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The effect of fiscal incentives on market penetration of electric vehicles: A pairwise comparison of total cost of ownership

Petra Zsuzsa Lévay*, Yannis Drossinos, Christian Thiel

Joint Research Centre, European Commission[1], Via Enrico Fermi 2749, I-21027 Ispra (VA), Italy

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ABSTRACT

An important barrier to electric vehicle (EV) sales is their high purchase price compared to internal combustion engine (ICE) vehicles. We conducted total cost of ownership (TCO) calculations to study how costs and sales of EVs relate to each other and to examine the role of fiscal incentives in reducing TCO and increasing EV sales. We composed EV-ICE vehicle pairs that allowed cross-segment and cross-country comparison in eight European countries. Actual car prices were used to calculate the incentives for each model in each country. We found a negative TCO-sales relationship that differs across car segments. Compared to their ICE vehicle pair, big EVs have lower TCO, higher sales, and seem to be less price responsive than small EVs. Three country groups can be distinguished according to the level of fiscal incentives and their impact on TCO and EV sales. In Norway, incentives led to the lowest TCO for the EVs. In the Netherlands, France, and UK the TCO of EVs is close to the TCO of the ICE pairs. In the other countries the TCO of EVs exceeds that of the ICE vehicles. We found that exemptions from flat taxes favour big EVs, while lump-sum subsidies favour small EVs.

1. Introduction

The transport sector is one of the main contributors to anthropogenic climate change worldwide, accounting for 23% of global energy-related greenhouse gas (GHG) emissions (IEA, 2015b). The number is similar in the European Union (EU). Transport has the second biggest share, after energy industries, accounting for almost a quarter of total emissions. The modal decomposition of transport GHG emissions shows that road transport had the primary role in GHG emissions with a share of 73% in 2014 (EC, 2016a).

In contrast to other sectors in the EU, GHG emissions constantly grew in the transport sector from 1990 to 2007. Although transport emissions have been declining since 2007, they still have not reached the 1990 level. The share and growth patterns of transport emissions justify and prompt policy actions. Electromobility can be an effective solution in tackling negative externalities associated with internal combustion engine (ICE) car usage. There is a strong worldwide political will to foster the market introduction of electric vehicles (EVs). The most recent advancement happened during the COP21 Paris Climate Conference in December 2015, where the collaborative initiative “Paris Declaration on Electro-Mobility and Climate Change and Call to Action” was accepted (IEA, 2015b). It aims to promote electromobility to achieve a more sustainable transport sector compatible with a lower than 2 degree global warming pathway. To achieve this goal, electric vehicles have to represent 35% of global vehicle sales by 2030, according to the action plan.

Besides global GHG emissions, ICE vehicles also cause noise and local air pollution, creating adverse health effects especially in urban environments (OECD, 2014). Car-related petrol and diesel demand can cause dependence on foreign energy sources, compromising energy security. In light of these problems, national and local governments adopt a wide range of measures to encourage electric vehicle[2] use. Fiscal incentives are important measures as they influence directly the vehicle purchase decision of individuals or companies. They can be total or partial tax exemptions, or direct subsidies. The aim of this study is to assess and evaluate how different fiscal incentives may have stimulated the market penetration of EVs in eight European countries: France, Germany, Hungary, Italy, Netherlands, Norway, Poland, and the United Kingdom. We focus on year 2014 and our analysis covers roughly 66% of all EV sales in the EU28 and European Free Trade Association (EFTA) countries in 2014. One of the biggest barriers to market breakthrough of EVs is that, in the absence of incentives, they are currently not cost-competitive. We conducted total cost of ownership (TCO) calculations to determine how costs and sales of EVs relate

* Corresponding author at: Herman Deleeck Centre for Social Policy, University of Antwerp, Sint-Jacobstraat 2, 2000 Antwerp, Belgium.
E-mail addresses: petra.levay@uantwerpen.be (P.Z. Lévay), yannis.drossinos@ec.europa.eu (Y. Drossinos), christian.thiel@ec.europa.eu (C. Thiel).

[1] The views expressed are purely those of the authors and may not in any circumstances be regarded as stating an official position of the European Commission.

[2] We consider as EVs battery electric vehicles (BEV) and plug-in hybrid electric vehicles (PHEV).

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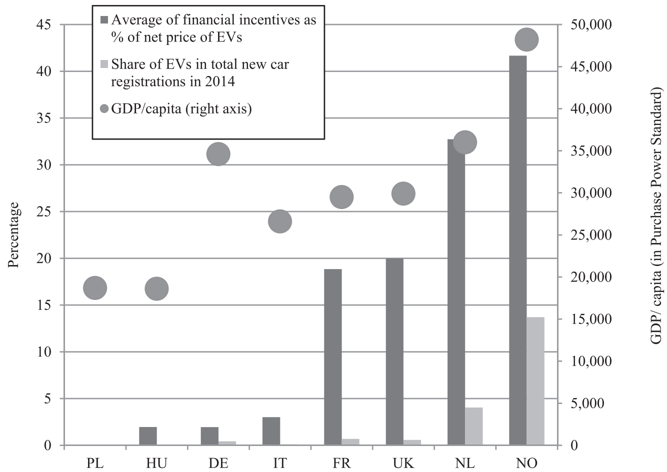

Fig. 1. GDP, fiscal incentives and share of EVs in 2014. Average incentives were calculated for the eight vehicle pairs in the eight countries analysed (see also sections 3.2 and 4.2). EV share data from Thiel et al. (2015) and EAFO (2017), GDP data from Eurostat (2017).

to each other, and to examine the role of fiscal measures in reducing TCO and thereby increasing sales of EVs.

An important aspect of our analysis is that we used real-life car prices. Previous cross-country comparisons of TCO either used vehicle prices from one country and generalized them to other countries (Mock and Yang, 2014; IEA, 2015a), or followed a bottom-up approach to calculate a hypothetical vehicle price from the costs of its components (Propfe et al., 2012; Wu et al., 2015). Some studies used real-world car prices but they were within-country comparisons (Windisch, 2013; Hagman et al., 2016).

Fiscal incentives, if sufficiently high to offset cost differences between EV and conventional cars, are the most important reason to buy an EV, according to a survey made among Norwegian BEV owners (Bjerkan et al., 2016). Fig. 1 shows the average national fiscal incentives provided for the vehicles included in our study, along with the share of EVs in total new car registrations in 2014, as well as the 2014 GDP/capita. The EV market shares vary greatly and do not seem to correlate strongly with GDP/capita levels, motivating the investigation of the differences in EV sales across countries and their relation to fiscal incentives and other costs associated with EV ownership. We performed pairwise comparisons of EVs to ICE vehicles, which are not subject to such incentives, to assess qualitatively the effects of fiscal incentives on market penetration of EVs.

The effect of fiscal incentives can depend on demand elasticities. Segmental price elasticities of vehicles have been investigated previously, see, for example, Berry et al. (1996); Coibion and Einav (2006); Eftec (2008). These works suggest that elasticity is lower in bigger-size car segments and higher in smaller-size, namely small-car demand is more price responsive than demand for big cars. There are two possible explanations: (i) substitution in small segments occurs as there are more models available; (ii) typical customers in the sports or luxury car segments have more income, thus they are less sensitive to price changes. We include small, medium, and big EVs in this study, a choice that allows us to assess segmental differences in the costs-sales relationship.

