The vehicle purchase tax as a climate policy instrument

By
Lasse Fridstrøm and Vegard Østli
Institute of Transport Economics (TØI), Oslo

Abstract
Since 2007, the Norwegian vehicle purchase tax includes a large CO₂ emission component. At the same time, generous tax exemptions and privileges are granted to battery electric vehicles. Continued application of the purchase tax instrument may induce large-scale penetration of electric cars into the passenger car stock, thus halving the fleet’s fossil fuel consumption and greenhouse gas emissions within two or three decades. The main tangible cost of this low carbon policy is the extra cost of acquiring technologically immature products with currently small economies of scale. This cost difference will decline over time. The main benefits consist in reduced energy consumption.

We calculate the gross and net tangible cost of the low carbon policy in a long-term perspective, i.e. towards the 2050 horizon. A crucial cost determinant is the speed at which the manufacturing costs of battery and plug-in hybrid electric vehicles will fall. Under moderately optimistic assumptions about impending economies of scale, net tangible costs by 2050 come out in the range €42 to 138 per tonne CO₂, depending on the discount rate and on battery renewal costs.

Key words:
passenger cars, greenhouse gases, fiscal incentives, electric vehicles, modelling, policy scenario
1 Introduction

The true costs of transport are larger than paid for by the traveller or shipper (EC 1995, Maddison et al. 1996). Externalities include environmental impacts, accidents, congestion, and infrastructure wear and tear (Korzhevych 2014, Santos et al. 2010a). Among the environmental impacts, climate change is generally viewed as the most menacing, as seen in a global perspective. According to Stern (2007: xviii), ‘climate change is the greatest market failure the world has ever seen’.

Responsible governments and supranational bodies worldwide are considering how to limit and reduce greenhouse gas (GHG) emissions in line with IPCC (2014) recommendations.

In the European Union (EU), an estimated 19 per cent of all greenhouse gas (GHG) emissions originate from transport. Roughly one half of these emissions come from private cars.

In the EU as well as in North America, certain policy measures to combat GHG emissions from cars are already in place. Among regulatory measures, emission standards are the most important. Economic policy measures consist mainly of emissions trading schemes and of various fiscal incentives, such as excise taxes, subsidies, and tax credits.

1.1 Emission standards

The Corporate Average Fuel Economy (CAFE) regulation requires that passenger cars and light trucks produced for sale in the USA obey, on average, certain minimal fuel economy standards depending on the vehicles ‘footprint’, defined as the product of the vehicle’s width and its wheelbase. For passenger cars with a footprint below 41 square feet, the 2015 standard is at least 39 miles per gallon (mpg), translating into a CO$_2$ emission rate of at most 140 gram per kilometre for a petrol driven car. For cars with a footprint of over 56 square feet the limit is 30 mpg, or 182 CO$_2$ g/km. For light trucks the standards are more lenient – 33 and 24 mpg, or 165 and 277 CO$_2$ g/km, respectively, although these vehicles are also to a large extent used for passenger transport (NHTSA 2010).

The European Union (EU 2014) has mandated maximum CO$_2$ emission targets for new passenger cars sold in 2015 and 2021, respectively. The targets are 130 grams of CO$_2$ per km in 2015 and 95 g/km in 2021, as averaged over all vehicles brought to the market. More lenient standards apply to manufacturers producing heavier than average vehicles (ICCT 2014).

To meet the targets, automobile manufacturers are introducing a widening range of battery and plug-in hybrid electric vehicles (BEVs and PHEVs). Special accounting

---

1 Source: Eurostat.
rules make sure than vehicles with a CO₂ emission below 50 g/km give rise to ‘super-credits’ towards the targets for 2020-2022.

1.2 Fiscal incentives

In addition to regulatory measures, fiscal incentives are being used. In the USA, new plug-in electric vehicles are eligible for a tax credit of up to $7,500, depending on the battery capacity.

In Europe, the incentives vary between countries. In France, the government has implemented a feebate system, whereby new passenger cars emitting less 110 g/km a receive a subsidy (bonus), whereas a purchase tax (malus) applies to vehicles with type approval CO₂ emissions above 135 g/km.

Most countries in the European Economic Area (EEA)² levy an excise tax on fossil fuel, with a rate that typically adds 100 per cent on top of the pre-tax value. In North America, fuel tax levels are generally much lower.

A considerable scientific literature exists on the respective merits of vehicle and fuel taxation³. Economists would typically argue that, since the external cost arises when the vehicle is used and the fuel is burned, rather than when the car is bought or owned, a pigouvian fuel tax would correctly internalise the cost and provide the right incentive, while taxing the vehicle would be misguided. Some studies have, however, emphasized the apparently greater GHG abatement potential of fiscal incentives directed towards vehicle purchase and ownership⁴.

1.3 Outline

The remarkable market uptake of low and zero emission vehicles in Norway, brought about by regulatory as well as fiscal incentives, has drawn international attention⁵. Starting, in Section 2, by an examination of the Norwegian experience, we go on to discuss its most important costs and benefits in Section 3. To assess the net costs in relation to the GHG abatement effects obtained, we present, in Section 4, a set of scenario projections on to the 2050 horizon. In Section 5, we discuss the interpretation of results and the possible limitations affecting our study. Conclusions are drawn in Section 6.

