and the goal of increasing overall alternative fuel use by 10 percent annually because of the limited availability of alternative fuel.

All federal agencies reported meeting or exceeding the requirement to acquire AFVs (GAO, October 22, 2008). However, they received some credit for AFVs not subject to the requirement, as allowed by Department of Energy's (DOE) implementing guidance. DOE's implementation of Executive Order 13423 is ambiguous regarding these credits; this leaves the incorrect impression that agencies are greatly exceeding requirements. While neither the DOE nor the agencies reported whether they were in compliance with the requirement to use only alternative fuel in AFVs, data from 2006 indicate that agencies primarily fueled their AFVs with gasoline instead of alternative fuel. GAO analysis found no evidence that this changed in 2007, and collectively agencies fueled their AFVs with alternative fuel only about 7 percent of the time. Roughly half of the agencies reported increasing their alternative fuel use by 10 percent and about two-thirds reported reducing petroleum use by 2 percent in 2007; however, persistent data problems call these results into question.

1.3.5 Examples of federalized national policy

The following examples illustrate that government has enacted policies that take into account local and regional considerations to improve the efficacy of the policies and optimize the distribution of benefits. These examples indicate that a "one size fits all" national policy is not always the best way to maximize welfare and may help inform the case of PHEV subsidy schemes.

As part of the ARRA, the Race to the Top Fund was created (ED, 2009). This was a grant program for states to compete with each other on the basis of creating the conditions for education innovation and reform, achieving significant improvement in student outcomes, and implementing ambitious plans in core education reform areas. States that won the awards received federal money even though education is largely funded and managed at state and local levels. This program is a direct example of comparing regions, in this case states, to determine which regions are better suited to produce benefits from federal spending.

The "Violence against Women and Department of Justice Reauthorization Act of 2005 (HR 3402, "Chapter 2 -- Building Community Capacity to Prevent, Reduce, and Control Crime" - <http://thomas.loc.gov/>) established the Office of Weed and Seed Strategies. The US Congress appropriated funds to assist various levels of government and other organizations to prevent, reduce, and control crime. To receive assistance in the form of strategy development and grants, communities must be certified by the encompassing

district's United States Attorney to several conditions regarding the level of crime and probability of improving the criminal justice system.

The federal highway system is under the jurisdiction of various highway programs; thus, various formulas apply to how money is distributed to pay for this infrastructure. This results in some states paying more into the Highway Trust Fund than they receive in benefits. For example, the Surface Transportation Program uses total lane miles of federal aid highways, total vehicle miles traveled on federal aid highways, and a state's share of trust fund tax payments to determine each state's apportionment (Utt, 2008). Furthermore, the Safe, Accountable, Flexible, Efficient Transportation Equity Act has numerous formulas to apportion funds to various geographic areas

(http://frwebgate.access.gpo.gov/cgi-bin/getdoc.cgi?dbname=109_cong_bills&docid=f:h3enr.txt.pdf).

1.4 Examples of ranking systems

In this thesis, not only are regional variations considered in tailoring policy to maximize the benefits from PHEV deployment, but these variations are used to rank these regions (counties) to determine which counties would likely produce the highest level of benefits. Ranking geographic areas or localities is not a novel concept.

- In fact, Forbes recently published an article where the best cities for singles are scored and ranked (Sherman, 2009). Their methodology involved ranking metropolitan areas in several categories based on quantitative data and weighing the categories equally. The total of the ranks then determined the final rankings.
- In a similar vein, the *Doing Business* project recently ranked national economies on their ease of doing business from 1 to 183 (DB, 2009). The overall ranking for an economy is based on rankings in ten topics, which are made of a variety of indicators. These indicators are used to compare an economy to other economy and rank them comparatively within this topic. The rankings in the ten topics are weighted equally and the overall ranking is based on the economies' average ranking.
- In the previous two examples, the categories used to determine the final ranking are weighted equally. A recent comparison test conducted by *Road and Track* compared several new vehicles to find the best production drift vehicle (Mitani, 2009). The final ranking was based on giving equal weight to performance scores and subjective scores; however, the performance and subjective scores are calculated from the sum of several metrics which are each weighted differently. Thus, each metric is a normalized score based on the weight of that metric. For example, the overall score is out of 200 possible points. Of that, a vehicle may score up to 50 points based on its normalized speed during the performance test but only up to 5 points based on the feel of the brake pedal during the test. Thus speed is weighted much more heavily than brake pedal feel in the overall score, and the final ranking is based on the overall score of each vehicle.

- In more scholarly literature, Florida and Gates (2001) analyzed measures of tolerance and diversity in fifty metropolitan areas to determine if they resulted in high-technology success in those areas. For these metropolitan areas, Florida and Gates examined the number of college graduates, concentration of gay residents, concentration of “bohemians”, and concentration of foreign-born residents as predictors of high technology success. The rankings of these metropolitan areas on these metrics are compared to how these areas rank in high technology success.
- Researchers at Harvard’s Kennedy School of Government have developed the Ibrahim Index of African Governance (Rotberg, Spring/Summer 2009). This Index evaluates sub-Saharan African nations on governance and leadership according to fifty seven metrics. These metrics are categorized into five categories of political goods that measure governance that include safety and security; rule of law, transparency, and corruption; participation and human rights; sustainable economic development; and human development.

2 Methodology

The goal of this thesis is to rank counties based on a set of metrics that proxy the key benefits of PHEV use. The nation’s counties will be scored on the following metrics explained in section 2.1: population density, health incidents reduced due to reduced ground level ozone emissions, VMT per capita, the existence of non-federal PHEV incentives, and CO₂ emitted per unit power generated. Data were consistently available only for the lower 48 states, so counties from Alaska and Hawaii were not considered. A scoring methodology, explained in detail in section 2.2, will use these metrics to develop a composite score to rank the counties. Section 3.5 introduces the sensitivity analyses that will be conducted on the composite score calculation. Section 2.3 introduces the question of whether early adoption of PHEVs will occur in areas where they would yield the greatest benefits and the analogous case of hybrid vehicle adoption.

2.1 Metrics

2.1.1 Population density (market transformation)

Another goal of market subsidies for alternative fuel vehicles is to help stimulate larger scale market adoption of these technologies (Leiby & Rubin, 2001). This market transformation effect is particularly important where complementary goods, such as alternative fuel vehicles and their supporting infrastructure (i.e., refueling stations and service facilities), create network effects that can help or hinder market development (Meyer & Winebrake, 2009; Sterman, 2000; Winebrake & Farrell, 1997). Given the geographic nature of fuel and service access, these network effects may be stronger in locations with greater population densities (Meyer & Winebrake, 2009; Winebrake & Farrell, 1997). In addition, larger population densities allow for the “neighborhood effect” to take place, whereby the probability of adoption of a new technology by one consumer is influenced if a “neighbor” (someone the consumer interacts with regularly) also has adopted the technology (Skerlos & Winebrake, 2010; Sterman, 2000). Indeed,

this effect has been demonstrated for conventional HEVs (Mau, Eyzaguirre, Jaccard, Collins-Dodd, & Tiedemann, 2008). We call this metric *market transformation*, and we use population density by county from the U.S. Census Bureau as a proxy for its effect (Census, 2009).

2.1.2 Reduction in health incidents due to reduced ozone emissions

Since the power used to charge PHEVs will be derived from a grid that is powered by point sources of pollution generation that is often removed from population centers, the use of these vehicles will result in less exposure by a county's population to pollutants that result in respiratory ailments (Sillman, 1999). Replacement of a conventional vehicle with a PHEV charged from the grid will result in population centers having lower exposure to ozone and other pollutants created by the combustion of petroleum (EPRI & NRDC, 2007). Skerlos and Winebrake (2010) point out that a one unit reduction in pollutant concentrations in an area of high pollution with a large exposed population would provide greater health benefits from PHEV deployment compared to areas with lower population and/or smaller exposed populations. *Thus, counties with the greatest reduction in health incidents due to reduced pollutant emissions are desirable for PHEV deployment to maximize health benefits.*

The EPA (<http://www.epa.gov/air/benmap/models/BenMapManualSept08.pdf>) defines incidences as any "adverse health effects" that include mortality and morbidity incidences. Therefore, another metric this thesis applies is based on the reduction in health incidences (i.e. hospitalizations, illnesses, or death), due to reductions in pollutant levels. This metric will quantify how many health incidents due to high pollutant levels can be reduced in a county by reducing the concentration level of ozone by one part per billion (ppb). However, reducing ozone concentration levels by one ppb in a county is a function of county size and local weather patterns. Specifically, the introduction of one PHEV in a county will not reduce ozone concentrations in every county by the same amount. Ideally, the metric would quantify how many health incidents could be reduced by removing a finite amount of ozone but this data is not readily available.

One source of ozone precursors include tailpipe emissions resulting from combustion (Sillman, 1999). Since tailpipe emissions occur near population centers while pollution from fossil fuel power generation occurs away from population centers, the use of PHEVs will result in less people exposed to pollutants like ozone. Thus, ozone health effects are a proxy of health benefits from cleaner air resulting from PHEV deployment. If power generation comes from sources that emit fewer pollutants, the cumulative creation of ozone is further reduced. The US EPA has developed a tool called Environmental Benefits Mapping and Analysis Program (BenMAP - <http://www.epa.gov/air/benmap/>) to determine how changes in pollutant levels across the country at many subdivisions including county affects the number of health incidents.

2.1.3 Vehicle miles traveled per capita (energy security)

One of the aforementioned benefits of PHEV usage is the displacement of petroleum consumption. However, data quantifying per vehicle petroleum consumption by county is not readily available, so per capita VMT by county will be used as a proxy for energy

security. Since the point of this analysis is to determine where the deployment of a single PHEV would yield the greatest societal benefit, a better metric to use would be VMT per vehicle. However, vehicle ownership data at the county level was not readily available and VMT per capita will have to serve as a proxy. This, in turn, is a proxy for petroleum consumption displaced since higher VMT results in higher petroleum consumption; however, this does not account for differences in vehicle characteristics. For the sake of simplicity, each vehicle mile traveled will be considered equal. It is desirable for PHEVs to be utilized by people that travel the highest number of vehicle miles to maximize the vehicle's social benefits. Those that travel the most miles consume the most petroleum and if these consumers utilized PHEVs charged from the grid, the greatest reduction in petroleum consumption would occur. As Skerlos and Winebrake (2010) note, highly congested regions can be considered high leverage in terms of the nature of its VMT. *Thus, counties with the greatest VMT per capita are desirable for PHEV deployment to maximize their social benefits.*

VMT per capita was calculated by dividing the vehicle miles traveled in a county in 2006 by the county's population in that year; VMT data was obtained from the Environmental Protection Agency

(http://www.epa.gov/pmdesignations/2006standards/final/TSD/tsd_J_county_vmt_data.pdf) while the population data came from Census data (see previous population density discussion). Laurel Driver at the EPA indicated that VMT data is based on state and some county data; since most county data was not available, the EPA estimated county VMT based on state mileage and the proportion of a state's road that a county has. EPA does not distinguish miles between the vehicle classes or whether vehicle trips start and end in the jurisdiction in question. An issue with using VMT per capita is that many vehicle miles occur in counties other than the county where the vehicle is owned. Thus, incentivizing PHEV deployment in counties where the highest VMT are may be ineffective if the vehicles are registered in adjacent counties.

