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## Abstract

Norway is the current per-capita leader in battery-electric vehicle (BEV) sales due in large part to generous government subsidies for BEV buyers. These subsidies are designed to support the government's goal of electrifying 20% of Norway's vehicle fleet to reduce national greenhouse gas emissions. Norway is not alone in its support of vehicle electrification, as many public policy makers around the world also use EV subsidies as a means of achieving emission reduction goals. Despite their widespread presence, however, very little analysis has examined the cost of the subsidies relative to the value of the consequent environmental and social benefits. This research uses a variety of scenarios to calculate the costs and benefits of Norwegian EV supports, and the general finding is that subsidy costs are much higher than the environmental benefits, resulting in negative ROIs. Implications of the Norwegian results for public policy makers in other countries are then discussed.

Keywords: electric car, government subsidy, return-on-investment, greenhouse gas emissions, market failure

## 1.0 Introduction

Although many governments around the world are encouraging vehicle electrification as a means of achieving energy security and environmental policy goals, battery-electric vehicles (BEV) remain a niche in most markets (Lomborg 2013; Mock and Yang, 2014). In contrast to the generally slow BEV adoption rates globally, Norway became the first national market where a BEV was the best selling new vehicle, as the Tesla S model topped the September 2013 sales chart (Dagenborg 2013). Only a month later, the Nissan Leaf BEV was the best seller and on it's way to becoming the 3rd best selling car model in Norway during 2013 (King 2013; OFV 2014). Norway was also the world leader in per capita BEV sales during 2013, where they captured almost 6% of the new car market due to a wide range of subsidies provided to BEV buyers including exemptions from purchase taxes, road tolls and parking fees, which has led some to call Norway the 'Shangri-La of electric transportation' (EVN 2014; Hockenos 2011; UNEP 2014).

Numerous studies have assessed the market attractiveness and environmental impact of green vehicles, and a common finding is that their adoption and consequent green benefits are hampered by unattractive high prices and performance deficits versus conventional gasoline and diesel fueled internal combustion vehicles (ICV) (Carlsson and Johannsson 2003; Delucchi and Lipman 2001; Olson, 2013a, 2015). As a consequence, other research has focused on how green vehicle handicaps might be offset by various types of government subsidies that can speed market acceptance and help achieve environmental policy goals (Beresteanu and Li 2011; Gallagher and Meuhlegger 2011; Klif 2006; Mock and Yang, 2014; Skerlos and Winebrake 2010). What are largely missing in such inquiries are attempts to calculate the costs of green vehicle subsidies relative to the value of the benefits they provide. For example, Norwegian public policy documents related to BEV goals and supports do not provide any subsidy return-on-investment (ROI) calculations related to achieving desired environmental benefits (Holtsmark 2012). Given the negative publicity regarding a number of recent green technology bankruptcies involving firms receiving government financial and regulatory support, such as solar panel maker Solyndra and electric car producer Fisker, showing a positive environmental and economic payoff for government green policies could be an important means of maintaining political and public support (Muller 2013; Olson, 2013b). The purpose of this study is to examine the cost effectiveness of Norwegian BEV subsidies in achieving the desired emission reductions that are the stated policy goal used to justify their implementation. The findings suggest that the subsidies produce very expensive environmental benefits, and that other national governments are likely to find it economically and/or politically difficult to emulate Norwegian BEV policies and results.

## 2.0 Government Justification for BEV Subsidies

Carbon-based fuels burned by motor vehicles generate about 33% of man-made greenhouse gases in Norway, and are a key reason that electrification of vehicle fleets is seen by many public policy experts and environmentalists as an important means of reducing greenhouse gas emissions and other pollutants (Climate Cure 2010). Reflecting this viewpoint is the Norwegian government's stated goal of achieving 20% electrification of the country's vehicle fleet to help in reducing overall national greenhouse gas emissions 30% by 2020 (Climate Cure 2010; Sovoll, Mathisen, and Jørgensen 2010). For similar reasons, U.S. President Barack Obama and German Chancellor Angela Merkel have each set a goal of putting one million electric vehicles on their nation's roads by 2015 and 2020 respectively (DOE 2011; Spiegel

2012). Such green public policy goals are frequently motivated by opinion polls that consistently find large majorities of citizens expressing strong support for environmental issues (Nisbett and Myers 2007). Yet public policy must also deal with the reality that consumer preferences over time have increasingly favored larger and more powerful vehicles that consume higher quantities of raw materials and energy in their production and use (Olson, 2015). For example, since the mid-1970s, the average weight and horsepower of American cars increased 20% and 100% respectively, while in Norway (and Europe) the best selling VW Golf grew 57% heavier and 125% more powerful (Olson, 2013a).

Thus a common theme in green technology adoption studies involving consumers is the presence of a value–action gap between the public's almost universal pro-green attitudes and their much rarer pro-green behaviors. This 'demand-side' value-action gap is widely attributed to the significant sacrifices that green technologies often require of users on conventional attributes (Olson, 2013a; Pujari et al., 2003). For example, compared to conventional ICVs, BEVs are typically uncompetitive in price, driving range, and 'refueling' speed, and these limitations have proven to be unacceptable to the vast majority of car buyers (Massey 2013; Spiegel 2012). Thus with limited market prospects, BEVs and other green technologies are often seen as unattractive investments by the 'supply-side' manufacturers that might produce and sell them (Ambec and Lanoie, 2008; Olson, 2013b).

