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Abstract

As a result of generous policies to increase the use of electric vehicles (EVs), the sales of EVs in Norway are rapidly increasing. This in sharp contrast to most other rich countries without such generous policies. Due to the subsidies, driving an EV implies very low costs to the owner on the margin, probably leading to more driving at the expense of public transport and cycling. Moreover, because most EVs' driving range is low, the policy gives households incentives to purchase a second car, again stimulating the use of private cars instead of public transport and cycling. These effects are analysed in light of possible greenhouse gas (GHG) emission benefits as well as other possible benefits of utilizing EVs versus conventional cars. We discuss whether the EV policy can be justified, as well as whether this policy should be implemented by other countries.

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1. Introduction

Road traffic gives rise to various health-damaging pollutants, noise and accidents. It requires expensive road construction as well as substantial maintenance and management costs, and the roads often occupy large and valuable land areas. Road traffic thus entails considerable social costs and at the same time places a significant burden on the public purse (Verhoef 1994). Therefore, many countries have systems whereby the government collects considerable revenues through fuel taxes, road taxes and turnpike tolls. Norway is no exception in that respect and has additionally high excise taxes on gasoline and diesel-fuelled car sales, on top of the standard 25 per cent value-added tax (VAT).

In contrast, electrical vehicles (EVs) are treated much more leniently in Norway. This includes certain tax exemptions as well as various driving privileges, like the use of bus and collective lanes in cities, exemption from parking fees in city centres and often battery charging at zero cost. As a result of this policy, the sales of EVs have increased dramatically over the last few years. While the number of EVs running on Norwegian roads counted only a few hundred up to about 2005, it constituted 1.4 per cent of the conventional new car sales in 2011 (see Table 1). That fraction increased to 5.5 per cent in 2013, and the stock of EVs doubled almost five times from 2011 to 2013, now (spring 2014) accounting for about 25,000 vehicles. The proportion of EVs is dramatically higher in Norway than in most, if not all, other countries. In Sweden, for example, which has basically the same taxes on EVs as on conventional cars, EVs represented well below 1 per cent of the new car sales in 2013. Denmark, like Norway, has also introduced certain tax exemptions on EV purchases as well as exemption from parking fees in Copenhagen. However, the EVs' proportion of the new car sales in 2013 was also below 1 per cent here. In the US, there are also certain tax exemptions with new car purchases of EVs, and the sales reached over 1 per cent of the new car sales in 2012. The world EV car sales in 2012 were led by Japan, with a 28 per cent market share of the global sales, followed by the United States with 26 per cent, China with 16 per cent, France with 11 per cent and Norway, housing a population of only 5 million people, with 7 per cent (Clean Energy Ministerial and International Energy Agency 2013, Wikipedia Electric cars).

Table 1 about here

It seems quite clear that the high number of EVs in Norway is the result of the generous policy for purchasing and using EVs. In this paper, we will review this policy and discuss whether the Norwegian EV policy can be justified and whether this policy should be implemented by other countries. We start in section 2 by reviewing the Norwegian EV subsidy policy and taking a first view of the arguments for this policy. In section 3, data on greenhouse gas (GHG) emission related to EVs and conventional cars are reviewed, while in section 4 we present a numerical example in which the cost of the possible GHG emission gain of EVs is assessed. Based on surveys, we discuss in section 5 whether EV driving may in fact increase the total use of cars and possibly also increase the number of cars. In section 6, some technological lock-in problems related to

EV technology are discussed. Finally, section 7 summarizes our study: we conclude that it is doubtful whether the Norwegian EV policy has a positive net benefit effect. The crucial issue is whether EVs replace conventional cars or whether the present EV policy induces families to add an EV to their already-existing conventional car. The policy is under any circumstances extremely costly, and should not be adopted by other countries.

2. The Norwegian subsidy policy

The generous Norwegian EV policy has been gradually implemented during the last 10–15 years and is now an integrated part of the so-called Climate Agreement ('Klimaforliket') among the parties in the Norwegian Parliament. The policy is rooted in certain laws and regulations, basically set by the Norwegian Ministry of Finance and the Norwegian Ministry of Transportation.[1] These laws and regulations, together with the policy measures implemented in some of the main cities, constitute the Norwegian EV policy. It consists broadly of a tax exemption package together with certain driving and economic privileges for the users of EVs. At present, it includes the following points:

- EVs are exempt from VAT and other taxes on car purchases and sales;
- Parking in public parking spaces is free;
- EVs can use most toll roads and several ferry connections free of charge;
- EVs are allowed to use bus and collective traffic lanes;
- The company car tax is 50 per cent lower on EVs, and the annual motor vehicle tax/road tax is also lower;
- Battery charging is free at a rapidly growing number of publicly funded charging stations.[2]

The Norwegian EV policy is founded on the widespread notion that EVs are far more environmentally friendly than conventional vehicles using gasoline and diesel fuel. The arguments are partly related to the possible short-term benefit of EVs and partly related to what *may* happen in the long term. The reduction of local emissions and the reduction of GHGs to fulfil the Norwegian emission reduction goals are an important part of the short-term story, while technological changes and possible battery technology improvements form part of the long-term picture. We discuss these arguments in terms, starting with the short term, and the local emission issue.

There is some support for the EV subsidy policy regarding local emissions, particularly in comparison with diesel vehicles. However, modern gasoline engines fitted with catalysers emit harmful substances in relatively moderate quantities (Ji et al. 2012). The reduction in health-damaging pollutants due to a shift to EV driving should therefore not be exaggerated. Additionally, if the purpose of the EV subsidy policy is to mitigate local environmental problems, promoting a switch from diesel vehicles to gasoline models is possibly both a simpler and a cheaper expedient. It is therefore a

[1] Important here are Ministry of Finance (17 March 2008): FOR 2001-03-19 nr. 268: Forskrift om engangsavgift på motorvogner and Ministry of Finance (1 September 2008): LOV 1969-06-19 nr. 66: Lov om merverdiavgift.

[2] Customers pay for electricity at fast-charging stations. A fast-charging station can recharge a battery in about 30–50 minutes, but only 1 vehicle at a time. A fast-charging station costs about NOK 100,000 (17,000 USD). A normal charging station needs about 8 hours and costs in the vicinity of NOK 30,000 (around 5,000 USD).

paradox that the Norwegian car tax policy favours diesel cars while sacrificing gasoline, meaning that the current (spring 2014) pumping price of gasoline is about 1 NOK/litre above that of diesel. Another local environmental problem related to car driving in Norway, especially in cities, is the use of spike tyres during the winter driving season and the associated asphalt particle pollutants. Therefore, if an important argument for the EV subsidy policy is rooted in local environmental problems, it is paradoxical that driving with these spike tyres in most big cities is not curbed at all, or not more curbed than today's practice. In Norway's third-largest city, Trondheim, for example, the previous policy of paying a tax for using spike tyres was abandoned in 2011.