2.1.4 Existence of complementary state and local policies

Since PHEVs will be more expensive than their conventional engine variant, consumers must be incentivized to accelerate their adoption. Even though PHEVs are not widely available on US markets, government incentives have been offered at all levels of government from local to national. Maximal incentives will occur where incentives are offered at multiple levels of government within a county. However, Skerlos and Winebrake (2010) note that there may be a diminishing return on a federal subsidy that rests on top of other subsidies for affluent consumers. This is not the case for lower income consumers and is not considered in the analysis. Since the federal incentive detailed in the ARRA is offered uniformly across the US, the magnitude of incentives will vary across counties based on the availability of state and local incentives. *Thus, counties with the greatest number of PHEV incentives are desirable to most rapidly accelerate adoption of these vehicles.*

The Alternative Fuels and Advanced Fuels Vehicle Data Center within the Department of Energy maintains a database of incentives and laws that encourage adoption of these vehicles (<http://www.afdc.energy.gov/afdc/laws/matrix/tech>). This database was used to

determine the total number of policies applied to a county. State-wide policies applied to all counties in that state. City policies applied to all counties within that city's Metropolitan Statistical Area (MSA). The existence of a policy added to a county's total; policies were not compared to or weighed against each other in terms of effectiveness in determining the county's total in the name of expediency. Federal policies, for example, ranged from tax credits for the purchase of PHEVs to research funding to fleet vehicle adoption requirements. Furthermore, incentives offered by electric utilities, which stand to see more consumption of their product, were not considered.

2.1.5 Carbon intensity of power generation (greenhouse gas mitigation)

Although there are social benefits obtained from charging PHEVs from the grid, the greatest environmental benefits from PHEV use occur when the vehicles are charged from a grid that is supplied by power that produces the least pollution (Moyer, 2010; Samaras & Meisterling, 2008; Stephan & Sullivan, 2008). If the electricity used to charge a PHEV results in high level of pollution emissions, PHEV deployment merely replaces pollution from petroleum consumption with pollution from power generation. *Thus, counties with the lowest CO₂ emitted per unit power generated are desirable for PHEV deployment to maximize their environmental benefits.*

The mass of CO₂ emitted per unit power generated (carbon intensity) is a measure of how polluting a county's power generation is. Carbon intensity estimate (kgCO₂/MWh) was employed as a proxy for this metric. This was calculated by dividing the metric tons of CO₂ emitted by a state's power sector by the megawatthours of electricity generated by the state in 2008. The carbon intensity is calculated using a top-down approach by dividing the metric tons of CO₂ emitted by a state's power sector by the MWh of electricity generated by the state in 2008, as reported by the U.S. Department of Energy (http://www.eia.doe.gov/cneaf/electricity/epa/epa_sprdshts.html). However, these data are only available at the state level and will have to suffice for use in scoring counties as policies and regulation of power generation is generally developed at the state level. Thus, all counties within a state will have the same carbon dioxide intensity even though this does not reflect reality. Furthermore, as Skerlos and Winebrake (2010) note, measuring the carbon intensity of the electricity used to charge a PHEV is complicated by the use of different energy sources for providing base-load, load-following, and peak load power. This metric therefore averages out any particular "time-of-day" charging patterns that may develop once PHEVs fully penetrate the market. Seasonal variations of VMT that may correlate with seasonal variations in electricity generation emissions are not considered due to a lack of data.

The EIA data is based on average emissions and was used as a proxy. However, states are not self-sufficient in generating electricity. Some states generate much more power than they use and other states are reliant on electricity imports from these states. Based on data from the EIA (<http://www.eia.doe.gov/cneaf/electricity/epa/fig2p1.html>, <http://www.eia.doe.gov/cneaf/electricity/epa/fig7p2.html>), 99% of the electricity used to power the District of Columbia is generated outside the District. For states that "import" large quantities of electricity, this metric may not accurately capture the carbon intensity of the power generated outside of the state in question. The United States as a whole is a

net importer of power with most trade occurring with Canada for hydroelectric power. California imports some power from Mexico, as well (http://www.eia.doe.gov/cneaf/electricity/epa/epa_sum.html).

Table 3 below presents how much of a state's electricity consumption is imported (negative value indicates electricity exported). "Total retail sales of electricity" in the table represents power consumption.

Table 3 - Percent electricity consumption imported

State	Net Generation (GWh)	Total Retail Sales (GWh)	Import	Percent consumption Imported	State	Net Generation (GWh)	Total Retail Sales (GWh)	Import	Percent consumption Imported
WY	46,500	16,690	-29,810	-	MO	91,000	84,382	-6,618	-
WV	91,100	34,221	-56,879	-	AK	6,800	6,325	-475	-
ND	32,700	12,416	-20,284	-	KY	97,900	93,428	-4,472	-
NH	22,900	10,977	-11,923	-	CO	53,400	52,142	-1,258	-
MT	29,600	15,326	-14,274	-	MS	48,200	47,721	-479	-
NM	37,000	22,038	-14,962	-	GA	136,200	135,174	-1,026	-
UT	46,600	28,192	-18,408	-	NV	35,100	35,192	92	0
AL	145,900	89,707	-56,193	-	CT	30,400	30,957	557	2
AZ	119,500	76,268	-43,232	-	NY	140,300	144,053	3,753	3
PA	222,400	150,401	-71,999	-	FL	219,600	226,173	6,573	3
ME	17,100	11,674	-5,426	-	NC	125,200	130,054	4,854	4
IL	199,500	144,620	-54,880	-	OH	153,400	159,389	5,989	4
OK	76,300	56,279	-20,021	-	RI	7,400	7,819	419	5
WA	110,800	87,333	-23,467	-	WI	63,500	70,122	6,622	9
SC	101,000	80,651	-20,349	-	TN	90,700	104,170	13,470	13
IN	129,500	106,981	-22,519	-	MN	54,800	68,792	13,992	20
AR	55,100	46,135	-8,965	-	NJ	63,700	80,520	16,820	21
OR	58,700	49,187	-9,513	-	CA	208,000	268,155	60,155	22
VT	6,800	5,741	-1,059	-	MA	42,500	55,884	13,384	24
KS	46,600	39,516	-7,084	-	MD	47,400	63,326	15,926	25
LA	92,500	78,722	-13,778	-	VA	72,700	110,106	37,406	34
IA	53,100	45,488	-7,612	-	SD	7,100	10,974	3,874	35
TX	404,800	347,059	-57,741	-	DE	7,500	11,749	4,249	36
NE	32,400	28,811	-3,589	-	ID	12,000	23,901	11,901	50
HI	11,400	10,390	-1,010	-	DC	100	11,851	11,751	99

2.2 Scoring system

The aforementioned metrics are used to compute the composite county score. The data for each metric was all normalized so that the county calculation could be made. When the maximization of the metric measuring the attribute is desirable, the normalized score, $n_{i,j}$, is based on the difference between the attribute value ($a_{i,j}$) for the county j and the maximum attribute value for all counties for attribute i ($a_{i,max}$), divided by the difference between $a_{i,max}$ and the minimum attribute value for all counties for attribute i ($a_{i,min}$). This is shown as:

$$n_{i,j} = \frac{a_{i,j} - a_{i,min}}{a_{i,max} - a_{i,min}}$$

Otherwise, if the minimization of the metric is desirable (i.e. carbon intensity of electricity generation), the equation follows the form:

$$n_{i,j} = \frac{a_{i,max} - a_{i,j}}{a_{i,max} - a_{i,min}}$$

This will ensure that the above metrics ($n_{i,j}$) will be normalized from zero to one with the highest scores corresponding to greater social benefits from PHEV use. The variable, i , refers to each metric while n refers to the normalized score. The benefits described above have varying level of importance and the benefits' relative importance is subjective. Thus, the scoring system will include relative weights (w_i) that rank these attributes against each other and these will be used to calculate a final weighted score for the county. The weights will be equal for all of the metrics in the base case. In all cases, the weights of the attributes will sum to one.

$$\sum_{i=1}^5 w_i = 1$$

The sum of the respective product of weights and normalized scores will be the county's final weighted score (s_j).

$$s_j = \sum_{i=1}^5 w_i \times n_{i,j}$$

Normalized scores will be used to determine the final county score, as opposed to simply using the averaged rankings, because normalized scores account for the disparity in the metric (and potential societal benefit from a deployed PHEV) between counties. For example, if one county scores highest in attribute x and second highest in attribute y while another county scores second highest in attribute y and highest in attribute x , normalization captures the differences between the two counties in the respective metrics.

Counties will then be ranked according to these scores to determine those most suitable for PHEV deployment. The final product of this thesis will be a ranked list of the counties based on their suitability for maximizing the social benefits of PHEVs. The drawback of this approach is that in the case of data sets with a large range of values, the normalized value of the highest attribute scores will cause the remaining normalized attribute scores to approach zero. This essentially reduces the weight of this metric relative to the others, and counties that score orders of magnitude better than the other counties in this metric will have a substantially higher final weighted score.

2.3 Does HEV ownership coincide with where social benefits are maximized?

Due to the cost premium of PHEVs over conventional vehicles and the potential societal benefits, the rationale for purchasing a PHEV is the same as the rationale for purchasing hybrid vehicles that cannot be charged from the grid. If the initial adopters of PHEVs have the same attributes as the initial adopters of HEVs, they will share the attributes common to all early adopters, i.e, higher levels of education, income, and home ownership. Thus, PHEVs will likely be deployed in the same areas where HEVs are currently in use. For a more in-depth discussion of HEV early adopters see Heffner, Kurani, & Turrentine (2007; 2006); Kurani, Axsen, Caperello, Davies, & Stillwater (2009); Curtin, Shrager, & Mikkelsen (2009); and Musti & Kockelman (2009).