² The European Union plus Norway, Iceland and Liechtenstein.
⁴ Johnstone and Karousakis (1999), Greene et al. (2005), Rogan et al. (2011), Brand et al. (2013).
2 The Norwegian experience

In their 2008 ‘climate policy agreement’, a large majority in the Norwegian Parliament defined a target for the average type approval CO\textsubscript{2} emission rate of new passenger cars sold in 2020. The target was set at 85 g/km.

Since there is no domestic car manufacturing, the target does not bind or penalize corporate stakeholders. It is, however, a strong political signal. The main strategy to reach the target is an accelerated market uptake of low and zero emission cars in general and of battery electric vehicles (BEVs) in particular.

The policy appears to work. As of January-April 2015, thanks to a 19 per cent BEV market share, the mean type approval rate of CO\textsubscript{2} emissions from new passenger cars registered in Norway was 99 g/km, equivalent to a fuel economy of 55 mpg for a petrol driven car.

The ownership and use of zero emission vehicles – BEVs and fuel cell electric vehicles (FCEVs) – are blessed with substantial incentives. These vehicles are exempt of value added tax (VAT), vehicle purchase tax, road tolls and public parking charges. They benefit from strongly reduced annual circulation tax and ferry fares. Moreover, they are allowed to travel in the bus lane and may be parked and recharged for free in many public parking lots.

The probably most important incentive in force is the CO\textsubscript{2} graduated initial vehicle registration tax, hereinafter called the purchase tax, applicable to all passenger cars equipped with an internal combustion engine (ICE). The purchase tax is a sum of four independent components, calculated on the basis of curb weight, ICE power, and type approval CO\textsubscript{2} and NO\textsubscript{X} emissions, respectively. All but the NO\textsubscript{X} component are distinctly progressive (see Figure 1).

For ICE vehicles, the four purchase tax components taken together typically add 50 to 150 per cent on top of the import value – or even higher for the largest and most powerful vehicles.

For plug-in hybrid vehicles (PHEVs), certain special rules apply. The electric motor is not considered part of the tax base for engine power. Also, so as to leave the standardized weight of the battery pack out of the tax calculation, the taxable curb weight of PHEVs is reduced by 26 per cent\textsuperscript{6}.

Since the CO\textsubscript{2} component is negative for cars emitting less than 105 g/km, light-weight PHEVs may come out with zero of near-zero purchase tax. The purchase tax cannot, however, become negative, as in a feebate system.

BEVs are altogether exempt of purchase tax. Most BEVs would, however, be subject to zero purchase tax even if the exemption were lifted\textsuperscript{7}, as the engine power and NO\textsubscript{X} components would be zero, while the negative CO\textsubscript{2} component would more than outweigh the positive weight component, except for the heaviest vehicle models.

\textsuperscript{6} As of 2015, up from 15 per cent in 2014.
\textsuperscript{7} Assuming that BEVs would then be subject to the same tax rules as PHEVs.
Hence, for BEVs the VAT exemption is presently more important than the purchase tax exemption. ICE and hybrid cars are subject to a standard 25 per cent VAT on the price exclusive of purchase tax.

The CO₂ component of the Norwegian vehicle purchase tax was introduced in 2007. Up until 2006, the purchase tax included a component based on the engine’s cylinder volume. Obviously, such a component is relevant for ICEs only. When this component was replaced by a CO₂ component, making the system technology neutral, the price of diesel cars dropped compared to that of petrol driven cars of similar size, simply because the diesel engine is more energy efficient. The car buyers responded by a massive shift towards diesel driven passenger cars in 2007, as shown in Figure 2.

In 2010, the issue of NOₓ emissions from diesel cars came to the fore, with the City of Bergen’s ‘winter of discontent’, when unfavourable atmospheric conditions led to prolonged and unprecedented levels of air toxicity in the downtown area (Strand et al. 2010). The fact that similar levels of air pollution are the rule rather than the exception in the capital City of Oslo received less attention at the time, but has become a more hotly debated issue in later years. Thus, in 2011 the first hints at a possible ban or heavy toll on diesel cars driving into the city centres were made public. Apparently, since 2012, consumers have responded to this by a certain reluctance to buy diesel driven cars, allowing petrol driven cars a certain renaissance. Also, since 2011, BEVs have exhibited rapidly growing market shares, reaching 12.5 per cent in 2014 and a full 19 per cent in January-April 2015.

---

Figure 1. Vehicle purchase tax as a function of curb weight, engine power, and type approval CO₂ and NOₓ emission rates, in Norway\(^8\) 2014. Source: Fridstøm et al. (2014)

---

\(^8\) NOK = Norwegian kroner. As of 1 July 2014, € 1 = NOK 8.43.
The introduction of the CO\textsubscript{2} tax component in 2007 and the subsequent sharpening made gradually during 2008-2014 seem to have had a considerable impact on the behaviour of Norwegian car buyers. Thus, from 2006 to 2014, the mean type approval rate of CO\textsubscript{2} emission among new petrol and diesel driven cars registered in Norway has fallen by 34 and 26 per cent, respectively. When BEVs are included in the calculation, the drop is 38 per cent (dotted blue line in Figure 3).