Car noise is also often a local environmental problem. The tyres, not the engines, represent the most serious problem here. Depending on the driving speed, Sandberg and Ejsmont (2000, p. 50) found that the noise from the power unit varied between about 76 dB and 79 dB. When the speed is around 50 km/h, the noise from tyres is approximately at the level of the engine. However, when the speed reaches 90 km/h, the noise from the tyres is around 88 dB and hence clearly exceeds that of the engine. Taking into account that increasing the noise by 3 dB means doubling the noise, this indicates that the noise from tyres is approximately 8 times as high as the noise from the engine with a driving speed of about 90 km/h. Hence, along highways, the noise-reducing effect of EVs is quite moderate, but the noise argument has some credit related to low-speed city driving.

The global environmental issue and curbing greenhouse gases (GHGs) are also an argument, and possibly the main argument, behind the Norwegian EV policy. This GHG policy and the need for more EVs to reach a certain amount of reduction in GHG emission from car driving are stated in a recent policy paper by the Norwegian Nature Management Authority (Miljødirektoratet 2014). According to a number of life cycle analyses, there are also some indications that driving EVs is actually more GHG emission friendly than driving conventional cars. For example, Hawkins et al. (2012) found that the life cycle GHG emission of a Nissan Leaf is in the range from 9 to 29 per cent lower than the GHG emission from a diesel/petrol car with an engine of comparable size. Life cycle emission means that both the GHG emission related to the production of the vehicle and its components and the driving over the whole lifetime of the car are taken into account. However, when assessing the possible GHG net benefit of EVs, we also need to take into account whether EVs replace or come as an addition to conventional cars. Data from Norway indicate that EVs may often be an additional car (see section 5 below). Possible changes in the energy mix related to electricity production also have to be considered.

In sum, we may state that the merits of the short-term arguments for the Norwegian EV policy are far from clear. The question, then, is whether it can be justified as a long-term policy instrument contributing to stimulating research and development of new battery technologies. In the history of technology, there are many examples of policy interventions and subsidies that have encouraged new and groundbreaking technology. Following standard economic reasoning, there are also often good arguments for subsidizing the development of new technologies (positive externalities). Most EVs sold today have a maximum range of 100–170 km before the batteries need recharging. An exemption is the Tesla Model S, and tests carried out by the US Department of Energy indicate that this car may have a driving range of about 360 km with the 85 kWh battery pack and with mixed driving, a distance sufficient even for many holiday trips. However, the Model S is quite expensive at approximately 90,000 USD delivered in Oslo (spring 2014), partly reflecting the high costs related to the production of the batteries. An important long-term motivation for the policy for the promotion of EVs in Norway, as well as in other countries, might therefore be that it gives battery producers incentives to work for improved technology such that the EVs will eventually become a viable alternative to gasoline and diesel vehicles all over the world.

However, there are two main problems with this argument. First, there are already strong incentives for research and development to improve battery technology as new battery technology is an essential part of laptops, tablets, mobile phones, etc. Lighter and smaller batteries with higher storage capacity therefore have far-reaching achievements, which will possibly generate large economic returns. For this reason, the research and development on battery technology is already highly significant, and the extent to which EV subsidies may further speed up this process is questionable. Second, two-thirds of the world's electricity, feeding the EV batteries, is currently generated from fossil sources, so if EVs are to contribute significantly to solving the world's CO_2 problem, there needs to be a fundamental revision of electricity production. This includes a much lower preponderance of coal together with large-scale adoption of carbon capture and storage of CO_2 at already-existing coal-fired power stations. These issues are discussed in the next section.

3. CO_2 emissions related to EVs' demand for energy

Globally, coal accounts for approximately 40 per cent of the electricity generated today (IEA 2013, Table 5.3). As the use of gas and oil is significant as well, fossil energy accounts for roughly 67 per cent of the world's production of electricity, while renewable sources account for about 19 per cent. The rest comes from nuclear energy (see Figure 1). According to the World Energy Outlook's 2013 'current policies' scenario (Table 5.3), this balance is supposed not to change dramatically over the next few decades. Indeed, fossil sources, the IEA predicts, will account for 65 per cent of global electricity production by 2035, while 25 per cent is expected to come from renewables. If this prediction holds, we need in other words to plan as if the feeding mix in the global electricity power production in the next 20–30 years will remain more or less the same as it is today, with a possible slight decline in the share of coal.

The World Energy Outlook also expects a significant efficiency improvement in fossil power stations. This, together with the possible breakthrough of capture and storage technology (CCS) from fossil-fuel-based power stations, may modify the modest prospect of reduced GHG emissions related to the world's future electricity production. However, according to the 'current policy' scenarios of the World Energy Outlook 2013, the CCS technology does not seem to play a significant role in the coming decades, and new coal-fired power plant facilities are supposed to be built in a large number in the coming years without CCS technology (IEA 2013). The installation of CCS in these plants at a later stage appears unlikely due to high costs (Golombek et al. 2012).

Figure 1 about here

What then is the CO_2 effect of EVs under this IEA scenario and the prospect that CCS will not play an important role? According to Helms et al. (2010) and Notter et al. (2010), the actual manufacturing processes for EVs and conventional cars are not very different with respect to their carbon footprint and GHG emissions. Therefore, we can obtain a reasonably good idea of the CO_2 properties of the conventional car technology versus EV technology by carefully comparing the use and driving-related emissions of gasoline- and diesel-powered motor vehicles with the fossil fuel mix and the related emissions in power stations producing electricity utilized for EV driving. The vehicles' use of energy is crucial here. All the statistics presented below on fuel economy and range are based on tests performed by the US Department of Energy (DOE) on the gasoline-driven hybrids Toyota Prius and Lexus ES 300h and the EVs Nissan Leaf and Tesla Model S, the latter both having the 60 kWh and 85 kWh battery pack.[3] The Leaf was awarded the 2011 European Car of the Year prize. The Prius and Nissan Leaf are two cars of similar size, as are the Tesla S and Lexus ES 300h, which is important for a fair comparison.