Directly related to maximizing the overall potential benefits from PHEV usage is directing the deployment of these vehicles in counties that will result in the greatest potential benefits. To shed light on this question, research will be conducted to determine whether HEVs are currently deployed in areas where they yield the greatest societal benefits. HEVs offer the same potential benefits as PHEVs, except that HEVs cannot displace petroleum consumption with electricity consumption. Thus, the research framework previously discussed will be modified by removing the carbon intensity attribute and used to determine which counties would offer the greatest societal benefits from the deployment of HEVs.

The areas that score highest in this analysis will be compared to HEV density across the US (from data procured from R.L. Polk & Co.). Discrepancies between the research analysis and actual HEV distribution may provide justification for better targeting of subsidies. This HEV distribution sheds light on where PHEVs will likely be deployed around the US, and may indicate discrepancies between where PHEVs are likely to be deployed and where they could be deployed to maximize social benefits.

3 Results

3.1 Individual metrics

In the initial analysis, all of the metrics were normalized from zero to one; these normalized scores were weighted equally and added together to obtain the final score for a county. Alaska and Hawaii were eliminated from consideration as complete data were not available for these states (more below in “Reduction of Health Incidents”).

Furthermore, the mean and standard deviation was calculated for each metric’s data set. The standard deviation was used to identify “outliers” in the data set. The number of standard deviations difference between each normalized data point and the mean for that metric’s data set were calculated to characterize the distribution of each metric’s data set and measure the “deviation” of each data point. Outlier data was not accorded any special treatment. Also, ArcGIS was utilized to display the tabulated data for all of the metrics, county scores, and sensitivity analyses. Gratitude goes to Arindam Ghosh for preparing the Geographic Information System (GIS) maps displayed subsequently.

3.1.1 Population density

The last US Census data was for the year 2000; from that data, the Census bureau has estimated the population of US counties for 1 July 2008. The dataset (<http://www.census.gov/popest/gallery/maps/maps-county2008.xls>) also captures the land area of the counties. From that the metric, people per square mile, was normalized such that the highest population density was one and the lowest was zero. Four New York City Metropolitan Statistical Area (MSA) counties were the most densely populated and deviated the most from the mean of the data set; these New York City counties deviated more than ten standard deviations from the mean population density.

Table 4 - Highest population density

Rank	FIPS	Geographic Area	State	Population Density
1	36061	New York County	New York	71758
2	36047	Kings County	New York	36104
3	36005	Bronx County	New York	33065
4	36081	Queens County	New York	20977
5	06075	San Francisco County	California	17259
6	34017	Hudson County	New Jersey	12888
7	25025	Suffolk County	Massachusetts	12606
8	42101	Philadelphia County	Pennsylvania	10799
9	11001	District of Columbia	District of Columbia	9687
10	51510	Alexandria City	Virginia	9575
11	36085	Richmond County	New York	8350
12	51013	Arlington County	Virginia	8096
13	24510	Baltimore City	Maryland	7868
14	34013	Essex County	New Jersey	6106
15	29510	St. Louis City	Missouri	5731
16	17031	Cook County	Illinois	5603
17	51610	Falls Church City	Virginia	5588
18	34039	Union County	New Jersey	5087
19	36059	Nassau County	New York	4750
20	51685	Manassas Park City	Virginia	4448
21	51710	Norfolk City	Virginia	4327
22	51540	Charlottesville City	Virginia	4048
23	55079	Milwaukee County	Wisconsin	3949
24	08031	Denver County	Colorado	3907
25	34003	Bergen County	New Jersey	3842

This metric exhibited the highest variance for the most and least densely populated counties, and has a standard deviation several times greater than the mean population density. Population density data for all counties are displayed in Figure 2 below:

Figure 2 - Population density

3.1.2 Reduction in health incidents

As mentioned previously, the EPA's BenMAP tool was utilized to estimate the health benefits of reducing pollutant concentrations. For each county, the reduction in health incidents was estimated for reducing ozone concentration one part per billion. Databases for pollutant concentration levels by county are already loaded into BenMAP, but there was no data for Alaska and Hawaii so analyses of those states were excluded.

BenMAP utilizes concentration-response (C-R) functions to estimate the relationship between ambient air pollution and adverse health effects (incidences). Incidences refer to the total number of adverse health effects in a geographic region in a given unit time. In BenMAP, this is the total number of adverse health effects avoided due to a change in air pollution. The health impact function calculation takes into account county population and the baseline number of incidences, i.e. the estimated number of health impacts due to all causes (not just air pollution-related causes). The inputs and settings for setting up the BenMAP analysis are tabulated in Table 5.

Table 5 - Configuration settings

Setting	Value
Grid creation	Monitor rollback
Pollutant	Ozone
Dataset	PM, O3
Year	2007
Interpolation method	Voronoi
Rollback grid	county
Rollback type	incremental
Rollback increment	1 ppb
Rollback background	0 ppb
Grid type	County
Incidence aggregation	County
Map grid (delta, baseline, and control)	8 hour mean
Population year	2010
Threshold	0

Once the model is run, data can be extracted from a Comma Separated Values output file that can be manipulated in Microsoft Excel. The definitions of pertinent outputs are summarized in the table below. Mean and point estimates are different ways of measuring the number of health incidents reduced by reducing the concentration of ozone in a county by one part per billion. The two measures do not differ in value significantly and point estimate was arbitrarily chosen to estimate the number of incidences reduced.

Table 6 - Results outputs

Variable	Definition
delta	Difference between the baseline and control scenarios for the metric used in the health impact function, corresponds to the rollback increment
percent of baseline	estimates the percentage change in health impacts due to the change in air quality from the baseline to the control scenario
point estimate	result from the health impact function, generally based on the mean estimate of the "Beta" from the health impact function
mean	average of the points in the Latin Hypercube for a result

BenMAP did not have data for Alaska and Hawaii loaded into its databases. As a result, counties from these states were excluded from the overall analyses. Also, Clifton Forge City (FIPS 51560), VA is no longer independent and was removed from the analysis. Broomfield County (FIPS 08014) organized as a new county in 2001 and is coextensive with Broomfield city. For the purposes of defining metropolitan statistical areas, Broomfield City was treated as if it were a county at the time of the 2000 Census; the standards were applied to data for Broomfield city.

Table 7 shows the counties with the greatest health benefit with a reduction in ozone concentration levels. The counties tend to have large cities whose residences largely rely on private automobiles for transportation. This data set also exhibited a great deal of

variation. In the following table, the highest ranked county will have twice as many reduced incidents as the fourth ranked county. This ranking is largely be a function of population. The data for all the counties is displayed in Figure 3.

Table 7 - Counties with greatest number of health incidents reduced

Rank	FIPS	Geographic Area	State	Point Estimate
1	06037	Los Angeles County	California	38904
2	17031	Cook County	Illinois	21877
3	04013	Maricopa County	Arizona	21558
4	48201	Harris County	Houston	1916
5	06073	San Diego County	California	14336
6	06059	Orange County	California	13642
7	48113	Dallas County	Texas	11805
8	06065	Riverside County	California	10966
9	32003	Clark County	Nevada	10905
10	06071	San Bernardino County	California	10809
11	48439	Tarrant County	Texas	9397
12	26163	Wayne County	Michigan	8680
13	36047	Kings County	New York	8501
14	36081	Queens County	New York	7960
15	12086	Miami-Dade County	Florida	7858
16	12011	Broward County	Florida	7762
17	48029	Bexar County	Texas	7401
18	06067	Sacramento County	California	7204
19	53033	King County	Washington	7081
20	06085	Santa Clara County	California	6992
21	36103	Suffolk County	New York	6501
22	36005	Bronx County	New York	6433
23	12099	Palm Beach County	Florida	6341
24	06001	Alameda County	California	6312
25	42101	Philadelphia County	Pennsylvania	6107

Figure 3 - Health incidents reduced

According to BenMAP

(<http://www.epa.gov/air/benmap/models/BenMapManualSept08.pdf>), the percentage reduction in the number of respiratory incidents ($\frac{\text{reduction in incidents}}{\text{baseline incidents}}$) corresponding to a unit reduction in pollutant concentration is equal for every county. The reduction in health benefits does not linearly correspond to population, i.e. that they are independent metrics and there are other factors in the C-R function that are not homogeneous across counties. The percentage reduction in incidents depends on the reduction in pollutant level. Areas with the dirtiest air and greatest population will see the greatest reduction in incidents by reducing pollutant levels.

From the BenMAP instruction manual, BenMAP estimates health impacts associated with changes in ambient air pollution per the following equation. The variables in the equation are defined per the BenMAP manual in Table 8.

$$\text{MortalityChange} = \text{AirPollutionChange} * \text{MortalityEffectEstimate} * \text{MortalityIncidence} * \text{ExposedPopulation}$$

Table 8 - Health impact function variables

Variable	Definition
Air Pollution Change	the difference between the starting air pollution level (the baseline) and the air pollution level after some change, such as that caused by a regulation
Mortality Effect Estimate	estimate of the percentage change in mortality due to a one unit change in ambient air pollution
Mortality Incidence	estimate of the average number of people that die in a given population over a given period of time
Exposed Population	number of people affected by the air pollution reduction

Population varies greatly from county to county. However, it was important to determine if the other variables in the above equation were sufficiently heterogeneous across all of the counties, to justify using the health benefits metric. The rankings of all the counties by *total* population were compared to the rankings of all the counties by health incidents reduced. A difference between the two rankings would indicate that the other variables in the above equation were varying with county. Ninety-one counties occur in the top one-hundred counties of both rankings. The disparity between the population density and health benefit rankings indicates that the BenMAP calculation for health incidents reduced is unique from a simple population metric. Table 9 compares the ten most populous counties and the ten counties that offer the greatest reduction of health incidents.