Other important non-fiscal factors can influence vehicles sales. Bounded rationality is an often mentioned problem with the purchase decision of EVs. As EVs have higher net price than ICE vehicles, consumers face big costs upon purchase, while benefits accrue during the ownership period. Consumers do not always have enough information about potential fuel, maintenance, etc. cost savings, which can result in suboptimal decisions. Another relevant cognitive factor is social norms, as suggested by, for example, Barth et al. (2016). They emphasised that social validation plays an important role in purchase decisions at the early stage of diffusion of new technologies. They argued that targeted education and experience programmes could effectively complement economic or technological interventions. Besides psychological considerations, range anxiety can also prevent customers from buying EVs. In a cross-country regression analysis, Sierzchula et al. (2014) found that the national market share of EVs is well explained by the number of charging stations. This is in line with the results of Lieven (2015). While bounded rationality, social norms, and range anxiety are important non-fiscal barriers to market penetration of EVs, in this study we follow a technical approach focusing only on EV costs.

We emphasize that our analysis is based solely on financial instruments used by national governments to promote electromobility. We do not consider additional city or national policies, for example availability of public charging points, use of bus lanes, parking in city centre, etc., that may be important factors in the decision to purchase an EV. Currently available data do not allow us to disentangle their effect and to evaluate and assess their impact. Future surveys may provide a means to eliminate the influence of these confounding factors.

2. Overview of EV-related policy context and incentives

2.1. Policy context

The level and design of incentives vary greatly in the different countries. The incentives are heavily influenced by wider policy considerations targeting, for example, climate change mitigation, air quality improvement, energy security, or industrial competitiveness. All analysed countries participate in the Emission Trading Scheme (ETS), with a 43% GHG reduction target by 2030 (versus 2005 levels) (EC, 2016b). The ETS covers approximately 45% of the EU's GHG emissions (EC, 2016c). GHG emission reduction targets for the non-ETS sectors, including road transport, are covered by the proposed effort sharing decision, which, amongst others, takes into account national GDP/capita levels for the definition of the GHG targets. The proposed reduction targets are high for Norway (40%), Germany (38%), France (37%), UK (37%), and the Netherlands (36%), medium for Italy (33%), and low for Hungary and Poland (7% each) (EC, 2016b).

The main motivation for Norway's commitment to EVs is to meet its climate goals, although originally the EV incentives, dating back to 1990, were also meant to establish a Norwegian EV industry (Figenbaum et al., 2015a). The aim of the Dutch government's CO_2-related vehicle taxation (since 2007) and EV incentive policy, which started in 2010, is to reduce CO_2 emissions, improve energy-efficiency, reduce dependency on fossil fuels, and reduce noise (Holland Trade and Invest, 2017).

EV incentives in the UK started in 2010: they were viewed as an opportunity to re-position the UK automotive sector to ultra-low emissions vehicle manufacturing and R & D. Additional motivations to introduce EV incentives are (i) to improve energy security; (ii) to meet the UK's carbon reduction targets; and (iii) to reduce local air and noise pollution (Office for Low Emission Vehicles, 2013).

France set up a plan for decarbonised vehicles in 2009. “For the government, the official ambitions of such a plan were energy independence, to cut CO_2 emissions to meet within EU criteria, and to ensure the competitiveness of the French automotive industry” (Hildermeier and Villareal, 2011). The French bonus-malus system was introduced in 2008.

The focus of Germany was on supply-side measures. From 2009, the government invested substantial amounts in R & D and market demonstration projects.[3] Regarding the wider policy context of German

[3] EV purchase subsidies started only in 2016.

EV incentives, the goals of the German Electromobility Development Plan were (i) to reach energy and climate policy goals, (ii) to become a market leader for electromobility, (iii) to develop competitiveness by innovation, (iv) to reduce dependence on oil, and (v) to foster social acceptance of electromobility (Die Bundesregierung, 2009).

Italy focuses on other alternative fuel options, with a high share of CNG (Compressed Natural Gas) cars in the market (EAFO, 2017). The largest Italian car manufacturer is sceptical about the viability and future prospects of electric vehicles (Reuters, 2014). Hungary sees electric vehicles as an opportunity to strengthen its automotive industry by supporting research and development (Lenner, 2015).[4] Poland has only recently announced a plan to accelerate the deployment of electric vehicles (Reuters, 2016).

Fig. 2 shows the development of the EV market share in the eight countries from 2010 to 2015. Even though we analyse 2014 data, we also present data for 2015 to render evident emerging trends. The figure also shows the number of models offered in Europe, growing from 3 models in 2010 to 28 in 2014 (38 in 2015). Since EV incentives remained stable throughout 2010–2015 (in the countries that had adopted them - Norway, Netherlands, UK, and France-) the figure reveals that the incentives became effective when the number of models started growing in 2011, an observation also made by Figenbaum et al. (2015b). By 2014 the EV market share (of new car registrations) was well above 5% in Norway, and close to 5% in the Netherlands. In 2014 (2015) the EV market share was above 0.5% (1.0%) in France and the UK, far below that of the Netherlands and Norway. In the other countries the EV market share remained well below 1% throughout 2010–2015. The relatively small decrease in EV registrations in the Netherlands in 2014 may be attributed to public debates in 2013 (and 2015) on the phasing-out of incentives for PHEVs in 2014 (and, respectively, in 2016). Eventually, the PHEV incentives remained in 2014; they were reduced only in 2016. The anticipated decrease of incentives most likely led to increased sales in 2013 (and 2015) (Thiel et al., 2015).

2.2. EV incentives in 2014

The eight countries considered in this study adopted different approaches in their fiscal policy: tax exemptions or subsidies. In Norway, Netherlands, Germany, Italy, and Hungary negative externalities associated with the usage of ICE vehicles are penalized with taxes from which EVs are partially or fully exempt. The higher the taxes, the more EV owners benefit from the exemptions. In the UK and France the main policy instrument is a subsidy given to EV owners upon purchase. In Poland there are no incentives. Table 1 summarizes VAT rates and tax bases country-wise.

Fiscal incentives are the most generous in Norway. The Norwegian vehicle taxation system taxes heavily ICE vehicles based on curb weight, engine power, CO_2 and NO_x emissions. In addition, there is a high 25% VAT rate. BEVs are fully exempt from both taxes and partly exempt from annual circulation taxes. Consequently, the monetary benefits of owning a BEV, in this study summed over the first 4 years of ownership, can reach more than half its net price. PHEVs are not exempt from these taxes, but, due to their low type-approval CO_2 emissions, their owners still pay less than owners of ICE vehicles.[5] Several non-fiscal and non-monetary incentives exist, such as access to bus lanes, free parking, road toll exemption, and reduced rates on ferries. Moreover, more than 4200 public charging stations provide free electricity for EVs (Carranza et al., 2013; Figenbaum and Kolbenstvedt, 2013).