Unfortunately, real world emissions have gone down less than the type approval values, which are based on the NEDC laboratory tests mandated by the European Commission. According to Mock et al. (2013, 2014), the discrepancy between on-the-road and type approval emission rates has grown from an estimated 8 per cent in 2001 to a full 38 per cent for the 2013 cohort of vehicle models.

When correction is made for this growing discrepancy, on-the-road emissions from new, Norwegian registered petrol and diesel cars are seen to have fallen by only 20 and 6 per cent, respectively, between 2006 and 2014 (solid red and green lines in Figure 3). The overall mean, which includes BEVs, has come down by 24 per cent (solid blue line), meaning that 36 per cent of the improvement according to type approval figures is fictitious. One may note in passing that in the EU, the inconsistency is even worse: No less than 80 per cent of the improvement ‘recorded’ between 2006 and 2013 is fictitious (compare solid and dotted black lines in Figure 3).
A taxonomy of cost and benefits

The costs of Norway’s policy for low and zero emission vehicles, and in particular the generous incentives for BEVs, is a widely discussed issue in Norwegian public debate. With the article by Holtsmark and Skonhoft (2014), hereinafter called H&S, the discourse has also reached the international research community.

3.1 Fiscal costs

H&S focus on the revenue loss incurred by the public treasury, on account of the exemptions from purchase tax, road toll, parking charges, and road use tax (embedded in the fuel tax) enjoyed by zero emission vehicles. For an example Nissan LEAF owner, they add up the values of these exemptions, arriving at US$ 8 100 per annum. Assuming an annual mileage of 7 500 km, of which 5 600 km are thought to replace trips made by a Toyota Prius, with a type approval CO₂ emission of 110 gram per km, they calculate the annual CO₂ emissions savings at 600 kg, resulting in a ‘cost per tonne CO₂’ of US$ 13 500.

---

But according to Nissan’s own telematics system, the average annual distance driven by European LEAF vehicles is 16 500 km\textsuperscript{10}. Also, a more realistic comparison would be against the average new, Norwegian registered petrol car, which emits 164 gram CO\textsubscript{2} per km (Figure 3). Using these inputs, the resulting CO\textsubscript{2} savings come out at 2 706 kg per annum, implying a ‘cost per tonne’ of US$ 2 993 – less than one fourth of the figure calculated by H&S.

More importantly, the interpretation of tax, toll and parking charge exemptions as ‘costs’ is seriously flawed. Far from being costs in the standard economic sense, these money flows are simply redistributive transfers between the private and the public sector, or between different segments of private consumers and businesses. Their economic significance, if any, is bounded by the marginal cost of public funds, i. e. by the assumed economic efficiency cost of raising an extra unit of revenue for the public treasury, as first noted by Pigou (1948)\textsuperscript{11}. We revert to this in Section 3.6 below.

To come to grips with the costs involved in Norway’s policy for low and zero emission vehicles, a much broader approach is, in our view, called for. While not presenting a full cost-benefit analysis, we aim to identify and quantify the most important economic benefits and costs that enter the picture.

### 3.2 Manufacturing costs

The main economic cost connected with the gradual substitution of low and zero emission vehicles for conventional ICE cars is the extra price paid for the former vehicles compared to the latter. With a history of just about 100 years of mass production, the manufacturing of ICE vehicles has accumulated huge amounts of technological knowhow and reaped vast economies of scale and scope. For BEVs, PHEVs and FCEVs this innovation process is just in its dawn, with unit production costs presently exceeding those of ICE vehicles. There is, however, reason to believe that the manufacturing and operating costs of electric vehicles will gradually converge to those of conventional ICE vehicles (Fulton and Bremson 2014).

Since there is no domestic car manufacturing in Norway, the foreign trade statistics can be used to draw a fairly complete picture of the unit costs involved. In Figure 4, we show deflated, average pre-tax prices of new\textsuperscript{12} passenger cars imported to Norway 1988-2014. To get rid of seasonality, we show 12-month moving averages.

The black and red curves, representing petrol and diesel driven cars, respectively, are seen to be trending upwards since the early 1990s. In fact, this development masks the fact that the average size of cars within each fuel segment has increased. A more

---


\textsuperscript{11} For more recent expositions, see Diamond and Mirrlees (1971), Stiglitz and Dasgupta (1971), Atkinson and Stern (1974), Browning (1976) or Dahlby (2008).

\textsuperscript{12} The foreign trade statistics do not distinguish between new and second hand BEVs imported. Thus, second hand BEVs are included in the overall average. In 2012, 2013 and 2014, second hand vehicles represented 7, 21 and 14 per cent, respectively, of the BEVs imported (source: www.ofv.no).
detailed scrutiny reveals that within most weight classes, real prices have actually fallen (Fridstrøm et al. 2015).