Table 9- Health benefit rankings versus most populous counties (highlighted counties appear in top 100 of both metrics)

Population Rank	FIPS	County	State	Population	Point Estimate	Health Benefit Rank
1	06037	Los Angeles	CA	9862049	38904	1
2	17031	Cook	IL	5294664	21877	2
3	48201	Harris	TX	3984349	19166	4
4	04013	Maricopa	AZ	3954598	21558	4
5	06059	Orange	CA	3010759	13642	6
6	06073	San Diego	CA	3001072	14336	5
7	36047	Kings	NY	2556598	8501	13
8	48113	Dallas	TX	2412827	11805	7
9	12086	Miami-Dade	FL	2398245	7858	15
10	36081	Queens	NY	2293007	7960	14

3.1.3 Vehicle miles traveled per capita

The average county VMT per capita is 13,711 miles; however, the counties that had the highest VMT per capita had values that seem unreasonable. For example, a resident of Kenedy County would have to drive over 1300 miles a day to achieve the tabulated VMT per capita. This data source did not differentiate between traffic made by local residents versus that of traffic whose origin and destination were outside the county. Thus, vehicle miles that originated outside of a county counted towards the county where the miles

were travelled not where the vehicle travelling the miles is necessarily registered. VMT per capita data is tabulated in Table 10 below:

Table 10 - VMT per capita

Rank	FIPS	County	State	VMT per capita
1	48261	Kenedy County	Texas	474855
2	48359	Oldham County	Texas	139836
3	48301	Loving County	Texas	139048
4	31049	Deuel County	Nebraska	128245
5	46075	Jones County	South Dakota	123475
6	48229	Hudspeth County	Texas	110235
7	48269	King County	Texas	107478
8	30103	Treasure County	Montana	96143
9	41021	Gilliam County	Oregon	95717
10	35019	Guadalupe County	New Mexico	95452
11	20063	Gove County	Kansas	89666
12	08111	San Juan County	Colorado	87501
13	48109	Culberson County	Texas	82999
14	41055	Sherman County	Oregon	82621
15	32011	Eureka County	Nevada	81998
16	38007	Billings County	North Dakota	78237
17	31105	Kimball County	Nebraska	74443
18	46071	Jackson County	South Dakota	72392
19	08019	Clear Creek County	Colorado	67210
20	30079	Prairie County	Montana	63291
21	20195	Trego County	Kansas	62179
22	48011	Armstrong County	Texas	62062
23	08065	Lake County	Colorado	59185
24	48311	Mc Mullen County	Texas	59114
25	13265	Taliaferro County	Georgia	58543

The VMT per capita data are displayed in Figure 4 below. Areas of high levels of VMT often correspond to counties with major US highways running through them. Counties like Kenedy County have a combination of low population and the existence of at least one major US Highway.

Figure 4 - VMT per capita

A map of the national highway system is shown in Figure 5; a larger version of the file can be found at http://www.wsdot.wa.gov/NR/rdonlyres/06CEF8C0-88B5-4E0A-93C4-BE4DAAF67F9E/0/WTPIVBMMapsg_NationalHighwaySystem.pdf.

Figure 5 - National Highway System

(see S_TX_VMT in appendix)

VMT data for Kenedy County is consistent with Texas Comptroller of Public Accounts website (<http://www.window.state.tx.us/specialrpt/tif/southtexas/infrastructure.html>).

Because population is so low, among the lowest in the nation, the VMT per capita is among the highest in the nation. As mentioned earlier in the section, since Kenedy County residents do not drive 1300 miles in a day the VMT includes pass through traffic. This likely includes cross-border traffic to Mexico that travels on US Route 77 based on Figure 5.

3.1.4 Existence of complementary state and local policies

City and local policies were aggregated up to county. Regional policies were applied down to all counties. Statewide policies were applied to all counties in state. The AFDC website (<http://www.afdc.energy.gov/afdc/laws/matrix/tech>) tabulates HEV and PHEV incentives and laws for all states; these are presented in Table 11. It includes the jurisdiction administering the policy.

Table 11 – HEV/PHEV policies by state

State	Policies	State	Policies	State	Policies	State	Policies
Alabama	1	Illinois	5	Montana	0	Rhode Island	1
Alaska	0	Indiana	4	Nebraska	0	South Carolina	3
Arizona	0	Iowa	0	Nevada	6	South Dakota	0
Arkansas	0	Kansas	0	New Hampshire	2	Tennessee	3
California	20	Kentucky	1	New Jersey	4	Texas	4
Colorado	4	Louisiana	2	New Mexico	2	Utah	2
Connecticut	3	Maine	1	New York	3	Vermont	3
Delaware	0	Maryland	1	North Carolina	3	Virginia	1
DC	1	Massachusetts	4	North Dakota	0	Washington	4
Florida	2	Michigan	7	Ohio	0	West Virginia	1
Georgia	0	Minnesota	2	Oklahoma	3	Wisconsin	3
Hawaii	1	Mississippi	1	Oregon	2	Wyoming	0
Idaho	1	Missouri	0	Pennsylvania	2		

All policies were considered equal in order to carry out the analysis in a timely manner. A more robust analysis would consider how effective a policy might be (this would be subjective since PHEVs are largely not available on the market). Conversely, areas that have more policies are more likely to have more effective policies so maybe this is an effective proxy. However, the analysis does not consider a county with fewer policies that would more effectively spur PHEV adoption and their benefits to be higher leverage than a county with many more less effective policies.

For information on local policies and what counties were included in their jurisdiction, the following websites were consulted. For the sake of simplicity, if a city within a county had a pertinent policy, the whole county was considered to have a pertinent policy. In reality, this would not be the case.

As discussed earlier, the individual policies were not analyzed with regards to their effectiveness. For example, in California, the California Energy Commission offers grants and loans for alternative fuel and vehicle research and development and users of qualified vehicles are allowed to use high occupancy vehicle lanes regardless of the number of occupants in their vehicle. These individual policies do not have the same effect in accelerating the benefits resulting from the use of PHEVs.

Table 12 - Existence of non-federal policies (all in California)

Rank	FIPS	County	Policies	Rank	FIPS	County	Policies
1	06037	Los Angeles	17	4	06107	Tulare	16
1	06065	Riverside	17	15	06001	Alameda	15
1	06085	Santa Clara	17	15	06003	Alpine	15
4	06019	Fresno	16	15	06005	Amador	15
4	06029	Kern	16	15	06007	Butte	15
4	06031	Kings	16	15	06009	Calaveras	15
4	06039	Madera	16	15	06011	Colusa	15
4	06047	Merced	16	15	06013	Contra Costa	15
4	06059	Orange	16	15	06015	Del Norte	15
4	06071	San Bernardino	16	15	06017	El Dorado	15
4	06075	San Francisco	16	15	06021	Glenn	15
4	06077	San Joaquin	16	15	06023	Humboldt	15
4	06099	Stanislaus	16				

As evidenced in the above tabulated results, counties located in California have more policies encouraging PHEV usage than any other counties. At the other extreme, some counties did not have any policies incentivizing the deployment of PHEVs. Another factor to consider is that PHEVs have not gained any appreciable market penetration.

Figure 6 - Existence of non-federal policies

3.1.5 CO₂ emitted per unit power generated

The carbon intensity of the electric power used to charge PHEV batteries is considered to predict what counties would mitigate the greatest amount of emissions if PHEVs were utilized there. This metric was calculated from statistics aggregated by the Department of Energy at the state level, as discussed earlier. Thus, county data follows the state data. The results are distributed almost normally with all of the data within four standard deviations. The state data is presented in Table 13 below:

Table 13 - Carbon intensity of power generated

State	gCO ₂ /kWh	Rank	State	gCO ₂ /kWh	Rank
Vermont	1	1	Texas	623	27
Idaho	85	2	Alaska	645	28
Washington	123	3	Tennessee	645	29
Oregon	184	4	Georgia	657	30
New Hampshire	296	5	Michigan	670	31
California	301	6	Montana	682	32
Connecticut	310	7	Minnesota	685	33
Maine	311	8	Nebraska	689	34
New Jersey	315	9	Oklahoma	696	35
New York	336	10	Colorado	776	36
Rhode Island	404	11	Wisconsin	777	37
South Carolina	421	12	Kansas	795	38
Arizona	489	13	Hawaii	795	39
Nevada	516	14	New Mexico	829	40
Massachusetts	523	15	Ohio	839	41
Illinois	530	16	Utah	844	42
Mississippi	537	17	Missouri	847	43
Florida	551	18	Iowa	863	44
Arkansas	553	19	Delaware	876	45
Pennsylvania	557	20	West Virginia	927	46
South Dakota	566	21	Kentucky	960	47
Alabama	568	22	Indiana	960	48
Virginia	569	23	District of Columbia	966	49
Louisiana	591	24	Wyoming	1000	50
North Carolina	601	25	North Dakota	1006	51
Maryland	615	26			

Total energy consumption in Vermont is the lowest of any State in the Nation (http://tonto.eia.doe.gov/state/state_energy_profiles.cfm?sid=VT). Nuclear power

accounts for about three-fourths of the electricity generated within Vermont, a higher share than in any other State. Vermont is one of only two States in the Nation with no coal-fired power plants. Data for all counties across the US are displayed in Figure 7 below:

Figure 7 - CO₂ intensity of power generated

3.2 Overall results

As mentioned previously, the aforementioned metrics were normalized from one to zero, weighted equally and summed to obtain the final score for each county. Normalization takes into account the difference in magnitude of the respective metrics between subsequently ordinaly ranked counties. The results are illustrated in Figure 8 below:

Figure 8 - Normalized scores

As evidenced in Table 14, California counties scored highly due in part to its high potential for health benefits upon pollutant level reductions and its policy support of vehicle electrification. New York County ranks highly because its population density is so much higher than that of other counties. This result can be directly attributed to normalization making the other counties' population density scores so low by comparison.