As in Norway, there is a strong political will to promote market penetration of EVs in the Netherlands. The progressive registration tax is based on type-approval CO_2 emissions with a lower limit of 88 g/km; all the BEVs and PHEVs in this study were exempt.[6] Fuel type also plays a role in the Dutch taxation system as a diesel surcharge of €73 per gram of CO_2 emitted is imposed for emissions above 70 g/km. The rate of the annual circulation tax depends on the fuel type (petrol/diesel) and the car weight. It differs slightly among provinces (ACEA, 2015). PHEVs and BEVs were exempt in 2014.[7] In contrast to Norway, EVs are not exempt from VAT, rendering the total amount of fiscal incentives lower in the Netherlands. The average savings from the tax exemption is approximately 24.5% of the net price of the EVs analysed here. Other policy tools are also employed in the Netherlands. The government spent 65 M€ on the National Action Plan for Electric Driving during the introduction period of EVs (2009–2011). A Formula-E team was established with parties from authorities and industry to spur market development of EVs. Subsidies were given to demonstration projects, charging and energy infrastructure installation, R & D, and production of EVs and their parts (IEA, 2016).

The French and British taxation schemes are different because EVs are eligible for direct subsidies upon purchase. In France, there is a bonus-malus system based on type-approval CO_2 emissions. Vehicles with CO_2 emission between 0 and 20 g per kilometre are entitled to a subsidy covering 27% of their purchase price with an upper limit of €6300. Vehicles with CO_2 emissions between 21 and 60 g/km are entitled to a subsidy covering 20% of their purchase price with an upper limit of €4000. Vehicles with CO_2 emissions above 131 g/km are subject to increased taxes (ACEA, 2015). Although the subsidy depends on the car net price, it becomes effectively a lump-sum subsidy for the vehicles in our study because their prices are high enough to be eligible for the maximum subsidy. There is, also, a regional registration tax based on CO_2 emissions and engine power. This tax does not exceed a few hundred euros, and some regions provide full or partial exemption to electric and/or hybrid vehicles. There is an annual circulation tax for vehicles with CO_2 emissions higher than 190 g/km, but all cars in this study have lower emissions. Non-monetary incentives include car-sharing schemes and governmental support for charging infrastructure installation (IEA, 2016). In the UK, the purchase subsidy covers 25% of the purchase price of EVs irrespective of their CO_2 emissions. The upper limit is £5000 (≈€6200) (ACEA, 2015). As in France, the EVs in this study were entitled to the maximum incentive in 2014. The progressive annual tax is based on CO_2 emissions, but did not exceed £130 (≈€161) for the chosen vehicles. Non-fiscal measures differ locally, such as exemption from congestion charge in London, or reduced parking charges (IEA, 2016).

Germany, Hungary, Italy and Poland did not provide significant incentives. In Germany, Hungary, and Italy EVs are exempt from the annual circulation tax, but its amount is not high; for conventional vehicles it is typically a few hundred euros per year (ACEA, 2015). In Hungary, BEVs are also exempt from registration tax (Registration tax calculator, 2017), but again, the amount is small. In Poland there are no incentives. Regarding non-monetary incentives, the German and Italian governments subsidized the installation of charging points.

EV incentive programmes can result in tax revenue loss, especially if revenue-neutrality is not considered during the design of the policies. The losses can become significant with higher EV market shares, as for example in Norway and the Netherlands, and corrective action may become necessary. In the Netherlands, CO_2-based vehicle tax policies were gradually implemented in 2007, when potential future tax erosion was politically acceptable. However, after an intermediate evaluation in 2011, CO_2-based limits were tightened to avoid future revenue loss

[4] A purchase subsidy for EVs was announced in 2016 (Nemzetgazdasági Minisztérium, 2016).

[5] PHEVs are eligible for a 15% weight reduction in the calculation of the registration tax to compensate for the excess weight of the battery. Only the ICE power is subject to the engine-power element of the registration tax.

[6] The lower limit was reduced to 82g/km in 2015 and 79g/km in 2016. Cars emitting below the limit are subject to registration tax, since the beginning of 2015 (Belastingdienst, 2016).

[7] This exemption was cancelled in 2016 (Rijksoverheid, 2016).

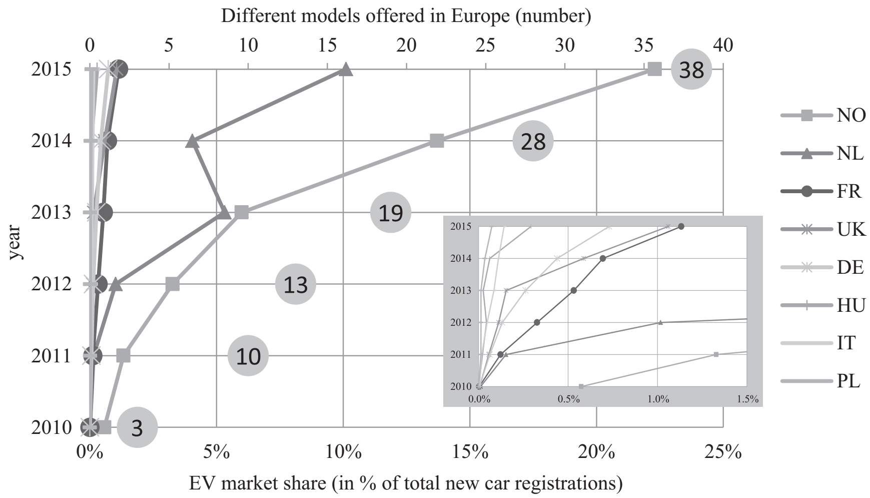

Fig. 2. 2010–2015 evolution of different EV models offered in Europe (horizontal axis, top) and EV market share in the different countries (horizontal axis, bottom).

Table 1
VAT rates and tax bases of EV and ICE vehicles in 2014.

Country	Start year of EV incentives	VAT (%)	Registration tax/fee/subsidy		Annual circulation tax	
		ICE/EV	ICE	EV	ICE	EV
Norway	1990	25/0[a]	CO_2, kg, kW, NO_x	-[a]	≈ €347 under 7500 kg	≈ €50 for BEVs
Netherlands	2010	21/21	CO_2, fuel type	–	fuel, kg, province	-[a]
United Kingdom	2010	20/20	€63 fee	€63 fee; subsidy	CO_2	–
France	2008	20/20	CO_2, kW, region	CO_2, kW[b], region; subsidy	CO_2, above 190 g/km	–
Hungary	n.a. (2016)	27/27	fuel type, ccm	-[a]	kW	-[a]
Italy	n.a.	22/22	kW, province, €135 fee	kW, province, €135 fee	kW, region	–
Germany	n.a. (2016)	19/19	€26 fee	€26 fee	CO_2, fuel type, ccm	–
Poland	n.a.	23/23	ccm, excise tax, €61 fee	ccm, excise tax, €61 fee	–	–

[a] BEVs are exempt, PHEVs are not.
[b] In some provinces EVs are partially or fully exempt from registration tax.

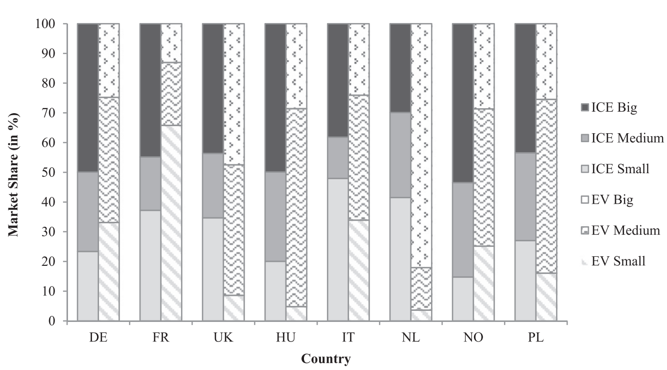

Fig. 3. Share of vehicle size for EV and ICE sales in 2014 per country (data from EEA (2015) and Norwegian Information Council for the Road Traffic).