With mixed driving, the Prius consumes 0.047 l/km, according to the DOE, the equivalent of 110 g CO_2/km. The somewhat larger Lexus ES 300h has a gasoline consumption of 0.059 l/km, corresponding to 137 g CO_2/km. Again, following the DOE, the Leaf consumes 0.21 kWh/km. With a 24 kWh battery pack, it thus has a driving range of about 115 km. The DOE found that the Tesla Model S consumes on average 35.5 and 37.9 kWh/km with battery packs of 60 kWh and 85 kWh, respectively. The difference in energy consumption is due to the higher weight caused by the 85 kWh batteries. Therefore, the increased range provided by the 85 kWh battery packs comes at a cost of 7 per cent higher energy consumption. The specifications of the Tesla Model S do not provide information about the battery weight. However, the 24 kWh battery of the Leaf weighs close to 300 kg.

The next question is how many CO_2 emissions are caused by the electricity generation. Emissions of CO_2 from coal-fired power stations vary according to the technology and the quality of the coal, among others. Following the International Energy Outlook (US Department of Energy 2011), the average coal-driven power plant in the US emits about 1000 g CO_2/kWh. According to Weisser (2007), this seems to be a reasonably robust global estimate. See the corresponding results in Moyer (2010) as well. Therefore, based on this emission estimate, a Leaf running on coal-produced electricity emits about 211 g CO_2/km, while the Tesla Model S emits about 230 g CO_2/km, as Figure 2 illustrates.

[3] See http://www.fueleconomy.gov/ (accessed 19 February 2013). All the figures are based on combined driving on highways and in cities.

If the power originates from gas, we obviously gain a picture more in favour of EVs. Gas-fired power stations emit about 400 g CO_2/kWh, less than half of coal-burning coal power plant facilities (Weisser 2007). Therefore, a Leaf running on gas-based electricity emits about 85 g CO_2/km, or 77 per cent of the emissions caused by the gasoline-based Prius. If we use the global electricity mix balance as our point of entry, with 40 per cent coal, 25 per cent gas and 5 per cent oil, the Leaf's CO_2 driving emission reaches 113 g CO_2/km: that is, close to the emissions of the Prius. With regard to the Tesla Model S, the CO_2 emissions with a global electricity mix as defined above are 118 and 126 g CO_2/km, respectively, slightly lower than the CO_2 emissions caused by driving the gasoline-based Lexus ES 300h.

Figure 2 about here

In short, in a world in which energy comes largely from fossil sources, EVs do not necessarily achieve lower driving CO_2 emissions than conventional vehicles running on gasoline or diesel. It greatly depends on the source of the electricity, the electricity mix and the production efficiency. Ji et al. (2012), who studied the emission effect of EVs in China, where about 85 per cent of the electrical energy comes from coal, confirm this general assertion.[4]

The GHG numerical driving examples above do not provide a complete comparison of the environmental properties of the vehicles considered. As indicated, a complete comparison should include a full life cycle assessment: that is, also taking into account the manufacturing process and the lifetime of the vehicles. Hawkins et al. (2012) found that there are considerable environmental challenges related to the production of batteries, which means that the production of EVs generates a greater carbon footprint than the production of conventional cars. With regard to GHG emissions, they nevertheless concluded that even today significant benefits could be achieved by switching to EVs. When assuming a lifetime of EVs of 150,000 km powered by the present European electricity mix, which is somewhat more renewable than the world electricity mix (World Energy Outlook 2013), a switch from conventional diesel or gasoline vehicles to EVs offers a 10 to 24 per cent reduction in the total lifetime GHS emissions for cars of comparable sizes. An exemption might be the Tesla Model S, of which the production process is more energy-intensive than the production of the Lexus ES 300h. A crucial factor here is the lifetime of the battery. If this Tesla battery has to be replaced after approximately 10 years, the GHG emissions from the Tesla from a lifetime perspective will be higher than those from a comparable gasoline car. Note, however, that these life cycle analyses are based on the assumption that any EV replaces a conventional car and that a trip with an EV replaces a trip with a conventional car.

[4] Ji et al. (2012) also studied whether EVs have an advantage by not emitting exhaust gases locally, unlike gasoline- and diesel-driven vehicles. The problem is the massive emissions of harmful substances from coal-fired power stations. Ji et al. discovered that EVs cause more harm to people's health than gasoline vehicles, despite power stations being located in rural areas. Indeed, the pollution from power stations is so dangerous and so widespread that even electric bicycles, of which China has 100 million, are only a fraction more environmentally beneficial than gasoline-driven cars.

4. Cost per tonne CO_2 – a numerical example

The increased demand for electricity because of EV driving will cause CO_2 emissions as long as the power plants, to varying degrees, are based on fossil fuels. However, the power-producing sector in Europe is part of the European Union's emissions trading system (EU ETS), which also includes Norway. This system, described at http://ec.europa.eu/clima/policies/ets/index_en.htm, means that there is a certain cap on emissions from the sectors and producers participating in this system, also including energy producers. Therefore, the increased demand for electricity in Europe does not increase the total GHG emission, but *ceteris paribus* instead leads to higher CO_2 permit prices. Consequently, if the emission cap on the EU ETS is fixed and binding and not influenced by, say, the permit price level, the CO_2 emissions from the increased use of EVs in Europe, including Norway, could be considered as zero. Whether the emission cap of the EU ETS really is fixed is a question not discussed here.

If we consider the cap of the EU ETS to be fixed, and a trip with a conventional car to be replaced with an EV, the emission reduction is equal to the CO_2 emissions that would have been caused by the conventional car. We take this as a starting point and ask whether the size of this emission reduction is reasonable in light of the costs. The following numerical illustration aims to shed light on the cost per unit emission through the Norwegian EV subsidy package.

Consider, as an example, a Nissan Leaf owner living in Sandvika, a commuting suburb slightly more than 10 km from the city centre of Oslo, where his/her workplace is assumed to be located. The car owner has a 5-day working week. Altogether, this workload and travelling distance add up to about 5,000 km driving per year. If we also assume some additional driving (errands, etc.), we end up with a yearly mileage of about 7,500 km with this Nissan Leaf. Let us also imagine that 75 per cent of these journeys, i.e., 5,600 km/year, replace trips with a Toyota Prius, which emits 110 g/km (section 3 above). In other words, the EV driving saves about 0.6 tonnes ($5{,}600 \cdot 110 / 10^6$) of CO_2 (tCO_2) emission yearly because the Prius is left in the garage under the binding EU ETS cap assumption. The remaining 25 per cent of the car owner's EV trips are assumed to represent more mileage on the roads caused by the low costs related to the use of the EV and/or replacement of what would otherwise have been trips by train or bike.

