THE INTRODUCTION OF ELECTRIC VEHICLES TO IRELAND: A SOCIOECONOMIC ANALYSIS

John Brady
PhD candidate in the Department of Civil, Structural and Environmental Engineering
Trinity College Dublin
Dublin 2
Ireland
Tel: +353 1 8962537
Email: bradyj7@tcd.ie

Margaret O'Mahony*
Department of Civil, Structural and Environmental Engineering
Trinity College Dublin
Dublin 2
Ireland
Tel: +353 1 8962084
Email: margaret.omahony@tcd.ie

*Corresponding Author

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ABSTRACT

The objective of this paper is to undertake a social cost-benefit analysis of the proposed deployment of 230,000 electric vehicles in Ireland by 2020. It analyses the socio-economic costs and benefits of this policy by comparing the environmental benefits, expressed in monetary value, with the associated reduction in tax revenues and the cost of the government's electric vehicle grant scheme. The 10% adoption of electric vehicles in Ireland will result in a monetary loss in the region of €324 million ($457 million) for the government (in the order of 0.5-1% of total tax revenue expressed at 2009 levels). The primary reason for this is due to losses in all sources of tax revenue due to the electric vehicle penetration rates required to achieve an appreciable reduction in greenhouse gas emissions.

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INTRODUCTION

In November 2008, the Minister for Transport in Ireland announced a government target for 10% (230,000 vehicles) of the private car fleet to be powered by electricity by 2020 *(1)*. In order to ensure the early availability of electric vehicles (EV) for the Irish market, the government have signed memorandums of understanding (MOU) with a Renault-Nissan alliance and Mitisubishi. Under the terms of the agreements, the car manufactuers will supply battery electric vehicles (BEVs), while the government will introduce policies and incentives to support the widespread adoption of EVs and will support the development of a nationwide charging infrastructure.

The imminent commercial deployment of EVs has the potential to address issues such as climate change, oil dependence and air quality. However, common to all new technologies, EVs face barriers to adoption, such as lack of knowledge by potential users, low consumer risk tolerance and high initial production costs *(2)*. In an attempt to address some of these market barriers it has become common for governments to introduce financial consumer incentives to encourage the purchase of EVs. Despite the proliferation of such incentive programmes, their efficiency in actually promoting the purchase of EVs is unclear and are often the subject of public and political debate. One argument put forward by Carlsson and Johansson-Stenman *(3)* is that "even though EVs may not be socially beneficial today, they probably will be tomorrow and that the introduction of EVs is a long process that must start today".

Cost-benefit analyses (CBA) are a useful tool for comparing the effects, positive and negative of different activities or projects. Large uncertainties and simplified assumptions are generally associated with a CBA. A common criticism of published research in this area is the outdated data on EV technology and the electrical generation mix on which they are based. However, Carlsson and Johansson-Stenman *(3)* argue that CBAs can be a valuable tool for policy making decisions provided that a detailed presentation of the assumptions made is outlined.

The objective of this paper is to examine the socio-economic costs and benefits of the proposed deployment of EVs in Ireland in 2020. We achieve this by comparing the environmental benefits, expressed in monetary value, with the associated reduction in tax revenues and the cost of the government's electric vehicle grant scheme. This is particularly important in countries with high fuel taxes, as is the case with most European countries.

COST BENEFIT ANALYSIS OF ELECTRIC VEHICLES

The concept of a social cost-benefit analysis is commonly used by policy decision-makers to attempt to measure the social benefits of a proposed project in monetary terms and to compare them with its costs (*4,5,6)*. Carlsson and Johansson-Stenman *(3)* attempted to calculate the costs and benefits of both EVs and HEVs and the private and societal costs attached to them. The study was conducted from a Swedish perspective for year 2010 and the primary objective was to estimate all relevant costs elements whilst simultaneously highlighting the effect of changed tax revenues, rather than focusing on manufacturing and maintenance costs. The social benefit/costs of replacing internal combustion engine vehicles (ICEV) with EVs was defined as the "difference between the benefit in terms of decreased external costs and the cost in terms of reduced taxation." In this context "external costs" refers to environmental costs. Consequently, the social marginal net benefit (MNB) can be calculated according to the following equation derived by Carlsson and Johansson-Stenman *(3)*