When green technology investment and consumption are thought to be inadequate for meeting the future energy and/or environmental needs of society, it is often deemed a market failure that creates incentives for governments to intervene (Greene, German and Deluchi 2009; Grossman, 2009). Environmentalists and government policy makers typically promote green subsidies and supports to correct two underlying causes of green technology unattractiveness that can lead to market failures. First, non-green alternatives can have an unfair cost advantage due to their failure to pay for negative externalities in the form of 'free' discharges of greenhouse gases and other pollutants (Langniss and Praetorius, 2006). Second, relatively new green technologies may require 'temporary' start-up subsidies to allow green industries to effectively compete with older conventional alternatives that benefit from technology advancements and accumulated learning and scale effects built over decades of use (Kahouli-Brahmi, 2009). Thus market failure is the justification used for a variety of policies implemented by governments around the world to reduce the environmental impact of automobiles and spur faster green vehicle development and diffusion. Such policies can typically be divided between the supply-side, which focus on technology development and commercialization, and the demand-side that focus on end users. Both the supply-side and demand-side can be further divided into policies designed to directly help green vehicle technology by means of research grants, loan guarantees, and tax credits (a.k.a. Pigouvian subsidies), or indirectly help by penalizing 'dirty' conventional ICVs with tougher emission and fuel economy regulations, and increasing fuel/vehicle taxes (a.k.a. Pigouvian taxes) (Beggs, 2013; DOE, 2011; Gecan, 2012; Olson and Thjømoe, 2010).

The Norwegian example presents a unique case not only due to the generous BEV subsidies and relative success in spurring BEV adoption, but also because it provides the cleanest possible means for isolating the costs of green vehicle policies and the specific environmental and societal benefits they are designed to achieve. The ability to link specific green vehicle public policies to specific outcomes in most countries is difficult, because subsidies are frequently linked to not only environmental benefits, but also other policy goals such as energy independence and support for green automotive sector jobs (DOE, 2011; Skerlos and Winebrake, 2010). In Norway, energy independence is irrelevant as the country is already a major exporter of carbon-based fuels and electricity. Similarly, the desire to support local green automotive jobs is also largely irrelevant given Norway's small home market, relative lack of automotive manufacturing history and capabilities, and generally high labor and material costs. A direct link between BEV public policy and emission reductions is also simplified by the fact that 99% of Norway's electricity is non-greenhouse gas emitting hydro-generated, which means BEV adoption does not shift emissions from a vehicle's tailpipe to the smokestack of a carbon-fueled electricity generating plant (Hawkins et al., 2012).

All current Norwegian BEV supports are demand-side focused, which started with the abolishment of BEV import taxes and reduced registration fees in 1990, and were completed by granting permission for BEV use of mass-transit lanes in 2003 (EVN, 2014). Recent analysis finds that Norwegian subsidies have been successful in erasing the financial penalties of BEV ownership versus ICVs, although technology related barriers such as short-range remain an obstacle to more widespread BEV adoption (Klif, 2006; Kvisle, 2010a; Mock and Yang, 2014). In contrast, other markets have used electric vehicle supports to address both supply-side and demand-side elements due to broader policy goals that include greater energy self-sufficiency and the creation of green industry jobs (Gecan, 2012). For example, U.S. supply-side supports include the 2007 Advanced Technology Vehicles Manufacturing program designed to provide development money for automakers and their suppliers, while the demand-side is incorporated in the 2009 American Recovery and Reinvestment Act that provides federal income tax credits of $7,500 for BEV purchasers (DOE, 2011).

Three years after the enactment of the electric vehicle tax credits, the U.S. Congressional Budget Office (CBO) released one of the few publicly available studies examining the cost effectiveness of the electric vehicle public policies in achieving stated goals (Gecan, 2012).

Using hypothetical comparisons between BEVs and ICVs of various sizes and types, the CBO analysis found the $7,500 tax credit to be insufficient to overcome current BEV lifetime cost disadvantages to US consumers, and that eliminating greenhouse gas emissions by means of BEV adoption was expensive at a calculated cost of up to $4,400 per CO2 equivalent ton (Gecan, 2012). It is therefore not surprising that 3 years after implementing the tax-credits, electric vehicle share of the U.S. new car market was 1.3% during 2013, which includes both plug-in hybrids and BEVs, and is below the share necessary to achieve the one-million electric vehicle goal by 2015 (DOE, 2011; EDTA, 2013; Mock and Yang, 2014). Thus is would appear that Norway's higher demand-side BEV subsidies are at least partly responsible for its global leadership in per capita BEV sales, but the unanswered questions that will be addressed in the next sections are: at what cost, and does Norway provide a policy model that others can follow?

## 3.0 Method

The calculation of the economic and environmental costs and benefits of Norwegian BEV subsidies employs comparisons between the two dominant selling BEVs and closely matched ICVs, which is a common method of assessing the relative attractiveness of green vehicles in many previous studies (e.g. Funk and Rabl, 1999; Gecan, 2012; Mock and Yang, 2014; Olson, 2013a). Financial metrics taken from earlier green subsidy research are utilized here to evaluate the cost effectiveness of Norwegian BEV subsidies, and include return on investment (ROI), and cost per ton reduction in CO2 equivalent emissions, both based on the estimated subsidy costs and financial valuations of the benefits derived from projected emission reductions (Gecan, 2012; Olson, 2013b; Tol, 2008).

The data utilized for this analysis is based on an extensive search of Norwegian public policy documents related to the transport sector in general and BEV supports specifically; together with recent government agency and industry data reflecting current taxes/fees, vehicle and fuel prices, and other operating costs, which have been converted from Norwegian kroner to U.S. dollars based on current exchange rates (e.g. Climate Cure, 2010; EVN, 2014; Klif, 2006; OFV, 2014; Sft, 2008). In analyzing the cost effectiveness of the Norwegian BEV subsidies, the study also addresses two weaknesses of the CBO analysis of U.S. electric vehicle tax credits. First, the CBO analysis compares hypothetical BEVs and ICVs, while the current study uses the actual fuel use, emission levels, and other relevant specifications of the most popular BEVs and their ICV competitors. Second, the CBO analysis does not consider the revenue losses from gasoline taxes not paid by BEV owners who ‘refuel’ with more lightly taxed electricity, while the current study accounts for all BEV policy related effects on various government revenue sources.

The focus of the current study are the costs associated with achieving reductions in CO2, NOx, and Particulates emissions through electrification of the country’s vehicle fleet, which is the stated goal of Norwegian BEV policy (Climate Cure, 2010). Since the government already collects carbon taxes of approximately $0.14 per liter of gasoline and diesel, and nearly 100% of Norway’s electricity is hydro-generated, the analysis makes the realistic assumption that upstream emission damages for vehicle fuels are either non-existent (hydroelectricity) or already paid for. This together with the fact that there is no current Norwegian ICV or BEV assembly, and therefore zero emissions from local vehicle manufacturing, means that calculating the emission reduction results from vehicle electrification in Norway can be based entirely on comparisons between BEVs and ICVs on the targeted tailpipe emissions.