Let us next assume that our Leaf owner from Sandvika saves the following taxes and charges:

- Tax on the purchase of this car (mainly VAT) estimated at nearly 10,000 USD, based on its current cost (spring 2014) of about 230,000 NOK. With a discount rent of 5 per cent and a lifetime of 10 years, this converts into a yearly cost (annuity) of 1,300 USD;
- Toll road charges in Oslo and Bærum (the municipality where Sandvika is located), estimated annually at 1,400 USD;
- Parking fees in the city centre of Oslo, estimated at about 5,000 USD per year;
- Road use charges (fuel charges) and VAT on fuel, assumed to be about 400 USD per year.

Additionally, our EV car owner can recharge the battery for free at public charging stations. As the economic benefit here is difficult to estimate, we exclude it from the calculation. We also do not include the time-saving benefit of using bus lanes, which also involves certain social costs as an alternative clearly could have been to let cars with a fixed minimum number of passengers enjoy this opportunity. Therefore, when ignoring these cost components, we end up with an annual amount of subsidies and support adding up to about 8,100 USD. In light of the above-calculated yearly fossil CO_2 emission reduction of about 0.6 tCO_2, the gain for the EV owner comes at a cost of roughly 8,100/0.6= 13,500 USD/tCO_2.

In comparison, the price of CO_2 on the European permit market is currently (spring 2014) around 5 USD/tCO_2. Consequently, the cost of supporting the Leaf owner in Sandvika is 2,700 times higher than the current CO_2 emission price. In other words, the yearly cost of subsidizing this single EV driver equals the value of 2,700 tCO_2 permits, and subsidizing 20,000 EVs, which is somewhat below the number of EV vehicles running on Norwegian roads today (section 1), under similar assumptions, adds up to the value of more than 50 million permits. As a comparison, Norway emitted about 52 million tonnes of GHGs in 2013 (Miljødirektoratet 2014). Hence, if a corresponding sum of public money had been spent on purchases of emission permits on the EU ETS market and these emissions had been kept unused, meaning that the quota supply actually shrank, Norway could have been 'carbon neutral'.

5. The EV policy and households' use of transport

The Norwegian EV policy is an example of incentivizing and subsidizing the use of an alternative rather than taxing the problem, the GHG emission, *per se*. Another recent example of this type of climate policy instrument is the establishment of the so-called green certificate market in Norway and Sweden, aiming to increase the supply of wind power and small-scale hydropower energy (see, e.g., Bye 2014). Usually economists favour the more direct policy use of taxation as the outcome here is more predictable. This policy is in accordance with the Pigovian notion of the 'polluter pays principle' (for a textbook treatment, see, e.g., Perman et al. 2011), and is indeed also the type of policy recommended in the Norwegian Government's white paper NOU 2007:8 (Norwegian Ministry of Finance 2007).

The EV-subsidizing policy will certainly be a success in the sense that there will be an increasing number of EVs on the roads. However, as already indicated, the extent to which EVs replace gasoline or diesel cars is unclear. Exemption from the toll road charges, access to bus and collective traffic lanes, free battery charging and VAT exemption are all incentives aiming to increase driving and the use of cars. Journeys that would not have occurred in the absence of these policy incentives will take place, or EV driving may replace journeys otherwise taken by train, bus or bicycle.

While battery technology has advanced considerably in recent years, and fast-charging stations are being installed in increasing numbers, EVs are far from being the perfect substitute for conventional cars. Given their limited driving range, especially with heavy loads, EVs are often impractical for holiday driving and more distant driving. Therefore, not surprisingly, EVs have come to be additional cars in many prosperous households. According to a study conducted by the consultancy Asplan Viak (Halvorsen and Frøyen 2009), 93 per cent of households that own an EV also own a conventional car. This two-car holding should be seen in light of the small number of Norwegian households owning two cars (see Figure 3).

Figure 3 about here

Access to bus lanes and the accompanying time savings are doubtless also important reasons why some opt for an EV. This is clearly indicated by the residence pattern of the EV owners, since we find a substantially higher fraction of EV owners in two municipalities just west of Oslo, where driving to Oslo using bus lanes indeed saves a great deal of time (see Figure 4). At the same time, EVs can park and recharge for free, including in the city centres of the major Norwegian cities. To enjoy these benefits, however, most families need to have two cars. The EV policy, in other words, implicitly rewards families that buy a second car.

Figure 4 about here

An important question is also how this policy affects people's travel patterns. This question was taken up by Halvorsen and Frøyen (2009) as well. They asked a group of EV owners how their driving pattern had changed after acquiring an EV. The results clearly indicate less use of public transport, and the respondents were more prone to use the car to travel to work (see Figure 5). Halvorsen and Frøyen also compared the driving habits of EV owners with those of a representative group of interviewees who did not own an EV. While more than half of the non-EV owners used either public transport or walked or cycled to work, the number of EV owners opting for these methods was found to be just 14 per cent (see Figure 6).

Figures 5 and 6 about here

Irrespective of the fact that this survey of driving habits and car holding is somewhat old and that the number of EVs at that time was much smaller than today, there are good reasons to believe that the picture is very much the same today. The exception may be that the fraction of two-car-holding families with an EV may have dropped to a certain extent due to the recent improvements and the longer driving distance without battery recharging. Anyway, there seems to be little doubt that the EV policy, especially perhaps through the permission to use bus lanes, free parking and exemption from toll road charges, has resulted in more families holding two cars together with a switch from the use of public transport and bicycles to the use of private cars. The Norwegian EV policy is evidently encouraging families to adopt travel patterns that harm the environment. Although there are some direct CO_2 benefits to be gained by switching from a conventional car to an EV under the binding EU ETS quota assumption, the total environmental accounting is far from clear.

6. On lock-ins, networks and technology

There are many examples of the dependency of new technology on other users of this technology, so-called network externalities. The telephone is the classic example. A closely related issue concerns harmful technological lock-ins, which leave society with a poor or inferior solution because a better one arrived too late or was sidelined for other reasons (Arthur 1989). The Dvorak keyboard is a well-known example, which is claimed to be faster and more efficient in use than the usual Qwerty layout. If society seems to be locked into an inferior technology, an argument is clearly present for government interventions and the use of policy instruments to move in the direction of the preferred technology.