(Kok, 2015). Furthermore, the Netherlands reduced the incentives for PHEVs starting in 2016 and beyond. When the target of 50,000 EV registrations in Norway was reached in 2015, the government reconfirmed its incentives until the end of 2017 (Automotive News Europe, 2017). For Norway, the estimated net welfare effect of EV incentives for society is estimated to be positive (Figenbaum et al., 2015b). It can also be seen as an investment towards meeting the GHG reduction targets of the intended nationally determined contributions, a follow up to the COP21 agreement, as well as improving air quality and decreasing other negative externalities (Aasness and Odeck, 2015).

3. Data and methodology: pairwise comparison of TCO and sales

3.1. Choice of vehicle pairs

We performed pairwise comparisons to quantify and compare incentives and cost differences across car segments and countries. We composed EV-ICE vehicle pairs and expressed the cost and sales of each EV as percentage of the cost and sales of their corresponding ICE vehicle pair. This enabled us to exclude differences in market and segment sizes among countries. The comparison of absolute sales numbers of the same vehicle across countries would be inappropriate because a bigger car market can imply higher EV sales. Moreover, the size and composition of a car market in a country is determined by several factors that are not included in our study, such as income, available financing options, demographics, or attractiveness of other transport modes. These effects can be ruled out by the pairwise comparison. A similar reasoning holds for segment-size differences across countries. For example, the share of small cars (A and B segments) in the total new vehicle registrations in 2014 was 23% in Germany and 48% in Italy (Thiel et al., 2015). Fig. 3 compares the share of vehicle size for EV and ICE sales in 2014. It not only shows large differences across countries but also between ICE and EV sales within a country. In the Netherlands, for example, the share of big vehicles within the EV group was 82%, while it was only 30% within the ICE vehicle group. The underlying factors, like diverse demand characteristics, that can drive such cross-country variations can be excluded if we compare the sales and costs of the EVs to ICE vehicles

Table 2
Vehicle pairs of EV and ICE models.

Segment	EV	ICE vehicle	Vehicle size
A	Volkswagen e-up!	Volkswagen up! 1.0 gasoline	Small
B	Renault Zoe	Renault Clio dci 75	Small
C	BMW i3	BMW Series 1, 116d	Medium
C	Nissan Leaf	Honda Civic 1.6 i-DTEC	Medium
C	Toyota Prius Plug-in Hybrid	Toyota Auris 1.4 D-4D	Medium
D	Volvo V60 Plug-in Hybrid	Volvo V60 D2	Big
S	Tesla Model S	Audi A7 3.0 TDI ultra	Big
J	Mitsubishi Outlander Plug-in Hybrid	Mitsubishi Outlander 2.2 DI-D 4 WD	Big

from the same segment in the same country. Lastly, the pairwise comparison enabled us to calculate the exact amount of fiscal incentives provided to EVs by quantifying tax differences between EVs and similar ICE vehicles.

We composed the vehicle pairs as presented in Table 2. We included EVs from every segment where the total EV sales in a country were more than 1000 in 2014. In each segment we chose the best-selling models. The sales of these EVs started in 2012/2013 in the EU: they were models in the middle of their life-cycle in 2014. One exception is the Nissan Leaf that was launched in 2010, but remained popular throughout the following years. For our calculations we used technical data of the latest car generation. The choice criterion for the ICE vehicles was that they resemble their EV pair as much as possible. Moreover, since brand loyalty among car owners is generally high, around 60% (Verhoef et al., 2007), we selected models from the same manufacturer with the most similar technical characteristics (if available). Regarding the Nissan Leaf and the Tesla Model S, there were no similar ICE vehicles from the same manufacturer in Europe; for the former we chose the Honda Civic and for the latter the Audi A7 as a pair. Once the EV-ICE model pair was determined, we chose the versions with the lowest CO_2 emissions and basic options (ICE) or the most basic in terms of performance and price (EV).

3.2. TCO calculations and data collection

We calculated the TCO of the EVs and ICE vehicles listed in Table 2 for each country. The concept of TCO is to summarize all present and future costs and revenues of an investment. This provides a more realistic picture of the economic value of an investment than the sole consideration of the purchase price. This is important for EVs because the savings associated with lower fuel expenses do not arise upon purchase, but during the ownership period. We calculated the TCO of each vehicle as follows:

$$TCO = P + VAT + T_r - S + T_c + F - R \quad (1)$$

where P is the net price, VAT is value added tax, T_r is the sum of other taxes on acquisition, S is the subsidy received upon purchase, T_c is the present value of annual circulation taxes, F is the present value of fuel and/or electricity costs, and R is the resale value of the vehicle.[8] Not all the costs were present in each country: for example, only two countries, France and the United Kingdom, provide subsidy upon purchase. The TCO calculations require a number of assumptions. We assumed that vehicles were owned for 4 years, the annual kilometres travelled were 12,000 km, and the discount rate for future costs and incomes was 1%.

We consulted several sources: the technical vehicle specifications, performance characteristics, and consumption data were extracted from the official websites of the manufacturers. The vehicle characteristics are presented in Table S1, their net 2014 prices in Table S2, and the sources of the prices are listed in the Excel file, Supplementary Material. The calculation of future fuel and electricity expenses required assumptions on the fuel/electricity costs. We calculated them using 2014 fuel and electricity prices (in each country), and we considered them constant for the four years of the TCO calculation. Petrol and diesel retail prices were obtained from the website of the European Environment Agency (EEA, 2016) for EU countries and from the German Federal Ministry for Economic Cooperation and Development (GIZ, 2015) for Norway. We averaged the weekly EEA data to obtain a single 2014 price. Electricity retail prices were downloaded from the Eurostat website (Eurostat, 2016). We obtained exchange rates from the website of European Central Bank, and calculated the average 2014 exchange rates (ECB, 2016). The fuel and electricity prices used in the TCO calculations are given in Table 3.

Table 3
Fuel and electricity prices in 2014.

Country	Retail petrol price (€/l)	Retail diesel price (€/l)	Retail electricity price (€/kWh)	Average relative fuel costs[a]	
				BEVs	PHEVs
Italy	€1.72	€1.61	€0.24	52%	81%
Norway	€1.71	€1.59	€0.17	36%	70%
Netherlands	€1.70	€1.41	€0.18	42%	77%
United Kingdom	€1.59	€1.66	€0.20	43%	73%
Germany	€1.54	€1.36	€0.30	75%	97%
France	€1.49	€1.29	€0.16	42%	76%
Hungary	€1.33	€1.35	€0.12	31%	65%
Poland	€1.26	€1.25	€0.14	40%	72%

[a] EV fuel costs as percentage of fuel costs of its ICE pair. (Assumption: four-year ownership period and 12,000 annual kilometres travelled. Average values were used.)

We used the webpage webarchive.org to find 2014[9] net prices of the 16 vehicles in the eight countries. We encountered some difficulties because prices were not published consistently. While some manufacturer and car web portals publish the net price, others include VAT, and/or registration tax, or other extra costs (e.g., metallic paint). Moreover, the same version of a model was not always available in all countries; thus, there could be slight differences in the technical characteristics, such as CO_2 emissions that serve as a reference for registration or circulation tax calculations. Currently, there is no official and consistent source of vehicle prices at European level.