$$MNB = \Delta MD - \Delta R \tag{1}$$

Where, ΔMD refers to the decrease in marginal damage, or external costs from replacing one ICEV with an EV and ΔR is the associated decrease in tax revenues. The analysis revealed that BEVs would be socially unprofitable primarily because the taxes applied to them are heavily subsidised compared to ICEVs. Hybrid electric vehicles (HEV) were found to be socially and privately profitable without subsidies, especially for city based delivery trucks. Herynkova *(7)* conducted a similar analysis for Denmark for the year 2020, based on Carlsson and Johansson-Stenman *(3)* social cost benefit analysis equation. It was found that from a pure financial perspective EVs are not socially profitable as their reduction in environmental costs is by far offset by the decrease in tax revenues. However, vehicles in Denmark are subject to particularly high registration tax of 180% and VAT of 25%. Forkenbrock *(8)* points out that the rising fuel efficiency of vehicles such as HEVs will result in reduced revenue from motor fuel taxes and as motor fuel tax becomes less productive, governments will have to change the ways in which they finance road infrastructure. Whilst BEVs do not directly consume fossil fuel, a study by Gonder et al. *(9)* suggests that plug-in hybrids (PHEV) will also result in "substantial petroleum displacement", which further strengthens the concept that motor fuel taxes will be significantly reduced as a result of the deployment of EVs into national private vehicle fleets. Earlier research by Delucchi & Lipman *(10)* presented a detailed life-cycle cost analysis for BEVs and found that the performance and cost of batteries must be significantly reduced in order for BEVs to become competitive. More recently Granovskii et al. *(11)* performed an economic and environmental comparison of ICEVs, EVs and hydrogen fuel cell vehicles (HFV). It was shown that if electricity generated by a gas turbine engine with an efficiency of 50-60% was used to charge a BEV with a high capacity battery, then an EV would be advantageous. Lipman and Delucchi *(12)* provide a detailed and comprehensive lifecycle cost analysis of HEVs based on significant modifications to a previous model presented in Delucchi and Lipman *(10)*. It was found that combining advanced vehicle improvements with mild vehicle hybridisation provides the least cost hybrid vehicle option, with life cycle costs close to those of baseline vehicles.

THE IRISH VEHICLE TAX SYSTEM

In 2006, the total contribution from all motor related sources to the Irish exchequer was over €5.5 ($7.76) billion. The main contributors were vehicle registration tax (VRT), annual motor taxes (AMT) and excise duty on fuels, which accounted for €1,257.5 ($1,775) million, €879.7 ($1,241) million and €2,042.3 ($2,882) million respectively *(13)*. Income from value added tax (VAT) receipts and revenue from road tolls also contributed significantly. Since July 2008, VRT and AMT rates are linked directly to the specific carbon dioxide (CO_2) emissions (CO_2 g/km) of the vehicle and are applied as a percenatge of the open market selling price (OMSP), as shown in Table 1. In addition, as shown by the range applied across the bands, the purchasing signal promoting lower emitting cars is strong. VRT rates vary from 14% on the purchase price for cars with CO_2 emissions of up to 120g/km to 36% for cars with CO_2 emissions greater than 225g/km. However, under current legislation, BEVs are exempt from vehicle registration tax and PHEVs are entitled to up to €2,500 ($3,528) off the VRT payable upon a new vehicle registration. Vehicles with emissions in the 0-120g/km category are subject to annual motor tax of €104 ($147).

TABLE 1 CO_2 based Vehicle Registration and Road Tax Bands

Emission Band	Specific CO_2 Emissions (g/km)	VRT (%OMSP)	AMT (€)
A	≤ 120	14%	104
B	> 120 - 140	16%	156
C	> 140 -155	20%	302
D	> 155 - 170	24%	447
E	>170 - 190	28%	630
F	>190 – 225	32%	1,050
G	> 225	36%	2,100

Since April 2010, a government grant is available towards the purchase price of BEVs and plug-in hybrids (PHEV). BEVs with an OMSP greater than €20,000 ($28,220) are eligible for a €5,000 ($7,053) governmental grant, whereas PHEVs with an OMSP greater than €18,000 ($25,391) are eliglible for a €2,500 grant *(14)*. The incentive for BEVs with an OMSP less than €20,000 will range from €2,000 ($2,821) for vehicles priced between €14,000 ($19,746) and €15,000 ($21,156) up to €4,500 ($6,347) for those priced between €19,000 ($26,792) and €20,000. Excise duties of 54.34 cent/litre (76.67 cent/litre) and 44.95 cent/litre (63.38 cent/litre) are applied to unleaded petrol and diesel fuelled vehicles respectively. These duties include the new carbon tax introduced in 2010 and are subject to VAT at 21%. A reduced VAT rate of 13.5% is levied on electricity utility bills.

