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EVOLUTION OF INCENTIVES TO SUSTAIN THE TRANSITION TO A GLOBAL ELECTRIC VEHICLE FLEET

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EXECUTIVE SUMMARY

Continued battery technology advancements and global market growth have routinely led to predictions about when the new market for electric vehicles might reach a tipping point, when government support is no longer needed. Many market predictions, however, often sidestep the critical questions about sustaining policy and financing through the transition to an electric vehicle fleet. The question of how long financial purchase incentives will be needed to sustain electric vehicle market growth is a difficult and relatively unexplored one.

This assessment analyzes near-term electric vehicle market trends to inform on how governments might optimally evolve their electric vehicle incentive programs to sustain market growth. We first analyze prevailing per-vehicle purchasing incentives and how government outlays increase to maintain these incentives as the market grows. Then we assess how electric vehicle costs are reduced in the approximate time frame of 2020–2025 with increased battery production. Based on these cost reductions, we analyze when the consumer proposition might tip in favor of electric vehicles, based on the first-owner cost of operation for seven major electric vehicle markets in North America, Europe, and Asia.

Figure ES-1 illustrates the key results of the work, that the deployment of lower-cost electric vehicles is likely to reduce electric vehicle costs toward cost parity with conventional internal combustion vehicles in the 2020–2025 time frame. Electric vehicles with 100-mile or 160-kilometer real-world electric range are likely to become cost-competitive around the 2020–2021 time frame. Longer range (i.e., a range of 150-200 miles) electric vehicles are more likely to be competitive for mainstream consumers several years later. The result shown is the average across the analyzed global markets, excluding consumer incentives. Markets like Norway and the Netherlands will approach electric vehicle market cost-competitiveness faster than shown, thereby reducing the need for consumer incentives sooner. On the other hand, for the same technology costs assumptions, cost competitiveness comes slower in markets such as Germany and the United States, largely due to their lower fuel prices.

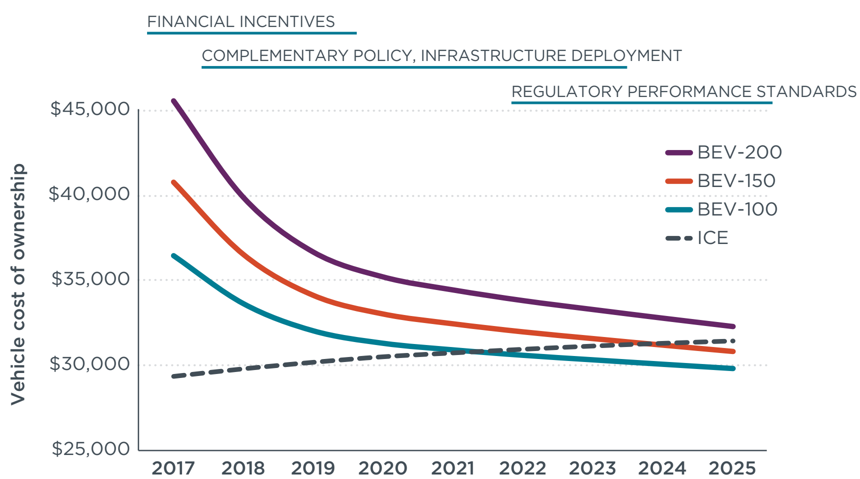

Figure ES-1. Average cost of ownership for battery electric vehicle technology (of 100-, 150-, and 200-mile electric range) compared with a conventional internal combustion vehicle

The analysis indicates that fiscal incentives will remain key to reducing this cost differential through 2020 in most markets. Additional complementary support policy will be important through 2025 or later to continue to address charging infrastructure and consumer awareness barriers. From this analysis, we see that incentives can be gradually reduced as the market grows. As automakers and governments meet their announced electric vehicle deployment goals, incentives will have to evolve to manage government revenues and provide stable support to sustain market growth of the new technology. Based on our analysis, we draw the following four conclusions on the evolution of electric vehicle consumer incentives:

> ***As electric vehicle technology costs are reduced, incentives can be lowered.*** Electric vehicle technology is advancing rapidly, much quicker than projections from just several years ago. Due largely to battery innovation and manufacturing scale, higher-range electric vehicle costs will be reduced by greater than $10,000 in the 2017–2022 time period. The electric vehicle range and cost improvements will greatly expand the electric vehicle market and reduce the need for incentives.

> ***Incentives can be strategically limited to electric vehicle models with lower vehicle prices and higher electric range.*** Incentives can target vehicles with the greatest mainstream consumer attractiveness for 2020 and beyond. Government incentive programs would benefit from incrementally shifting eligibility criteria to vehicles that are lower-cost (e.g., vehicles priced closer to average new vehicle prices) and higher-range (e.g., all-electric vehicles with greater than 200 miles in real-world driving) in the 2018 and later time frame.

> ***Incentive instruments would ideally be adopted for greater financial durability.*** Noting the importance of maintaining incentives for the next several years, governments could gain from installing vehicle taxation schemes and shifting to progressive polluter-pay systems (e.g., Norway) or "feebate" systems (e.g., France) that lock in a revenue source to the electric vehicle incentive.

> ***As fiscal incentives phase down, regulatory policy, charging infrastructure, and complementary policy remain critical in the transition to electric-drive***. Direct monetary incentives can bring electric vehicles through these initial high-cost years to approach cost-competitiveness with conventional vehicles. Expanded charging infrastructure and consumer education and awareness campaigns will continue to be important. From 2025 on, fuel economy and carbon dioxide regulations will become critical to push electric vehicles to the mass market.

Several governments have multi-year electric vehicle incentive programs that partially embrace these findings. However, few governments have locked in their incentive programs through a transition that acknowledges the technology improvements, increased vehicle sales, and long-term mainstream consumer expectations for lower-cost and higher-range vehicles. These findings could help inform robust conversations among relevant ministries, automakers, and other stakeholders about the future of incentive programs. Although the study is focused on major North America, Europe, and Asia markets, the findings apply broadly, as the technology factors are global in nature and the underlying vehicle use and fuel price assumptions fall within the markets analyzed here. A rich area for future research would be to analyze the optimal ways for electric vehicles to be promoted with performance standards after incentive subside.

I. INTRODUCTION

Continued battery technology advancements and global market growth have routinely led to predictions about when the new market for electric vehicles might reach a tipping point, when government support is no longer needed. These quick predictions, however, often sidestep the critical underlying policy and financing questions related to the complete transition to a wholly new and advanced electric drivetrain. Electric vehicle market growth through 2016 has almost entirely been in automobile markets with substantial regulatory policy and financial incentives in place. The question of how long financial incentives will be needed to sustain electric vehicle market growth is a difficult and relatively unexplored one.

Governments are increasingly taking action to accelerate the transitions to electric drive and low-carbon energy sources to help meet their climate change mitigation targets (Lutsey, 2015b). Although early in the transition, the electric vehicle market is firmly on the upswing. The markets of Europe and Asia have especially shown dramatic growth most recently, surpassing North America's electric vehicle sales in 2015. Within these three regions, the vast majority of electric vehicle sales are in markets that offer substantial consumer financial incentives for their purchase. Within those three regions, nine national auto markets account for more than 90% of global electric vehicle sales, as shown in Figure 1 (based on Pontes, 2016). Governments in these markets have generally implemented and maintained consistent fiscal and policy support to help develop the early electric vehicle market (e.g., IEA, 2016; OECD, 2015; Lutsey, 2015a). These government policies are generally meant to address the cost, convenience, and information barriers related to increasing consumer uptake of electric vehicles.

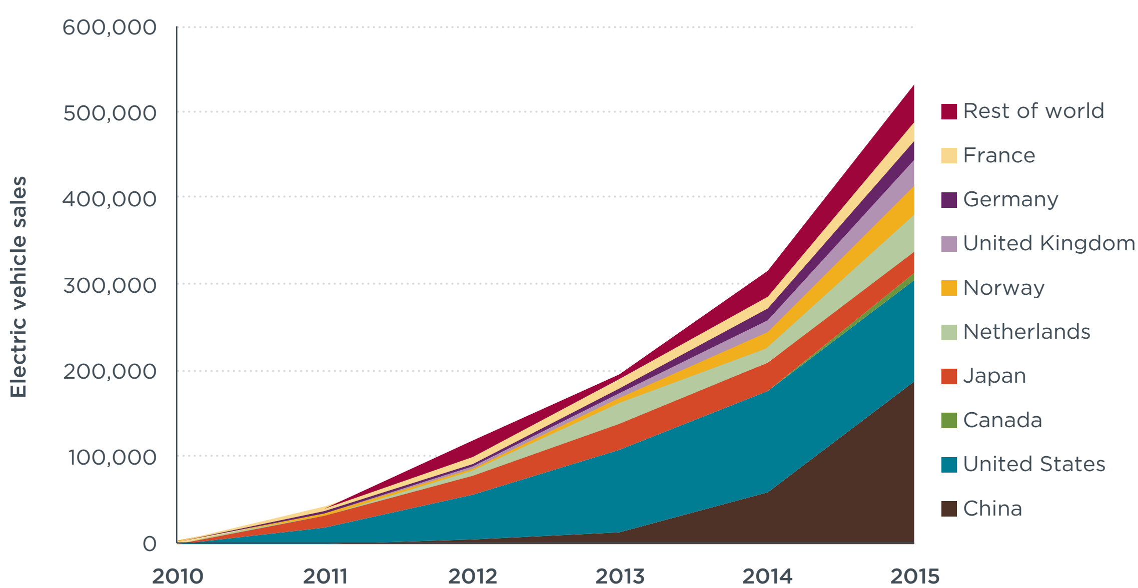

Figure 1. Annual electric vehicle sales globally through 2015

In addition to providing purchasing incentives for consumers (e.g., see Yang et al, 2016), the governments in electric vehicle growth markets have tended to implement more direct policies to directly push greater electric vehicle deployment. For example, ten states in the United States have adopted the Zero-Emission Vehicle (ZEV) regulatory program, requiring an estimated 15% of new vehicle sales in 2025 to be electric-drive (CARB, 2012; NESCAUM, 2014). The United States and the European Union use long-term efficiency standards with special regulatory incentives to promote electric vehicles (ICCT, 2015). China is developing an electric vehicle credit-trading scheme to bolster its efficiency standards and purchasing incentives (Reuters, 2016). In addition, local governments are implementing electric vehicle promotion policies. Beijing and Shanghai have used quota systems in which new vehicle licenses must be obtained through a lottery, and electric vehicles are exempted from such restrictions. Others, such as London, have implemented congestion charge pricing and exempted electric vehicles from it. Norway uses a system of perks, including free access to parking, bus lanes, and toll roads, to supplement its consumer financial incentives.

There is great uncertainty about the future global electric vehicle growth trajectory and what markets might experience the fastest growth due to their system of incentives and regulatory policy. Automobile manufacturer efforts are of course key parts of the equation. Several manufacturers have publicly stated electric vehicle targets that indicate dramatically higher electric vehicle sales volumes and shares. In particular, Volkswagen's 2025 goal (i.e., 2–3 million sales) and Daimler's 2020 goal (i.e., 100,000 sales) would amount to annual electric vehicle sales growth rates 40–50% over their 2015 electric vehicle sales (Volkswagen Group, 2016; Pandey, 2015). More electric vehicle-focused companies such as Tesla and BYD, and battery companies such as LG Chem, continue to indicate much faster annual growth rates (Groom, 2015; Hull, 2016; Randall, 2015; Yoo-chul, 2015). To address consumer barriers and grow the market, companies are deploying lower-cost battery packs, greatly increased electric model offerings across vehicle classes, and double and triple the electric driving range (Slowik et al, 2016).