By the same token, the average price of all ICE vehicles (the pink curve, until 2012 hidden behind the thick blue curve) has risen, mostly because the more expensive diesel driven cars have acquired increasing market shares, as shown in Figure 2.

The average price of new and second hand BEVs is shown by the green curve. While in the early stages of BEV market uptake (1999-2008), electric vehicles were generally small, simple and relatively inexpensive, from 2009 onwards we see an upsurge in the average cost of BEVs, as full size and compact vehicles like the Nissan LEAF entered the market. Another upsurge occurred from August 2013, when the Tesla Model S was launched in Norway, boosting the average price of BEVs sold.

![Figure 4. Average real pre-tax value of passenger cars imported to Norway 1988-2014, by energy carrier. Source: Statistics Norway](image)

The thick blue curve represents the overall mean price of all new cars imported, including second hand BEVs. From 2012 onwards, the market share of BEVs is large enough to visibly pull the overall average up from that of ICE cars, opening a gap between the blue and pink curves. One can interpret this gap as a rough indication of the extra costs paid by Norwegian society for the substitution of BEVs for ICE vehicles.

More precisely, this is the tangible cost incurred – the part of economic costs that manifests itself in the gross domestic product and in the books and bank accounts of private households and companies.

In addition to this observable, objective cost, there is a subjective, intangible cost involved, determined by changes in consumer utility. A case in point is range anxiety.
The welfare loss involved in converting to cars with a more limited range would have to be taken into account in a full cost-benefit analysis.

More generally, when consumers are led to choose low and zero emission vehicles over larger and more powerful ICE cars, because the former are cheaper after tax, they are left with a car fleet that differs from the ‘original’ one in several respects. The ensuing change in consumer surplus is, in principle, calculable by means of methods described by Train (2009). Such an analysis has, however, been outside the scope of this paper. We therefore limit our attention to the (most important) tangible cost and benefits.

Aggregating over all months between January 1988 and December 2014, we calculate at NOK 3 208 million (= approx. € 381 million) the extra expenditure paid for all new cars (plus second hand BEVs) compared to the hypothetical cost of importing an equal number of averagely priced ICE vehicles. During 2014 alone, the corresponding cost differential is NOK 1 813 million (= € 215 million) – an about 7 per cent margin embedded in the annual outlay of NOK 28 billion (= approx. € 3.3 billion).

### 3.3 Energy consumption

What are the tangible benefits of the low carbon fiscal policy? First and foremost, they relate to energy costs. While ICE vehicles at best exploit 30-45 per cent of the energy contained in their fuel, and at start-up and low speed much less, BEVs are remarkably energy efficient, exploiting 85-90 per cent of the energy already from the first metre driven. On the average, BEVs are at least three times as energy efficient as comparable ICE cars.

Even if the unit cost of energy would be the same for electricity and petrol/diesel, there is thus a potential for saving two thirds of the energy costs.

What are the relative prices of electricity versus fossil fuel? The spot price of electricity in Norway is of the order of € 0.030-0.035 per kWh excluding surtax and VAT. The energy content of one litre of petrol being about 9 kWh, with a pre-tax price hovering around € 0.6, one notes that, before taking account of grid costs, the resource cost of electricity in Norway is only about half as high as for fossil fuel.

In our scenario projections, an energy consumption rate of 0.2 kWh/km is assumed for BEVs, while PHEVs are assumed to consume an average of 0.1 kWh of grid electricity per km.

### 3.4 Life expectancy of electric vehicles and batteries

A third, tangible cost element is vehicle maintenance, in particular battery renewal. The batteries of some BEVs may not outlast the vehicle itself. In our scenario projections, it is foreseen that all or some BEVs renew their battery in their 10th life.

---

13 As of 2015, the electricity tax is NOK 0.1365 per kWh = € 0.0162, up from NOK 0.1239 in 2014.
year, at an average cost of NOK 50 000 per vehicle (= € 5 931). For PHEVs, a unit battery renewal cost of NOK 20 000 is assumed.

Other maintenance and depreciation costs are unlikely to differ greatly between BEVs, PHEVs and ICE vehicles. In our scenarios, BEVs and hybrids are assumed to exhibit life expectancies and lifetime mileages comparable to those of ICE vehicles. The average life expectancy of a passenger car in Norway is around 17 years (Fridstrøm et al. 2015).

3.5 Infrastructure
A fourth element is recharging infrastructure. While most BEV owners will charge their vehicle through an outlet at home, for BEVs to become the preferred option of a majority of car buyers, public charging stations should become available along major travel corridors, as well as for those who cannot park their vehicles anywhere but in the street.

In a calculation, the costs of developing and operating a recharging infrastructure must be balanced against the savings made on fossil fuel distribution, as steadily fewer vehicles are propelled by petrol or diesel.

3.6 External costs
In addition to the tangible and intangible private costs involved in the policy for low and zero emission vehicles, several external effects arise. Indeed, the very rationale for this policy is to limit certain externalities, notably the exhaust emission of greenhouse gases (GHGs) and of locally toxic substances, such as particulate matter (PM) and nitrogen dioxide (NO₂).