METHODOLOGY AND KEY ASSUMPTIONS

We explore two different scenarios, a Business as Usual (BAU) scenario and an 'EV' scenario, in which the 10% electric vehicle target is achieved and 230,000 vehicles are deployed. We employ Carlsson and Johansson-Stenman's *(3)* social cost benefit analysis equation, however, we include an additional parameter to account for the Irish government's EV grant scheme. Thus the equation is expanded to the following

$$MNB = \Delta MD - \Delta R - G \qquad (2)$$

Where, ΔMD is the total decrease in marginal damage, or external costs from replacing ICEVs with EVs, ΔR is the associated decrease in tax revenues and G represents the cost of the BEV grant scheme.

This section also details the general assumptions made in this analysis. These assumptions provide a natural benchmark case, since it is not known whether economic or technical parameters such as prices, taxes and vehicle characteristics will fluctuate over the next decade.

Vehicle parameters

Two particular vehicles, which are due to be released in 2011 and 2012 respectively were taken as representative of EV vehicles; the Nissan Leaf (BEV) and the Toyota Prius Plug-in hybrid (PHEV). Fourteen ICEV models were taken to represent conventional vehicles. Each of the seven road tax bands (A-G) were allocated two representative vehicles, one petrol and one diesel vehicle. The characteristics of each vehicle are based on published specifications. However the price of the PHEV has yet to be released and is assumed to be competitive with a similar-sized car. Table 2 lists both the actual and assumed technical and economic parameters of each vehicle. It is recognised that the future passenger vehicle requirements are difficult to predict and so these values are hypothetical indicators, which enable us to calculate resource consumption in a range of areas such as fuel consumption and electricity supply requirement. This in turn allows us to estimate projected tax revenue from a variety of sources.

TABLE 2 Technical and economic parameters

	Emission Band	Fuel Type	Engine Size (L)	CO_2 Emissions (g/km)	Fuel consumption (l/100 km)	OSMP (€)	Battery Capacity (kWh)
Toyota Aygo	A	Petrol	1.0	106	4.5	10,670	-
Volkswagen Polo Trendline	A	Diesel	1.2	92	3.4	17,000	-
Nissan Leaf	A	Electric		0	0	29,995	24
Toyota Plug-in Prius	A	Electric/ Petrol	1.8	89	3.9	30,000	5.2
Toyota Auris	B	Petrol	1.3	139	5.9	18,945	-
Volkswagen Jetta Trendline	B	Diesel	1.6	122	4.7	21,700	-
Toyota Avensis	C	Petrol	1.6	152	6.5	24,165	-
Volkswagen Passat CC	C	Diesel	2.0	146	6.1	38,520	-
Toyota Verso	D	Petrol	1.6	161	6.8	29,040	-
Volkswagen Tiguan	D	Diesel	2.0	164	6.4	35,760	-
Toyota RAV4	E	Petrol	2.0	174	7.4	28,695	-
Nissan X-Trail	E	Diesel	2.0	179	6.8	37,170	-
Mercedes-Benz S-Clas	F	Petrol	3.0	200	7.6	98,600	-
Nissan Qashai+2	F	Diesel	2.0	209	7.9	38,785	-
Mercedes-Benz SL-Clas	G	Petrol	3.5	236	8.8	136,635	-
Toyota Land Cruiser	G	Diesel	3.0	243	9.1	36,735	-

Emissions calculation

The potential reduction in tailpipe greenhouse gas (GHG) emissions was calculated using the COPERT 4 computer model *(15)*. The COPERT 4 model is part of the EMEP/CORINAIR Atmospheric Emissions Inventory Guidebook (AEIG) and is recommended by the European Environment Agency (EEA) to calculate national emission inventories *(16)*. Over twenty European member states including Ireland use the COPERT 4 model.