Transnova is a task force set up by the Norwegian Ministry of Transport aiming to reduce GHG emissions in the transport sector in Norway. Transnova is mandated to take steps to 'facilitate the phasing in of technology which [...] technological lock-in has prevented from breaking into the market' (Transnova.no; homepage 2012). This raises the question of whether Norway, as well as all other countries, is today locked into a fossilized transport infrastructure, while a solution based on electricity is essentially better. However, the questions are whether this is true and, if so, can it then justify the use of the hard-hitting government subsidies and interventions?

EVs indeed require a network of charging stations. At the same time, however, given the quality and driving range of the batteries in the EVs today, EVs cannot replace gasoline/diesel-powered vehicles. Even with a 'complete' grid of charging stations and correct pricing of the car use and environmental damage linkages, one-car families will probably continue to prefer gasoline/diesel-powered cars to EVs because of conventional cars' longer driving range and lower price. For these reasons, the fossilized transport sector is unlikely either to be a technological lock-in or to represent a deficient recharging infrastructure. It is more likely to be present because currently, and for the next few decades, there is no cheaper integrated solution for personal transport present than the one based on gasoline/diesel-powered cars.

A technological lock-in is nevertheless an important reference in this discussion. The major cities can choose to invest more in public transport infrastructure, with the addition of cycle lanes, or to invest more in roads, paving the way for even more private cars and even more driving. Alongside investments in the transportation sector, households obviously make their own investment decisions and transport options. These decisions also create a certain degree of lock-in over the longer term; households choose either the one or the other alternative. If the Government, regional and city authorities decide to build more roads at the expense of rail and bus tracks and cycle lanes, then households will certainly invest in more cars.

7. Final remarks

In this paper, we have reviewed the Norwegian EV policy and discussed whether this policy can be justified. It is widely believed that this EV policy will result in less energy consumption based on fossil fuels and a reduction in the local emission and noise problems. However, our discussion and analysis show that unfortunately the issue is not that simple. One of the most worrying aspects of the current EV policy incentives in Norway is that they motivate high-income families to buy a second car. At the moment, two-car households make up a minority. However, if two cars per household become more common, they will pose an environmental challenge across several dimensions and will doubtless mean that the EV policy as a GHG emission reduction instrument is totally missing its point.

We have also presented a numerical example under the most favourable EV policy CO_2 emission option, namely the European Union's emissions trading system (EU ETS), such that when a trip with a conventional car is replaced with an EV, the emission reduction is equal to the CO_2 emissions that would have been caused by the conventional car. Under certain reasonable assumptions, we then find that the EV subsidy package that the single EV owner gains comes at a social cost of about 13,500 USD/tCO_2 *per year*. As pointed out, this is about 2,700 times higher than the current CO_2 emission price. Therefore, under similar assumptions, subsidizing 20,000 EVs adds up to the value of more than 50 million permits, or about the present yearly GHG emission in Norway. Rather than supporting EV owners, the Norwegian Government could have bought emission rights in the same amount in the quota market and kept these rights unused, meaning that the quota supply would actually have shrunk. This would have driven the quota price up and possibly contributed to a technology push along different lines. At the same time, this measure would have made Norway 'carbon neutral'.

The merits of the short-term arguments for the Norwegian EV policy are therefore far from convincing, and this policy is extremely costly. The question is then whether it can be justified as a long-term policy instrument through, say, stimulating research and development of new battery technology. As discussed, there are already strong incentives for research and development to improve such technology, and it is highly questionable whether and to what extent EV subsidies may further speed up this process. It is also important to keep in mind that two-thirds of the world's electricity supply feeding the EV batteries is currently generated from fossil sources. Therefore, if EVs replacing conventional cars are to contribute significantly as a solution to the world's CO_2 problem, there needs to be a fundamental revision of electricity production. This includes a much lower preponderance of coal, together with massive adoption of carbon capture and storage of CO_2 at already-existing coal-based power stations.

These observations are in line with the conclusions drawn by others. For example, Thomas (2012, p. 6061) stated that '… BEVs [Battery Electric Vehicles] alone will not be able to make substantial reductions in GHGs or oil consumption until a) higher specific power batteries are developed …, and b) almost all carbon is eliminated from electricity generation'. Prud'homme and Koning (2012, pp. 67–68), who compared the private and social costs of a single pair of comparable electric and conventional vehicles, reported that 'The conclusions of this analysis are not encouraging for the success of the purely electric car. On the basis of available information of costs and performance, it appears that the … electric car fares much less well than a standard conventional fuel car … It is hard to justify such enormous costs by the CO_2 gains that will be produced.'

Our main conclusion is that the Norwegian EV subsidy policy should be ended as soon as possible, and that this policy certainly should not be implemented by other countries. The solution to the GHG problem of the transportation sector in the next few decades in a world in which the GDP and population growth are the main drivers of the road traffic volume (Bosetti and Longden 2013) is not to offer subsidies making it cheaper to buy and run EVs, or other alternatives, but to introduce more taxes and restrictions on car use. There are simply too many social costs associated with car transportation (Sterner 2007). The subsidization idea, which informs so much of environmental policy today, not least within Europe, is ineffective, has several unintended consequences and will in many cases be counterproductive (Helm 2012). The Norwegian policy for the support of EVs is an example of this.

References

Arthur, W.B. (1989). Competing technologies, increasing returns, and lock-in by historical events. *Economic Journal* 99: 116–131.

Bosetti, V. and T. Longden (2013). Light duty vehicle transportation and global climate policy: The importance of electric drive vehicles. *Energy Policy* 58: 209–219.

Bye, T. (2014). Vannkraftøkonomi og elektristetsøkonomi (Hydropower Economics). Ch. 10 in O. Flaaten and A. Skonhoft: Naturressursenes økonomi (The Economics of Natural Resources). Gyldendal Akademisk, Oslo.

Clean Energy Ministerial and International Energy Agency (2013). Global EV Outlook.

Golombek, R., M. Greaker, S.A.C. Kittelsen, O. Røgeberg and F.R. Aune (2012). Carbon capture and storage technologies in the European power market. *Energy Journal* 32: 209–237.

Halvorsen, B. and Y. Frøyen (2009). Trafikk i kollektivfelt. Kapasitet og avvikling. Elbilens rolle. (Traffic in Public Lanes. Capacity and Handling. The Role of Electric Cars). Report from Asplan Viak.

Hawkins, T.R., B. Singh, G. Majeau-Bettez and A.H. Strømman (2013). Comparative environmental life cycle assessment of conventional and electric vehicles. *Journal of Industrial Ecology* 17: 53–64.