## 3.1 Comparison Vehicles

Utilizing the comparison format from Olson (2015), the baseline scenario assumes that BEV buyers, in the absence of subsidies, would otherwise purchase an ICV of similar size and capability, which is reflected by the comparison vehicle specifications displayed in table 1. The top selling Nissan Leaf and Tesla Model S, which represent 77% of 2013 Norwegian BEV sales, are each compared with the two top selling ICV competitors offering the most similar size and performance. The Leaf's ICV competitors are the Toyota Auris gas-electric hybrid (2nd best selling vehicle in Norway during 2013), and the top selling VW Golf diesel. The Tesla's competitors are the BMW 5-series diesel, the top selling large luxury ICV in Norway, and the VW Passat diesel, the best selling large ICV in Norway during 2013 ($11^{th}$ best overall). Vehicle size based sales weights are applied to overall emission and financial results reporting, which reflect the relative 2013 sales of the Leaf sized BEVs, with 85% share, and Tesla sized BEVs accounting for the remaining 15%.

Table 1 about here

## 3.2 Scenarios

A variety of scenarios utilizing differing annual mileage, vehicle life, subsidy use and cost assumptions are employed for estimating the amount and value of emission reductions, and the costs of Norwegian BEV subsidies. Lifetime vehicle emission reductions due to the conversion from ICV to BEV are dependent on assumptions regarding vehicle annual mileage and age at scrapping. In Norway, the typical ICV is scrapped at age 18, but previous lifecycle studies have used shorter BEV life spans due to limited battery longevity and high replacement costs (e.g. Funk and Rabl, 1999; Gecan, 2012). Similarly, the average Norwegian ICV is driven

15,000 kilometers annually (9,300 miles), but most previous studies estimate lower annual mileage for BEVs due to lengthy recharging periods and assumed predominance of slow speed city usage. Thus all scenarios employ two vehicle life conditions for emission calculations: 1) short-life: 10,000 km x 10 years, and 2) normal- 'ICV' life: 15,000 km x 18 years.

Subsidy cost estimation requires accounting for both the 'fixed' (i.e. not use dependent) and 'variable' (i.e. use dependent) subsidies provided to BEV owners, and tax expenditure versus direct expenditure costs to the government. Tax expenditure subsidies are those that involve no 'out-of-pocket' expenses, and thus do not result in government revenue losses unless the BEV directly substitutes for a non-subsidized ICV purchase. For example, 93% of all BEVs are registered within commuting distance of the four largest Norwegian cities, including 67% in the Oslo area, which suggests that some BEV purchases are serving as an extra household vehicle for city commuting, and therefore is not serving as the primary household vehicle that substitutes for an ICV purchase (Holtsmark, 2012; Vidal, 2014). Direct expenditures are those that involve 'out-of-pocket' government expense even when the BEV does not substitute for an ICV purchase, and all scenarios assume that 100% of the 'free' parking and electricity provided to BEV owners is paid by the government to private suppliers, and are therefore the only direct expenditure subsidies. The BEV exemption for purchase taxes and reduction in business car taxes are classified as fixed tax expenditures, while the BEV reductions in road taxes and road toll exemptions are variable tax expenditures, and the 'free' parking and electricity for battery recharging are variable direct expenditures.

Variable subsidy cost valuations are based on assumptions about vehicle use and subsidy lifespan. The low and normal vehicle annual mileage conditions employed in the emissions calculation section are used again here, but with the added scenario components of low and normal variable subsidy use, which are assumed to be annually constant throughout life of the subsidies. Norway's current BEV subsidies are scheduled to end after the first 50,000 BEVs are sold or until 2018, whichever occurs first (Vidal, 2014), thus current subsidies have a maximum life of 4 years or less depending on when the BEV is purchased. The low use scenario employs figures from a 2006 study by the Norwegian Climate and Pollution Agency, which assumes weekly free parking and road tolls valued at $5.25 and $5.08 respectively, roughly equivalent to about 1 hour of parking and 2 road tolls per week (Klif, 2006). The high use scenario assumes 15 hours of parking (3 hours per work day), and 5 road tolls per week, as might be expected when BEVs are used by daily commuters. The low use scenario assumes zero use of this free recharging (i.e. all recharging is done with owner paid electricity at home), while the normal use scenario assumes 33% of BEV recharging is from free public sources valued at the VAT-free price of $0.20 per kWh. Another important BEV operating-benefit is the permission to use the collective lanes normally reserved for public transit vehicles and taxis, which allows BEV drivers to avoid rush hour congestion common in major Norwegian cities. For purposes of this analysis no financial value is given to this subsidy, as there is currently no direct cost to the government in providing it, although traffic studies suggest that higher BEV penetration may come at the cost of reducing public transit bus speeds and schedule reliability (Halvorsen and Froyen, 2009).

Baseline valuations of both the fixed and variable BEV subsidy costs to the Norwegian government are determined by the total value of BEV exempted taxes and fees that would otherwise be paid by a comparable ICV buyer. Both the low and normal subsidy use scenarios employ two subsidy lifespan values; 1) a 4-year subsidy life on the variable subsidies reflecting the value received by current BEV buyers, and 2) a 1-year subsidy life received by BEV buyers during the last year of subsides. Within both of these subsidy life conditions, three further subsidy cost variations are utilized: a) 1 for 1 BEV-ICV substitution (i.e. each new BEV replaces a similar ICV purchase), b) 1 in 10 BEV-ICV substitution (i.e. 90% of BEV purchases are extra household vehicles), and c) counting only direct expenditures EV subsidies for ‘free’ parking and ‘free’ electricity.