These technology and market trends lead to questions about whether incentives through the early electric vehicle growth period will be attractive and durable enough to meet governments' climate change mitigation and air quality goals. Electric vehicle sales growth is increasingly amounting to substantial government outlays in the form of subsidies and exempted taxes. These trends, of consistently substantial financial incentives and increasing electric vehicle sales volumes, may ultimately result in governments' forgone taxes and subsidy outlays greatly escalating and becoming unsustainably high. Incentive programs could then become increasingly unstable, and unpredictable incentive availability could undermine the market by creating uncertainty for automakers and prospective consumers.

This assessment seeks to analyze trends in the near-term electric vehicle market, informing on how governments might optimally evolve their electric vehicle incentive programs for light-duty passenger vehicles over the 2017–2025 period to sustain market growth. We first analyze prevailing per-vehicle electric vehicle purchasing incentives and how government outlays increase to maintain consumer incentives as the market grows. We then analyze dynamics with respect to increased electric vehicle sales and technology shifts as battery costs are reduced in the approximate 2020–2025 time frame. To inform when the consumer proposition might tip in favor of electric vehicles, first-owner four-year cost of operation is assessed for a C-segment medium passenger car for seven major electric vehicle markets: Canada, China, Germany, the Netherlands, Norway, the United Kingdom, and the United States.

II. BACKGROUND

This section provides some background information and context for this assessment of electric vehicle incentives. First, some context on the fleet transition is provided, considering both the 2015 baseline state of the diffusion of electric vehicles in world markets, and the broader context of financial incentives for electric vehicles.

One framework to characterize how electric vehicle technology is advancing in the market is through the "diffusion of innovation" theory of Rogers (1962). In this framework, the diffusion of a new technology is categorized according to five groups of technology adopters. In 2015, global electric vehicle sales accounted for less than 1% of the market. Figure 2 shows the five consumer categories of technology adoption: innovators, early adopters, early majority, late majority, and laggards. In basic terms, the state of electric vehicle market of three leading markets, along with the rest of the world, is plotted on the figure to illustrate the relative diffusion of the technology. Electric vehicles have moved beyond innovators to early adopters in leading electric vehicle markets such as the Netherlands and California, at approximately 10% and 3% sales share in 2015, respectively. At 22% market share in 2015, electric vehicles in Norway have moved beyond innovators and early adopters, reaching early majority consumers. At a regional level, electric vehicle uptake can be significantly greater than averages shown in the figure, based on additional support policies that have been implemented (e.g., see Lutsey et al, 2015; Tietge et al, 2016).

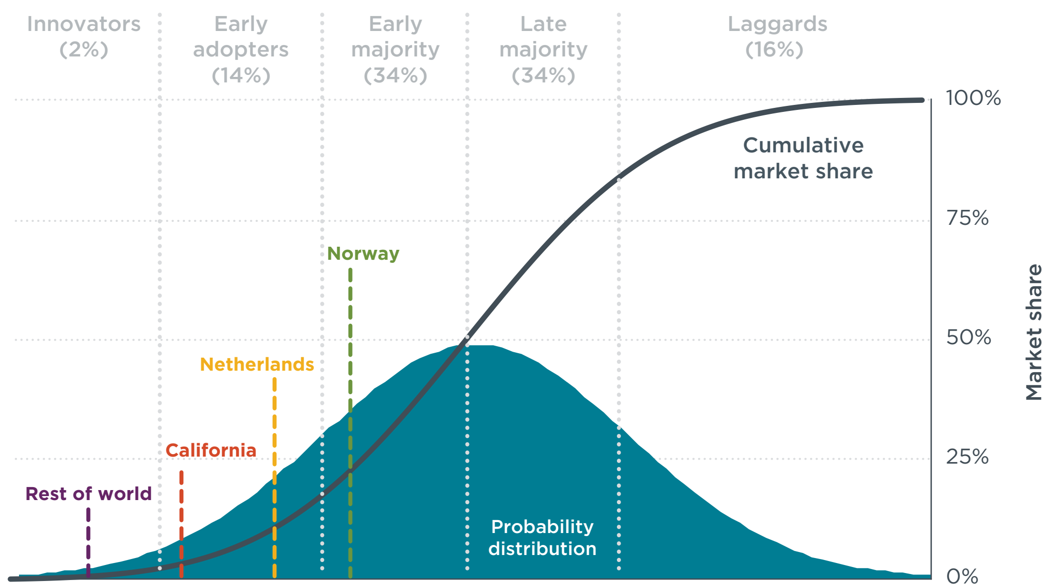

Figure 2. Technology adoption curve including select electric vehicle markets

As illustrated in Figure 2, the diffusion of electric vehicle technology in the overall vehicle market is at a very early stage globally. National markets, and regions within them, vary greatly in terms of electric vehicle uptake. Electric vehicles will inevitably reach the majority market earlier in some markets than others, reducing the importance of government support. Others may require government support for longer periods of time, as the technology more gradually extends beyond innovators and early adopters into the majority market. On the other hand, many electric vehicle markets that are expanding more slowly in the near-term could ultimately experience faster growth if and when the electric vehicle market achieves greater economies of scale. There is great uncertainty about all the factors that will ultimately be involved in such a transition to an electric fleet, beyond the more narrow technology cost factors examined in this report.

ELECTRIC VEHICLE TRANSITION COSTS AND BENEFITS

This paper is focused on consumer fiscal incentives for electric vehicles. Several factors drive the rationale for such incentives. Many governments at various levels (i.e., national, provincial, state, local) implement financial incentives and other policies to promote electric vehicles to help them cut oil consumption and achieve climate change mitigation and air quality goals. The literature on electric vehicles shows their widespread emissions and energy use benefits (see, e.g., Nealer et al, 2015; EPRI and NRDC, 2015a, 2015b) and also how critical they are for meeting climate goals for the transportation sector over the long-term (e.g., Creutzig et al, 2015; Lutsey, 2015b; Deetman et al., 2013; Greenblatt, 2015). In addition, governments support electric vehicle technology companies to help develop domestic industry leaders in the new technology. Governments frequently support the developing electric vehicle industry with policy and financial support to promote electric vehicle charging infrastructure, manufacturing, and research and development activities.

Other research has sought to tally the costs and benefits of electric vehicles, including putting consumer purchasing subsidies in a longer-term context (e.g., Greene et al, 2013, 2014). Figure 3 shows the estimated net present value of the costs and benefits of incentivizing electric vehicles in the United States, based on data from the National Research Council (NRC, 2013). The scenario shown is for a transition that leads to over 5 million electric vehicle sales per year by 2030. The costs shown are for financial incentives for electric vehicles (red), and the associated benefits stem from fuel savings and emission reductions (blue). The figure shows that within five years of implementing a major incentive program, the annual benefits of electric vehicles outweigh the subsidies that initially spur the longer-term market transition. The figure also indicates how incentives are maintained and phased down gradually. That same analysis indicates that that cumulative long-term benefits of such an electric vehicle incentive program are approximately six times the cumulative incentive costs.

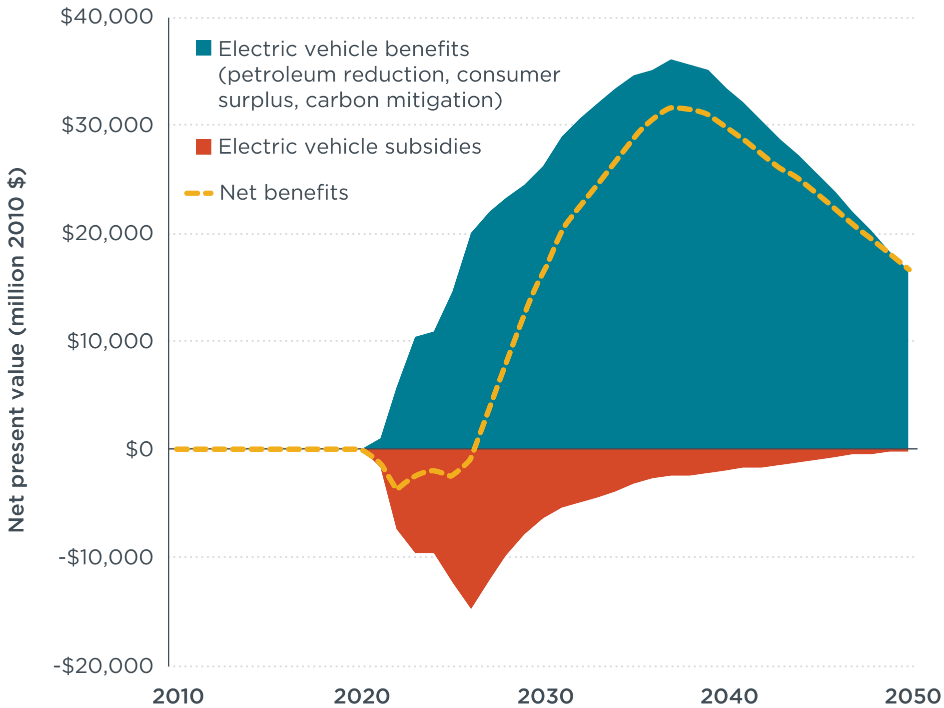

Figure 3. Estimated net present value of the costs and benefits of incentivizing electric vehicles in the United States (Based on NRC, 2013)

Several additional points help to put the magnitude of the potential U.S. government outlays displayed in Figure 3 in context of overall government outlays to promote various energy sources. Based on research by the International Monetary Fund, government subsidies for petroleum in the United States are estimated to be approximately $14 billion per year in 2013, while estimated petroleum subsidies for all seven electric vehicle markets in this study total approximately $22 billion per year (IMF, 2015). Another point of context for these electric vehicle subsidies is overall consumer transport fuel expenditures. Based on data from the U.S. Energy Information Administration, gasoline consumption over the 2010–2015 time frame costs consumers an average of more than $400 billion per year (U.S. EIA 2016a,b). These data show that the anticipated government outlays to support the electric vehicle market are orders of magnitude lower than both oil subsidies and transportation fuel expenses. We highlight a U.S.-specific example of electric vehicle subsidies and benefits, although similar dynamics are likely in other markets.

III. ANALYSIS

This section includes an assessment of per-vehicle electric vehicle incentives and potential future government outlays as a result of increasing electric vehicle sales. The analysis applies a hypothetical scenario for electric vehicle deployment that is based on plausible, optimistic electric vehicle growth that is consistent with sustained government support and technology improvements in the 2015–2023 time frame (Slowik et al. 2016). In addition, we analyze how decreasing electric vehicle costs impact the overall cost of ownership over the 2016–2025 time frame to quantify how the phasing down of incentives might best be matched with reductions in electric vehicle costs.

INCENTIVES PER VEHICLE

As an input to our analysis of major markets' incentive programs, we quantify per-vehicle incentives in the major electric vehicle markets. We base this work on vehicle specification data from official regulatory sources and auto manufacturer specification information, and vehicle sales data are based on Pontes (2016). The proliferation of electric vehicle models and combination of the associated rebates and tax exemptions (see, e.g., Mock and Yang, 2014; Yang et al, 2016) makes a comprehensive quantification of their incentives increasingly complex. As a result, we assess the incentives for a representative electric vehicle based on vehicle specification data from 2015 sales data for each market.

Governments provide financial incentives to electric vehicle consumers in a variety of ways. These incentives generally fall into one of two categories: subsidies (including income tax credits and vehicle purchase rebates) and vehicle tax reductions (including the one-time vehicle tax reduction and the annual vehicle tax reduction). Of the markets considered in this study, some offer subsidies (United States, British Columbia, Québec, Ontario), some offer vehicle tax reductions (Norway, Netherlands), and some offer both (United Kingdom, Germany, China). The exact monetary value of incentives is generally not consistent across all consumers and electric vehicle models. Incentive programs commonly have complex indexing of the incentive magnitude to factors such as consumer income, engine size, vehicles' emission rates, battery size, or comparable non-electric vehicles. Therefore, in many of the markets analyzed here, the value of incentives differs per vehicle, sometimes significantly.