Table 14 - Final scores – normalized

Rank	FIPS	County	State	Overall
1	06037	Los Angeles	CA	1.000
2	06059	Orange	CA	0.663
3	06065	Riverside	CA	0.636
4	06073	San Diego	CA	0.631
5	36061	New York	NY	0.624
6	06075	San Francisco	CA	0.604
7	06071	San Bernardino	CA	0.603
8	06085	Santa Clara	CA	0.592
9	06067	Sacramento	CA	0.545
10	06001	Alameda	CA	0.538
11	06019	Fresno	CA	0.528
12	06029	Kern	CA	0.527
13	06077	San Joaquin	CA	0.521
14	06013	Contra Costa	CA	0.516
15	06099	Stanislaus	CA	0.510
16	06107	Tulare	CA	0.505
17	06047	Merced	CA	0.497
18	06111	Ventura	CA	0.488
19	06081	San Mateo	CA	0.484
20	06031	Kings	CA	0.483
21	06039	Madera	CA	0.481
22	06095	Solano	CA	0.479
23	06053	Monterey	CA	0.470
24	06097	Sonoma	CA	0.469
25	06083	Santa Barbara	CA	0.467

For comparison, the rankings (r_i) of the counties with regards to the different metrics were averaged to determine if the overall rankings changed, per the formula below:

$$s_j = 0.2 \times \sum_{i=1}^5 r_{i,j}$$

The highest scoring counties based on this methodology are tabulated in Table 15 below:

Table 15 - Non-normalized rankings

Rank	FIPS	County	State
1	25021	Norfolk	MA
2	25001	Barnstable	MA
3	36079	Putnam	NY
4	36103	Suffolk	NY
5	06031	Kings	CA
6	06047	Merced	CA
7	06073	San Diego	CA
8	06113	Yolo	CA
9	06053	Monterey	CA
10	34001	Atlantic	NJ
11	06095	Solano	CA
12	34027	Morris	NJ
13	06081	San Mateo	CA
14	34005	Burlington	NJ
15	17163	St. Clair	IL
16	36071	Orange	CA
17	47037	Davidson	TN
18	34033	Salem	NJ
19	06097	Sonoma	CA
19	34003	Bergen	NJ
21	34023	Middlesex	NJ
22	36001	Albany	NY
23	06029	Kern	CA
24	06077	San Joaquin	CA
25	45051	Horry	SC

In the non-normalized ranking, there is no control for the magnitude in the difference in metric scores between two counties. But, the normalized scoring system controls for this. However, the normalized scoring system can skew the results if there is one really high or really low value for a metric. Thus, a tradeoff exists. The graphical depiction of the average metric ranking is shown in the map below. The highest ranked countries have the lowest number on the map. See Figure 9 below:

Figure 9 - Average rankings (non-normalized metrics)

Although many California counties still score highly, the rankings look quite differently from those of Figure 8. The list of highest scoring counties is compared side by side in Table 16. Of the counties that scored in the top 100 of the normalized scoring scheme, only 31 were ranked in the top 100 of the non-normalized scoring scheme (shaded in Table 16). Interestingly, the four highest scoring counties in the non-normalized scheme did not score in the top 100 counties in the normalized scheme. The use of an ordinal ranking system results in greater heterogeneity among counties within states.

Table 16 - Normalized vs non-normalized rankings

FIPS	Normalized	Rank	FIPS	Non-normalized
06037	Los Angeles	1	25021	Norfolk
06059	Orange	2	25001	Barnstable
06065	Riverside	3	36079	Putnam
06073	San Diego	4	36103	Suffolk
36061	New York	5	06031	Kings
06075	San Francisco	6	06047	Merced
06071	San Bernardino	7	06073	San Diego
06085	Santa Clara	8	06113	Yolo
06067	Sacramento	9	06053	Monterey
06001	Alameda	10	34001	Atlantic
06019	Fresno	11	06095	Solano
06029	Kern	12	34027	Morris
06077	San Joaquin	13	06081	San Mateo
06013	Contra Costa	14	34005	Burlington
06099	Stanislaus	15	17163	St. Clair
06107	Tulare	16	36071	Orange
06047	Merced	17	47037	Davidson
06111	Ventura	18	34033	Salem
06081	San Mateo	19	06097	Sonoma
06031	Kings	20	34003	Bergen
06039	Madera	21	34023	Middlesex
06095	Solano	22	36001	Albany
06053	Monterey	23	06029	Kern
06097	Sonoma	24	06077	San Joaquin
06083	Santa Barbara	25	45051	Horry

Based on the metrics selected to grade counties, especially population density, health benefits, and the existence of complementary policies, counties containing large cities are expected to score more highly than rural areas. Thus, the analysis further examined all of the counties that make up the one hundred most populous metropolitan statistical areas (MSAs) based on Census data (<http://www.census.gov/popest/metro/files/2009/CBSA-EST2009-alldata.csv>). These MSAs account for 575 counties and in the unadjusted normalized scoring system, ranged in rank from the highest scoring county to the 3028th highest scoring county. In the non-normalized scoring system, these counties ranked from one to 3047. Thirty-two of these 575 counties appear in the top hundred of unadjusted, normalized county scores and sixty appear in the top hundred of non-normalized county scores. Table 17 lists the 25 most populous MSAs that do not have counties scoring in the top 100 counties of the normalized methodology, non-normalized methodology, or either methodology. Three of these MSAs did not rank in the top 100 counties by the normalized methodology; two of these MSAs did not rank in the top 100

counties by the non-normalized methodology; twelve of these counties do not rank in the top 100 counties by either methodology.

Table 17 - Most populous MSAs with no counties scoring in the top 100 of ranking methodologies (numbers in parenthesis are MSA ranking by population)

No counties in top 100 of normalized methodology	No counties in top 100 of non-normalized methodology	No counties in top 100 of either methodology
Philadelphia (5) Boston (10) Tampa (19)	Phoenix (12) Portland (23)	Dallas (4) Houston (6) Miami (7) Washington, DC (8) Atlanta (9) Detroit (11) Minneapolis (16) St. Louis (18) Baltimore (20) Denver (21) Pittsburgh (22) Cincinnati (24)

3.3 Does high HEV ownership occur where social benefits are maximized?

Directly related to maximizing the overall potential benefits from PHEV usage is directing the deployment of these vehicles in counties that will result in the greatest potential benefits. As aforementioned, the early adopters of PHEVs will likely be very similar to the first consumers of hybrid vehicles. Extrapolating the above results, the counties that offer the highest level of benefits from PHEV usage, as presented in Section 3.2, will likely not be the same counties where PHEVs are adopted at the highest densities. *This indicates the need for realigning the current incentive policy if the benefits derived from PHEV usage are to be maximized such that potential consumers in geographic areas that offer the greatest benefits from PHEV usage are more greatly incentivized than other consumers.*

As mentioned earlier, consumers will most likely purchase PHEVs where HEVs are currently deployed. To shed light on the question that opened this section, an analysis was conducted to examine whether the counties that offer the greatest benefits from PHEV deployment are where HEVs are currently deployed. HEV density across the US was calculated from vehicle registration data purchased from R.L. Polk & Co. Discrepancies between the research analysis and actual HEV distribution may provide justification for better targeting of subsidies. Discrepancies between where PHEVs are likely to be deployed and where they could yield the greatest social benefits may indicate the need for policy realignment.

The one-hundred highest scoring counties in terms of benefits derived from PHEVs were compared with the one-hundred counties with the highest HEV density. If the two lists have a great degree of overlap, this is an indication that the counties that offer the greatest

benefits from PHEV deployment also have the greatest penetration of HEV deployment. However, this is not the case as the lists differ greatly and only twenty-six counties show up on both lists. This indicates that incentives can be better targeted to the counties that offer the greatest benefits from hybrid vehicle deployment to maximize these benefits. Of the 25 counties that offer the greatest benefits from PHEV deployment 12 have HEV densities that fall outside of the top hundred counties for that measure (counties that are among the top 100 in terms of benefits and HEV density are shaded in Table 18).

Table 18 - Counties with highest benefits vs. counties with greatest HEV density (vehicles/person – shaded counties show up in top one-hundred counties for both metrics)

Rank	FIPS	Benefits	State	Density	FIPS	HEV/person	State
1	06037	Los Angeles	CA	109.2886	06041	Marin	CA
2	06059	Orange	CA	106.9763	08097	Pitkin	CO
3	06065	Riverside	CA	62.88931	51610	Falls Church	VA
4	06073	San Diego	CA	107.6382	06081	San Mateo	CA
5	36061	New York	NY	33.88804	25007	Dukes	MA
6	06075	San Francisco	CA	179.4491	06087	Santa Cruz	CA
7	06071	San Bernardino	CA	49.17744	06097	Sonoma	CA
8	06085	Santa Clara	CA	174.3158	06075	San Francisco	CA
9	06067	Sacramento	CA	84.40244	06085	Santa Clara	CA
10	06001	Alameda	CA	154.6764	51179	Stafford	VA
11	06019	Fresno	CA	44.95393	35028	Los Alamos	NM
12	06029	Kern	CA	41.80107	51013	Arlington	VA
13	06077	San Joaquin	CA	50.41732	06055	Napa	CA
14	06013	Contra Costa	CA	155.3361	51059	Fairfax	VA
15	06099	Stanislaus	CA	42.45204	51107	Loudoun	VA
16	06107	Tulare	CA	40.4902	08013	Boulder	CO
17	06047	Merced	CA	34.9021	06013	Contra Costa	CA
18	06111	Ventura	CA	116.4414	06001	Alameda	CA
19	06081	San Mateo	CA	222.6354	53031	Jefferson	WA
20	06031	Kings	CA	33.17326	37135	Orange	NC
21	06039	Madera	CA	37.07874	41003	Benton	OR
22	06095	Solano	CA	97.54242	35049	Santa Fe	NM
23	06053	Monterey	CA	93.45039	53055	San Juan	WA
24	06097	Sonoma	CA	182.6066	51153	Prince William	VA
25	06083	Santa Barbara	CA	122.8922	51061	Fauquier	VA

Table 19 lists the thirty-five counties show up in the top hundred of both metrics from Table 18:

Table 19 - Counties in top-100 of PHEV benefits and HEV density (vehicles/person)

FIPS	County	State
6001	Alameda	CA
6009	Calaveras	CA
6013	Contra Costa	CA
6017	El Dorado	CA
6023	Humboldt	CA
6037	Los Angeles	CA
6041	Marin	CA
6043	Mariposa	CA
6045	Mendocino	CA
6053	Monterey	CA
6055	Napa	CA
6057	Nevada	CA
6059	Orange	CA
6061	Placer	CA
6073	San Diego	CA
6075	San Francisco	CA
6079	San Luis Obispo	CA
6081	San Mateo	CA
6083	Santa Barbara	CA
6085	Santa Clara	CA
6087	Santa Cruz	CA
6095	Solano	CA
6097	Sonoma	CA
6111	Ventura	CA
6113	Yolo	CA
50001	Addison	VT
50007	Chittenden	VT
50013	Grand Isle	VT
50017	Orange	VT
50023	Washington	VT
50025	Windham	VT
50027	Windsor	VT
53033	King	WA
53035	Kitsap	WA
53067	Thurston	WA

3.4 Outliers

3.4.1 Outliers

The population density of New York City area counties were all over ten standard deviations higher than the nation's mean population density. New York County's population density was over forty standard deviations greater than the nation's mean. This greatly skewed the population density attribute and accounts for much of the difference between the normalized and non-normalized ranking scores.

Kenedy County, in Texas has an incredibly low population; however, there is still a high level vehicle miles travelled resulting in a very high per capita VMT. The high level of VMT may be attributable to its location near the border with Mexico and the existence of the only federal highway that runs through Brownsville, TX, a major border town between Texas and Mexico.