These costs are also intangible. They can, however, be assessed to the extent that a unit monetary value has been assigned to them. Thune-Larsen et al. (2014) provide up-to-date monetary values for a wide range of local pollutants originating from Norwegian road transport.

The marginal cost of public funds (cf. Section 3.1) is another external cost, for which there exists a government mandated statutory value. According to the Norwegian Ministry of Finance (2014), the rate should be set at NOK 0.20 per NOK 1 public expenditure or revenue. The need to balance the government budget is a real constraint in many European countries, whence it makes sense to confer extra value to a unit of public money.

4 Scenario projections
To assess the outcome of a policy, one has to judge it against some alternative. Standard cost-benefit analysis (CBA) is based on the comparison between two or more possible paths of development, one of which – the ‘business-as-usual’ or ‘do-nothing’ alternative – is typically labelled the ‘reference path’ or ‘benchmark’.
If one were, however, to calculate the cost of Norway’s policy for low and zero emission vehicles up to and including, say, 2014, one quickly runs into the challenge of specifying a meaningful benchmark. What is the alternative to the policy that has actually been followed? How should the taxation system be fathomed in a ‘do-nothing’ scenario? How would CO₂ emission rates have developed in such an arbitrary, counterfactual case?

To circumvent these difficulties and to offer a logically consistent, meaningful and rigorous analysis, we set out to explore certain well-defined, potential future development paths rather than to delve into an impervious past.

4.1 Reference path and modelling framework

In our reference path, the Norwegian vehicle purchase tax does not change between 2014 and 2050. For realism, however, we successively abolish most other privileges enjoyed by BEVs. The road toll and ferry charge exemptions are assumed to end on 1 January 2018, the purchase tax exemption on 1 January 2020, and the VAT exemption on 1 January 2022.

A key input to any scenario projection for the passenger car fleet and its GHG emissions is the relative prices between competing vehicle models, and in particular the prices of low and zero emission vehicles as opposed to conventional cars. In our reference path, the pre-tax prices of cars are assumed to develop like in Figure 5.

Figure 5. Assumed real price development for new passenger cars. Pre-tax averages for five vehicle segments.
For petrol, diesel and battery electric vehicles, the paths develop from the average price observed during the 12-month period from July 2013 to June 2014 (see Figure 4). For hybrid vehicles, since no data are available from the foreign trade statistics, certain discretionary estimates have been made for the plug-in and ordinary hybrid vehicle segments, respectively.

Energy efficiency improvements are assumed to take place for all ICE and hybrid vehicles. The mean type approval rate of fuel consumption of new petrol and diesel driven cars is assumed to drop by 1 per cent per year throughout the period 2014-2050. For hybrid vehicles, the rate is set at 3 per cent per year, reflecting an assumption than an increasing share of these vehicles will be plug-in hybrids.

On top of the improvements in fuel economy and manufacturing costs, BEVs are also assumed to undergo gradual quality improvements (e. g., extended range), valued at NOK 100,000 (= € 11,862) per vehicle by 2022 and another NOK 60,000 by 2050. For hybrid vehicles, half as large an improvement is assumed.

To predict the composition of new car sales under these assumption, we make use of a nested logit model estimated on the basis of complete passenger car sales data covering the period between January 1996 and July 2011. Since the discrete choice model is entirely generic, we may use it to predict the demand for hypothetical new car models, in particular the demand for low and zero emission vehicles, such as BEVs and PHEVs (Østli et al. 2015).

To account for the long-term changes in the car fleet, the new car sales are fed into a dynamic spreadsheet model, in which each cohort of cars is followed through its life span. In this cohort model, each year’s stock of cars is calculated from that of the preceding year, as modified by the flows of new car sales, second hand import, scrapping, and deregistration (Fridstrom et al. 2015).

The car fleet is divided into 22 segments and 31 age classes. There are nine segments for petrol driven cars and nine for diesel driven ones, each fuel class being subdivided into weight classes. In addition, there is one segment for hybrid vehicles, one for BEVs, one for FCEVs\(^\text{14}\), and one for vehicles using other energy carriers (compressed natural gas, ethanol, etc).

To each cell in the 22 x 31 matrix of the car fleet, various attributes are assigned, such as mean type approval fuel consumption per km, mean NO\(_x\) emission rates, mean annual distance driven, annual rate of scrapping, and an annual rate of second hand import. There is also a residual outflow of vehicles defined, with its own annual rate, covering second hand export and net temporary or permanent deregistration.

Using this framework, we may simulate several paths of development, differing in terms of vehicle taxation, up until the 2050 horizon.

---

\(^{14}\) Since there are virtually no market data available on FCEVs, we cannot at present assess their future demand. Hence these vehicles are not separately accounted of in our projections. Instead, one may choose to interpret the BEV category as including all zero emission vehicles.
4.2 Low carbon fiscal policy scenario

In addition to the reference path, we specify a rather forceful fiscal scenario, where the CO₂ component of the vehicle purchase tax is assumed to increase by NOK 75 per CO₂ g/km each year from 2015 on, while the deduction applicable to cars emitting less than 105 gram/km is doubled from 2016 on (Figure 6).