The greenhouse gases which are considered are CO_2, methane (CH_4) and nitrous oxide (N_2O), which can each be described in the form of carbon dioxide equivalents (CO_{2e}), where CO_2 is given the value of 1 CO_{2e} *(17)*. The actual weighting used to convert CH_4 and N_2O to CO_{2e} depends on the particular global warming potential lifetime used. In this paper it is taken as 100 years, and as such CH_4 and N_2O assumed weightings of 25 and 298. *(17)*. The other main pollutants related to traffic (PM, NMVOCs, NO_x) are also evaluated. The external costs of the tailpipe emissions in €/tonne are estimated based on the European Commission's handbook of external costs in the transport sector *(18)*.

The temperature data required for the COPERT models was sourced from the European Climate Assessment & Dataset *(19)*. For the period 2006-2008, the 2005 advanced fuel specification provided by COPERT 4 was used. However, for the period 2009-2020, despite there being an advanced fuel specification provided by COPERT 4 for 2009 stage fuel, the fuel specifications which are defined in the Air Pollution Act of 1987 were utilized instead *(20)*. The only difference is that the 2009 stage fuel specifications, have a reduced sulphur content from 50 parts per million (ppm) to 10 ppm. The polycyclic aromatic hydrocarbon value given in the Irish Statutes is in % m/m, and not in % v/v as demanded by COPERT 4, so the default figure was used instead.

The COPERT 4 methodology is based on average speeds and corresponding average speed emission factors to calculate vehicle emissions *(21)*. It includes a total of 37 different classes of gasoline passenger cars. A given car belongs to one of three different "subsectors" depending on the cylinder volume (<1.4 litre , 1.4–2.0 litre and >2.0 litre), and each subsector contains 12–14 different "technology classes", reflecting the various stages of the EU exhaust regulation (e.g. EURO 1, EURO 2 etc.). For diesel passenger cars there are two different subsectors (<2.0 litre and >2.0 litre), each containing seven different technology classes. A mix of urban (30% of total distance), rural (50% of total distance) and highway (20% of total distance) driving was considered with average speeds of 40 km/hr (rural), 60 km/hr (urban) and 100 km/hr (highway).

The future size and breakdown of the private car fleet

In 2008 there were 1,924,281 private cars registered in Ireland, of which 3,579 (0.15%) were classified as EV *(22)*. We use the ISus private car stock model *(20)*, developed by the Economic and Social Research Institute (ESRI) of Ireland, to make assumptions about the future size and breakdown of the private car fleet. The model, which is driven by forecasts on the economy and the population, is constructed from a long history on data sales, which has been calibrated to recent data on the actual stock. The model distinguishes cars between fuel type, engine size and age and projects that there will be approximately 2.2 million private cars in Ireland in 2020. Because taxation levels are calculated based on emissions per kilometer rather than engine size, concordances constructed by the ESRI are used to transform engine sizes into emissions bands. The concordance tables used are based on actual sales in 2008-2009 *(23)*.

From the analysis of the Society of Irish Motor Industry's (SIMI) new vehicle registration statistics over the period 2000-2007, approximately 158,309 new cars are registered in Ireland each year. Due to the deterioration of the economy, new car registrations significantly decreased to 151,607 (-18%) and 57,460 (-62%) in 2008 and 2009 respectively. Early indications for 2010 (June) suggest a recovery in the industry with a 45% increase in sales (67,864) on the same period in 2009 *(24)*. For the purposes of this study, we assume that the industry will return to its position where it otherwise would have been by 2020, prior to the global economic recession and that there will be approximately 158,000 new cars registered in Ireland in 2020.

Annual passenger kilometers

In 2009, the average annual passenger car kilometers (PCkm) for passenger cars was 16,708 km *(25)*. Cars with a small engine size typically tend to travel less than the average annual mileage. For example, cars with an engine size of less than 1.4 litres travelled approximately 13,000 km in 2009. For this study, we adopt the results of the ESRI's distance model, which projects the distance travelled for each engine size for a given year *(23)*. The model accounts for changes in the composition of the car stock and is driven by the elasticity estimate and change in the relative price of fuel.

For the purposes of this study we assume that PHEVs are viable substitutes for all ICEVs with an engine size between 1.4 and 2.0 litres, but that BEVs will only replace engine sizes less than 1.4 litres because of their limited driving range. We assume that the EVs are distributed evenly across both fuel types and engine sizes and hence will have a similar annual mileage.