Similarly, three counties in South Dakota score very highly in the VMT metric causing them to score very highly in the overall results compared to other South Dakota. Jones County has a combination of very low population (lowest in the state of South Dakota) and two major highways running through it (Interstate 90 and US Highway 83) resulting in a very high VMT per capita. Lyman and Jackson Counties also have a combination of low populations and high VMT due to federal highways passing through them.

These incredibly high metric scores explain why the above counties score well in all sensitivity analyses, even when the weight of the attribute the counties score highly in is minimized.

3.4.2 Data adjustment

To eliminate the effect of outliers on normalized scores, the individual metrics that feed into the county scores were all adjusted so no counties scored greater than two standard deviations out from that metric's mean. Thus, the highest scoring county for each metric was adjusted so its metric score was exactly two standard deviations greater than the mean for that metric. All remaining counties whose metric scores were greater than two standard deviations out from the metric's mean were incrementally reduced down by one unit in the metric score's fifth significant digit from the highest scoring county's adjusted score. Then, all the counties' metric scores were renormalized.

For example, the twenty seven most densely populated counties had population densities that exceeded the mean population density for all counties by two standard deviations. Thus, the highest scoring county (New York) was assigned the population density that was exactly two standard deviations out from the mean population density. Thus, New York's population density was reduced and truncated to 3792.9. Subsequent counties had their population densities adjusted to 3792.8, 3792.7, 3792.6, etc if there "unadjusted" population density was greater than two standard deviations out from the mean density. All of the county scores were subsequently renormalized, and a snapshot of this adjustment is presented in Table 20. This adjustment was conducted for all metrics.

Table 20 - Adjusted population density outliers

FIPS	Rank	County	Population Density	Normal	Deviation
36061	1	New York	3792.9	1.000	2.000
36047	2	Kings	3792.8	1.000	2.000
36005	3	Bronx	3792.7	1.000	2.000
36081	4	Queens	3792.6	1.000	2.000
06075	5	San Francisco	3792.5	1.000	2.000
...	...	...	...	...	...
51600	26	Fairfax City	3790.4	0.999	1.999
06059	27	Orange	3790.3	0.999	1.998
51683	28	Manassas City	3546.75	0.935	1.861
51760	29	Richmond City	3376.898	0.890	1.765
12103	30	Pinellas	3324.368	0.876	1.735

Table 21 summarizes how much each metric was adjusted to get all of the data points to within two standard deviations of the respective metric's mean.

Table 21 – Summary of outlier adjustments

Metric	Counties greater than 2σ from mean	# of deviations between highest scoring county and mean
Population density	27	40
Health benefits	83	27
VMT/capita	57	36
Complementary policies	59	5
CO ₂ intensity	133	3

As a result of adjusting the data sets for each metric, the overall county scores for all of the counties increased. This affected how the counties ranked based on their final scores. See Table 22:

Table 22 - Normalized scores after outlier adjustment

Rank	FIPS	County	State	Normal	Rank	FIPS	County	State	Normal
1	6059	Orange	CA	1	14	34023	Middlesex	NJ	0.834
2	6037	Los Angeles	CA	0.904	15	6073	San Diego	CA	0.825
3	34003	Bergen	NJ	0.881	16	36081	Queens	NY	0.812
4	6075	San Francisco	CA	0.874	17	36005	Bronx	NY	0.809
5	6001	Alameda	CA	0.872	18	36061	New York	NY	0.808
6	26163	Wayne	MI	0.851	19	36047	Kings	NY	0.808
7	6067	Sacramento	CA	0.848	20	6077	San Joaquin	CA	0.803
8	6013	Contra Costa	CA	0.845	21	17043	DuPage	IL	0.798
9	36059	Nassau	NY	0.845	22	6065	Riverside	CA	0.79
10	6085	Santa Clara	CA	0.843	23	6029	Kern	CA	0.789
11	34013	Essex	NJ	0.839	24	6019	Fresno	CA	0.777
12	17031	Cook	IL	0.834	25	6071	San Bernardino	CA	0.776
13	6081	San Mateo	CA	0.825					

The top 25 counties before and after adjustment are tabulated in Table 23. Thirty-eight counties rank in the top hundred counties of the unadjusted normalized analysis and in the adjusted analysis; the highest ranking of these are shown shaded in Table 23.

Table 23 - Impact of outlier adjustment on final scores

Rank	FIPS	Unadjusted	State	FIPS	Adjusted	State
1	06037	Los Angeles	CA	06059	Orange	CA
2	06059	Orange	CA	06037	Los Angeles	CA
3	06065	Riverside	CA	34003	Bergen	NJ
4	06073	San Diego	CA	06075	San Francisco	CA
5	36061	New York	NY	06001	Alameda	CA
6	06075	San Francisco	CA	26163	Wayne	MI
7	06071	San Bernardino	CA	06067	Sacramento	CA
8	06085	Santa Clara	CA	06013	Contra Costa	CA
9	06067	Sacramento	CA	36059	Nassau	NY
10	06001	Alameda	CA	06085	Santa Clara	CA
11	06019	Fresno	CA	34013	Essex	NJ
12	06029	Kern	CA	17031	Cook	IL
13	06077	San Joaquin	CA	06081	San Mateo	CA
14	06013	Contra Costa	CA	34023	Middlesex	NJ
15	06099	Stanislaus	CA	06073	San Diego	CA
16	06107	Tulare	CA	36081	Queens	NY
17	06047	Merced	CA	36005	Bronx	NY
18	06111	Ventura	CA	36061	New York	NY
19	06081	San Mateo	CA	36047	Kings	NY
20	06031	Kings	CA	06077	San Joaquin	CA
21	06039	Madera	CA	17043	DuPage	IL
22	06095	Solano	CA	06065	Riverside	CA
23	06053	Monterey	CA	06029	Kern	CA
24	06097	Sonoma	CA	06019	Fresno	CA
25	06083	Santa Barbara	CA	06071	San Bernardino	CA

Thus, it is clear that adjusting for outliers has a significant impact on the final rankings. The adjusted metrics are preferred for the analysis as outliers for a metric have the unintended consequence of vastly reducing the scores of non-outlier counties. In the case of population density, the most dense counties are not the most practical for PHEV deployment as personal transportation for all constituents of that county is not feasible (i.e. in New York County). Similarly, in the case of VMT per capita all of the miles occurring in the county may not be due to county constituents. Adjusting outliers in the manner previously prescribed controls for these types of effects.

3.5 Sensitivity analysis

There will likely be contention regarding how scores are calculated for the metrics and how the metrics are weighted as these factors both affect the final ranking of the counties. Thus, the sensitivity analysis was conducted to determine how varying the weight assigned to the metrics affects the overall rankings. Each scenario analysis represents affecting the emphasis on various policy goals. The various sensitivity analyses were

carried out to indicate if certain counties could offer the greatest societal benefits under any weighting scenario and are truly where PHEVs should be deployed, or if different counties scored highly in terms of suitability for PHEV deployment. In the latter scenario, PHEVs should be promoted in counties based on the policy goals that the scenario analysis represents.

In the base case analysis, all of the metrics were weighted equally against each other. However, one could assign various weights to the different metrics to emphasize policy goals and/or priorities. Furthermore, determining if varying the weights affects the final rankings tests the robustness of the original rankings. Specifically, if a certain county scores highly regardless of the weights assigned to the metrics, that county is one that yields high benefits for the deployment of PHEVs. Similarly, if a county scores poorly in all scenarios, subsidizing PHEV deployment there may be counterintuitive.

For these sensitivity analyses, scenarios were constructed in the analysis where one of each of the five attributes was assigned either twice as much weight as the other attributes or half as much weight. In the base case, since all five metrics are considered equally they are assigned a weight of 0.2. If an attribute were to be emphasized in a scenario, the weight assigned to this metric would be 1/3 and the weight assigned to the other metrics would be 1/6. Conversely, if this attribute were to be deemphasized it would be assigned a weight of 1/9 while the other weights would be assigned a weight of 2/9. In either scenario, the sum of the weights of the five attributes would sum to one. The scenarios are summarized in Table 24 below.

Table 24 - Sensitivity analysis scenarios

Scenario emphasis	Description
Network effects maximization	2X weight population density metric
Network effects minimization	½X weight population density metric
Health benefits maximization	2X weight health incidents reduced density metric
Health benefits minimization	½X weight health incidents reduced metric
Petroleum consumption displaced maximization	2X weight VMT per capita metric
Petroleum consumption displaced minimization	½X weight VMT per capita metric
Policy synergy maximization	2X weight complementary policy metric
Policy synergy minimization	½X weight complementary policy metric
Greenhouse gas emissions mitigated maximization	2X weight CO ₂ intensity metric
Greenhouse gas emissions mitigated minimization	½X weight CO ₂ intensity metric

3.5.1 Network effects maximization

As discussed previously, higher population densities maximize the utilization of centrally placed infrastructure and aid in accelerating the adoption rate of this new vehicle technology. Thus, to give more weight to maximizing these potential network effects the

weight of the population density was doubled compared to the other metrics. Although the order of the top 100 counties differs from that of the base case, the same 100 counties appear on both lists. Counties that are among the 100 highest in terms of potential PHEV benefits in the base case and the respective scenario analysis are highlighted in all tables in Section 3.5. The full results of the analysis can be found in the appendix. The top ten of the base case and this scenario analysis are presented in Table 25:

Table 25 - Population density heavily weighted

Equal weight metrics				Population density weight increased		
Rank	FIPS	County	State	FIPS	County	State
1	06037	Los Angeles County	CA	36061	New York County	NY
2	06059	Orange County	CA	06037	Los Angeles County	CA
3	06065	Riverside County	CA	06075	San Francisco County	CA
4	06073	San Diego County	CA	06059	Orange County	CA
5	36061	New York County	NY	36047	Kings County	NY
6	06075	San Francisco County	CA	06065	Riverside County	CA
7	06071	San Bernardino County	CA	06073	San Diego County	CA
8	06085	Santa Clara County	CA	06071	San Bernardino County	CA
9	06067	Sacramento County	CA	06085	Santa Clara County	CA
10	06001	Alameda County	CA	36005	Bronx County	NY

The data for all of the counties in this scenario is graphically presented in Figure 10.

Figure 10 - Heavily weighted population metric

3.5.2 Network effects minimization

In this sensitivity analysis, the weight of the population density attribute was reduced compared to the weights of the other metrics to determine its effect. This weighting may be preferred to offset the skew in the distribution of population density values. The results of this scenario analysis very closely resemble the baseline results. Counties that had the highest population density had a somewhat lower desirability ranking for PHEV deployment, but 99 of the top 100 counties from the base case were in the top 100 of this scenario analysis. The ten highest scoring counties from the base case and this scenario analysis are presented in Table 26.