**4.0 Annual and Lifetime Emission Results**

The calculated annual and lifetime CO2, NOx, and Particulate emissions reported in table 2 are based on the respective average emissions per kilometer reported for the four comparison IVCs in table 1. Note that BEV tailpipe emissions are assumed to be zero, while the three types of ICV emissions are reported in CO2 equivalent figures. CO2 equivalent values are used to simplify reporting and are based on multiplying the raw NOx and Particulate emission levels by their damage per ton relationship to CO2 emissions based on figures from the Norwegian Pollution Control Authority (Sft, 2008). This Sft report estimates that the environmental damage and social costs (i.e. human illnesses, premature deaths) associated with each metric ton of CO2, NOx, and Particulate emissions in typical Norwegian driving conditions at $49.18, $8,197, and $172,131 respectively. This means the CO2 equivalence for NOx emissions is calculated by multiplying tons of NOx tailpipe emissions by the conversion factor of 167 (i.e. $8,197 / $49.18 = 167). Thus, under vehicle life conditions 1 and 2, the calculated average lifetime CO2 equivalent emissions for the four comparison ICVs are 12.03 and 32.48 tons respectively. These ICV emissions are considerably lower than the figures used in early ICV-BEV comparisons (e.g. Funk and Rabl, 1999), largely due to steady reductions in ICV fuel use and emissions caused by improved ICV technology during the intervening period. These improvements are reflected by the drop in average $CO_2$ emissions for new cars sold in Norway, which has gone from 300g/km in 1990 to 113 g/km in 2014 (OFV, 2014).

Table 2 about here

### 4.1 Damage Costs from Emissions

Estimating the value of eliminating the ICV emissions by means of BEV substitution is achieved by multiplying the Norwegian Pollution Control Authority estimate of $49.18 per ton for damages by the lifetime $CO_2$ equivalent tons, which yields vehicle lifetime valuations of $1,066 and $1,600 under the short and normal vehicle life conditions respectively (see table 2). These emission reduction valuations are now compared to the estimated valuations of Norwegian government BEV subsidy costs to determine if they are an economically sensible means of reducing the country's greenhouse gas and pollutant emissions.

## 5.0 BEV Fixed Subsidy Cost Results

### 5.1 Purchase Tax Exemption

Norway's new car taxes, from which BEV are exempted, are among the highest in the world (Economist, 2011), and based on vehicle weight, horsepower, $CO_2$ and $NO_x$ emissions, plus a 25% value-added-tax (VAT). The purchase tax values reported for the comparison ICVs in table 2 are based on the Norwegian government's new car tax calculator (Toll, 2014), and comprise between 34% and 53% of their retail prices. Thus in comparison to similar ICVs, table 2 shows that Norwegian BEV buyers receive a weighted average subsidy of $19,867, which is higher than the BEV purchase subsidies in other markets such as the USA ($7,500) and the UK (£5,000), and is not dependent on the buyer's taxable income as is the case with tax credit based subsidies (Gecan, 2012; Ingham, 2013).

5.2 BEV Business Car Income Tax Adjustment Subsidy

As compensation for personal use of a business car, Norwegians that receive a new ICV from their employer must add 25% of the car's retail price to their income for each of the car's first 3 years of use. This rate drops to 15% from year 4 until the car is sold by the employer, but in reality most business cars are only kept for 3 years before being replaced, which means the lower rate rarely applies. The same tax rates apply for BEVs, but the subsidy is based on an assumed 50% reduction in the retail price of the car, thus a $30,000 BEV is considered a $15,000 car for income tax adjustment purposes. The income tax rates that must be paid on this extra 'business car' income vary from 28% to 49% with the actual rate depending on income level and qualifying exemptions, but for this analysis a conservative tax rate of 30% is assumed. Thus for purposes of this analysis, the business car income tax adjustment is halved for the 30% of current Norwegian BEV purchases that are used as business cars (Grønnbil, 2012). Since the common practice is to replace business cars at age 3, this analysis further assumes the maximum business car tax adjustment benefit for the 4-year subsidy life scenarios and spreads it across all BEV cars at the proportional reduced rate. Thus the business car tax reported in table 2 uses the following two formulas for calculating the business car subsidy per BEV business car (BCSpEVBC) and the business car subsidy per BEV (BCSpEV) respectively:

BCSpEVBC = (car retail price * 50% BEV reduction)* income tax rate))

BCSpEV= (BCSpEVBC * (30% BEV bus. cars / 100% BEV cars)).

5.3 BEV Variable Rate Subsidies

The first variable subsidy is the reduction in the annual licensing fee from \$407 for ICVs to \$66 for BEVs. Since BEVs do not use carbon-based fuels, they are also exempt from paying the associated motor fuel taxes, which include a road use tax of \$0.76 and \$0.59 per liter of gasoline and diesel respectively, a \$0.14 per liter CO2 tax, and 25% VAT. For purposes of this analysis the exclusion from paying CO2 taxes on fuel are not included as BEV subsidies, since the purpose of the tax is to account for the oil well to gas pump emission damage of the fuels.

Instead of buying taxed diesel or gasoline, a Norwegian BEV user can benefit from over 5,000 free recharging facilities around the country (EVN, 2014). This allows BEV owners to escape the \$0.26 per kWh average electricity price (including 25% VAT) for the portion of their battery recharging they do away from home (Eurostat, 2014). The value of the VAT paid on owner supplied electricity and the value of the free recharge electricity is subtracted from the value of the ICV carbon-fuel tax exemptions. The 'free' electricity analysis does not include, however, any government 'start-up' expenditures related to the installation of the recharging facilities around the country that supply the free electricity, since their lifespan cannot be easily predicted, nor the costs reliably allocated to a non-fixed population of BEVs. Among the BEV operating-benefits, the exemptions from paying road tolls and parking fees can be very financially valuable when BEVs are used in daily commutes to congested city centers (Holtsmark, 2012). As with the 'free' electricity, however, the 'free' parking benefit is assumed to involve 'out-of-pocket' direct expenditures as the government compensates private suppliers for the lost revenue.