The most important part of the TCO is the resale value of the car. We analysed vehicle depreciation on the websites of the most important online automotive information sources, such as Edmunds.com, NADA, KBB, Whatcar.com, and Autoscout24. They provide information on the resale value of vehicles based on millions of transactions. Some have depreciation calculators detailed enough to include specific versions of vehicle models. As for conventional vehicles, EV depreciation is higher in the smaller segments and lower in the bigger, last column of Table S1, Supplementary Material. Depreciation data are well-grounded for ICE vehicles. The second-hand market for EVs, however, is not well established yet in the EU. New EV sales became considerable only in 2011 when registrations reached almost 10,000 units in the EU. Consequently, not sufficient data exist on the price of an EV that was 4 years old in 2014. It is evident that EVs loose a larger share of their initial value. In fact, some of the small electric cars, such as the Nissan Leaf, are among the vehicles that depreciate the most during the first years of ownership (NADA, 2015; Woodyard, 2013). A partial reason is that the purchase price of some EV models decreased during their life-cycle as a result of technological advances, e.g., battery cost reduction, leading to a decrease of the resale value of earlier variants (Zhou et al., 2016).

[8] Insurance, repair, replacement, and maintenance costs are not considered as they depend strongly on user behavior and car usage: they do not relate systematically to the powertrain choice.

[9] We were unable to find 2014 data for Norway: 2015/2016 car prices were used, instead.

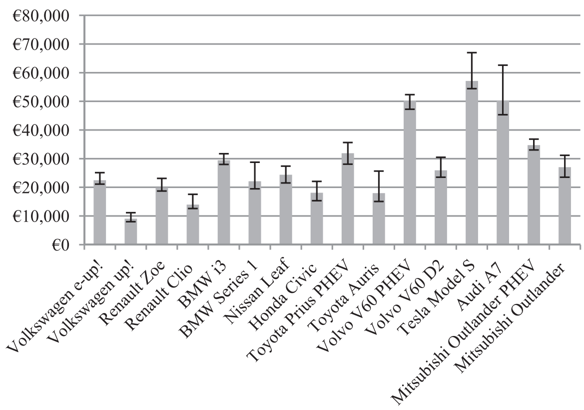

Fig. 4. Average net price and price spread of EVs: average country prices (columns), minimum and maximum prices (error bars).

We obtained registration data of new vehicles from the CO_2 monitoring database of the European Environment Agency (EEA, 2015). The raw data were processed as described in Thiel et al. (2015). Data on national vehicle registration and ownership taxes were taken from the Tax Guide of the European Automobile Manufacturers Association (ACEA, 2015) and from the websites of national governments.

4. Results and discussion

4.1. Price and fuel costs

The average, minimum, and maximum net price of each vehicle are presented in Fig. 4. We note that: (i) all EVs are more expensive than their ICE pairs; (ii) bigger EVs seem to be relatively cheaper than their ICE pairs; and (iii) the price difference between EVs and their corresponding ICE pairs is higher for plug-in hybrids than battery electric vehicles. The main reason of the price difference between EVs and ICE vehicles is the high cost of the electric battery as discussed, for example, in Thiel et al. (2010). The authors estimated that in 2010 battery costs were € 600 per kWh. Although the cost of lithium-ion battery packs has been falling since then, it still remains high enough to keep the net price and the TCO of electric vehicles high (McKinsey and Company, 2014). Our second observation is that smaller EVs are relatively more expensive than big EVs, compared to their ICE vehicle pairs. For the BEVs in our study, the country average EV net price relative to its ICE pair decreases for the bigger car segments. The average net price of the Volkswagen e-up! (A segment), Renault Zoe (B segment), BMW i3 (C segment), Nissan Leaf (C segment), and Tesla Model S (S segment) is 165%, 45%, 40%, 38%, and 16% higher than the average net price of their ICE pair, respectively. This indicates that the expensive electric battery creates a larger cost penalty on small EVs. Our third observation is that PHEVs are more expensive than BEVs. Additionally, the PHEV version of the Toyota Prius and the Volvo V60 are 90% and 99% more expensive than the ICE versions, respectively. The Outlander is an exemption: its average EV price across countries is only 30% higher than the price of the ICE Outlander.

Subsidy policies can lead to gaming by manufacturers in their pricing policy. We noticed, for example, that the Volkswagen e-up! had a higher price in the UK. Without government subsidy its price (including VAT) was around € 30,121, while it dropped to € 23,915 after the deduction of the subsidy. In the Netherlands, France, Germany and Italy, the price was € 25,520; € 26,250; € 26,900; and € 27,150, respectively.

Fuel cost savings provide an important cost advantage of EVs. The last two columns of Table 3 present fuel costs of BEVs and PHEVs as percentage of the fuel costs of their ICE pairs during the assumed four-year ownership period and 12,000 annual kilometres travelled. As electricity prices are lower than fuel prices, operating costs are the highest for ICE vehicles and the lowest for BEVs, while PHEVs costs are in between. Average electricity expenses of BEVs are between 31% and 52% of the average fuel expenses of their ICE pairs, whereas average electricity and fuel expenses of PHEVs are between 65% and 81% of the average fuel expenses. The case of Germany is different, because the high electricity price increases the operating costs of EVs: the average relative fuel costs of BEVs and PHEVs are 75% and 97%, respectively. Polish and Hungarian prices are low, and fuel is much more expensive than electricity, resulting in high potential savings. Besides the two Central European countries, cost savings are the highest in Norway. The average fuel costs of BEVs and PHEVs in Norway are 36% and 70% of their ICE pairs, respectively. This is a result of high fuel and low electricity prices.

4.2. Fiscal incentives and sales

We calculated the fiscal incentives as percentage of the net price of the EVs. The total amount of incentives is the sum of subsidy, VAT, registration tax, and circulation tax differences between EVs and their ICE pair,

$$Incentives = S + (VAT_{ICE} - VAT_{EV}) + (T_{r,ICE} - T_{r,EV}) + (T_{c,ICE} - T_{c,EV}) \quad (2)$$

Although we chose vehicle pairs as similar as possible, characteristics that serve as a basis for tax calculations still vary (e.g. power, weight). Thus, payable taxes differ for the EVs and their ICE vehicle pairs even in the absence of incentives. To overcome this problem, we considered only those terms in Eq. (2) that are direct fiscal incentives to EVs. For example, in Germany, where EVs are exempt from circulation tax, we calculated the amount of incentives as the present value of circulation taxes paid by their ICE vehicle pair, neglecting the other terms. The incentives amount for each EV was expressed as percentage of its net price to obtain comparable quantities across vehicles and countries. Fig. 5 presents the results against relative sales, each point representing an EV. Fig. 5 in conjunction with Table 4 may be used to unravel the incentives-sales relationship. Table 4 shows the electric vehicles ranked according to the calculated incentives amount per country.[10] We also present their relative sales rank and their size: dark, medium dark, and light grey represent big, medium and small cars, respectively. With the help of Table 4 each EV in Fig. 5 may be identified.

Inspection of Fig. 5 allows the identification of three groups of countries. The first group consists of Norway only, where incentives are the highest ranging between 39–67% (17–23%) of the net price of BEVs (PHEVs). Such high incentives are the result of massive taxation of ICE vehicles and tax exemption of EVs (mainly BEVs). The second group consists of the Netherlands, France, and the UK, where the calculated incentives vary between 10% and 40% of the net EV price. The third country group consists of Germany, Italy, and Hungary where incentives are the smallest and do not reach 10% of the net EV price. Poland is also part of this group, where government stimuli are absent.