According to Smith *(26)*, the fraction of PCkm completed by a PHEV in electric driving (ED) mode is dependent on the trip length, fleet penetration, kinematic profile and the vehicles characteristics such as its all-electric range (AER). From an analysis of Irish passenger car trip length distributions and assuming one overnight charge per twenty four hour period, Smith *(26)* estimates that 67% of PCkm could be completed by PHEVs with all AER of 40 km. For simplicty we assume the same.

The electrical energy requirement of an electric vehicle

In order to quantify the potential electrical requirement of the EV fleet, it is first necessary to quantify the energy required to move a vehicle. Smith *(26)* developed a model to determine the minimum theoretical energy required to move a given vehicle a fixed distance over a specific drive cycle. The model was then used to calculate the minimum energy requirement (MER), in kWh km^{-1}, of a range of vehicles representative of the Irish PC fleet, operating over a selection of legislative and real-world drive cycles. Based on this analysis we assume the electrical energy requirement of a PHEV to be 0.209 kWh km^{-1}.

In a review of transport options to alleviate the effects of climate change, urban air pollution and oil dependence, Thomas *(27)* reports that under optimum condition, the average fuel economy of a BEV is 2.6 times greater than that of an ICE engine, giving a specific energy consumption of 0.26 kWh km^{-1}. However, Foley et al. *(28)* report that under real world driving conditions the specific energy consumption is 10-25 kwh/70 km. We assume that the electric energy requirement of a BEV to be 0.209 kWh km^{-1}.

Size of the electric vehicle fleet

The accurate prediction of the market penetration of EVs includes great uncertainties and depends on a multitude of influencing factors. In this study the rate of penetration is estimated using a logistic S-curve.

The shape of the curve is determined if one specifies two years and the expected market penetration of EVs at those particular years. Assuming that EV sales commence in 2011, that 28% and 90% market penetration is achieved by 2020 and 2035 respectively and that the average number of sales per year is 158,000, we estimate 44,240 EV sales in 2020 (Figure 2). Cumulative sales over the period 2011-2020, are calculated to be 231,474, which compares with the government target of 230,000. It should be noted that market penetration refers to the penetration of annual sales - penetration of the entire car fleet would take significantly longer.

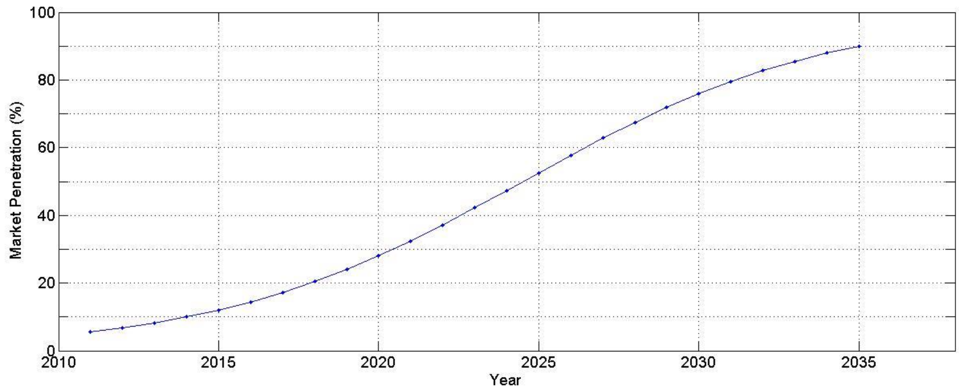

FIGURE 1 Projected EV market penetration

In the reviewed studies the range of conceivable market penetration scenarios varies widely. The majority of studies estimate the market penetration of EVs, but few differentiate between PHEVs and BEVs. We assume that PHEVs will become widely available in the near future and that rapid growth will lead to mass commercialisation. However, we do not expect mass market production of BEVs for a number of years due to the premium price and limited consumer acceptance with regard to recharging times and driving range. The Irish Electricity Utility, the Electricity Supply Board (ESB), who is responsible for the development of the national EV charging infrastructure, forecast that in 2020 the EV fleet in the Ireland will consist of 70% PHEVs and 30% BEVs *(29)*. We assume the same and that sales in 2020 will be of a similar nature.

Tax and electricity rates

As previously discussed, under current legislation PHEVs are entitled to up €2,500 off the VRT payable upon a new vehicle registration and BEVs are exempt from VRT. It is assumed that this policy will be extended to 2020. The excise duties and VAT applied to fuels are assumed to remain unchanged in 2020. Furthermore, we assume the annual motor tax rates will be similar to those in 2010.