Hawkins, T.R., O.M. Gausen and A.H. Strømman (2012). Environmental impacts of hybrid and electric vehicles – a review. *International Journal of Life Cycle Assessments* 17: 997–1014.

Helm, D. (2012). The Carbon Crunch: How We're Getting Climate Change Wrong – And How To Fix It. Yale University Press.

Helms, H., M. Pehnt, U. Lambrecht and A. Liebich (2010). Electric vehicle and plug-in hybrid energy efficiency and life cycle emissions. Paper presented at the 18th International Symposium on Transport and Air Pollution.

International Energy Agency (2013). World Energy Outlook 2013.

Ji, S., C.R. Cherry, M.J. Bechle, Y. Wu and J.D. Marshall (2012). Electric vehicles in China: Emissions and health impacts. *Environmental Science & Technology* 46: 2018–2024.

Miljødirektoratet (2014). Faglig grunnlag for videreutvikling av den nasjonale og internasjonale klimapolitikken (Further Development of the National and International Climate Policy). Oslo.

Moyer, M. (2010). The dirty truth about plug-in hybrids. *Scientific American* 303: 1.

Notter, D.A., M. Gauch, R. Widmer, P. Wager, A. Stamp, R. Zah and H. Althaus (2010). Contribution of Li-ion batteries to the environmental impact of electric vehicles. *Environmental Science & Technology* 44: 6550–6556.

Norwegian Minstry of Finance (2007). NOU 2007:8. An Assessment of Norwegian Excise Taxes. (En vurdering av særavgiftene. Utredning fra et utvalg oppnevnt av Finansdepartementet). Norwegian Minstry of Finance, Oslo.

Perman, R., Y. Ma, M. Common, D. Maddison and J. McGilway (2011). Natural Resource and Environmental Economics. Addison Wesley, Harlow, England.

Prud'homme, R. and M. Koning (2012). Electric vehicles: A tentative economic and environmental evaluation. *Transport Policy* 23: 60–69.

Sandberg, U. and Ejsmont, J.A. (2000). Tyre/Road Noise Reference Book. Informex, Stockholm, Sweden.

Sterner, T. (2007). Fuel taxes: An important instrument for climate policy. *Energy Policy* 35: 3194–3202.

Thomas, C.E. (2012). How green are electric vehicles? *International Journal of Hydrogen Energy*, 37: 6053–6062.

Unger, N., D.T. Shindell and J.S. Wang (2009). Climate forcing by the on-road transportation and power generation sectors. *Atmospheric Environment* 43: 3077–3085.

US Department of Energy (2011). International Energy Outlook.

Verhoef, E. (1994) External effects and social costs of road transport. *Transportation Research: Policy and Practice* 28: 273–287.

Weisser, D. (2007) A guide to life-cycle greenhouse gas (GHG) emissions from electric supply technologies. *Energy* 32: 1543–1559.

Table 1. Yearly new vehicle sales in Norway. Fraction of EVs in brackets (as a percentage)

	Number of conventional cars	Number of EVs
2011	138345	1996 (1.4)
2012	137967	3950 (2.8)
2013	142151	7882 (5.5)

Source: Opplysningsrådet for veitrafikken (ofvas.no)

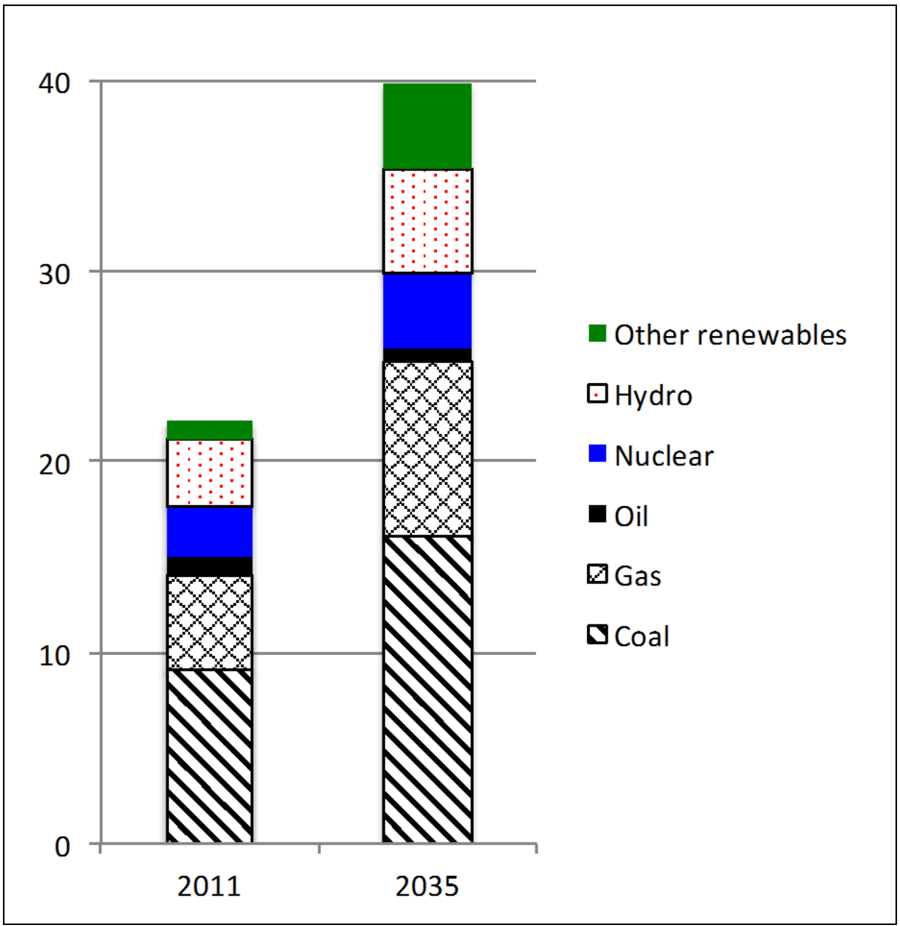

Figure 1. World electricity supply by energy source for 2011 and prognosis for 2035 with current policies
Source: World Energy Outlook 2013