Electric vehicle uptake varies widely, with each market having a unique mix of electric vehicle technology types. For example, sales of battery electric vehicles (BEVs) and plug-in hybrid electric vehicles (PHEVs) and their average performance attributes (e.g., battery capacity, range) vary greatly. To assess the approximate incentive per vehicle in each market, we determine a representative electric vehicle for each powertrain (i.e., BEV and PHEV) based on each market's sales data and how closely the electric vehicle specifications fit the average for each region in 2015. Figure 4 below shows the selected representative BEV and PHEV, including current battery capacity and electric range in 2015, for the seven key electric vehicle markets in this study. Squares represent BEVs and circles represent PHEVs. The figure shows the battery capacity (horizontal axis) and electric range (vertical axis) for each vehicle model. The electric range data shown here are based on the United States combined cycle test. From very limited test data on several electric vehicle models, the European NEDC test cycle data from electric vehicles is similar (typically within 10%) of the United States test cycle values shown. Vehicles' real-world electric range is typically about 30% lower than the United States tested range reported (U.S. EPA, 2016c). The figure shows how the average electric vehicle specifications tend to differ among markets. Four BEVs (Nissan Leaf, Volkswagen e-Golf, Renault Zoe, and BAIC EV200) and four PHEVs (Chevrolet Volt, BYD Qin, Mitsubishi Outlander, and Volkswagen Golf GTE) are representative of one or more of the key electric vehicle markets in this study.

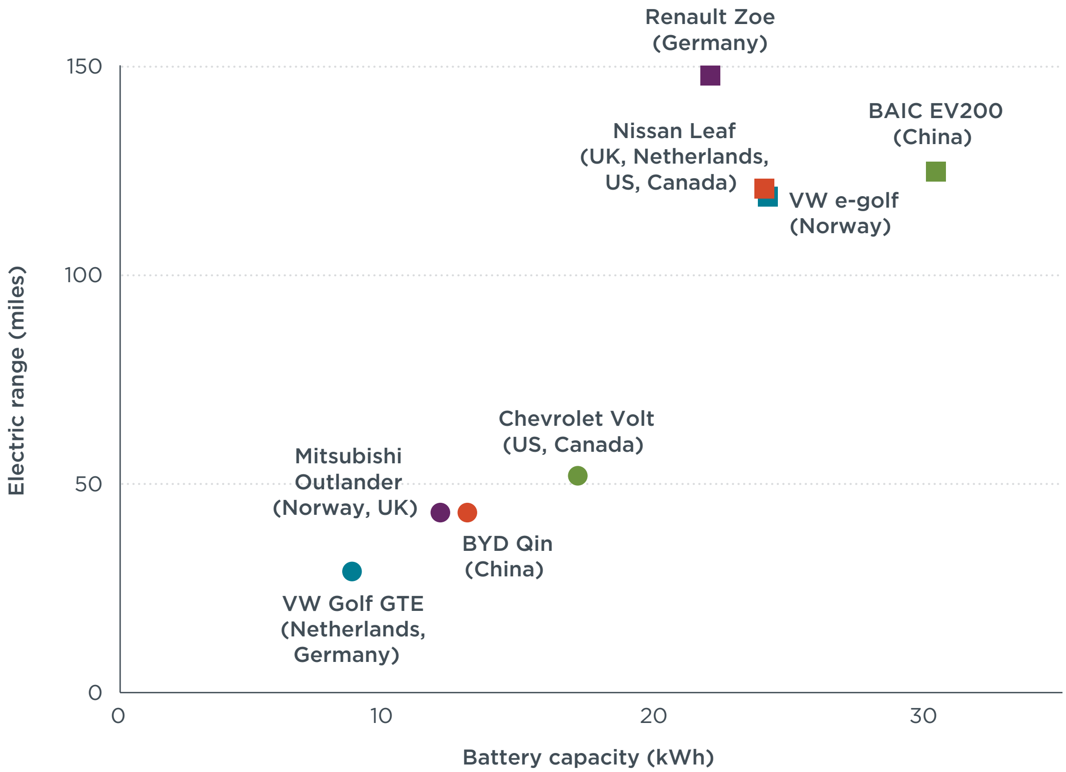

Figure 4. Representative electric vehicle models in major markets in 2015

Based on Figure 4, we use each of the above representative electric vehicles to quantify the approximate value of government incentives per vehicle in each market. Figure 5 shows the approximate value of government incentives in U.S. dollars for the representative BEV and PHEV in each major market. These estimates include applicable subsidies and national taxation policies in order to quantify the tax difference between electric vehicles and their non-electric counterparts, using the same method as applied previously (see Mock and Yang, 2014; Yang et al. 2016) with updates through early 2016. Information on the incentive programs in each market comes from ACEA (2016), as well as official national and provincial government resources. As shown in the figure, the incentive value per vehicle often differs greatly, both across technology types and across markets. The figure also shows how per-vehicle incentives tend to be greater for BEVs than for PHEVs. For conversion of various currencies, we adopt currency exchange rates from the beginning of 2016.

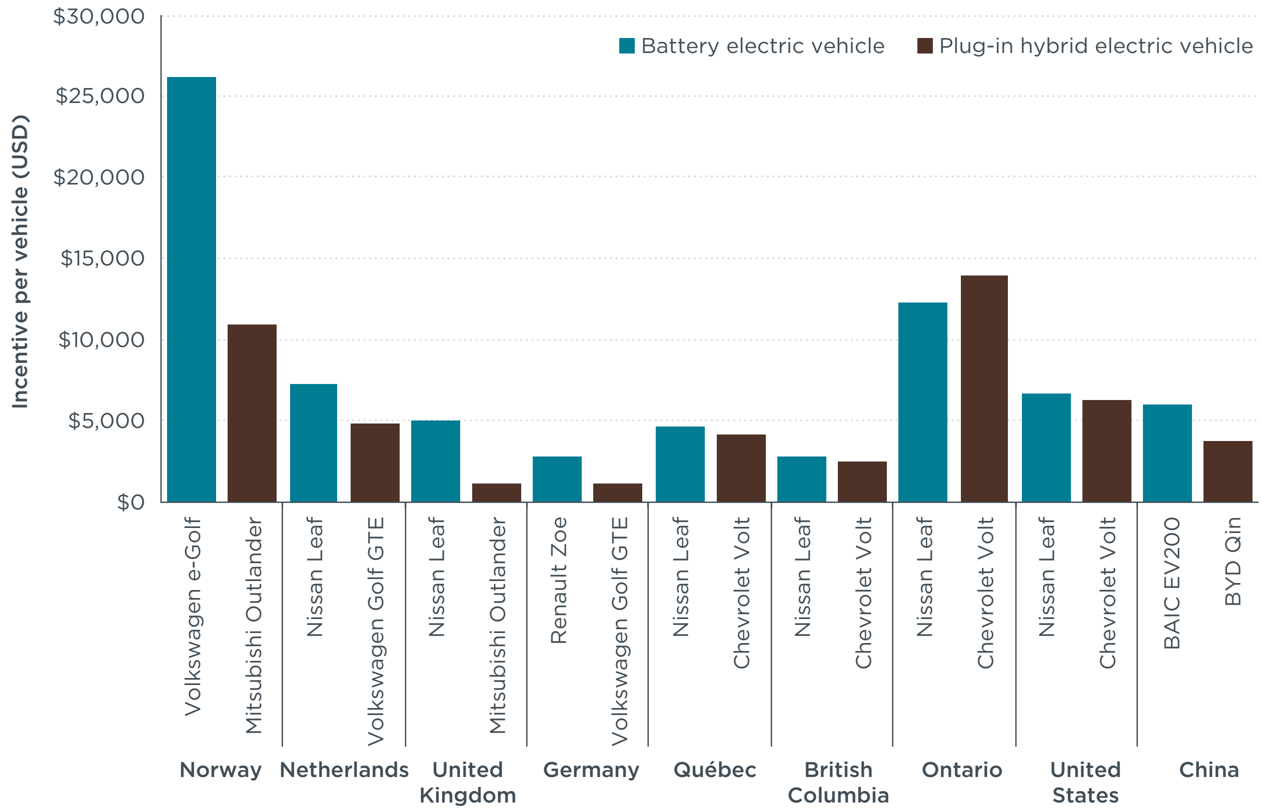

Figure 5. Available incentives per vehicle in major electric vehicle markets in 2016

Additional information on the incentive programs in each market is described below. We highlight the key electric vehicle incentive policies in place in 2015 and a few program updates for 2016, as announced by governments. These short descriptions provide context for how various elements of the electric vehicle incentive regimes could evolve over time. We note that the following discussion and analysis only include incentives available at the national level, with the exception of Canada, where the three Canadian provinces' incentives are included and there is no national-level incentive. In doing so, we note that the incentives available to a consumer in each market may in fact be larger than what is documented here. For example, states in the United States that provide incentives typically offer $1,000 to $3,000 per BEV and about half that amount per PHEV (see Lutsey et al, 2016). Similarly, a number of pilot cities in China offer local subsidies that are approximately of similar value to the national incentive (see Yang et al, 2016).

Norway. As indicated above, Norway has implemented incentives in the form of vehicle tax reductions; the value of incentive per vehicle is therefore dependent on a comparison non-electric vehicle as well as the taxation system in place. Norway levies high value-add tax (VAT) and registration taxes on vehicles. BEVs are exempt from both, whereas PHEVs pay the full VAT and claim partial exemption to the registration tax. The one-time registration tax is calculated based on vehicle weight, power, nitrogen oxide (NO_x) emissions, and carbon dioxide (CO_2) emissions. This incentive scheme is reflected in Figure 5, which shows that incentives for the representative Volkswagen e-Golf BEV are more than twice as high as the Mitsubishi Outlander PHEV. VAT exemption incentives for BEVs in Norway are available through 2017 (Autonews, 2015). Vehicle registration tax policies are subject to review on an annual or semiannual basis.

Netherlands. Like Norway, the Netherlands incentivizes the purchase of electric vehicles by offering vehicle tax reductions. There are both one-time and annual vehicle tax reduction incentives for which electric vehicle buyers may qualify. The one-time registration tax is calculated based on vehicle carbon dioxide (CO_2) emissions; BEVs are fully exempt and PHEVs receive partial exemptions. Consumers also pay an annual circulation road tax, which is based on vehicle weight, fuel, and CO_2 emissions. Through 2015, vehicles with emissions of 0-50 gram CO_2 per kilometer (g/km) were exempt from the annual road tax. Electric vehicle incentives in the Netherlands are altered periodically, as both the vehicle registration and circulation taxes are typically reconsidered and adjusted every one to two years (Yang et al, 2016).

United Kingdom. In the United Kingdom, electric vehicles benefit from both direct subsidies and vehicle tax reductions. In 2015, a £5,000 plug-in car grant was available to new vehicles that produce less than 75 gram CO_2 per kilometer (g/km). As of March 2016, the program was modified to a tiered system that is based on vehicle CO_2 emissions, electric range, and purchase cost. Under the new program, most BEVs are eligible for up to £4,500 whereas most PHEVs are eligible for up to £2,500. Vehicles with a purchase price of £60,000 or more are ineligible for the grant. In addition to the available subsidy, electric vehicles benefit from lower one-time and annual excess duty taxes, which are based on CO_2 emissions. The current value of the Plug-in Car Grant is available through March 2017, or until a predetermined sales threshold is met, whichever is sooner (Office for Low Emission Vehicles, 2016a). The government has committed to the Plug-in Car Grant through March 2018, but the exact value of the grant after March 2017 (or after the predetermined sales threshold is met) is uncertain (Office for Low Emission Vehicles, 2016b).