![Graph showing CO₂ component of vehicle purchase tax under low carbon fiscal policy scenario.](image)

Figure 6. Assumed development of the CO₂ component of the vehicle purchase tax under the low carbon fiscal policy scenario.

Apart from the changes in the purchase tax, the low carbon policy scenario is based on the same assumptions as the reference scenario.

4.3 Policy impact on car fleet and emissions

The new car registrations under the two scenarios are depicted in Figure 7.

In the low carbon policy scenario, our nested logit model of car choice predicts a massive shift towards hybrid and battery electric cars. In the reference scenario, however, the market growth period for BEVs lasts only as long as the VAT exemption (2022).

The mean type approval rates of CO₂ emission from new cars in the two scenarios are shown as dotted lines in Figure 8.
Figure 7. New car sales 2012-2050 under reference and low carbon policy scenarios.

Figure 8. Mean type approval and estimated on-the-road CO\textsubscript{2} emission rates of Norwegian passenger cars 2013-2050, under reference and low carbon policy scenarios.

In the reference path, the rate comes down from 110 g/km in 2014 to 95 g/km in 2020, 88 g/km in 2030, and 75 g/km in 2050. In the low carbon policy scenario, the corresponding levels are 80, 59 and 37 g/km, respectively.
The composition of the car fleet and its emission characteristics change more slowly. In the low carbon policy scenario, although hybrid and battery electric vehicles will represent more than 50 per cent of new car registrations in 2025, it will take until 2039 before the same is true of the car stock (Figure 9).

By the same token, the car fleet’s emissions on the road will come down only slowly. In the low carbon policy scenario, real-world emissions are seen to drop by 9 per cent by 2020, by 34 per cent by 2030, and by 63 per cent by 2050 (solid red line in Figure 8)\(^\text{15}\). On account of the gradual substitution of new vehicles for older ones, the CO\(_2\) emissions from the car fleet will come down even in the ‘do-nothing’ scenario — by 7 per cent by 2020, 21 per cent by 2030 and 36 per cent by 2050 (solid green line in Figure 8).

In terms of absolute CO\(_2\) emission cutbacks, the low carbon policy scenario saves an estimated 1.7 million tonnes in 2050 compared to the reference path, and a full 4.1 million tonnes compared to the 2014 level.

\(^{15}\) Here, we have made the conservative assumption that for future car generations, the discrepancy between type approval and real-world emissions does not increase from the 2011 level of 28 per cent. For vehicle cohorts prior to 2011, we use correction factors consistent with Mock et al. (2013).
4.4 Differential tangible costs

In Figure 10, we show differential tangible costs incurred under the low carbon policy scenario as compared to the reference path. Benefits, or cost savings, are shown as bars below the horizontal axis.

The main cost element is the extra cost of car acquisition, which reaches NOK 2.5 billion (= € 0.297 billion) in 2016 and 2017, before gradually tapering off as hybrid and battery electric cars become cheaper. A slight increase in car purchase costs occurs between 2025 and 2050, as the more expensive plug-in hybrids are projected, in the low carbon policy scenario, to replace ordinary hybrids and petrol driven cars. In general, however, differential car acquisition costs peak in the early phase of the process.

The opposite is true of fuel costs. As long as low and zero emission vehicles make up only a few per cent of the car fleet, fuel savings are modest. But when, under the low carbon policy scenario in 2039, BEVs and hybrids make up more than 50 per cent of the car fleet, annual fuel savings amount to NOK 3.25 billion (= € 0.386 billion), as evaluated at pre-tax prices.

Electricity costs will, of course, go up as more and more vehicles become electrified. As of 2039, differential electricity costs are projected to reach NOK 0.944 billion (= € 0.112 billion), less than one third of the corresponding fossil fuel cost.
Battery renewal, if applicable to all BEVs in their 10th life year, is in 2039 projected to cost NOK 1.141 billion (= € 0.135 billion) more under the low carbon policy scenario than under the reference scenario.

The accumulated net differential cost per tonne of CO₂ emissions avoided is shown in Figure 11, under four alternative sets of assumptions.

![Figure 11. Accumulated tangible economic costs per avoided tonne of CO₂ under low carbon policy vs. reference scenario.](image)

When all BEVs with a life longer than 10 years are assumed to have their battery replaced, the net present value of costs accumulated until 2050 comes out at NOK 634 (= approx. € 75) per tonne CO₂. Here, tangible costs and benefits have been discounted at a rate of 4 per cent per annum. CO₂ emissions savings have, however, not been discounted, since their impact in terms of climate change is practically independent of when emissions occur (IPCC 2013). Only the aggregate total over time matters.

If we disregard battery renewal costs, assuming that the batteries of future BEVs will outlast the vehicles themselves, the cost per tonne CO₂ comes down to NOK 356 (= approx. € 42) at the 2050 horizon.

If a zero discount rate is assumed, the costs per tonne CO₂ comes out at NOK 1 166 (= approx. € 138) at the 2050 horizon, including battery renewal.