It is understood that the ESB will introduce a special night time electricity rate under which customers will be able to charge their cars *(30)*. However since details of such rates have yet to be released it is assumed that the rate will be similar to the ESB’s current “Night Saver Tariff”. Under this rate customers in living in urban areas are charged a reduced rate of €0.0745 (excluding VAT) per kWh of electricity consumed.

RESULTS

Monetary cost of CO_2 emissions from electricity generation

Assuming that the electrical power requirement of a PHEV and a BEV is 0.209 $kWhkm^{-1}$ and 0.25 $kWhkm^{-1}$ respectively and that 67% of the annual PCkm of a PHEV will be completed in ED mode, we estimate that the total electrical power requirement of EVs in 2020 will be 244 GWh. In calculating the emissions produced from electricity generation, it is assumed that 40% of the electricity mix will come from renewables and that the electricity CO_2 emission intensity factor will be 393 g/kWh in 2020 *(29)*. Based on these assumptions, the total energy-related CO_2 emissions associated with electricity generation is projected to be 235 kt.

The European Commission prescribes a monetary value of €40/tonne of CO_2. This equates to a monetary loss of €9.39 ($13.24) million for CO_2 emissions emitted from the generation of the electricity required to power EVs.

Monetary benefit of reduced tailpipe emissions

Table 3 presents the estimate of total emissions (CO_{2eq}, PM, NMVOCs, NO_x) for each scenario and the calculated monetary benefit. The largest benefit will be as a result of decreased CO_{2eq} emissions. The BAU or baseline CO_{2eq} emissions for 2020 from the private car feet are projected to be 5.93 Mt CO_{2eq}. Under the EV scenario it is expected that this will decrease to 5.36 Mt CO_{2eq}, a saving of 570,000 t CO_{2eq}, a monetary benefit of €22.8 ($32.09) million. Overall, the total reduction in CO_2 emissions and other types of pollutants equates to a monetary benefit of €31.27 ($44.02) million.

TABLE 3 Emission results

Pollutant	External cost (€/tonne)	EV scenario		BAU scenario		Monetary benefit (million €)
		Emissions	Monetary cost (million €)	Emissions	Monetary cost (million €)	
CO_{2eq} (Mt)	40	5.36	214.4	5.93	237.2	22.80
NO_x (t)	3,800	5920	22.50	6394	24.30	1.80
NMVOC (t)	700	1361	0.95	1530	1.07	0.13
$PM_{2.5}$ (t)	126,200	391	49.34	422	53.26	3.92
PM_{10} (t)	50,500	623	31.46	675	34.09	2.63
Total			318.65		349.92	31.27

Estimated Vehicle Registration and Motor Tax Revenue

The 2020 vehicle procurement is based on an average of a 158,000 new registrations per year and the progressive development in sales of EVs between 2010 and 2020. The expected VRT revenue in 2020 under the BAU scenario and EV scenario are projected to be €857 ($1208) million and €759 ($1,070) million respectively.

The annual motor tax rates for each road tax band are presented in Table 2. Currently the annual motor tax rate for both BEVs and PHEVs is €104. Under the EV scenario, the figure is calculated assuming that the PC fleet consists of 230,000 EVs and that the remainder of the fleet consists of ICEVs. Taking these factors into account, the expected AMT revenue in 2020 under the

BAU scenario and EV scenario are projected to be €859 ($1211) million and €824 ($1162) million respectively. From the introduction of EVs, the calculations indicate a monetary loss of €98 ($138) million and €35 ($49) million in VRT and annual motor tax revenue respectively.

Estimated cost of the governmental EV grant scheme

In a worst case scenario the OMSP of all BEVs and PHEVs purchased in 2020 will be greater than €20,000 ($28,193) and €18,000 ($25,374) respectively. Under this scenario, the EV grant scheme could potentially cost the government €143.77 ($203) million.