Germany. In 2015, Germany offered vehicle tax reduction incentives for electric vehicles. Electric vehicles registered before 2016 received a ten-year exemption from the annual circulation tax, vehicles registered in 2016 and beyond receive a five-year exemption. As of March 2016, Germany implemented a subsidy program, granting up to €4,000 per BEV and €3,000 per PHEV. Vehicles with a list price of €60,000 or greater are not eligible for the subsidy. Electric vehicle subsidies are available in Germany through 2019 or until the €600 million program budget is exhausted, whichever occurs first (Tietge, 2016).

Québec. Québec offers electric vehicle subsidies through its Drive Electric rebate program. Most BEVs are eligible for up to 8,000 Canadian dollars (CAD). The rebate value for PHEVs is dependent on vehicle battery capacity; buyers of PHEVs may receive 500, 4,000, or 8,000 CAD. For example, the Chevrolet Volt PHEV with a battery capacity of 17 kWh is eligible for the maximum 8,000 CAD rebate. The Drive Electric rebate program is in place through 2020, or until funds are exhausted, whichever occurs first (Québec, 2016a). In January 2016, the government modified its annual vehicle registration fee to discourage high-emitting vehicles by scaling the fee magnitude with engine displacement, granting electric vehicles an additional relative incentive (Québec, 2016b).

British Columbia. Like Québec, British Columbia offers subsidies for the purchase or lease of electric vehicles through its Clean Energy Vehicle program. Funds were exhausted in early 2014, but the government reinstated the program in April of 2015. Under the new program, BEVs are eligible for a 5,000 CAD subsidy. PHEVs with battery capacity above 15 kWh are eligible for the full 5,000 CAD whereas PHEVs with a battery capacity between 4 and 15 kWh are eligible for half that amount. As of March 2016, vehicles with a purchase price of over 77,000 CAD are not eligible for rebates. Incentives under the Clean Energy Vehicle program are available through March 2018, or until program funds are depleted, whichever occurs first (British Columbia, 2016).

Ontario. Ontario has offered subsidies for the purchase or lease of electric vehicles since 2010. Under the 2016 incentive program, electric vehicles are eligible for a rebate between 6,000 CAD and 10,000 CAD, depending on battery capacity. To be eligible for rebates, vehicles must have at least 5 kWh of battery capacity. Vehicles with a battery capacity greater than 16kWh are eligible for an additional 3,000 CAD incentive. Electric vehicles with five or more seats are also eligible for an additional 1,000 CAD. Vehicles with a purchase price between 75,000 CAD and 150,000 CAD are eligible for a maximum of 3,000 CAD. The Ontario government has not announced an end date or funding cap to the program (Ontario Ministry of Transportation, 2016).

United States. In the United States, the federal government provides electric vehicle incentives in the form of income tax credits. The value of the tax credit starts at $2,500, increasing based on battery capacity; electric vehicles with a battery capacity of 17 kWh or greater are eligible for the maximum $7,500 incentive. The federal income tax credit incentive is available for each manufacturer's vehicles until 200,000 qualifying vehicles are sold (U.S. Internal Revenue Service, 2016). In addition to this national subsidy, many states, such as California, Connecticut, Maryland, and Massachusetts, offer additional rebates, which typically range from $1,000 to $3,000 per BEV and are about half that for PHEVs. These state-level incentives vary greatly in their amounts, eligibility, and expected durability over time, and they are therefore excluded from this analysis.

China. China incentivizes new energy vehicles (i.e., BEVs, PHEVs, fuel cell vehicles) with both subsidies and vehicle tax reductions. The central government only offers rebates to electric vehicles that meet certain electric range criteria: BEVs with a range of over 250 km are eligible for the maximum 55,000 CNY whereas PHEVs with an electric range of over 50 km are eligible for up to 30,000 CNY. The central government subsidies are available through 2020; the value decreases by 20% in 2017 and by another 20% in 2019. In addition to subsidies, electric vehicles benefit from vehicle tax reduction incentives. Electric vehicles are fully exempt from the one-time acquisition tax. Compared to conventional vehicles, electric vehicles also benefit from lower excise duty taxes, which are partially based on engine displacement. In addition to one-time tax incentives, the central government announced in May 2015 that electric vehicles are fully exempt from the annual vehicle and vessel tax. Similar to the United States, additional incentives are also available from subnational governments (e.g., Beijing, Shenzhen, Shanghai, Hefei, and Hangzhou). These local incentives can be approximately equal in per-vehicle value to the national incentives, but they are excluded from the analysis here.

A number of the governments described above are considering, or have already established, a timeline to phase down their respective incentive programs. This tapering of their incentives helps to set a timeline for government financial support for the emerging industry. Figure 6 below shows three markets that have established incentive programs that include a reduction in incentive value over the next several years. We note that the value of incentives in each market has been converted to U.S. dollars. China, for example, has announced that the value of the available subsidy for both BEVs and PHEVs will be reduced by 20% in 2017, another 20% in 2019, and eventually be eliminated by 2021. The figure shows the maximum available incentive for BEVs (brown line) and PHEVs (brown hashed line) in China. In the United States, the incentive phase-down is triggered by cumulative manufacturer-specific electric vehicle tax credits reaching 200,000 vehicles. The figure shows an illustrative high-volume manufacturer (blue hashed line) reaching the 200,000-vehicle threshold in the United States in early 2019, at which point the maximum $7,500 incentive for vehicles by that manufacturer quickly scale down and are eliminated after one year. An illustrative medium-volume manufacturer that is assumed to reach the 200,000-vehicle threshold sometime after 2022 is also shown (blue line); incentives remain at $7,500 until the threshold is reached. The figure also shows the United Kingdom plug-in car grant. The grant was modified in 2016 from a flat £5,000 subsidy for all plug-in electric vehicles to a tiered system based on vehicle range, emissions, and cost. In other markets the phase-down of incentives might occur, but there is no prescribed timetable at present.

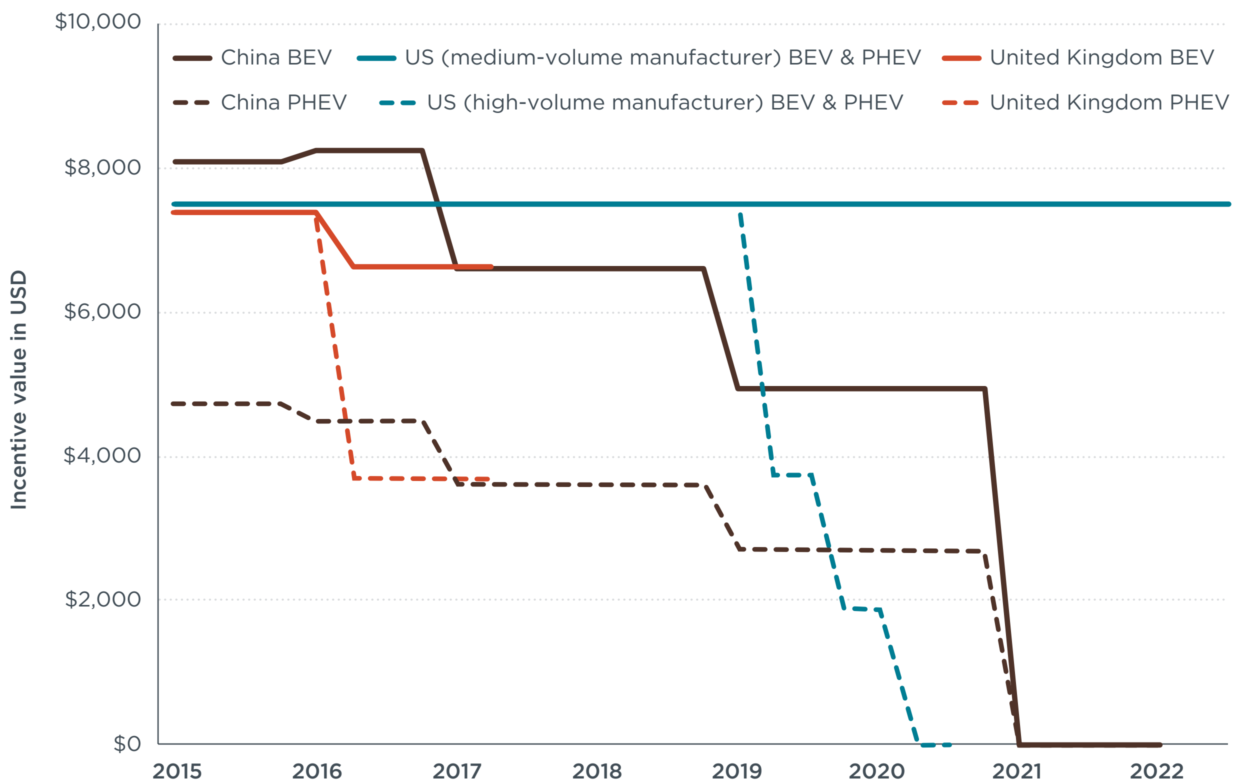

Figure 6. Electric vehicle incentives in China, the United States, and the United Kingdom for BEVs and PHEVs from 2015 through 2022

TREND FOR TOTAL GOVERNMENT INCENTIVES

As indicated above, because of electric vehicles' relatively high costs, incentives are a key part of helping to buy down the initial investment in the new technology. Building off the previous section on representative BEV and PHEV incentives and scheduled changes to them, we factor in continued electric vehicle growth to assess how total government outlays could increase in future years. As defined earlier, government outlays include expenditures from subsidies as well as foregone taxes from incentives in the form of tax exemptions. The ultimate government outlays depend on a number of factors, including the amount of incentives per vehicle, as discussed above, and future sales volumes of electric vehicles.

As a first step for this government incentive analysis (and for the analysis below of how electric vehicle costs reduce over time), we develop two hypothetical scenarios for increased electric vehicle deployment. Figure 7 shows a hypothetical high-growth scenario of future annual electric vehicle sales for the seven key markets in this study. As done previously (Lutsey, 2015b), Figure 7 is based on electric vehicle sales goals that have been announced by governments. The figure shows annual electric vehicle sales increasing from about 500,000 per year in 2015 to over 5 million per year in 2025. The average compounded annual growth rate for all regions in the hypothetical scenario shown from 2015–2025 is 30%. Based on the scenario outlined, more than half of annual global electric vehicle sales over the next decade are anticipated to be in China.