Obviously, the per tonne cost of the low carbon policy is going to depend on the time scale. In the short term, the costs largely outweigh the benefits. As of 2025, for instance, the net accumulated cost exceeds € 600 per tonne CO₂. To reap the benefits
without incurring excessive costs, an informed, resolute and stable long-term policy is called for.

4.5 Differential fiscal revenues

The fiscal revenue implications of our low carbon policy are shown in Figure 12.

Since many consumers and companies will continue to buy ICE vehicles, the long-term fiscal impact of a steadily sharpened CO$_2$ taxation on new cars will be positive, as viewed by the public treasury.

Fuel tax revenue will, however, relentlessly go down in the low carbon policy scenario, in line with fossil fuel consumption. As of 2039, the fuel tax difference between the low carbon policy and reference scenarios is NOK 2.674 billion$^{16}$.

Assuming that the lower rate of annual circulation tax applicable to BEVs will persist, even this tax revenue will shrink.

---

$^{16}$ When this amount is added to the pre-tax fuel cost savings shown in Figure 10 (NOK 3.25 billion), the gross fuel expenditure reduction enjoyed by car owners in 2039, between the low carbon policy scenario and the reference path, can be calculated at NOK 5.82 billion = approx. € 0.69 billion exclusive of VAT, or approx. € 300 per passenger car including 25 per cent VAT.
While large parts of the political debate on Norway’s generous BEV incentives are focused on the purported large indirect subsidies, our scenario projections show that a forceful low carbon fiscal policy can easily be made to have the opposite long-term effect, bringing extra revenue into the public treasury.

5 Discussion

Like any modelling exercise, our calculations are subject to uncertainty and some qualifications.

The CO₂ emissions calculated in either scenario are those occurring on Norwegian territory only. A life cycle analysis (LCA) of the vehicles would necessarily include emissions in the countries of manufacturing. Battery production being a rather energy demanding process, a life cycle analysis of Norway’s low carbon fiscal policy would result in widely varying assessments of the climate footprint depending on the energy mix at the site of battery production.

Our approach is in line with the principles of the Kyoto protocol, by which each signatory country is answerable for emissions on its own territory. If one were to take into account production effects in other countries, it would be logical to also consider the international impact of Norway’s accelerated market uptake of BEVs, which helps bring about economies of scale in BEV manufacturing, to the benefit of buyers worldwide. Such an extended perspective would, however, quickly become intractable.

A second issue bearing on international relations is the climate footprint of increased electricity use. In our calculations, the CO₂ emission generated by a marginal kWh of electricity consumption is set to zero. While this may appear reasonable given Norway’s almost 100 per cent hydro power based electricity system, power exchange with other northern European countries means that the energy mix is not entirely fossil free even in Norway. Some would argue that the marginal kWh originates from a thermal plant. However, since all power plants in the European Economic Area\(^\text{17}\) (EEA) are covered by the European Trading System (ETS), an extra tonne of CO₂ emitted from a power plant simply replaces a corresponding amount of emissions elsewhere. At least this will be true from the time when the cap on emissions becomes effective. Until then, increased demand for electricity to power BEVs and PHEVs will serve to boost the price of emission allowances and enhance the incentives for renewable energy production.

Yet, the power market impact of vehicle electrification should not be overstated. Six per cent of Norway’s domestic hydropower output would be sufficient to operate the country’s entire passenger car fleet, if completely electrified.

The price development for BEVs, PHEVs and hybrids as compared to ICE vehicles is a crucial input to our analysis (Figure 5). The assumption that the manufacturing costs of BEVs will undercut that of petrol driven vehicles from 2023 onwards may

\(^{17}\) The EU plus Norway, Iceland and Liechtenstein.
seem optimistic. A sensitivity analysis based on a much slower price convergence, where BEVs and petrol ICE vehicles break even as late as 2040, gives a cost estimate per tonne CO\textsubscript{2} of NOK 1 111, versus NOK 356 in our corresponding low carbon policy scenario with a 4 per cent discount rate.

On the other hand, the most recent data available from Norway’s foreign trade statistics (July-December 2014) suggest that BEV prices are already coming down at a rate faster than assumed in our scenario projections. If such a development materializes, our cost estimates are likely to be on the high side. Under favourable circumstances, it is conceivable that the long-term net tangible cost of the low carbon fiscal policy could drop below zero, yielding a net benefit even before GHG abatement effects.

When certain externalities, such as the marginal cost of public funds and the value of reduced NO\textsubscript{X} emissions, are taken into account, the net cost is indeed found, in the best of cases, to be negative (Fridstrøm and Østli 2014).

The market uptake of BEVs and PHEVs will depend, not only on their average prices, but also on the variety of models offered. The more models become available in the market, the higher their aggregate market share will be. It is possible, and indeed likely, that our scenario assumptions are too conservative in this respect. This translates into an upward bias in our CO\textsubscript{2} emission estimates under both scenarios. The impact on differential CO\textsubscript{2} emissions and cost per tonne CO\textsubscript{2}, between the two scenarios, is hard to tell.