5.4 Total Subsidy Costs

Table 3 presents the subsidy scenario valuation results, which in the 4 year baseline 1 for 1 BEV-ICV substitution condition range from \$27,861 per BEV in the short vehicle life and low subsidy use scenario, to \$47,650 in the average vehicle life average subsidy use scenario. In the 4 year 1 in 10 BEV substitution condition, the subsidy valuations range from \$5,671 to \$24,252 per BEV, while the direct expenditure 4 year totals range from \$3,205 to \$21,652. The elimination of the purchase taxes is by far the biggest single component of the overall BEV subsidy, with a sales weighted average value representing 60% of the ICV retail price, 91% of the total subsidy costs in the low use scenario 1 year condition, and 74% in the average use scenario 1 year condition. The direct expenditure BEV subsidy elements, which are comprised of the government paid 'free parking' and 'free electricity' account for approximately 4% to 21% of the total subsidy costs in the low and average use scenarios respectively.

## 6.0 Subsidy Costs versus Emission Reduction Benefits

The comparison of BEV subsidy valuations over either the 1 or 4 year conditions from table 3, with the valuations of BEV emission reduction benefits over the 10 or 18 year vehicle life from table 2, are used to calculate the BEV subsidy return-on-investment (ROI) based on the formula:

$$\text{BEV Subsidy ROI} = \frac{\text{(Value of BEV Emission Reduction – Value of BEV subsidies)}}{\text{Value of the BEV subsidies}}$$

As reported in table 3, ROIs in the low subsidy use scenario conditions range from 99.8% of the average vehicle life scenario and 1 year direct expenditure condition, to –96.2% in the short vehicle life 4 year subsidy 1 to 1 replacement condition, while in the average subsidy use scenario conditions, ROIs range from –70.4% to –97.7%. Thus only in scenario conditions where subsidy use is minimized, short in duration (1 year), and only direct expenditure subsidy costs are counted, is the valuation of the subsidies below the valuations provided by 10 to 18 years of lower CO2 equivalent emissions from BEV adoption.  In all other scenario conditions, the subsidy valuations are substantially higher than the estimated value of emission reduction, and result in negative ROIs.

Table 3 about here

In terms of BEV subsidy costs per ton of CO2 equivalent emission reduction, the values range from $25 per ton in the average vehicle life and low subsidy use scenario under the 1 year direct expenditure condition, to $3,902 per ton under the short vehicle life and average subsidy use scenario and 4 year 1 to 1 condition (see table 3).  Only the $25 per ton condition is below the $49.18 value per ton used by Norwegian public policy documents to support the BEV subsidies, and the $50 per ton (or less) valuations from various international studies of the economic, social, and environmental damages caused by greenhouse gas emissions (Sft, 2008; Tol, 2007).  All other scenario conditions have cost per ton figures that are substantially higher than the valuation placed on the health and environmental benefits derived from BEV related emission reductions.

## 7.0 Discussion and Conclusion

Although many governments around the world provide BEV subsidies as a means achieving environmental public policy goals, they have generally not been successful in achieving widespread BEV adoption by car buyers (Mock and Yang, 2014).  Norway's relatively successful BEV subsidies might therefore be seen as a model for other nations to follow for achieving substantial BEV adoption. Unfortunately the current analysis suggests that under all but the most generous to BEV policy assumptions, the financial value of the environmental benefits derived from electrification of Norway's vehicle fleet is far smaller than the cost of the BEV subsidies. Furthermore, the generally very negative financial payoffs regarding Norwegian BEV subsidies are derived from analysis of conditions that in many ways are a 'best case' scenario for BEVs, because they do not include several common BEV related emission and subsidy cost items that would likely worsen the BEV subsidy ROI in other markets. The first is that a significant portion of the electricity needed for recharging BEV batteries in most countries will come from carbon-fuel based electricity generation plants, which would transfer some portion of the eliminated tailpipe emissions to the electricity generating plant and consequently reduce the BEV emission reduction benefits versus ICVs (Anair and Mahmassani, 2012; Hawkins et al., 2012).

Second, this analysis limits the ROI calculation to only the Norwegian government's BEV policy goals, which focus solely on vehicle emissions occurring in Norway. This means the analysis does not include greenhouse gases and other pollutants from the foreign manufacture of BEVs. Recent life-cycle analysis studies have found that the manufacture of BEVs and their batteries can emit 50 to 125% more CO2 equivalent tons than comparable ICV manufacturing, and that making-up this BEV manufacturing deficit would require many years of zero-emission BEV driving (Hawkins, et al., 2012; Patterson et al., 2011). Thus under the short vehicle life scenario utilized here, global life-cycle emissions for a BEV could be higher than a comparable ICV, even though the BEV provides a local (Norwegian) reduction in tailpipe emissions. Furthermore, the 'off-shoring' of BEV manufacturing emissions is also magnified in cases where BEV sales result in a net addition to the national vehicle fleet size, even though the 1 in 10 substitution conditions utilized here resulted in a somewhat less unattractive financial outcomes for the Norwegian BEV subsidies. It should also be noted that the U.S. CBO study did not calculate the differential energy use and emissions from BEV versus ICV manufacturing, even though a stated U.S. goal for the program is to support American BEV manufacturing (Gecan, 2012). The failure to include total life-cycle analysis in calculating BEV subsidy ROI provides an example of national pro-environmental public policies being potentially at odds with global pro-environmental goals, a topic that has received scant attention in the public policy and environmental literatures (Davis and Caldeira, 2010).

Third, this analysis did not include the ‘start-up’ costs and emissions associated with the installation of battery charging infrastructure. Although not an issue in Norway, where the current hydroelectricity supply and grid are thought to be capable of handling the power needs of a large BEV fleet, other countries might also need to invest in expensive power generation and electrical grid expansion to accommodate BEVs (Hagman, Assum, and Amundsen, 2011; Pooley, 2010). Such additional ‘start-up’ infrastructure investments, if financed or subsidized by governments, will further weaken the already unattractive BEV subsidy ROIs reported here.

Finally, the scenarios do not consider sources of BEV customers beyond ICV purchasers/users. For example, attractive BEV subsidies might encourage mass-transit users to trade-in their bus-passes for their own private BEV, and have negative effects on mass-transit passenger load factors. This is supported by a survey finding that Norwegian BEV owners use public transit for commuting at a 75% lower rate than non-BEV owners (Halvorsen and Froyen, 2009). Although some studies suggest that mass-transit buses and trains are not necessarily ‘greener’ than BEVs and hybrid ICVs, such conclusions are dependent on low passenger load-factors and the use of dirty mass-transit fuels and vehicles (Kvisle, 2010b; O’Toole, 2008).