Table 26 - Reducing population density weight

		Equal weight metrics		Population density weight reduced		
Rank	FIPS	County	State	FIPS	County	State
1	06037	Los Angeles County	CA	06037	Los Angeles County	CA
2	06059	Orange County	CA	06059	Orange County	CA
3	06065	Riverside County	CA	06065	Riverside County	CA
4	06073	San Diego County	CA	06073	San Diego County	CA
5	36061	New York County	NY	06071	San Bernardino County	CA
6	06075	San Francisco County	CA	06085	Santa Clara County	CA
7	06071	San Bernardino County	CA	06075	San Francisco County	CA
8	06085	Santa Clara County	CA	06067	Sacramento County	CA
9	06067	Sacramento County	CA	06019	Fresno County	CA
10	06001	Alameda County	CA	06001	Alameda County	CA

Data for all of the counties in this sensitivity analysis are presented in Figure 11.

Figure 11 - Reduced population metric weight

3.5.3 Health incidents reduced maximization

In this sensitivity analysis, the weight of the health benefits attribute was twice the weight of the other metrics to determine its effect on the final county rankings. This analysis would be preferred if policy makers wished to maximize the health benefits from PHEV deployment. This weighting may be preferred if policy makers wanted to determine which counties would offer the greatest health benefits if PHEVs were to be deployed there. Ninety-four counties of the top 100 in the baseline analysis rank in the top 100 of this scenario. The order of the rankings differ somewhat. The ten highest scoring counties from the base case and this scenario analysis are presented in Table 27.

Table 27 - Increasing weight of health benefits

		Equal weight metrics			Health benefits weight increased	
Rank	FIPS	County	State	FIPS	County	State
1	06037	Los Angeles County	CA	06037	Los Angeles County	CA
2	06059	Orange County	CA	06059	Orange County	CA
3	06065	Riverside County	CA	06073	San Diego County	CA
4	06073	San Diego County	CA	06065	Riverside County	CA
5	36061	New York County	NY	06071	San Bernardino County	CA
6	06075	San Francisco County	CA	06085	Santa Clara County	CA
7	06071	San Bernardino County	CA	36061	New York County	NY
8	06085	Santa Clara County	CA	06067	Sacramento County	CA
9	06067	Sacramento County	CA	06075	San Francisco County	CA
10	06001	Alameda County	CA	17031	Cook County	IL

All of the data for the heavily weighted health benefits weight scenario are presented in Figure 12.

Figure 12 - Heavily weighted health benefits metric

3.5.4 Health incidents reduced minimization

In this sensitivity analysis, the weight of the health benefits attribute was half the weight of the other metrics to determine its effect on the final county rankings. This analysis is

relevant to policy makers if the health benefits of PHEVs were less important than policy goals represented by the other metrics. Ninety-eight counties of the top 100 in the baseline analysis rank in the top 100 of this scenario. The ten highest scoring counties from the base case and this scenario analysis are presented in Table 28.

Table 28 – Reducing weight of health benefits metric

		Equal weight metrics			Health benefits weight reduced	
Rank	FIPS	County	State	FIPS	County	State
1	06037	Los Angeles County	CA	06037	Los Angeles County	CA
2	06059	Orange County	CA	06075	San Francisco County	CA
3	06065	Riverside County	CA	36061	New York County	NY
4	06073	San Diego County	CA	06059	Orange County	CA
5	36061	New York County	NY	06065	Riverside County	CA
6	06075	San Francisco County	CA	06085	Santa Clara County	CA
7	06071	San Bernardino County	CA	06071	San Bernardino County	CA
8	06085	Santa Clara County	CA	06073	San Diego County	CA
9	06067	Sacramento County	CA	06019	Fresno County	CA
10	06001	Alameda County	CA	06029	Kern County	CA

Data for all of the counties in the health benefits weight reduced scenario are presented in Figure 13.

Figure 13 - Reduced health benefits metric weight

3.5.5 Petroleum consumption displacement maximization

In this sensitivity analysis, the VMT metric carried twice the weight of the other attributes. This analysis is relevant if policy makers wanted to maximize the displacement of petroleum consumption by deploying PHEVs charged from the grid. This scoring scheme would be employed to emphasize the benefits of petroleum consumption as counties with high per capita VMT consume the greatest volume of petroleum with conventional internal combustion engines. Ninety-seven counties of the top 100 in the baseline analysis rank in the top 100 of this scenario. The ten highest scoring counties from the base case and this scenario analysis are presented in Table 29.

Table 29 – Increasing weight of VMT metric

		Equal weight metrics			VMT/capita weight increased	
Rank	FIPS	County	State	FIPS	County	State
1	06037	Los Angeles County	CA	06037	Los Angeles County	CA
2	06059	Orange County	CA	48261	Kenedy County	TX
3	06065	Riverside County	CA	06059	Orange County	CA
4	06073	San Diego County	CA	06065	Riverside County	CA
5	36061	New York County	NY	06073	San Diego County	CA
6	06075	San Francisco County	CA	36061	New York County	NY
7	06071	San Bernardino County	CA	06071	San Bernardino County	CA
8	06085	Santa Clara County	CA	06075	San Francisco County	CA
9	06067	Sacramento County	CA	06085	Santa Clara County	CA
10	06001	Alameda County	CA	06067	Sacramento County	CA

Data for all of the counties in the VMT/capita weight increased scenario are presented in Figure 14.

Figure 14 - Heavily weighted VMT metric

3.5.6 Petroleum consumption displacement minimization

In this sensitivity analysis, the weight of the VMT attribute was half the weight of the other metrics to determine its effect on the final county rankings. This scenario is relevant if policy makers want to reduce the importance of displacing petroleum consumption relative to other policy goals. Ninety-nine counties of the top 100 in the baseline analysis rank in the top 100 of this scenario. The ten highest scoring counties from the base case and this scenario analysis are presented in Table 30.

Table 30 – Reducing weight of VMT metric

		Equal weight metrics			VMT/capita weight reduced	
Rank	FIPS	County	State	FIPS	County	State
1	06037	Los Angeles County	CA	06037	Los Angeles County	CA
2	06059	Orange County	CA	06059	Orange County	CA
3	06065	Riverside County	CA	06065	Riverside County	CA
4	06073	San Diego County	CA	06073	San Diego County	CA
5	36061	New York County	NY	36061	New York County	NY
6	06075	San Francisco County	CA	06075	San Francisco County	CA
7	06071	San Bernardino County	CA	06071	San Bernardino County	CA
8	06085	Santa Clara County	CA	06085	Santa Clara County	CA
9	06067	Sacramento County	CA	06067	Sacramento County	CA
10	06001	Alameda County	CA	06001	Alameda County	CA

Data for all of the counties in the reduced weight VMT/capita scenario are presented in Figure 15.

Figure 15 - Reduced VMT metric weight

3.5.7 Maximizing synergies with state and local policies

This scoring scheme would be employed to emphasize counties that would likely result in the greatest policy synergies due to the existence of both federal incentives and incentives at other levels of government. This analysis is relevant if policy makers want to leverage

non-federal policies in maximizing consumer incentives for purchasing PHEVs. In this sensitivity analysis, the weight of the policy attribute was twice the weight of the other metrics to determine its effect on the final county rankings. Ninety-five counties of the top 100 in the baseline analysis rank in the top 100 of this scenario. The ten highest scoring counties from the base case and this scenario analysis are presented in Table 31.

Table 31 – Increasing weight of policy metric

		Equal weight metrics			Policy weight increased	
Rank	FIPS	County	State	FIPS	County	State
1	06037	Los Angeles County	CA	06037	Los Angeles County	CA
2	06059	Orange County	CA	06065	Riverside County	CA
3	06065	Riverside County	CA	06059	Orange County	CA
4	06073	San Diego County	CA	06085	Santa Clara County	CA
5	36061	New York County	NY	06075	San Francisco County	CA
6	06075	San Francisco County	CA	06071	San Bernardino County	CA
7	06071	San Bernardino County	CA	06073	San Diego County	CA
8	06085	Santa Clara County	CA	06019	Fresno County	CA
9	06067	Sacramento County	CA	06029	Kern County	CA
10	06001	Alameda County	CA	06077	San Joaquin County	CA

The data for all the counties in the heavily-weighted policy metric scenario are presented in Figure 16.

Figure 16 - Heavily weighted policy metric

3.5.8 Minimizing synergies with state and local policies

In this sensitivity analysis, the weight of the policy attribute was half the weight of the other metrics to determine its effect on the final county rankings. This analysis is relevant if policy makers want to deemphasize the importance of deploying PHEVs in counties with non-federal incentives relative to other policy goals. Ninety-eight counties of the top 100 in the baseline analysis rank in the top 100 of this scenario. The ten highest scoring counties from the base case and this scenario analysis are presented in Table 32.

Table 32 – Reducing weight of policy metric

		Equal weight metrics			Policy weight reduced	
Rank	FIPS	County	State	FIPS	County	State
1	06037	Los Angeles County	CA	06037	Los Angeles County	CA
2	06059	Orange County	CA	36061	New York County	NY
3	06065	Riverside County	CA	06059	Orange County	CA
4	06073	San Diego County	CA	06073	San Diego County	CA
5	36061	New York County	NY	06065	Riverside County	CA
6	06075	San Francisco County	CA	36047	Kings County	NY
7	06071	San Bernardino County	CA	06075	San Francisco County	CA
8	06085	Santa Clara County	CA	06071	San Bernardino County	CA
9	06067	Sacramento County	CA	48261	Kenedy County	TX
10	06001	Alameda County	CA	06085	Santa Clara County	CA

The data for all of the counties in the policy weight reduced scenario are presented in Figure 17.

Figure 17 - Reduced policy metric weight

3.5.9 Maximizing GHG emissions mitigation

Since charging PHEVs displaces GHG emissions from the vehicle's tailpipe to the electric grid, nonpolluting power must be used to power these vehicles in order to achieve a significant reduction in emissions. If prioritizing the mitigation of GHG emissions, this scoring scheme would be preferred. In this sensitivity analysis, the weight of the carbon intensity attribute was half the weight of the other metrics to determine its effect on the final county rankings. Ninety-five counties of the top 100 in the baseline analysis rank in the top 100 of this scenario. The ten highest scoring counties from the base case and this scenario analysis are presented in Table 33.