If and when low and zero emission vehicles make up a large share of the car fleet, the average cost of car use will go down, spurring demand. This is the so called rebound effect\textsuperscript{18}. Fridstrøm et al. (2014) calculated that a 50 per cent reduction in the per km fuel consumption would lead to 13 per cent more car use on short haul trips, but a 40 per cent reduction in CO\textsubscript{2} emissions, all modes considered. On long haul trips, the overall rebound effect was found to be much smaller in terms of CO\textsubscript{2}. This is so because, under Norwegian conditions, cars compete primarily against the air mode rather than against long distance coach or rail.

As of today, European levels of fuel tax serve to internalise a major part of the road use externalities – more so, though, for petrol than for diesel driven vehicles (Thune-Larsen et al. 2014). The concern, held by many, that vehicle electrification may undermine the most important market correction mechanisms presently at work, is a valid one. To counteract the growth in car use, with its associated increased congestion, road wear and other externalities, novel forms of market correction, such as generalised GPS-based road pricing, might become necessary.

To the extent that the future car fleet include a large share of plug-in hybrid or battery electric vehicles, certain infrastructure investments will be necessary. The grid itself may need to be strengthened, households must invest in charging points\textsuperscript{19}, and more public charging points will become necessary as well. These tangible costs are

\textsuperscript{18} See, e. g., Schipper and Grugg (2000) or Small and van Dender (2005).  
\textsuperscript{19} Crist (2012) suggests a cost per home charging point of € 1 200, or € 0.03 per kWh if divided by a single vehicle life time mileage of 200 000 km at 0.2 kWh/km. Figenbaum and Amundsen (2013) state a cost interval of NOK 3 000 - 16 000, roughly € 350 - 1 900, under Norwegian conditions.
not explicitly accounted for in our assessment. However, the unit pre-tax price of electricity used in our calculations – NOK 0.6761 (≈ approx. € 0.08) per kWh – leaves room for considerable grid and infrastructure costs on top of the current spot price of € 0.030-0.035, without our assumptions becoming overly optimistic.

Our analysis is focused on one single policy instrument – the purchase tax. Some – and a majority of economists – would say that this instrument is far from ideal, since emissions are caused by car use rather than by ownership. Hence a fuel tax would be more appropriate for the purpose of GHG abatement.

But the elasticity of demand for fossil fuel seems to be too small (in absolute value) for politically feasible levels of fuel taxation to bring about sizeable GHG emission cuts (Brand et al. 2013). The large, upfront expenditure involved in buying a (more expensive) car is more likely to affect consumer behaviour than the relatively marginal extra cost caused by a fuel tax. Thus, Brand et al. (2013) find, in a comprehensive analysis of UK incentives, that ‘… car purchase feebate policies are shown to be the most effective in accelerating low carbon technology uptake, reducing life cycle gas emissions …’

The high initial levels of VAT, purchase tax, toll rates and ferry fares in Norway make it possible to create strong incentives without introducing direct subsidies. This experience cannot readily be transferred to other countries. But steep feebates could possibly do the same trick (Lindgren and Fridstrøm 2015).

6 Conclusions

Vehicle purchase taxes and feebates have a large potential for GHG abatement. Such taxes can be designed as fiscally neutral or even revenue generating for the public treasury.

The merit of a feebate or purchase tax system should be judged, not by its impact on the public treasury, but primarily by its tangible and intangible costs to all sectors of society, as in a cost-benefit analysis. The main economic cost of an incentive scheme for low and zero emission vehicles is the extra cost of manufacturing technologically immature products with currently small economies of scale. This cost differential is likely to be in large part temporary.

A conversion to low and zero emission vehicles will entail large energy savings in the long term. Since these savings occur much later than the incremental manufacturing cost, it is essential that the policy be assessed in a long-term perspective. The policy itself must be long-term, too, since the car fleet is an inert matter. Converting to a low emission car fleet will require political perseverance over several decades.

The net tangible costs of a forceful policy for low emission passenger cars in Norway has been calculated at NOK 356 to 1 166 (= € 42 to 138) per tonne CO$_2$. Under more optimistic assumptions, such as quickly developing economies of scale in BEV and PHEV manufacturing, a quickly expanding supply of different BEV and PHEV models, and/or a positive marginal cost of public funds, it is conceivable that the net tangible cost of a low carbon fiscal policy for passenger cars could drop below zero.
In such a case, the policy would yield net tangible benefits to society even before considering GHG abatement effects.

The intangible parts of the changes in consumer surplus are, however, not taken into account in this analysis. One such subjective cost is the limited range of BEVs and the associated range anxiety. To assess these welfare cost elements, further research would be needed.

Acknowledgements

The basic research underlying this study was made possible through the TEMPO project funded by the Research Council of Norway (grant number 195191) and supported by 12 stakeholder partners, viz. the Norwegian Public Roads Administration, the Ministry of the Environment, the National Rail Administration, the Norwegian State Railways (NSB), Akershus County Council, Ruter AS, the Norwegian Automobile Association (NAF), NHO Transport, NOR-WAY Bussekspress, DB Schenker, Norsk Scania AS, and Vestregionen. The last mile funding for the analysis presented herein came from the Norwegian Electric Vehicle Association and the Institute of Transport Economics (TOI). All contributions are gratefully acknowledged.

References