In Norway, only BEVs are exempt from VAT and registration tax. Although the excess weight of the battery makes PHEVs eligible to a 10–15% reduction of the weight-based part of the registration tax (Grønn Bil, 2013), this is just a fraction of the total tax. Thus, there is a strong fiscal support for BEVs, but not for PHEVs. The PHEV models are the three lowest Norwegian points in Fig. 5 and the last three Norwegian rows in Table 4. The relative sales of EVs reflect the pattern

[10] We compare only France, the UK, Norway, and the Netherlands because these countries spent the highest amounts of incentives (i.e. more than 10% of the net price of the EVs).

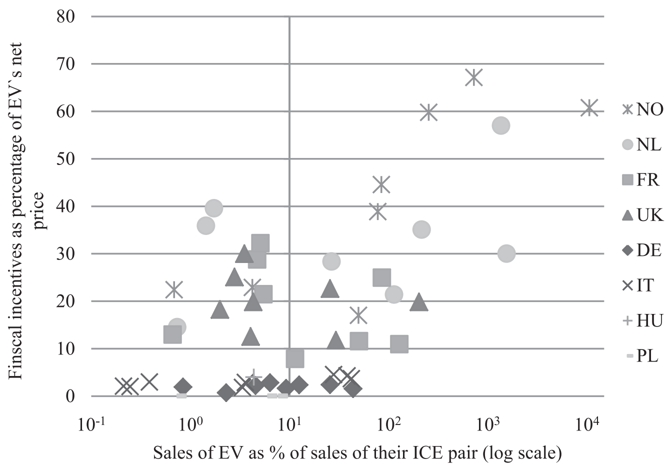

Fig. 5. Fiscal incentives and EV sales.[11]

have lower relative sales. Although the French and UK subsidies are 20–27% of the purchase price, they become lump-sum in practice because all available EVs are expensive enough to be eligible for the maximum amount. Consequently, the spread of data points along the fiscal-incentives axis depends mainly on and represents the purchase price differences between the EVs. This lump-sum subsidy causes the small EVs (light grey) in France and in the UK to be ranked at the top places in Table 4: the fixed subsidy corresponds to a higher percentage of the net price of small EVs.

Models with relative sales above 10% in the second group are the Mitsubishi Outlander PHEV, the Tesla Model S, and the Nissan Leaf. They had the highest relative sales ranks in France, the UK, and the Netherlands in 2014. The sales of other EVs are mainly below 10%. The three models with the lowest relative sales rank are the Volkswagen e-up!, the Renault Zoe, and the Toyota Prius PHEV. The effect of relatively higher subsidies of small EVs in France and UK is not reflected in the sales ranking, suggesting that other factors, possibly non fiscal, are necessary to understand the sales figures. We will address this issue in the next sub-section.

Table 4
Rank of EVs according to the fiscal incentives they receive as percentage of their net price.

FR		UK		NL		NO	
EVs in order of incentives	Sales rank	EVs in order of incentives	Sales rank	EVs in order of incentives	Sales rank	EVs in order of incentives	Sales rank
Renault Zoe	6	Renault Zoe	6	Mitsubishi Outlander PHEV	2	Nissan Leaf	2
Volkswagen e-up!	7	Volkswagen e-up!	7	Renault Zoe	6	Tesla Model S	1
Nissan Leaf	2	Nissan Leaf	3	Toyota Prius PHEV	7	BMW i3	3
BMW i3	5	BMW i3	4	Nissan Leaf	3	Renault Zoe	4
Toyota Prius PHEV	8	Mitsubishi Outlander PHEV	1	Tesla Model S	1	Volkswagen e-up!	5
Tesla Model S	3	Toyota Prius PHEV	8	BMW i3	5	Volvo V60 PHEV	7
Mitsubishi Outlander PHEV	1	Volvo V60 PHEV	5	Volvo V60 PHEV	4	Toyota Prius PHEV	8
Volvo V60 PHEV	4	Tesla Model S	2	Volkswagen e-up!	8	Mitsubishi Outlander PHEV	6

Note: Dark, medium dark, and light grey represent big, medium and small cars, respectively. Sales refer to relative sales, i.e. the sales of EVs as percentage of the sales of their ICE pairs.

of these incentives. BEVs have the highest relative registration numbers, while the lowest three are the Toyota Prius PHEV (0.7%), the Volvo V60 PHEV (4.2%), and the Mitsubishi Outlander PHEV (49.7%). The Mitsubishi Outlander PHEV sells well because its net price is close to the ICE version and the TCOs of the pair are similar. In contrast, the Toyota Prius PHEV and Volvo V60 PHEV cost 10 and 22 thousand euros more than their ICE pairs, respectively. Hence, the fuel cost and CO_2 tax savings cannot offset the net price difference: these models are not price competitive at current incentive levels.

It can be clearly seen that Norway is more generous than the other countries in terms of fiscal incentives. ICE vehicles are taxed heavily upon first registration, and they are subject to 25% VAT. BEVs, being exempt, have significant financial support. For example, the net price of the Volkswagen e-up! was € 21,898 in 2014, and that of its ICE variant € 11,153. The ICE version was subject to € 2788 VAT and € 4839 registration tax, adding up to a gross price of € 18,781. This is still cheaper than the net price of the electric version, but it excludes fuel costs and circulation tax savings, as well as other non-fiscal incentives. The three highest sales points in Fig. 5 are the Nissan Leaf, the Tesla Model S, and the BMW i3 in Norway with calculated fiscal incentives of 67%, 61%, and 60% of their net price, respectively. We highlight that the consequence of a flat VAT and registration tax rate is that the more expensive a BEV is the higher the absolute savings from the tax exemptions. The two small EVs coloured in light grey are the last among the BEVs in the incentive ranking, Table 4.

EVs in the second country group lie lower on both axes in Fig. 5 than BEVs in Norway: they are entitled to less government support and

[11] All sales-related figures contain a vertical line at the sale share of 10% as a separation between niche sales (below 10%) and mass market sales (above 10%).

The Dutch Mitsubishi Outlander PHEV is special, ranked first in Table 4, as its calculated incentives are much higher than those of the other Dutch vehicles. This is the result of the combination of three factors: (i) the net price of the ICE and the hybrid versions are relatively closer than the net prices of the other vehicle pairs; (ii) the ICE version has the highest CO_2 emissions (139 g/km) among the vehicles included in this study, thus it was subject to a € 6069 registration tax; and (iii) as diesel is penalized in the Netherlands, an € 5032 diesel surcharge had to be paid for the ICE version in 2014.

Although the amount of fiscal incentives in the third country group is much lower, some models reached noteworthy relative sales. The pattern is similar to the second country group: the models that exceed relative sales of 10% are the Nissan Leaf, the Mitsubishi Outlander PHEV, and the Tesla Model S.

We note that different taxation systems favour different car segments. As mentioned, the *de facto* lump-sum French and UK subsidies favours small EVs. The exemption from the flat tax rates in Norway and the Netherlands favours expensive EVs in terms of incentives as percentage of the net price. As Table 4 shows, small cars (light grey) in Norway and the Netherlands are lower in ranking than in France and the United Kingdom. Thus, our investigations support the widely held observation that subsidy policies in Norway and the Netherlands subsidize affluent members of the society by supporting the purchase of big segment EVs.