Since mass-transit systems are frequently owned or subsidized by governments, and cannot be eliminated due to the need to serve the non-driving public, the loss of fare-paying customers via BEV owners deserting the system may decrease operating revenues with detrimental economic and environmental impacts, and thus would also likely dampen the ROI of BEV subsidies.

## 7.1 Public Policy Implications

Norway is a world leader in both BEV subsidies and BEV sales per capita (Mock and Yang, 2014). Few other countries, however, are likely to have the means to provide similar subsidy levels, which are affordable in large part due to the taxes on North Sea oil and natural gas that account for almost 30% of the Norwegian government's revenue (Doyle and Adomaitis, 2013). Another major source of tax revenue that helps pay for the generous BEV subsidies comes from Norway's high ICV related taxes that typically generate over 10% of government revenues. BEV exemptions from paying vehicle related taxes and fees means that most of the Norwegian subsidies are tax expenditures that involve little out-of-pocket expense for the government. For a variety of cultural and historic reasons, Norwegians are generally accepting of their high car-related tax burdens, but unless other countries are able to raise fuel and vehicle taxes to Norwegian levels in order to provide tax expenditure based subsidies, emulating Norway's generous BEV subsidies will require huge direct expenditures. For example, the tax-exempt price for the Nissan Leaf is 7% lower than the tax inclusive price of the ICV comparison vehicles in Norway, but 46% more expensive the tax-free price, which together with the operating-cost subsidies makes the Leaf a relative bargain to Norwegian car buyers (see table 1). In comparison, the UK retail price of Leaf is 42% more expensive than the comparison Auris and Golf, and still 17% more expensive after subtracting the £5,000 BEV subsidy, which is an direct expenditure for the UK government that has not been successful in convincing significant number of UK car buyers to adopt BEVs (Ingham, 2013). To provide a similar BEV pricing discount as allowed by Norway's tax expenditure purchase tax exemption, would require the UK government to more than double their current 'out-of-pocket' BEV subsidy. Similarly, Norway's high motor fuel taxes make gasoline more than 300% more expensive than in the U.S., while Norwegian electricity prices are more similar, making BEV 'fuel' savings comparably more attractive in Norway (Mock and Yang, 2014). Other countries that also have high motor fuel taxes, but which also heavily subsidize renewable energy, such as Germany and Denmark, thwart the relative attractiveness of electricity as a substitute motor fuel because the high costs of renewable power increase electricity prices to rates that are 50% higher than Norway (Mock and Yang, 2014; Myhrvold, 2011). Thus subsidies that promote renewable energy may cancel out much of the BEV fuel cost benefit, which may provide at least a partial explanation for Denmark's 0.5% BEV share of new car sales while offering BEV subsidies that are almost as generous as Norway's (Mock and Yang, 2014).

Although Norway's generous tax-expenditure funded subsidies make BEV ownership more competitive with ICVs, the much lower BEV penetration rates in other countries with less generous BEV subsidies would suggest that Norwegian BEV market share may drop dramatically when the subsidies expire in 2018 (Vidal, 2014). Yet continuance of generous BEV subsidies may jeopardize the automotive tax revenues that are an important funding source for public spending needs. For example, the BEV exemption from paying road tolls means BEV drivers do not contribute towards the revenue source that pays for 50% of road construction and maintenance costs in Norway, while road tolls and motor fuel taxes are also commonly used by governments around the world to fund both roads and mass-transit systems (Styles, 2009). The loss of such funding could force governments to find new ways of generating vehicle-based revenues such as mileage-based taxation that might also hit BEV users and reduce BEV attractiveness unless technology improvements can reduce the need for subsidies (Doyle and Adomaitis, 2013; Krishen et al., 2010).

Figure 1 about here

The need for BEV technology and product improvements is reinforced by the BEV sales history in Norway as displayed in figure 1. While the Norwegian government has offered its current mix of generous BEV subsidies since 2003, BEV sales were until recently only a few hundred units per year or less (EVN, 2014). For example, the BEV annual sales average was 323 units during 2008 and 2009, which accounted for 0.3% of the new car market (OFV, 2014). It was not until the 2011 market introductions of the Mitsubishi I-MIEV and Nissan Leaf that BEV sales took off towards the current world leading levels. Previous BEV models such as the Think City were small 2-passenger vehicles with modest range, very low driving performance, few luxuries, and relatively high prices even with the purchase tax exemption. The Leaf and I-MIEV, with 4 passenger seating, highway speed capability, ‘normal’ luxury appointments such climate-control and electric windows, and a competitive price (with subsidy), were the first BEVs that could substitute for a ‘regular’ ICV within the confines of their still limited range and body style selection.

Yet the current subsidies when combined with the introduction of more attractive BEV models such as the Leaf and Tesla have yielded a Norwegian BEV penetration that has reached only 6% of new car sales, which means they can still be defined as a niche product. This suggests that the mass-market is still concerned about the unresolved BEV disadvantages highlighted in table 1; namely driving range, recharging time, and poor resale value (Holtsmark, 2012; Stevens, 2011; Spiegel, 2012). Driving range and recharging time have been BEV problems for over 100 years, and Norway's cold winters further reduce the battery's ability to store energy (Lane, 2011). Uncertain battery life is also the major reason for the low resale value of BEVs, as battery replacement costs can easily exceed the second-hand value of the car, which is a big BEV handicap when depreciation is already the single biggest cost of car ownership (Gertner, 2011; Lange, 2012; Magnussen, 2012). Although depreciation figures are not available in Norway, in the UK the projected 3-year depreciation is about 30% greater for the BEVs than the comparison ICVs (see table 1). Until technology improvements greatly reduce these BEV disadvantages, it can be argued that low BEV demand is not a sign of market failure, but a rational decision on the part of mainstream buyers to choose 'brown' alternatives that offer better value even after the societal costs of their emissions are considered. Thus unless foreseeable technology improvements and price reductions can eliminate most BEV disadvantages, it is unlikely that the generally negative BEV subsidy ROIs found here can turn positive, which raises questions regarding the political viability of maintaining taxpayer support for BEV subsidies (Olson, 2013b).