Table 33 – Increasing weight of carbon intensity metric

		Equal weight metrics			Carbon intensity weight increased	
Rank	FIPS	County	State	FIPS	County	State
1	06037	Los Angeles County	CA	06037	Los Angeles County	CA
2	06059	Orange County	CA	06059	Orange County	CA
3	06065	Riverside County	CA	06065	Riverside County	CA
4	06073	San Diego County	CA	06073	San Diego County	CA
5	36061	New York County	NY	06075	San Francisco County	CA
6	06075	San Francisco County	CA	06071	San Bernardino County	CA
7	06071	San Bernardino County	CA	36061	New York County	NY
8	06085	Santa Clara County	CA	06085	Santa Clara County	CA
9	06067	Sacramento County	CA	06067	Sacramento County	CA
10	06001	Alameda County	CA	06001	Alameda County	CA

The data for all the counties in the carbon intensity metric increased scenario are presented in Figure 18.

Figure 18 - Heavily weighted carbon intensity metric

3.5.10 Minimizing GHG emissions mitigation

In this sensitivity analysis, the weight of the carbon intensity attribute was half the weight of the other metrics to determine its effect on the final county rankings. This analysis is pertinent if policy makers want to emphasize policy goals other than mitigating

greenhouse gas emissions. Eighty-six counties of the top 100 in the baseline analysis rank in the top 100 of this scenario. The ten highest scoring counties from the base case and this scenario analysis are presented in Table 34.

Table 34 – Reducing weight of carbon intensity metric

		Equal weight metrics			Carbon intensity weight increased	
Rank	FIPS	County	State	FIPS	County	State
1	06037	Los Angeles County	CA	06037	Los Angeles County	CA
2	06059	Orange County	CA	06059	Orange County	CA
3	06065	Riverside County	CA	06065	Riverside County	CA
4	06073	San Diego County	CA	06073	San Diego County	CA
5	36061	New York County	NY	36061	New York County	NY
6	06075	San Francisco County	CA	06075	San Francisco County	CA
7	06071	San Bernardino County	CA	06071	San Bernardino County	CA
8	06085	Santa Clara County	CA	06085	Santa Clara County	CA
9	06067	Sacramento County	CA	06067	Sacramento County	CA
10	06001	Alameda County	CA	06001	Alameda County	CA

The data for all the counties in the carbon intensity weight reduced scenario is presented in Figure 19.

Figure 19 - Reduced carbon intensity metric weight

3.5.11 Robustness of analysis

Many of the same counties score highly in all analyses. At least 85 of the top 100 counties in the baseline analysis scored in the top 100 of the respective scenario analyses. Seventy four counties appeared in the top 100 counties of the baseline analysis and all of the scenario analyses. None of the GIS projections of the scenario analyses differed noticeably from the baseline analysis or from each other. This indicates that manipulating the weights of the policy metrics in the analysis does not greatly affect which counties are the most desirable for PHEV deployment in terms of providing the greatest benefits. The baseline analysis with all metrics weighed equally is sufficient for identifying counties that may offer the highest level of social benefits; however, policy makers could further manipulate the metric weights to emphasize certain policy goals.

4 Implications and conclusions

4.1 Characterizing highest ranking counties

The five counties that offer the greatest level of societal benefits from PHEV deployment according to the base analysis (unadjusted, normalized scores) are all in California except for New York County (Manhattan). New York County scores highly because of its population density which skew the entire population density metric (see Section 3.4.1); this high population density accounts for part of the high level of health benefits derived from pollution level reduction. The next highest ranked non-Californian county is Kings County (Brooklyn) and is ranked sixtieth in terms of benefits. Californian counties all have a high level of complementary policies to promote PHEV adoption, many of which are managed at the state level and relatively low carbon intensity¹. More urban Californian counties score especially highly due to high population density and potentially high levels of reduced health incidents. The Californian counties plus New York County score more highly in terms of benefits than any of the other counties.

The rest of the top one hundred counties are summarized in Table 35:

Table 35 - Top 100 benefits-yielding counties

County	Characteristic
New York City MSA (NY-NJ)	highest population densities
Cook County (IL)	contains Chicago (high population density and health benefits)
Counties in Washington State	low carbon dioxide intensity
Counties in Vermont	lowest carbon dioxide intensity
Maricopa County (AZ)	contains Phoenix (high health benefits)

¹ California imports 20% of the electricity consumed in the state from surrounding states. Power imported from states in the Pacific Northwest is primarily from hydroelectric sources while imports from the Desert Southwest are derived primarily from coal sources (http://www.eia.doe.gov/state/state_energy_profiles.cfm?sid=CA) . California also imports electricity from Mexico (http://www.eia.doe.gov/cneaf/electricity/epa/epa_sum.html).

The high scores of counties containing the largest metropolitan areas and counties that scored so highly in a metric they were many standard deviations higher than the mean for that metric (see next section) was unexpected. Similarly, homogeneity across California and most states in general was unexpected. For example, all 58 California counties score in the sixty counties that offer the greatest level of societal benefits.

4.2 Policy implications

The research suggests the level of benefits derived from PHEV usage does vary appreciably by county; thus, a dollar spent in one county may result in a higher quantity of benefits than a dollar spent in another county (depending on the county). Investment in these “higher leverage” counties should thus be more greatly incentivized than in other counties based on efficiency policy goals. PHEV usage results in benefits wherever they are used, although the benefits may be local or non-dependent on location of vehicle deployment. The implication is not to take the current level of incentives and investment and limit to only the counties that score highest in the analysis. However, a more “progressive” subsidy scheme may result in a higher level of benefits, i.e. greater incentives are offered to PHEV consumers in counties that offer the highest level of benefits from PHEV deployment. If certain policy goals are to be emphasized, the weights used in calculating the county scores could be manipulated to favor the applicable metric at the expense of the other metrics. For example, if a policy wanted to maximize health benefits, the metric associated with reducing health incidents would be more greatly weighted.

Skerlos and Winebrake (2010) discussed whether targeting a subsidy scheme to areas where PHEVs could yield greater benefits would result in more benefits from these vehicles per dollar spent. This analysis shows that not all counties across the US would yield the same societal benefits from deploying a PHEV; if these vehicles are to be incentivized on the basis of their providing these benefits, greater incentives should be provided to the areas that would provide the greatest benefit. As shown earlier in Figure 1, HEV ownership is scattered across the country. The purchase of the majority of these vehicles is subsidized at the federal level, so it is clear from the figure that more federal subsidies are spent in some counties versus others. It is not reasonable to expect policy that only subsidizes PHEV purchases in the counties that scored highest in this analysis, because these vehicles provide some level of benefit no matter where they are deployed and for political considerations. However, counties that provide the greatest magnitude of societal benefits could possibly receive more subsidy dollars as part of some larger exchange with other counties.

In the case of PHEVs, tailoring federal policies to account for regional and local attributes will likely yield greater benefits than a broad national incentive scheme like the one in place currently. In the latter case, every consumer has the equal opportunity to take advantage of the tax subsidy; however, considering regional heterogeneity considers to potential to improve cost-effectiveness (efficiency) of the subsidy scheme while potentially resulting in higher levels of benefits. Although a policy that takes into account regional considerations will prevent all consumers from having the equal opportunity to take advantage of the subsidy, “equity” is a function of the stakeholder in

question. Whether or not tailoring national policies would offer greater results for other policy questions requires more investigation. In considering policies to create benefits, the level of overall benefits resulting from the policy can vary if sufficient regional heterogeneity exists and these nuances are incorporated into the distribution of resources to create these benefits.

4.3 Weaknesses

4.3.1 Omission of consumer characteristics

This analysis only seeks to determine the locations where the societal benefits of PHEVs are greatest. Where social benefits occur and where PHEVs are most likely to be purchased are independent factors. However, it does not consider how those vehicles get there. PHEVs will command a price premium compared to standard ICE vehicles, especially in the short term as they are uniquely design vehicles. This was also the case with conventional hybrid vehicles, and only in later model years did manufacturers bring hybrid variants of existing conventional ICE vehicles to the market. The initial adopters of PHEVs will likely be very similar in characteristics; however, whether consumers with those characteristics exist in the counties that would yield the highest societal benefits is not examined in this thesis. For example, the purpose of the existing PHEV tax rebate is to increase the number of people that can purchase these vehicles. Whether or not a consumer can afford to purchase a PHEV is a function of that consumer's income. However, consumer income is not within the scope of this analysis.

4.3.2 Environmental justice

Rev. Benjamin Chavis, Jr. notes that environmental racism exists in the US (Bullard, 1993). He observes that minorities are exposed to greater health and environmental risks than the general population because they are powerless to resist this scenario. He also notes that racial discrimination is codified in environmental policy-making. Dorceta Taylor observes that most polluted urban communities have crumbling infrastructure and ongoing economic disinvestment (Bullard, 1993), making them score poorly in the metrics of this thesis. Thus, targeting subsidies towards counties that score higher in this analysis leaves the economically neglected communities in a self-reinforcing holding pattern of high exposure to pollutants and dependence on petroleum-based transportation (especially where public transportation is not viable or practical).

This conundrum is somewhat alleviated by utilizing a county-level resolution in the analysis. For example, counties like Los Angeles County and New York County have high populations of low income minorities that may benefit from a targeted subsidy regime. However, counties like Jefferson and Claiborne in Mississippi have a majority of black persons, according to the US Census site (<http://quickfacts.census.gov/qfd/index.html>), and score poorly according to the research analysis.

4.4 Future research

Currently, this literature acknowledges the existence of environmental justice but fails to investigate it further. It may be insightful to see how counties with traditional minorities

(black, Hispanic, or Native American) score in the analysis and to determine their per capita HEV ownership. Furthermore, another step could compare the average income of a county with how that county scores in the analysis and/or how that county's HEV ownership rate. This analysis could also be done in the near future.

In longer range analyses, more sophisticated models could be developed that include demographic data that influence purchase decisions. Also, the impacts of PHEV implementation could be explored more precisely to develop a more accurate scoring metric for evaluating counties. Furthermore, all of this information could be combined with systems dynamics modeling to determine how policies targeted towards maximizing PHEV adoption in the areas where their societal benefits are greatest actually yield these benefits and how the quantity of these benefits compare to the existing subsidy scheme.

5 Acronyms

CO₂ – carbon dioxide
EIA – Energy Information Agency
EPA – Environmental Protection Agency
FIPS – Federal Information Processing Standard
GHG – greenhouse gases
GIS – geographic information system
HEV – hybrid electric vehicle
ICE – internal combustion engine
IPCC – International Panel on Climate Change
LDV – light duty vehicle
MSA – metropolitan statistical area
PHEV – plug-in hybrid electric vehicle
VMT – vehicle miles travelled

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