The distributional effects of the Dutch and Norwegian policies may be interpreted via Rogers' (1962) innovation distribution theory. It describes how new technologies spread in society by defining innovators, early adopters, early majority, late majority, and laggards as different consumer groups adopting innovation in sequence. Innovators and early adopters have higher income, higher social status, and higher willingness to take risks than the rest of the society. Recent research on Norwegian EV owners seems to support the theory, the majority of them being highly educated, middle-aged men with above-average income, living in metropolitan areas (Bjerkan et al., 2016; Haugneland, 2014). Plötz et al. (2014) argue that identifying and targeting early adopters contribute to efficient promotion of EV utilization. Additionally, as discussed by Figenbaum et al. (2014), the lower marginal cost per km of EVs can motivate their owners to switch from other forms of transportation, like walking, cycling and public transport. The quantification of distributional and efficiency effects, and possible transport-mode choice shifts of different fiscal incentive schemes, is beyond the scope of this work.

Our results on the relationship between fiscal incentives and new registrations are mixed. Norway is clearly distinct from the other countries in terms of both incentives and sales: fiscal incentives provided by the Norwegian government played an important role in the market breakthrough of EVs. For the second and third country groups, a clear link is not easily discernible. EV sales are evenly spread along the sales axis in Fig. 5, irrespective of the level of incentives. However, there is a difference between the second and the third group; the relative sales of EVs in Germany, Italy, Hungary, and Poland are less than the relative sales in the Netherlands, France, and the UK. As the incentives-sales relationship remains blurred, we investigated other factors that can affect the purchase decision of potential EV owners by calculating the total cost of ownership of each vehicle by country.

4.3. TCO and sales

As incentives affect only a fraction of the monetary costs that EV owners face, we calculated vehicle TCO to incorporate additional costs and benefits, such as depreciation and fuel cost savings. First, we compare and contrast the relationship of EV sales with net price (left) and TCO (right) in Fig. 6. Each point represents an EV. We followed the pairwise comparison approach described in Section 3.1. The sales (x axis) and costs (y axis, either TCO, left, or net price, right) of EVs are expressed as the corresponding percentage of its ICE vehicle pair. Data points are labelled by country.

Whereas both subfigures in Fig. 6 suggest a negative relationship between either TCO or net price with sales, namely higher costs are associated with lower sales, we shall concentrate on the TCO subfigure and calculations. Such a choice is dictated by the larger amount of information TCO provides. The negative relationship between TCO (net price) and sales is reminiscent of the law of supply and demand according to which the higher the price of a product at a given utility, the lower the demand for it. The range of the relative TCO is between 45% and 224%, but the majority of the data points are located between 70% and 200%. Vehicles below 100% are mainly from Norway and the Netherlands indicating that their cost is relatively lower than in other countries. Moreover, sales are also more considerable in the Netherlands and Norway. The three highest sales values located above 1000% are the Tesla Model S and the Mitsubishi Outlander PHEV.

The data points may also be presented in terms of vehicle model to reveal possible variations of the cost-sales relationship in car segments. We present then for big (Fig. 7, left), medium (Fig. 7, right), and small (Fig. 8) cars. This separation shows that the bigger an EV is the higher its sales and the lower its TCO compared to its ICE pair. Small EVs have the lowest relative sales and the highest relative TCOs, while big EVs have the highest relative sales and lowest relative TCOs.

The spread of the TCO data points reveals remarkable differences in the relative TCO. Small EVs seem to have a higher TCO disadvantage than medium and big EVs. The majority of the data points in Fig. 8 are above 100%, meaning that small EVs have higher TCOs than their ICE pairs. The TCO of the electric Volkswagen e-up! is more than 150% of the TCO of the petrol version in all countries, except Norway. On the other hand, the TCO of the Renault Zoe does not exceed 150% of the TCO of the Renault Clio in any of the countries. For medium-sized cars, only two data points lie above 150%, whereas 8 data points are below 100%, i.e., EVs that are cheaper (in terms of TCO) than their ICE pairs. Big EV models exhibit the same pattern as medium-sized cars, with the exception of the Volvo V60 PHEV that remained consistently above 150%, i.e., it is more expensive than the Tesla Model S and the Mitsubishi Outlander PHEV.

The spread of the sales data shows big differences in EV sales between vehicle segments. All but two data points of small EVs in Fig. 8 are located below relative sales of 10%: the two exceptions are EVs in Norway. In contrast, we find eight medium-sized EVs above 10% (Fig. 7, right), and the majority of the big EVs (Fig. 7, left) are located above 10%. Thus, relative EV sales are lower in the small segments, in agreement with absolute sales numbers. The sum of newly registered EVs in 2014 of the EVs considered in this study is 13,904 (small vehicles), 20,503 (medium), and 27,971 (big), Table S3, Supplementary Material. In 2014, 93,865 EVs were registered in the EU and EFTA countries (Thiel et al., 2015). Even though both relative and absolute sales suggest that big EVs had higher sales than small, there is an important observation about the *magnitude* of the difference. The pairwise comparison approach provides insight because the small and medium car segments in the conventional car market feature many more sales than the big car segments. The 13,904 small EVs are in market segments where their ICE pairs sold 316,410. The

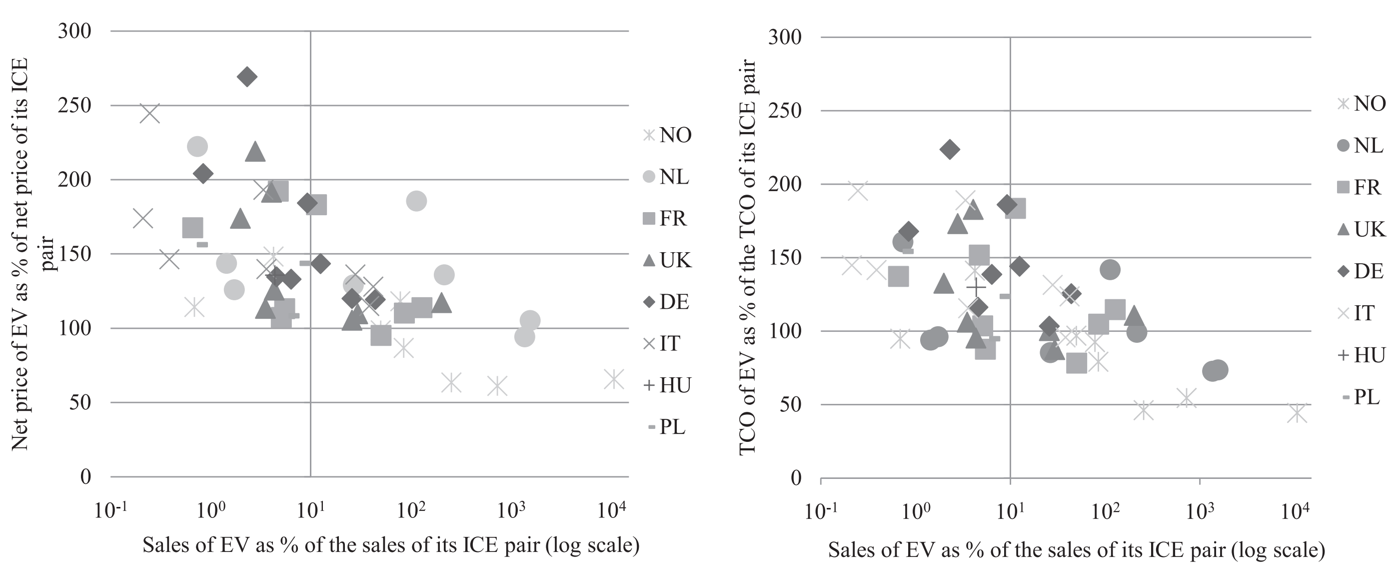

Fig. 6. Relative net price (left) and relative TCO (right) versus relative EV sales by country.