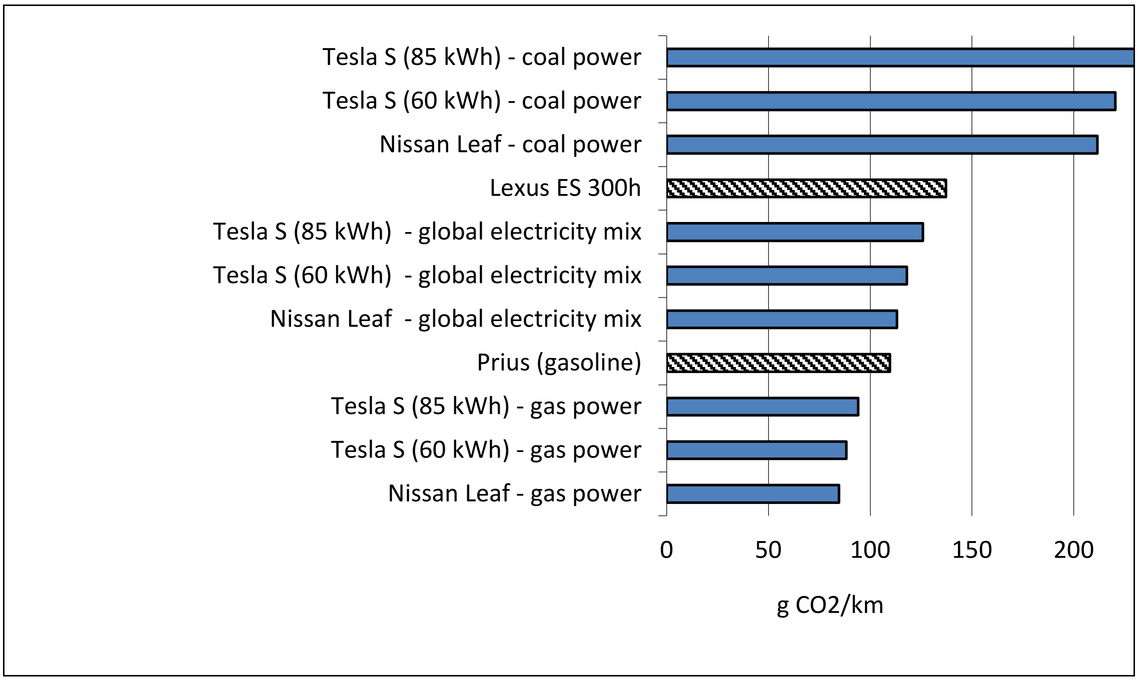

Figure 2. Estimated CO_2 emissions from mixed driving on gasoline by the hybrids Toyota Prius and Lexus ES 300h and the EVs Nissan Leaf, Tesla Model S, with 60 and 85 kWh battery packs, based on consumer tests conducted by the US Department of Energy (DOE). A global electricity mix is assumed to comprise 40 per cent energy from coal, 25 per cent from gas and 5 per cent from oil, the rest being CO_2-free. Emissions related to the production of the cars are not included.

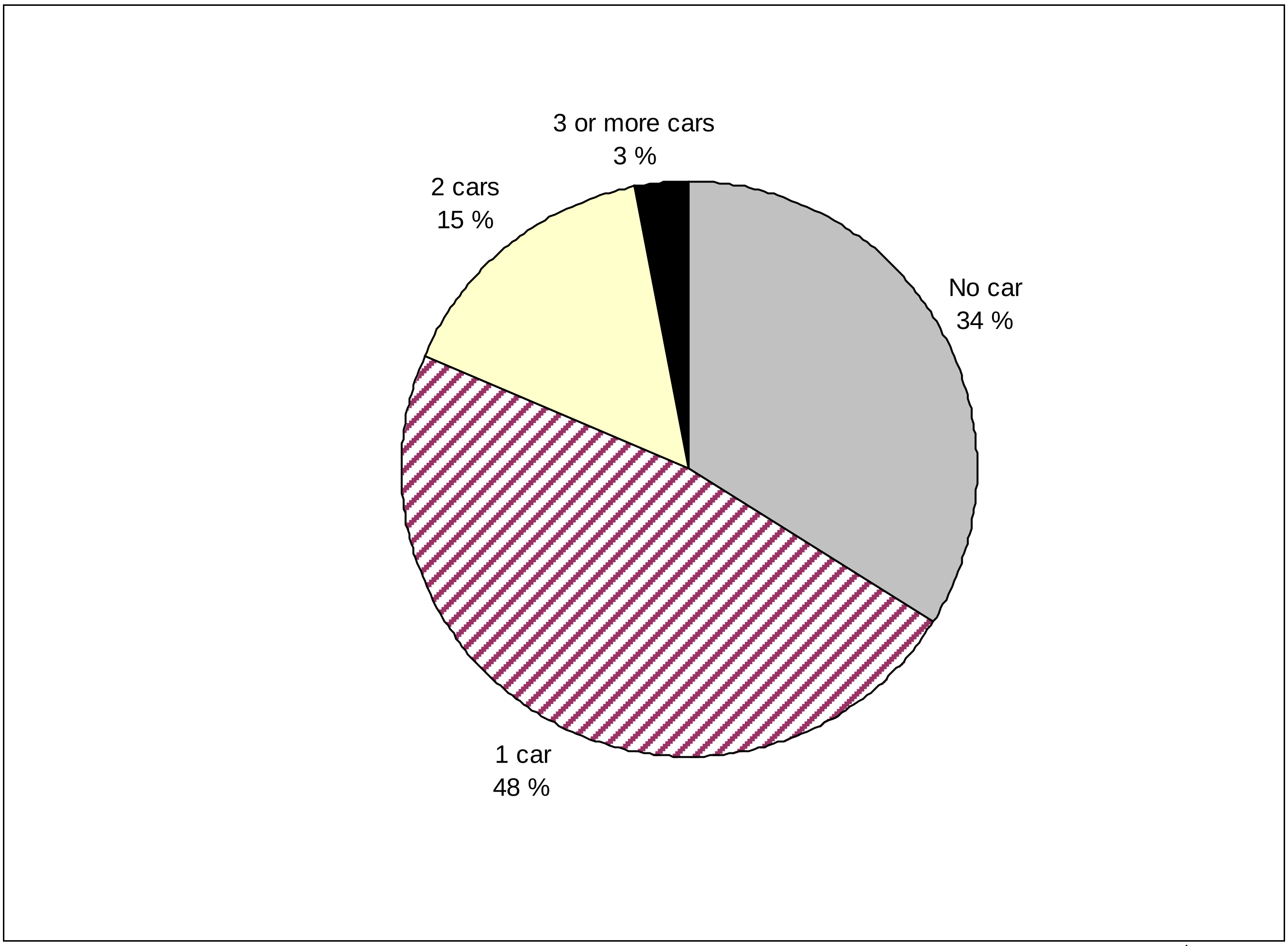

Figure 3. Proportion of Norwegian car-owning families and families without a car, 2005 (as percentages)
Source: Statistics Norway