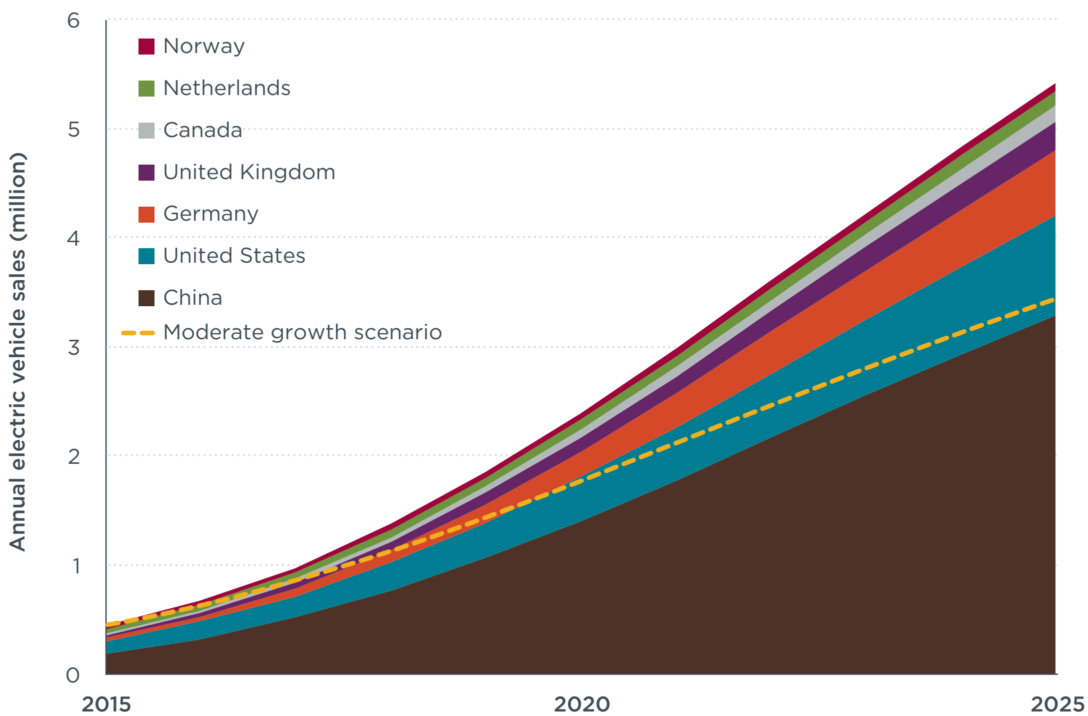

Figure 7. Hypothetical annual electric vehicle sales by region for this assessment (with additional illustration of moderate growth scenario)

In addition to the hypothetical high-growth scenario shown in Figure 7, we consider a second, more moderate scenario (hashed line). The moderate growth scenario would not achieve government targets, but would still amount to a robust growth trajectory that matches aggressive automaker projections, as done in Slowik et al. (2016). In the hypothetical moderate scenario, annual sales amount to approximately two-thirds of the high-growth scenario, reaching nearly 3.5 million sales per year in 2025. The 2015–2025 average compounded annual growth rate in the moderate growth scenario is 25%. Both the high- and moderate-growth scenarios are used to estimate future government outlays below. We first present estimated annual incentive outlay findings for two national markets, the United States and China, and then summarize results for all seven markets further below.

Figure 8 shows a hypothetical electric vehicle sales growth scenario and the corresponding upper bound for federal government outlays in the United States from the income tax credit incentive. The figure includes hypothetical sales growth by manufacturer (stacked wedges, left axis) and annual federal tax credit outlays (hashed line, right axis). The illustrative growth, to over 900,000 electric vehicle sales in 2025, follows that of the "high-growth" scenario outlined above; we apply the "high-growth" scenario growth rates to manufacturers' electric vehicle sales volumes in 2015. As shown in the figure, annual tax credit outlays peak at over $1.5 billion in 2018. Around the 2018–2019 time frame, a number of high-volume manufacturers such as Tesla, Nissan, and General Motors, under this scenario, are anticipated to reach the manufacturer-specific 200,000 plug-in electric vehicle threshold, triggering the tax credit phase out. Other manufacturers are expected to reach the 200,000-unit threshold in later years.

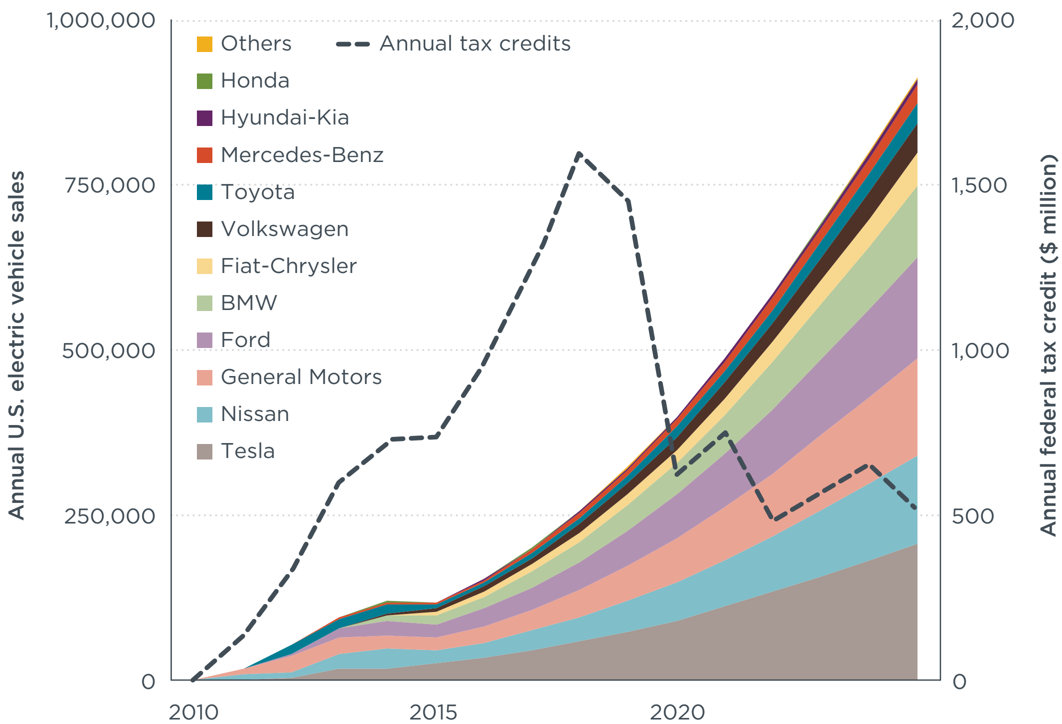

Figure 8. Hypothetical electric vehicle growth scenario and estimated government outlays in the United States

For the above analysis of the United States, we emphasize that these results are the maximum potential tax credits if all vehicle owners receive the full federal tax credit benefit, even though not all electric vehicle owners are eligible or file for these incentives. In comparison, per context provided above in the background, the approximate $700 million in U.S. federal tax credits for electric vehicles provided in 2015 amounts to about 5% of annual petroleum subsidies and less than 0.2% of total consumer transport fuel expenses in the United States.

In addition, we provide a similar estimation of electric vehicle growth and government outlays in China. Figure 9 shows the hypothetical high-growth (blue line) and moderate-growth (yellow line) scenarios, as well as the corresponding annual government outlays (hashed lines). We note that outlays are the national central government purchase incentives, and therefore do not include research and development expenditures or all of the pilot cities' additional incentives, which are typically of similar value (see Yang et al, 2016, for more information). For this analysis, we assume that the mix of electric vehicles remains constant at two-thirds BEV in the future. Based on the moderate- and high-growth scenarios, the figure shows electric vehicle sales in China reaching approximately 1.0 million to 1.5 million per year in 2020and 1.5 to 2.5 million per year in 2023. The total associated annual outlays peak in 2020 at $2.5 billion (moderate growth) to $3.5 billion (high growth) per year, before incentives phased out entirely in 2021. As discussed above (see Figure 6), China has established a timeline to phase down their incentive program. The figure shows the impact of reducing the value of incentives by 20% in 2017 and another 20% in 2019.

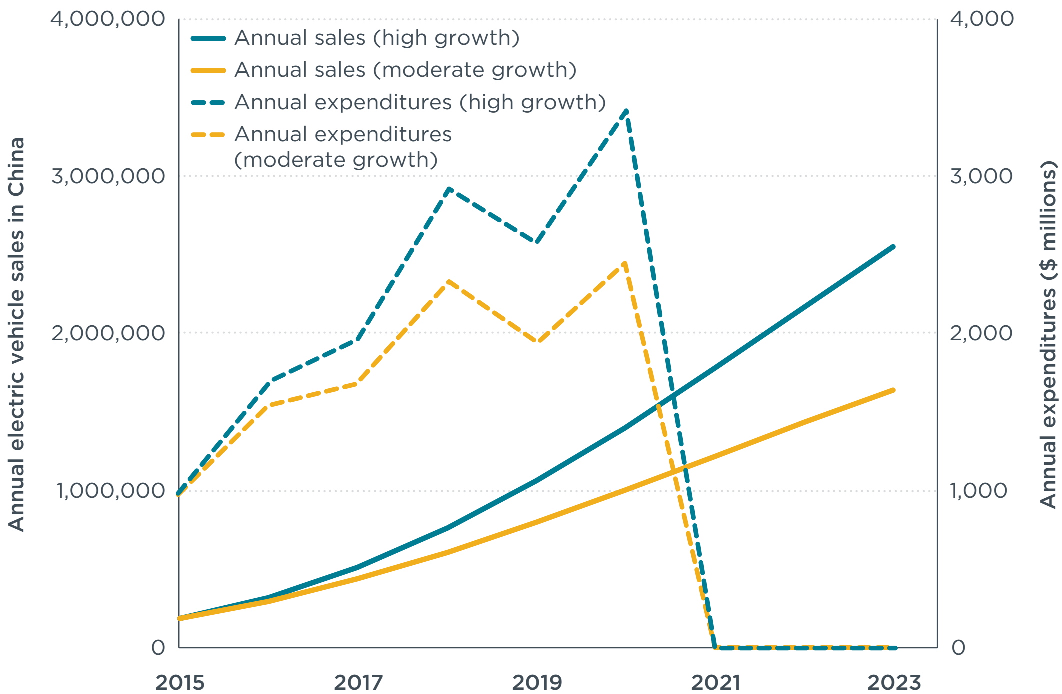

Figure 9. Hypothetical electric vehicle growth scenario and estimated government outlays for consumer electric vehicle incentives in China

We conducted similar analyses as above for China and the United States for the other five markets in this analysis. The results for the total potential electric vehicle incentive outlays across the seven markets are summarized in Table 1. As above, we are assuming incentives continue as in their 2016 form, unless they have established timetables for their elimination. As shown, the total annual national China incentives begin at approximately $1 billion in 2015, and increase to approximately $2.1-$2.6 billion in the 2016–2020 time frame. In comparison, annual outlays in the United States increase from $0.7 billion in 2015 to approximately $1.1-$1.2 billion in the 2016–2020 time frame; the slower growth in total outlays in the United States is partially due to high-growth manufacturers losing incentive eligibility as they reach the 200,000 sales threshold. In the United Kingdom, where the plug-in car grant has been committed through March 2018, annual outlays are shown to be greater in 2015 than the 2016-2020 average. Locking in the current plug-in car grant through 2020 would increase the 2016-2020 annual average outlays in the United Kingdom to approximately $0.2 billion. For the seven markets in this study, the total estimated average government outlays over 2016–2020 are approximately $4.6-$5.6 billion per year. As above, we note that this evaluation only considers incentives that are available at the national level. Canada is the exception. It has no national-level electric vehicle incentive, but we include the incentives available at the provincial level in Québec, British Columbia, and Ontario.

Table 1. Potential government impacts from continued electric vehicle incentives for two hypothetical electric vehicle growth scenarios

		Approximate annual government outlays with 2016 electric vehicle incentive programs (billion USD)		
	2015 electric vehicle sales	2015	2016-2020 average (25% annual moderate-growth scenario)	2016-2020 average (30% annual high-growth scenario)
China [a]	190,000	$1.0	$2.1	$2.6
United States [a]	110,000	$0.7	$1.1	$1.2
Norway	34,000	$0.7	$0.8	$1.0
Netherlands	44,000	$0.2	$0.3	$0.4
United Kingdom	28,000	$0.1	$0.05	$0.06
Germany	23,000	$0.0	$0.1	$0.2
Canada [b]	7,000	$0.03	$0.2	$0.2

Numbers in the table are rounded
[a] *Excludes state, province, city level consumer electric vehicle incentives*
[b] *Includes provincial level incentives for British Columbia, Ontario, Québec*

FIRST-OWNER FOUR-YEAR COST OF OWNERSHIP

Due to the increasing outlays as a result of providing electric vehicle incentives, governments will face questions about when incentive programs become too costly and when electric vehicle technology improvements might make incentives unnecessary. We sought to more narrowly investigate whether reduced battery and electric vehicle costs in upcoming years provide an opportunity to reduce incentives. In particular, we investigated the circumstances under which electric vehicle technology might experience reduced costs from greater production scale, and thus enable cost-competitiveness with comparable conventional vehicles.