Estimated fuel tax revenue

The fuel economy of the vehicles is based on the specifications provided in Table 2. BEVs are powered solely by electricity. Hence they consume no fossil fuel and it is assumed that 67% of the annual PCkm of a PHEV will completed in ED mode. Taking these factors in account, approximately 875 and 1235 mega litres of petrol and diesel respectively will be consumed in 2020 under the EV scenario. Assuming that excise duties of 54.34 cent/litre and 44.95 cent/litre are applied to unleaded petrol and diesel fuelled vehicles respectively, the corresponding fuel tax revenues in 2020 under the BAU scenario and EV scenario are projected to be €1.09 ($1.54) billion and €1.03 ($1.45) billion respectively. The calculations suggests a potential loss in fuel tax revenue of €60 ($84) million.

Estimated VAT revenue

In July 2010, the average price per litre of petrol and diesel in Ireland was 133.3 cents and 124.9 cents per litre respectively *(30)*. Assuming similar prices in 2020 and that fuel will be subject to VAT at 21%, the expected VAT revenue from fuel consumption under the BAU scenario and EV scenario are projected to be €308.95 ($435.47) million and €291.43 ($410.56) million respectively. The calculations indicate that the reduced fuel consumption associated with the introduction of EVs will result in a reduction of €17.52 ($24.68) million in VAT revenue.

The operation of EVs will result in increased electricity consumption and hence increased VAT revenue. Assuming that a VAT rate of 13.5% is levied on electricity utility bills, this increased consumption will yield approximately €6.00 ($8) million in VAT revenue.

Total social marginal net benefit of electric vehicles

Table 4 presents a summary of the benefits of reduced environmental damage with the costs associated with the losses in fuel tax revenue and the government BEV grant scheme. From the results, it is clear that the deployment of EVs in Ireland will lead to a net benefit in terms of environmental costs (€26; $36 million). However, this will be offset by the projected losses in tax revenue and the cost of the government's EV grant scheme. The total tax revenue is projected to decrease by 6.6% from €3,116 ($4,389) million to €2,910 ($4,098) million under the BAU and EV scenarios respectively, a loss of €206 ($216) million. However, the total exchequer taxation receipts for 2009 were €32,570 ($45,859) million *(32)*, which indicates that this loss will likely only be in the region of 0.5% to 1% of the government's total tax revenue, based on 2009 levels. Including the likely cost of the EV grant scheme (€144; $203 million), the overall indication is that the deployment of EVs is not socio-economically beneficial and results in a social marginal net loss of €324 ($456) million. The potential loss per EV is approximately €1,408 ($1,982).

TABLE 4 Summary of total social marginal net benefit

	Total marginal (environmental) damage (MD)	Tax revenue (R) (Million €)
BAU scenario		
CO_2 emissions from electricity generation	n/a	
Tailpipe emissions (CO_{2eq}, NO_x, NMVOC, $PM_{2.5}$, PM_{10})	350	
VRT revenue		857
Motor tax revenue		859
Fuel tax revenue		1091
VAT from fuel sales		309
VAT from electricity consumption		n/a
Total	350	3,116
EV scenario		
CO_2 emissions from electricity generation	9	
Tailpipe emissions (CO_{2eq}, NO_x, NMVOC, $PM_{2.5}$, PM_{10})	319	
VRT revenue		759
Motor tax revenue		824
Fuel tax revenue		1030
VAT from fuel sales		291
VAT from electricity consumption		6
Total	324	2,910
Total marginal benefit of reduced emissions (ΔMD)	26	
Total tax revenue loss (ΔR)	206	
Cost of governmental EV grant scheme (G)	144	
Total social marginal net benefit (MND) MNB = ΔMD - ΔR - G	-324	
Total social marginal net benefit per EV (€)	-1408	

Study Limitations

This study is relatively narrow in scope, in that it does not include a full life cycle analysis of an EV and the full range of operating costs. Rather this study is meant to contribute to a better understanding of the potential implications that the replacement of ICEs with EVs could have on tax revenue whilst estimating the environmental benefits. It is intended to expand over time to become a broader social cost-benefit analysis model that will include multiple time frames, different government incentive scenarios, market penetration, fuel and electricity price scenarios. It will also incorporate energy consumption and EV travel data collected from household EV trials.