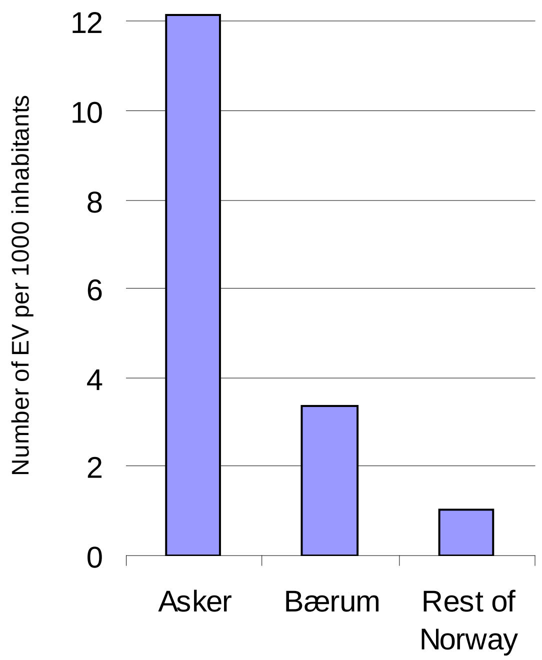

Figure 4. EV ownership per 1,000 pop., December 2011
Source: Norwegian Public Roads Administration and Statistics Norway

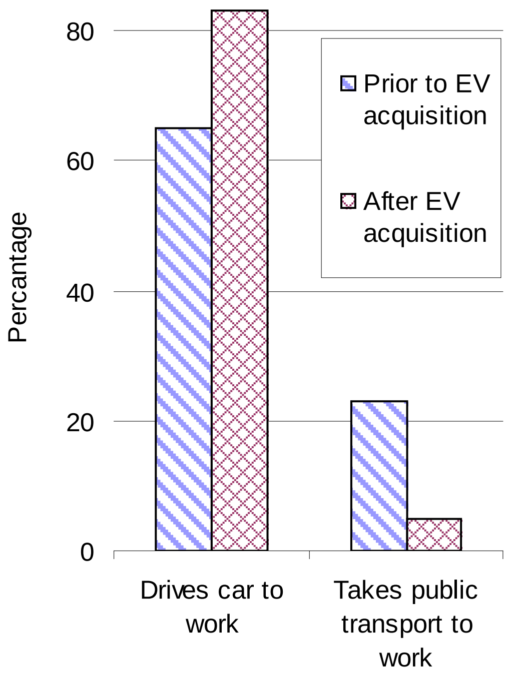

Figure 5. Travel patterns to and from work before and after EV acquisition (as percentages)
Source: Halvorsen and Frøyen (2009)

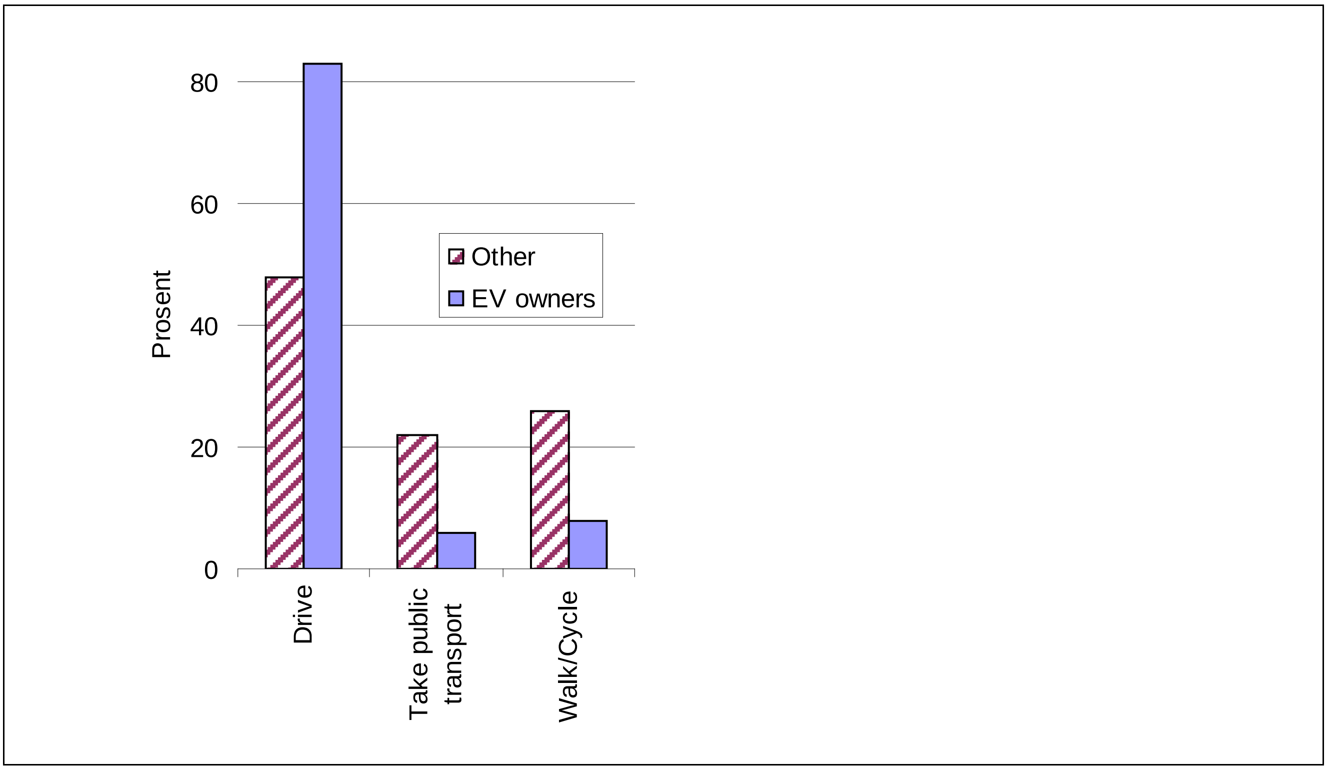

Figure 6. Travel patterns to and from work. Representative sample of the population and of EV owners
Source: Halvorsen and Frøyen (2009)