For this analysis we make a series of assumptions in order to approximate when electric vehicles are likely to become cost-competitive with comparable conventional vehicles for a first-owner of an electric vehicle. We estimate the four-year cost of ownership of a typical battery electric vehicle versus its non-electric counterpart over the 2017–2025 time frame. The cost of ownership includes information on vehicle purchase, fueling, and maintenance costs over a four-year ownership period. Vehicle purchase price is assumed to be consistent across each of the markets assessed. For electric vehicles, the cost of ownership evaluation also includes information on service equipment costs (e.g., home charging) as well as the replacement cost of utilizing another vehicle for longer trips (see Lin and Greene, 2011; Lutsey, 2015c). We assume a four-year ownership period in order to take a realistic view of a consumer who is leasing or owning the vehicle for expected basic consumer ownership costs and benefits. Yet we acknowledge there are much greater vehicle lifetime energy savings and other benefits (e.g., battery second life, grid services, etc.) than those we have included in this narrow first-owner analysis.

This analysis incorporates additional information and projections on many technology and cost factors from government agencies, national laboratories, utilities, and international organizations. This cost of ownership evaluation does not incorporate the government incentives for electric vehicles, as assessed above, for several reasons. Foremost, the various electric vehicle incentives (e.g., rebates, tax credits, registrations, value-add tax exemptions) are excluded because the importance and the durability of these incentives into the future is a core question of this research. As we investigated the details of the various incentive provisions, we found that there was uncertainty as to how long and to what extent each aspect of the governments' incentives would continue between 2016 and 2020. Removing the incentives removed that analytical uncertainty. This exclusion also allows us to consistently isolate and compare how the gap between electric vehicle and conventional vehicle costs is converging in each market, rather than holding some incentives in place and phasing down the ones that are more like to go away. This approach was chosen to best and most simply inform on when the various tax and subsidy mechanisms could be reduced.

We hold similar technical assumptions for a standard electric vehicle the size of a Nissan Leaf across global markets. We also maintain similar technical assumptions for its comparable conventional gasoline vehicle. For this analysis, we are simply identifying the time at which—for given vehicle use, initial purchase price, fuel, electricity, maintenance, service equipment, and replacement vehicle services—the consumer proposition tips in favor of the electric vehicle. We include vehicle efficiency improvement over time for the electric and conventional vehicle. We analyze the impact of varying electric vehicle battery size, range, and cost, as specified below. In so doing, the analysis here depicts how the same electric vehicle models might become more attractive at varying time scales, depending on location. Details on the assumptions across the seven markets are summarized in the Annex.

The largest determinant of electric vehicles' purchase price and incremental cost over internal combustion vehicles is the cost of battery packs. As analyzed previously (see Slowik et al, 2016; Wolfram and Lutsey, 2016), battery costs are expected to decrease from an industry-average $400/kWh in 2015 to $150–$175/kWh in 2025, primarily as a result of shifting to higher-volume battery manufacturing scale. We compare our analysis here with that of the National Research Council, which previously estimated battery costs falling from approximately $360–$380/kWh in 2015 to approximately $240–$280/kWh in 2025 (NRC, 2013).

Figure 10 shows the incremental vehicle costs of electric vehicles compared with those of a conventional internal combustion engine (ICE) vehicle in 2010. The ICE (grey line) shows the anticipated additional cost of up to $1,500 in 2025 to comply with adopted efficiency standards. The figure also shows the NRC electric vehicle incremental costs for their case of a 130-mile test cycle BEV, in their mid- and optimistic cases. The NRC incremental BEV costs are estimated as falling from $11,000–$12,000 in 2015 to $5,000–$7,000 in 2025. In comparison, our analysis (based on Slowik et al, 2016; Anderman, 2014, 2016a,b; Nelson et al, 2015) indicates lower costs even for higher-range electric vehicles. We find that the incremental cost of the 100-mile real world BEV compared with a reference year 2010 ICE vehicle is approximately $6,000 in 2018, falling to approximately $3,000 in 2025 (blue line). As also indicated, our analysis shows the 150-mile real world BEV is similar in cost to the NRC optimistic case for a significantly lower range vehicle. We provide these comparisons with NRC for context on how updated research estimates have changed over the past several years; however, we note there are differences in the precise methods and underlying assumptions (e.g., range, vehicle specifications) between the two studies.

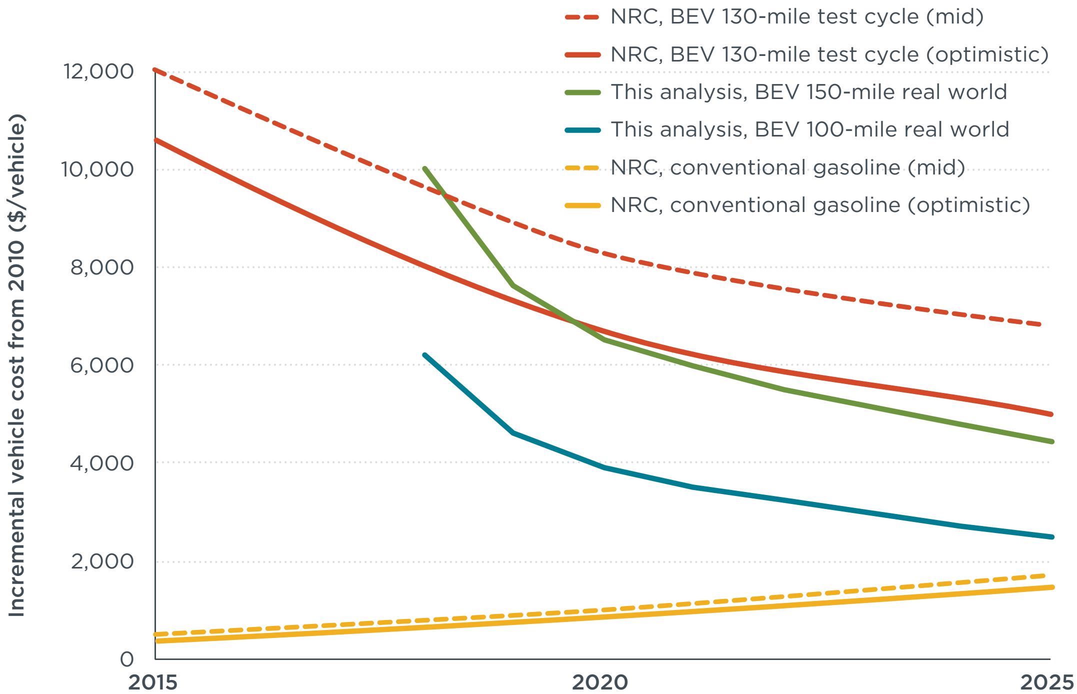

Figure 10. Incremental vehicle cost compared with a 2010 internal combustion engine vehicle

As shown in the figure, electric vehicle cost reductions are occurring faster than previously projected. This is the case for a number of different reasons. As found by Nykvist and Nilsson (2015) previous analyses were likely conservatively overestimating battery pack costs. Since then, there have been many innovations in the lithium-ion chemistries as suppliers emerged and began to manufacture cells at increasing scale. In addition, as lithium-ion battery technology has matured, researchers have developed a better understanding of the link between battery pack costs and production scale (see Anderman, 2014, 2016a,b; Nelson et al, 2015). Competitive battery production volume is ramping up faster than NRC (2013) and others projected. Production volumes of six industry-leading electric vehicle battery manufacturers surpassed 50,000 battery packs per year by 2015, and additional upstart companies are ramping up and competing for automaker contracts (See Slowik et al, 2016).

Based on the assumptions outlined above, Figure 11 shows the estimated cost of ownership in 2017 and 2025 for battery electric vehicles of varying range as well as a comparable gasoline ICE vehicle. We show a gasoline vehicle for reference because it is the dominant conventional vehicle in most of the seven vehicle markets analyzed in this paper. We show one particular example, for the United Kingdom, but we conduct the analysis for all the seven markets. The vehicles assessed include a gasoline car with a real-world fuel economy of 35 miles per gallon (mpg) in 2017 (approximately 110 g CO_2/mile and 50 mpg on the U.S. test cycle), increasing at 3% per year to 44.4 mpg to approximate achieving efficiency and carbon emission standards through 2025. The BEVs shown are for real world driving range of 100, 150, and 200 miles of electric range (e.g., the BEV-150 is assumed to be able to travel 150 miles on a single charge).

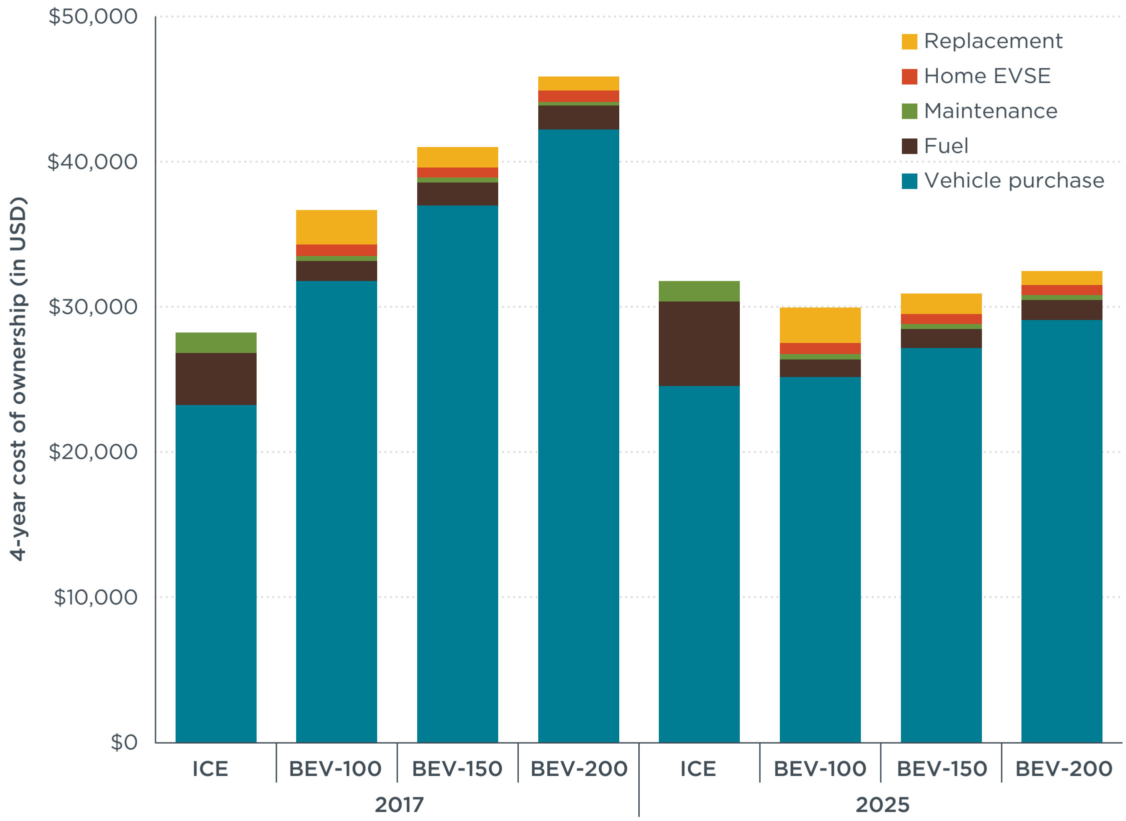

Figure 11. Evaluation of the cost of ownership for various vehicle technologies in the United Kingdom in 2017 and 2025

We provide further details on the assumptions regarding the Figure 11 and subsequent analysis here, and further details on the vehicle assumptions are summarized in the Annex. For context, the reference gasoline car specifications indicate that its comparable range on a full tank of gasoline is 400 miles. Electric vehicles' real world electric range is typically about 30% lower than the United States tested range reported (U.S. EPA, 2016c). For comparison, the U.S. combined cycle test values for each of these BEVs would be 143, 214, and 286 miles (230, 344, and 460 km), respectively. The electric vehicles used here are assumed to have battery capacities of 33, 50, and 66 kWh in 2017. BEV energy consumption per mile is assumed to reduce by 2% per year from approximately 0.3 kWh/mile in 2017 to 0.25 kWh/mile in 2025. As a result, the more efficient electric vehicles require lower-capacity battery packs, which are assumed to be 28, 42, and 56 kWh by 2025, respectively. As indicated above, we hold similar technical assumptions for a standard electric vehicle the size of a Nissan Leaf across global markets. We maintain similar technical assumptions for its comparable gasoline vehicle. By doing so, we set realistic benchmark vehicles today to help assess future technology and cost differences.