The results are based on a number of critical assumptions, some of which are rather uncertain. Above all, we only focus on the year 2020, as this year has been identified by the Irish government as a significant target year to have 230,000 EVs deployed. Whilst emissions benefits may not be significant by this time, they will continue to increase post 2020 whereas social costs in terms of incentives and VRT tax breaks will most likely have been discontinued. Additionally, we only run a single market penetration scenario in which a certain percentage of new car sales each year are electric. Our model does not allow us to examine whether EVs replace old high emitting vehicles or whether they are only purchased by environmentally concerned consumers who already own a vehicle with relatively low emissions. A discrete choice model of consumer preferences to assess the impact of the consumer on EV purchases similar to Brownstone and Train *(33)* would be required. Instead we make assumptions about the vehicle engine sizes that EVs will replace and how certain targets will be reached in terms of market share of sales.

In this study the market penetration of EVs was estimated using a logistic S-curve, but in reality it is likely to be a function of a number of factors such as fuel price, the purchase price of the vehicles after government subsidies and the relative utility of EVs compared to ICEs. The latter would be difficult to estimate considering that EVs are not yet available on the market. Due to fuel price volatility no projections were attempted for the future price of fuel or electricity. Current incentives and tax rates, were assumed to remain static. However, vehicle production may become commercially viable before 2020 leading to a reduction in retail prices, which in turn may lead to the termination of government incentives and VRT tax breaks prior to 2020. Additionally, the future composition of the EV fleet was assumed to consist of 30% BEVs and 70% PHEVs. This is important because each vehicle type is entitled to different incentives and have different performance characteristics in relation to fuel consumption and their electrical power requirements. The CO_2 emission intensity of the electrical generation system in 2020 was taken to be 393 g/kWh assuming that the government target of 40% electricity generation from renewable sources by 2020 is achieved. The COPERT 4 model used to estimate emissions from the passenger car fleet is based upon international averages and as such may be subject to some error in the emissions calculated.

Areas for future study

This study provides a host of possible new directions for future research. First, it could be extended as noted above, by including a comprehensive analysis of the full life cycle costs to society of EVs. Additionally the extent of emission reductions depends on what vehicles types are replaced by EVs. A discrete choice model of consumer preferences as described above would facilitate a more realistic representation of market penetration. There is a need to quantify the disutility to the consumer associated with the usability of an EV in terms of the limited driving range and lack of recharging infrastructure. As a starting point, one could estimate the disutility of the costs associated with the installation of home recharging equipment and garage space requirements. A further analysis would be possible when EVs come to market. It would be useful to integrate a more careful assessment of travel patterns and how these impact on both BEV and PHEV miles driven in ED mode. This would be possible through EV trials and would allow a better analysis of the emissions and fuel consumption savings. Additional sensitivity analysis on the assumed fuel efficiency of EVs, fuel and electricity prices would also provide insights and eliminate ambiguity. A comparison of multiple time frames of different lengths would benefit an analysis of this type to monitor how the social net benefit changes over time.

CONCLUSIONS AND RECOMMENDATIONS

This paper presents a simplified social cost-benefit analysis of the adoption of EVs in Ireland. The authors have found that by 2020 the 10% adoption of EVs will result in a social marginal net loss of €324 ($456) million or €1,408 ($1,982) per EV. The primary reason for this is due to losses in all sources of tax revenue compared to the EVs penetration rates required to achieve an appreciable reduction in emissions. This loss of €206 million ($289 million) is in the region of 0.5% to 1% of total tax revenue in Ireland at 2009 levels. However, this result should be interpreted carefully in light of the assumptions and study limitations outlined above. Critically this analysis focuses on the year 2020, which would be in the early stages of a transition from ICEs to EVs. At this time costs in terms of incentives and VRT tax breaks are highest to encourage adoption whilst the benefits in terms of reduced emissions are lowest due to low fleet penetration. A similar analysis conducted over a longer time frame could possibly yield a positive social net benefit. Furthermore, it is difficult to predict when the current government incentive scheme and VRT tax break will be terminated. Combined these account for 77% (€242 million; $341 million) of losses, which if discontinued prior to 2020 could result is a positive outcome in the short term. However, our analysis suggests that even if current government incentives and VRT tax breaks are continued to 2020 the short term social costs of EVs will be close to that of the BAU scenario. The transition from ICEs to EVs will be lengthy process, therefore, post 2020 assuming reasonable anticipated technological progress, increased market penetration and the termination of government incentives, the full social lifetime costs of EVs will most likely surpass the short term losses and could well be lower than the full social lifetime costs of ICEs. However, as both new EV and ICE designs and concepts continue to emerge, continued research is needed in this area.

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