Public policy makers often promote green subsidies as a means for developing a market of sufficient size to give manufacturers the economies of scale necessary to compete with 'brown' alternatives (Grossman, 2009; Holtsmark, 2012; Myhrvold, 2011). In the context of Norway's small car market, where even the best selling ICV model has less than 10,000 sales annually, such demand-side BEV subsidies are unlikely to have much effect on BEV economies of scale globally when profitability typically requires several hundred thousand unit sales per year. Low sales in major auto markets are the reason currently available BEVs are generally thought to be money losers for their manufacturers (Henkel, 2014; Pyper, 2013; Tung, 2013), which again reinforces the need for dramatic improvements in BEV technology before they can be profitably sold to consumers with small or zero subsidies. Unfortunately this need for improved technology is also a conclusion from BEV studies that are over 10 years old (e.g. Delucchi and Lipman, 2001; Funk and Rabl, 1999). In part, the failure of BEVs to close the performance and cost gap with ICVs during the intervening period is due to the improving fuel economy and decreasing emissions of modern ICVs, as manufacturers have adopted fuel saving technologies such as turbocharging, direct fuel injection, stop-start systems, lightweight materials, and aerodynamic styling (Olson, 2013b). This suggests that government revenues directed at demand-side BEV subsidies in Norway and elsewhere might more profitably be employed on the supply-side, with a particular focus on BEV related R&D that could close performance and cost gaps with ever improving ICVs (Hargadon and Kenney, 2012; Lomborg, 2013; Olson, 2015).

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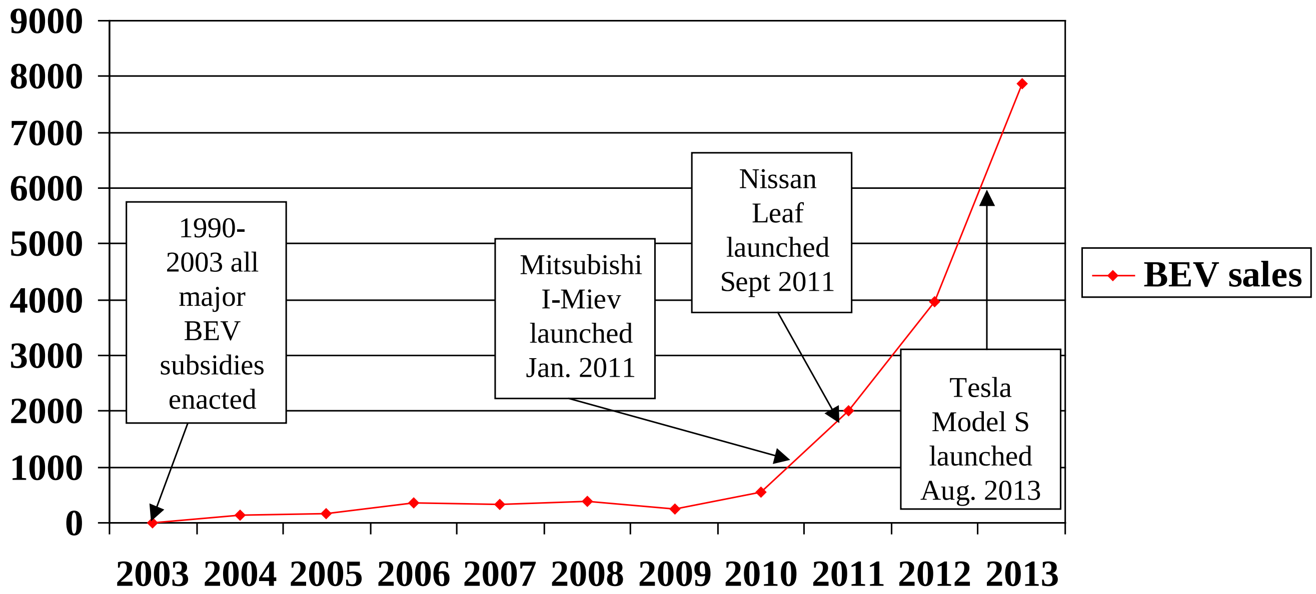
Figure 1

Norwegian BEV Subsidy and Annual Sales Timeline




Sources: subsidy history from EVN (2014) sales fron OFV (2014)

# Table 1

## Comparison Vehicles

| | Nissan Leaf electric | Toyota Auris gas-el hyb. | VW Golf diesel | Tesla S 85 electric | BMW 530d diesel | VW Passat diesel | Weighted ICV avg. (1) | BEV % of ICV |
|---|---|---|---|---|---|---|---|---|
| 2013 Norwegian Sales (2) | 4,604 | 4,818 | 7,366 | 1,983 | 1,285 | 2,997 | 5,499 | 77% |
| 2013 Sales Rank | 3 | 2 | 1 | 20 | 32 | 11 | | |
| Norwegian Retail Price | $39,457 | $43,574 | $41,164 | $85,738 | $114,066 | $70,377 | $49,847 | 93% |
| Tax-Free Retail Price | $39,457 | $28,910 | $25,124 | $85,738 | $53,847 | $39,691 | $29,980 | 155% |
| length (mm) | 4,375 | 4,275 | 4,255 | 4,970 | 4,899 | 4,771 | 4,351 | 103% |
| weight (kilo) | 1,546 | 1,310 | 1,295 | 2,190 | 1,710 | 1,526 | 1,350 | 122% |
| horsepower (3) | 107 | 136/99 | 90 | 362 | 258 | 140 | 106 | 115% |
| 0-60 mph (sec) | 11.9 | 10.9 | 11.9 | 5.6 | 6.0 | 10.0 | 10.9 | 101% |
| top speed (mph) | 91 | 113 | 115 | 125 | 156 | 130 | 118 | 81% |
| fuel use (mpg) (4) | 112 | 62 | 62 | 90 | 41 | 45 | 59 | 184% |
| maximum driving range (miles) | 100 | 464 | 503 | 300 | 469 | 520 | 485 | 27% |
| refueling time (minutes) | 420 | 5 | 5 | 600 | 5 | 5 | 5 | 8940% |
| 3 yr depreciation % (UK) (5) | 74% | 62% | 49% | 64% | 61% | 56% | 56% | 130% |
| CO2 g/km | 0 | 87 | 99 | 0 | 134 | 135 | 99 | 0% |
| NOx g/km | 0 | 0 | 0.012 | 0 | 0.04 | 0.012 | 0.0090 | 0% |
| Particulate g/km | 0 | 0.001 | 0.005 | 0 | 0.005 | 0.005 | 0.0033 | 0% |