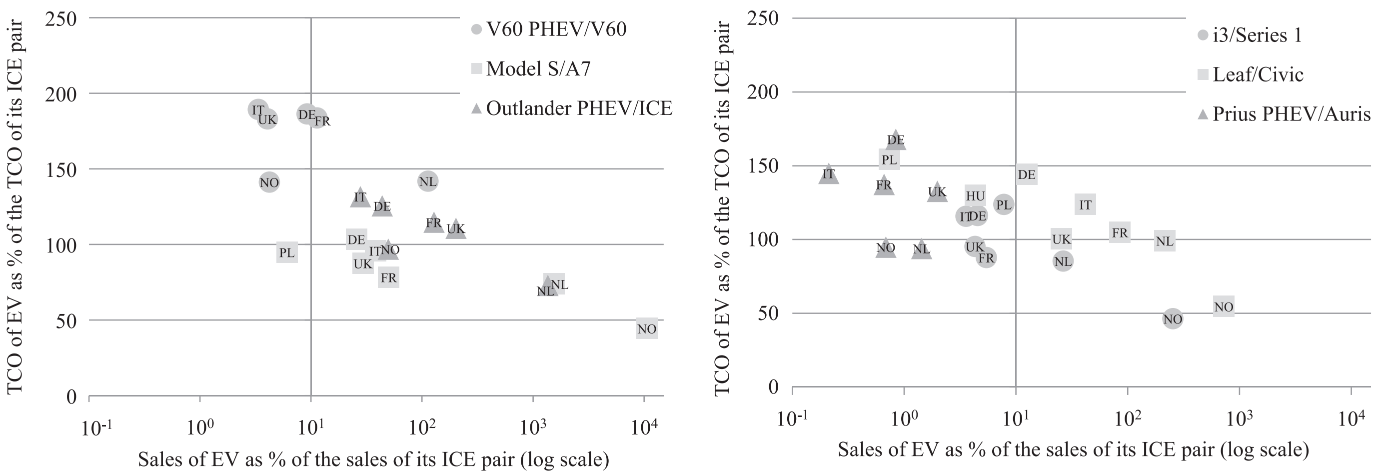

Fig. 7. Relative TCO and relative sales of big (left) and medium size (right) EVs.

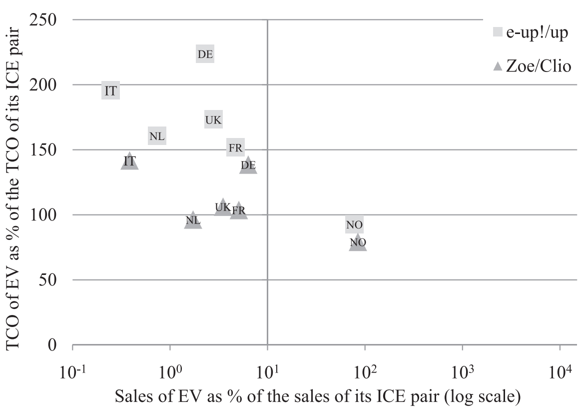

Fig. 8. Relative TCO and relative sales of small EVs.

27,971 big EVs are in market segments where their ICE pairs sold 35,407 units. The number of newly registered medium sized ICE vehicles was 201,190. While the number of small EVs sold is much smaller than the number of sales of their ICE pairs, sales of big EVs, like Tesla Model S and Mitsubishi Outlander PHEV, constitute a considerable percentage within their segments.

The TCO analysis supports a number of observations. While big cars show a fairly strong cost-sales relationship (Fig. 7, left), the relationship becomes weaker for medium sized vehicles (Fig. 7, right), weakening even more for small vehicles (Fig. 8). In addition, not only the dispersion of sales and costs data changes from big to small segments, the trend seems to become flatter, in support of the observation that demand for small EVs is more price responsive than demand for big EVs. The segmental differences in price responsiveness can affect how consumers of small, medium or big cars react to TCO changes due to fiscal incentives. Our findings suggest that sales of EVs in smaller segments would grow more in response to properly chosen fiscal incentives.

5. Conclusions and policy implications

We analysed the relationship between fiscal incentives, TCO, net price, and sales of eight EV-ICE vehicle pairs in eight European countries (France, Germany, Hungary, Italy, Netherlands, Norway, Poland, and the United Kingdom) using 2014 data. The sales of the EV models considered represent about 2/3 of the total 2014 EU/EFTA EV market. A pairwise comparison approach was used, a choice that allowed us to exclude general car market differences between countries. We quantified net price, fuel, and electricity price differences across countries, and concluded that small EVs are relatively more expensive than big EVs, and PHEVs are more costly than BEVs compared to their ICE pairs. We found that the registration and circulation taxes exemption in Norway and the Netherlands favours big EVs. In contrast, *de facto* lump-sum subsidies in France and UK (20–27% of purchase price with a maximum cap) favour small EVs.

The TCO calculations contribute to our understanding of the interaction between fiscal incentives and sales. Incentives can play a crucial role in the market breakthrough of EVs, but larger market penetration can only be achieved if EVs become price competitive. Small, medium and big cars exhibit different relative TCO-sales relationships, both in terms of price responsiveness and spread of sales and TCO. It is important to consider these dependencies when fiscal policies are designed or modified because different incentive schemes favour different car segments and may affect different population sectors.

In Norway, various fiscal incentives made EVs cost competitive to ICE vehicles. This had a big impact on EV sales. In the other countries, the majority of EVs are still more expensive than their ICE pairs on a TCO basis. The relative TCO vs relative sales scatterplots revealed that in a cross-country comparison, big EVs seem to be less price responsive than small, and to exhibit a stronger cost-sales relationship. Such a relationship is an important aspect to consider when deciding the implementation of incentive schemes. A few models (Tesla Model S, Mitsubishi Outlander PHEV, and Nissan Leaf) had the highest relative sales, and they achieved noteworthy registration numbers even in countries where EV support policies were absent in 2014.

Limitations of our work include our inability to quantify the effect of fiscal incentives on the sales of EVs, because the number of data points was not sufficient for a statistical analysis. Furthermore, cognitive and cultural factors can influence the relationship between incentives and EV sales. Important examples are range anxiety and uncertainty in valuing potential future benefits associated with EV use. The adopted methodology of pairwise comparison can rule out some of these confounding effects. Our conclusions can provide qualitative guidance for countries that consider introducing or modifying incentive schemes. Further research on socio-economic aspects to assess how existing national policies may be transferred to other circumstances is needed. In particular, surveys may be used to assess and evaluate the importance of non-financial policies, for example access to bus lanes and the city centre, parking availability. In addition to investigations of the effectiveness of support policies, the environmental effects of EVs, such as CO_2 emissions resulting from electricity generation for EVs or life cycle emissions of EV including battery recycling/ disposal, remain important issues that have to be addressed.

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Appendix A. Supplementary material

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.enpol.2017.02.054.

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