Several points help explain the results in Figure 11. The figure shows low-range electric vehicles approximately reaching cost parity with comparable conventional vehicles in the United Kingdom by 2025. As shown, the purchase price (blue) of the combustion vehicle in 2017 is shown as approximately increasing by $1,200 from 2017 to 2025 due to its additional efficiency technology. The figure shows that the four-year cost of owning and operating an illustrative conventional vehicle in the United Kingdom is estimated to increase from approximately $28,000 in 2016 to $32,000 by 2025, with the increase primarily due to increasing projected fuel costs that offset the efficiency fuel savings from the ICE efficiency technology. We assess the electric vehicle costs based on the battery pack cost projections outlined in Slowik et al., 2016. As shown in the figure, the initial purchase prices of the BEV-100, -150, and -200 are approximately $32,000, $37,000, and $42,000 in 2017. By 2025, the purchase price for these same vehicles are expected to be approximately $25,000, $27,000, and $29,000, representing cost reductions of approximately $7,000, $10,000, and $13,000, respectively, due to battery cost improvements.

Figure 11 shows the four-year cost of ownership for the illustrative BEV-100 and BEV-150 vehicles reaching cost-competitiveness with the ICE vehicle before 2025. This is as a result of the battery cost improvements as well as the much lower energy costs (compared with conventional gasoline refueling) and, to a lesser extent, lower maintenance costs. In the case of the BEV-100, the net benefits tip the cost of ownership in favor of the electric vehicle. As indicated, energy costs are approximately four times greater for the ICE gasoline refueling than the BEV electric charging in 2025. Additional expenses exclusive to electric vehicles include the cost of purchasing and installing electric vehicle service equipment (approximated as $750, shown in red), as well as occasionally utilizing a replacement vehicle for longer trips (shown in orange).

We conducted similar analyses as above for the United Kingdom for each of the seven key markets in this study. Figure 12 shows the four-year cost of ownership for the same illustrative vehicles using the same methodology as outlined above, but for each year over the 2017–2025 time frame, rather than a 2017 and 2025 snapshot. As shown, the cost of ownership curves differ slightly in each market. The differences are a result of regional variation in petroleum fuel prices, electricity prices, and average annual consumer travel demand. Fuel prices in Europe, for example, tend to be more than twice as high as in North America. Annual consumer travel in North America is typically 50% greater than in Europe (based on ICCT, 2016). Evaluating future cost of ownership requires an assumption of future oil and electricity prices. Based on data from the International Energy Agency, we assume global average crude oil prices reach approximately $60/barrel in 2017, $80/barrel in 2020, and $100/barrel in 2025 (IEA, 2015). For context, based on these projections, gasoline in the United States would reach $3/gallon by 2020 and remain below $4/gallon through 2025. Any additional increase in global oil prices would improve the consumer proposition for electric vehicles. For electricity price projections, we assume residential electricity costs over the 2016–2030 time frame increase at a rate of less than 1% per year in North America and Europe, and at approximately 4% per year in China. These assumptions align with those outlined in the World Energy Outlook (IEA, 2015). Details on the assumptions are summarized in the Annex.

Cost parity for each of the electric vehicle models is shown at the point where the cost of ownership cost curves intersect those of the ICE vehicle. The figure shows how the BEV-100 cost of ownership is anticipated to become cost-superior to the ICE around 2020 in Norway and the Netherlands; around 2021 in the United Kingdom, Canada, and China; around 2023 in Germany; and around 2025 in the United States. In each market, the BEV-150 and -200 tend to cross the ICE cost-parity threshold approximately two and five years, respectively, after the BEV-100.

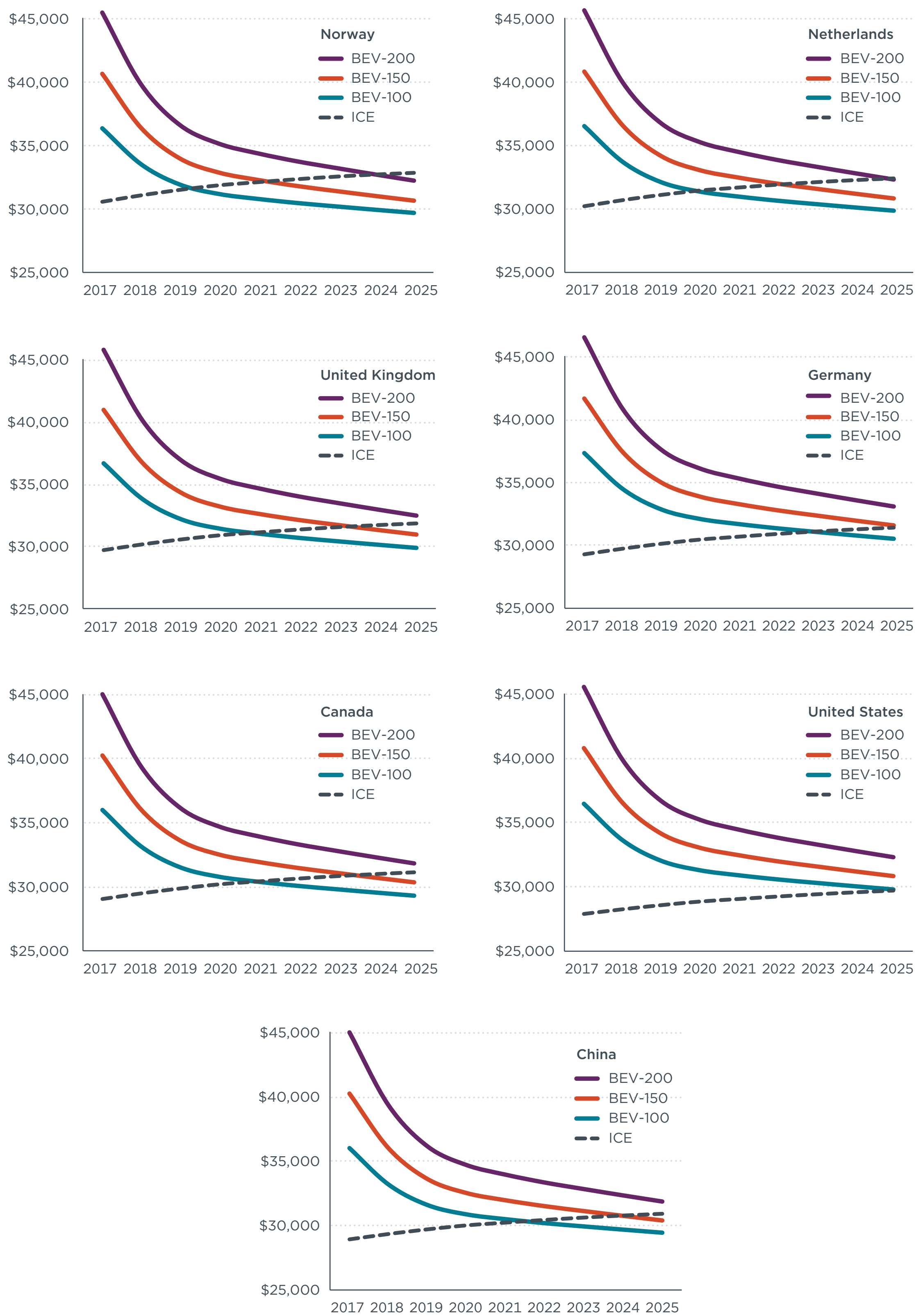

Figure 12. Evaluation of cost of ownership for battery electric vehicle technology (of 100, 150, and 200 mile electric range) compared with a conventional internal combustion vehicle in seven major electric vehicle markets

IV. DISCUSSION

FINDINGS ON TECHNOLOGY COSTS AND INCENTIVES

As indicated in the analysis above, electric vehicles' technology improvements and reduced costs greatly improve the consumer cost proposition within the next five to ten years. We find that battery electric vehicles are approaching conventional vehicle costs much more rapidly than earlier projections. This work, based on the latest research on battery costs (e.g., Anderman, 2014, 2016a,b; Nelson et al, 2015) and overall electric vehicle costs (Slowik et al, 2016; Wolfram and Lutsey, 2016), finds that the upfront costs of shorter-range (e.g., 100 miles or 161 km) electric vehicles reach cost parity with conventional vehicles by 2025, and that the upfront costs of longer-range electric vehicles come within several thousand dollars of conventional vehicles by 2025. This analysis indicates that these cost reductions are occurring faster than major previous analyses projected (see e.g., NRC, 2013). As explained above (see Figure 10), this is largely because of conservative estimates in previous analyses, recent breakthroughs in lithium-ion chemistries, a better understanding of the linkage between battery pack costs and production volume, and increased manufacturing plant production scale. This suggests that the need for incentives to promote electric vehicles may be shorter than numerous works (e.g., NRC, 2013; Greene 2013, 2014) have suggested.

Based on the analysis, we can make several findings about the regional differences in the viability of electric vehicles to grow in the mainstream market. The cost-competitiveness when including fuel savings could reduce the need for electric vehicle incentives even before the initial purchase price of battery electric vehicles are equal to that of conventional gasoline vehicles. The analysis reveals that in 2021–2022 the four-year cost of ownership for 150-mile (241 km) real-world range battery electric vehicle models reach cost-competitiveness in Norway and the Netherlands. In the 2023–2024 time frame, 150-mile electric vehicles become cost-competitive in the United Kingdom, Canada, and China. The analysis also reveals that 100-mile real-world range battery electric vehicles tend to reach cost-competitiveness two years earlier than 150-mile electric vehicles. In contrast, 200-mile real-world range battery electric vehicles tend to reach cost-competitiveness several years later than the 150-mile electric vehicles. These results strongly suggest that financial incentives and other support policies for electric vehicles will remain important to grow the market through 2020 in some markets, and perhaps 2025 in others.

Putting the findings together on a global basis, we can also draw broader conclusions regarding maintaining incentives globally. There are three major electric vehicle markets—China, Europe, and North America—through 2016 that have expressed a strong interest in promoting the development of electric vehicles. For success in driving up sales and manufacturing scale to the volumes indicated here, thus greatly reducing electric vehicle costs, these markets would probably need to maintain electric vehicle incentives until their markets collectively reach something like 3 million electric vehicle sales per year. Three million sales per year for these markets means there would be perhaps five to ten competing battery manufacturers with electric vehicle battery pack production volumes over 300,000 units per year to supply these markets. The companion analysis on next-generation electric vehicle technology indicates that production scale is what leads to $150/kWh battery packs (Slowik et al, 2016). The analysis above indicates that this is when markets start to tip in favor of electric vehicles, when incorporating cost competitiveness for first-owners of electric vehicles.