Sources: specification data from manufacturer websites. (1) Leaf competitors 85% and Tesla competitors 15% weighting (2): Norwegian sales from ofvas.no. (3): Auris 99 taxable hp, 134 total hp. (4): fuel use for EVs is based on btu energy conversion from electricity consumption to equivalent amount of gasoline per mile. (5): Depreciation from www.whatcar.com.

# Table 2

## Overall Emission and Annual Subsidy Results for ICV comparison vehicles

| | | |
|---|---|---|
| Vehicle Type (1) | ICV | ICV |
| Vehicle life expectancy (2) | 10 yrs | 18 yrs |
| EV Subsidy Use (3) | low | normal |
| | | |
| EMISSIONS: (4) | | |
| annual CO2 tons | 0.992 | 1.488 |
| annual NOx tons (C02 equivalent) | 0.001 | 0.001 |
| annual Particulates tons (C02 equivalent) | 0.00003 | 0.00005 |
| Annual Emission Tons (C02 equivalent) | 1.203 | 1.805 |
| Lifetime Emission Tons (C02 equivalent) | 12.030 | 32.481 |
| Lifetime Emission Damages (USD) | $1,065 | $1,597 |
| SUBSIDIES: (5) | | |
| Car Purchase Taxes | $19,867 | $19,867 |
| Annual Business Car Tax | $561 | $561 |
| Annual Road Taxes | $407 | $407 |
| Annual Fuel Taxes | $197 | $532 |
| Annual Road Tolls | $529 | $1,321 |
| Annual Parking Fees | $273 | $4,092 |

(1) ICV = weighted 85% Leaf comparison ICVs + 15% Tesla comparison ICVs average from table 1, (2) 18 years @ 15k = Norwegian ICV average, (3) low subsidy use = weekly tolls = 2 @ $5.08 per toll and 1 hour parking @ $5.25 and 0% free recharging; high subsidy use = weekly 5 tolls and 15 hours per parking and 33% free recharging @ $.256 Kwh, (4) CO2 equivalent = actual tons * (damage value per kilo / damage value per kilo CO2), lifetime emissions = 10 or 18 years, damage per ton USD conversion at $49.18 per ton from SFT (2008), (5) purchase taxes from Norwegian imported car tax calculator (Toll, 2014); Business car tax = 25% of car retail price * income bracket tax rate, with assumed 30% tax bracket (BEV owners get 50% reduction in this rate); Road Tax = $473 for gasoline and diesel cars, $66 for BEV; Fuel Taxes $.76 and $.59 per liter of gasoline and diesel respectively + 20% VAT on May 2014 Norwegian fuel prices.

.

Table 3

BEV Subsidy Valuations, ROI, and $ Per CO2 Equivalent Ton Reduced

| | **Short Vehicle Life : (1)** | | | **Average Vehicle Life Scenario (2)** | | |
|---|---|---|---|---|---|---|
| Emission Reduction Value (3) | $1,066 | | | $1,600 | | |
| Emission Reduction Tons (4) | 12.03 | | | 32.48 | | |
| **Low Subsidy Use Scenario (5)** | Value | ROI | $ per ton | Value | ROI | $ per ton |
| 4 yr 1 to 1 | $27,861 | -96.2% | $2,316 | $28,256 | -94.3% | $870 |
| 4 yr 1 in 10 | $5,671 | -81.2% | $471 | $5,710 | -72.0% | $176 |
| 4 yr direct expenditure | $3,205 | -66.7% | $266 | $3,205 | -50.1% | $99 |
| 1 yr 1 to 1 | $21,833 | -95.1% | $1,815 | $22,055 | -92.7% | $679 |
| 1 yr 1 in 10 | $2,917 | -63.5% | $242 | $2,927 | -45.3% | $90 |
| 1 yr direct expenditure | $801 | 33.1% | $67 | $801 | 99.8% | $25 |
| **Average Subsidy Use Scenario (6)** | | | | | | |
| 4 yr 1 to 1 | $46,939 | -97.7% | $3,902 | $47,650 | -96.6% | $1,467 |
| 4 yr 1 in 10 | $24,181 | -95.6% | $2,010 | $24,252 | -93.4% | $747 |
| 4 yr direct expenditure | $21,652 | -95.1% | $1,800 | $21,652 | -92.6% | $667 |
| 1 yr 1 to 1 | $26,725 | -96.0% | $2,222 | $26,903 | -94.1% | $828 |
| 1 yr 1 in 10 | $7,544 | -85.9% | $627 | $7,562 | -78.8% | $233 |
| 1 yr direct expenditure | $5,413 | -80.3% | $450 | $5,413 | -70.4% | $167 |

(1) Short vehicle life emissions calculated for 10 years @ 10K km; (2) Emission calculated over 18 years @ 15K km 2 notes. (3-4) from table 2; (5) Low Subsidy Use Scenarios = 2 free tolls, 1 hour free parking per week; 4 yr 1 to 1 = 4 year subsidy life and each BEV purchase substituting for a similar ICV purchase; 4 yr 1 in 10 = 4 year subsidy life and 1 BEV in 10 substituting for a similar ICV purchase; 4 yr direct expenditure = 4 years subsidy life, but only counting free parking and electricity; 1 yr conditions are identical except for 1 year subsidy life. (6) Average Subsidy Use Scenarios = 5 free tolls, 15 hours parking per week, 33% free electricity; 4 year and 1 year scenario conditions are otherwise identical to low subsidy descriptions above. ROI = (Emission reduction value-Subsidy value)/Subsidy value. $ per ton = subsidy value / emission reduction tons.