PRINCIPLES FOR TAPERING INCENTIVES

We conclude with a discussion of principles to help inform policy through the transition toward greater electric vehicle penetration in the 2020–2030 time frame. Our general conclusion is that that incentives can be gradually reduced in most markets starting around 2020 as the market grows. This can happen more quickly in some markets than others, due to particular circumstances that make the cost proposition relatively better for some consumers—for example in Europe, where gasoline and diesel prices are much higher than elsewhere. As automakers and governments meet their announced electric vehicle deployment goals, incentives will have to evolve to manage government revenues and provide stable support to sustain market growth of the new technology. Without evolution of incentive programs, electric vehicle outlays will increase and programs are likely to become unstable and vulnerable to abrupt removal, which would be detrimental to the growing market, just as more attractive products are reaching the market in larger volumes. Based on the analysis, we draw the following four conclusions on the evolution of electric vehicle consumer incentives.

First, expected technology improvements allow for reduced fiscal support for electric vehicles over time, while still supporting early market growth. The right match of the reduction of electric vehicle incentives with technology cost reduction trends can be reasonably estimated at this time because the movement to lower-cost battery packs is so widely projected, including by leading automakers, battery suppliers, and independent researchers. Electric vehicle technology is advancing rapidly, much quicker than projections from just several years ago. Due largely to battery innovation and manufacturing scale, electric vehicle costs are expected to be reduced by $7,000 to $13,000 in the 2017–2022 time period, depending primarily on their battery capacity. The electric vehicle range and cost improvements have the potential to greatly expand the electric vehicle market and reduce the need for incentives over this period.

Following from the above points, the second conclusion is that incentive eligibility can evolve to strategically promote only higher-range and lower-cost electric vehicles. This evolution in incentive eligibility would target the technologies that would help overcome the two major consumer barriers of cost and charging convenience. To some extent this progression is underway, as many governments use vehicle price ceilings, and others scale incentives to vehicle range or battery size. These provisions can progressively become increasingly restrictive over time. Incentives can strategically be made available for vehicles with specifications with the greatest consumer attractiveness for 2020 and beyond. The evolution of government incentive programs would benefit from incrementally shifting eligibility criteria to vehicles that are lower-cost. For example, incentive eligibility could shift toward vehicles that are priced closer to average new vehicle prices (e.g., which were about $34,000 in the United States in 2016) and/or toward higher-range (e.g., all-electric vehicles with greater than 200 miles in real-world driving) in the 2018 and later time frame. Setting a timetable for this progression would create a steady signal for automakers, dealers, and consumers. Additional benefits of pushing more incentives to longer-range vehicles is that it increases the amount of travel activity that is displaced by electric vehicles and could also reduce the requirements for public charging infrastructure.

Our third concluding point relates to the evolution of the form of the electric vehicle consumer incentives to ensure greater durability. A consequence of increasing success of electric vehicle growth is that markets can become more vulnerable to abrupt incentive removal. As analyzed above, even with dramatic cost reductions, electric vehicle costs will remain above conventional vehicles for several years yet. Having incentives move toward more sustainable fiscal instruments could minimize the annual uncertainty and risk of subsidies and rebates being abruptly discontinued or reduced (e.g., in Georgia in 2015, California in 2016, and Denmark in 2016). Unstable incentives disrupt consumer awareness and marketing campaigns, and ultimately electric vehicle deployment. Governments could gain from shifting to progressive, multi-year, emissions-indexed "polluter pay" vehicle taxation systems (e.g., Norway); linking electric vehicle incentive funding to a larger carbon cap-and-trade system; or "feebate" systems (e.g., France) that lock in an incentive revenue source to the electric vehicle subsidy.

Fourth, as electric vehicle fiscal incentives are phased down, regulatory policy and other complementary policy will become more important in the transition to an electric-drive fleet. As shown in the analysis above, fiscal incentives can help bridge the cost gap between electric and conventional vehicles in the initial high-cost years. There are other prominent electric vehicle barriers that can be addressed with actions that increase model availability, charging infrastructure, and consumer education and awareness. Additional regulatory policy, such as the California Zero-Emission Vehicle regulation and China's emerging New Energy Vehicle credit trading scheme, specifically make more electric vehicles available. By the 2025 time frame, electric vehicles will be within reasonable cost-competitiveness for electric vehicle owners in many markets. From this point, fuel economy and carbon dioxide regulations will become critical to push electric vehicles to the mass market. Relatedly, as fiscal incentives become less workable and less necessary, nonfiscal incentives and other policies could remain important drivers. Charging infrastructure and local complementary policy (e.g., access to low-emission vehicle zones, preferential lane access, and parking) help address issues related to convenience, awareness, and understanding for consumers.

Figure 13 summarizes the report's results and illustrates several of the conclusions above. The figure shows the average of the electric vehicle cost of ownership, as well as for a conventional internal combustion engine vehicle, across the seven markets in this analysis. As depicted, electric vehicles are expected to go through a dramatic cost reduction through 2020. Starting around that time, progressively higher-range electric vehicles will reach cost-competitiveness for electric vehicle owners. As next-generation electric vehicle models (lower range with lower cost, and higher cost with higher range) become more competitive in the market, fiscal incentives become less important for the broader majority market. Beyond fiscal support, complementary policy will likely still be important to overcome mainstream market barriers, including broader electric vehicle understanding and awareness and the availability of charging infrastructure (see NRC, 2015). When electric vehicles are competitive in the market, around the 2025 time frame, regulatory performance standards can become a primary driver for the technology.

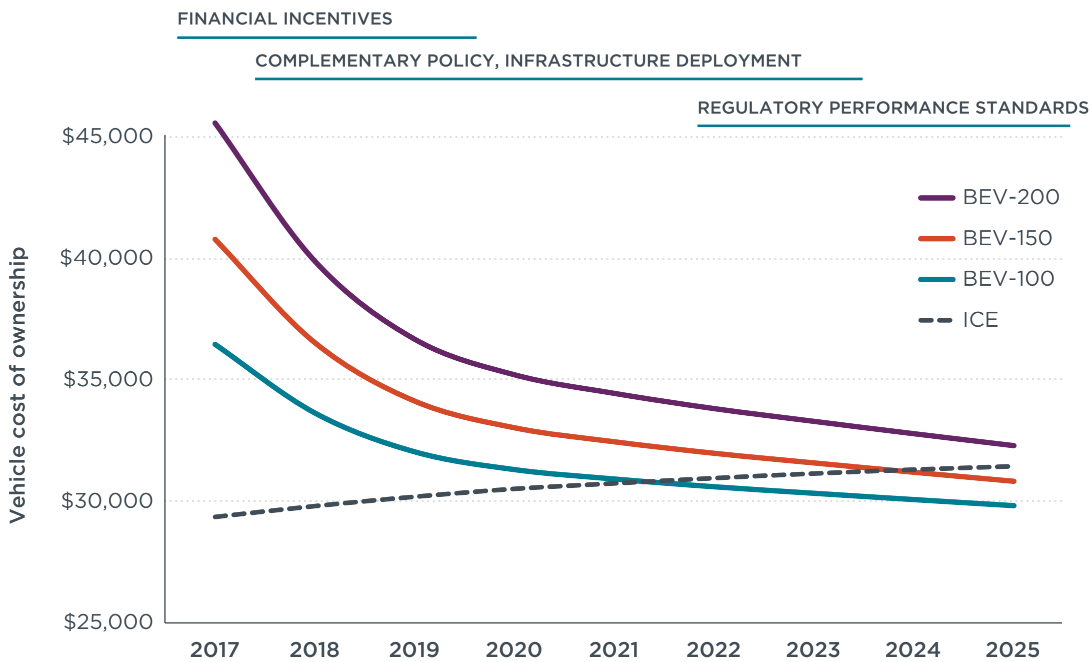

Figure 13. Average vehicle cost of ownership for battery electric vehicles (of 100, 150, and 200 mile electric range) compared with a conventional internal combustion vehicle

Several governments have multi-year electric vehicle incentive programs that partially embrace these findings. However, few governments have locked in their incentive programs through a transition that acknowledges the technology improvement, increased vehicle sales, and long-term mainstream consumer expectations for lower-cost and higher-range vehicles. These findings could help inform robust conversations among relevant ministries, automakers, and other stakeholders about the future of incentive programs. Although the study is focused on major North America, Europe, and China markets, the findings apply broadly. The technology factors are global in nature and the underlying vehicle use and fuel prices assumptions elsewhere generally fall within those of the markets analyzed here.

This work points toward several rich areas for future research. This assessment focused on consumer vehicle purchasing incentives, but also very important would be the evaluation of the potential benefits from electric power utilities and fuel policy to help deploy charging infrastructure and encourage greater use of electric vehicles. Although this study is focused on sustaining light-duty passenger electric car growth, applicability across larger passenger vehicle segments could be examined further. Furthermore, questions about how to accelerate electric-drive heavy-duty vehicle are increasingly pressing. One especially important area for future analysis would be to investigate the optimal ways for electric vehicles to be promoted within regulatory performance standards, primarily in the 2025 and beyond time frame. With the increasing likelihood of cost-competitive electric vehicles, progressively stringent regulatory standards around the world could become the key driver for the transition to an electric fleet.

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ANNEX

The four-year cost of operation calculations in the Analysis section is based on many data sources and assumptions. The following text and tables provide more detail on the assumptions used in this analysis. Table A1 summarizes the fuel, electricity, and travel assumptions in the seven key markets. Based on data from the International Energy Agency, we assume global average crude oil import prices reach approximately $60/barrel in 2017, $80/barrel in 2020, and $100/barrel in 2025 (IEA, 2015). The relative oil prices in each market are based on historic pump price data and are based on information provided by the World Bank (World Bank, 2016). Electricity price projections align with those outlined in the World Energy Outlook (IEA, 2015) and are assumed to increase at a rate of less than 1% per year in North America and Europe, and at approximately 4% per year in China. The relative electricity prices in each market are based on historic data and are based on information provided by the U.S. Energy Information Administration (U.S. EIA, 2014), the European Union Statistical Office (European Union Statistical Office, 2016), and others.

Table A1. Summary of assumptions for four-year cost of ownership calculations

Market	2017 Fuel price ($/gal)	2017 Electricity Price ($/kWh)	Average annual travel, BEV-150 (km/year)	Average annual travel, conventional (km/year)
China	$3.50	$0.08	14,400	16,400
United States	$2.30	$0.12	16,300	18,400
Norway	$6.50	$0.17	10,600	12,100
Netherlands	$6.10	$0.20	10,600	12,100
UK	$5.60	$0.21	10,600	12,100
Germany	$5.10	$0.32	10,600	12,100
Canada	$3.40	$0.08	15,300	17,400

Numbers in the table are rounded

Table A2 summarizes additional vehicle specification assumptions used in the the cost of ownership calculations. The analysis is for a C-segment vehicle. We assume the conventional ICE meets future efficiency regulations, reducing test-cycle and real world per-mile CO_2 and fuel consumption by 3% per year. Average annual conventional vehicle travel by region are based on the ICCT roadmap model (ICCT, 2016). Average annual travel for the BEV-100, BEV-150, and BEV-200 are assumed to be, respectively, 80, 89%, and 93% that of the conventional vehicle, based on electric vehicle utility factors outlined in SAE International (SAE, 2013).

Table A2. Summary of vehicle assumptions for cost of ownership calculations

Market	ICE		BEV100		BEV150		BEV200	
	2017	2025	2017	2025	2017	2025	2017	2025
Real world FE (mpg)	35	44						
Electricity use (kWh/mile)			0.3	0.25	0.3	0.25	0.3	0.25
Real world range (mi/km)			100 / 161	100 / 161	150 / 241	150 / 241	200 / 322	200 / 322
Test cycle range (mi/km)			143 / 230	143 / 230	214 / 344	214 / 344	286 / 460	286 / 460
Battery pack (kWh)			33.0	27.9	49.5	41.8	66.0	55.8
EVSE equipment			$750	$750	$750	$750	$750	$750
Vehicle cost	$23,300	$24,600	$31,800	$25,200	$37,000	$27,200	$42,200	$29,100

Numbers in the table are rounded