

Title: Travel to work in Dublin. The potential impacts of electric vehicles on climate change and urban air quality.

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## **Abstract**

The Irish government has outlined plans for 10% of the national road fleet to be powered by electricity by 2020. The objective of this paper is to evaluate the potential reduction in road traffic related emissions due to commuting in the Greater Dublin Area (GDA) under different electric vehicle market penetration scenarios. The results indicate that the introduction of electric vehicles offers the potential for reductions in all road traffic related emissions. However, the time required for electric vehicles to acquire a significant share of the fleet, suggests that they will have a limited impact on climate change and urban air quality for at least the next decade.

## **1. 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 (Dempsey, 2008). The imminent commercial deployment of electric vehicles (EV) has the potential to address issues such as climate change, oil dependence and air quality. Research suggests that typical commuter profiles are particularly suited to EVs due to the repetitive nature, fixed distances of the trips and because vehicles are available for recharging either during daytime or overnight (Turrentine et al., 1992).

In 2008, transport emissions in Ireland accounted for 21.3% (14,255 MtCO<sub>2eq</sub>) of the national total, which represents an increase of 176% on 1990 levels (EPA, 2009a). This upsurge can be attributed to a period of unprecedented economic growth, which led to an increase in vehicle numbers, the purchase of larger vehicles and the reliance on private cars for commuting to and from work (EPA, 2009). Employment and household incomes have also increased significantly in Ireland over the last decade. This has subsequently led to a substantial increase in the level of car dependence and private car registrations in the country. These trends are particularly noticeable in the Greater Dublin Area (GDA), which saw an increase in employment by 48.9% and private car registrations by over 60% over the period 1996-2006 (Central Statistics Office, 2007a). The GDA is defined as Dublin City and the surrounding counties of Fingal, Dun Laoghaire-Rathdown, South Dublin, Kildare, Wicklow and Meath. Furthermore, in 2006, 51.8% of commuters in the GDA travelled to work by car, an increase of 5% on 1996 levels (Commins & Nolan, 2008). Morgenroth (2001) utilized data supplied by the Irish Revenue Commissioners to estimate the extent of the commuting belt around Dublin and concluded that in fact the commuter belt extends beyond the GDA and that a substantial number of individuals commute long distances from counties outside the GDA. This is referred to as the 'Outer Belt' region in Figure 1.

Insert Figure 1 here.

Figure 1. Commuter Belt for Dublin City. Source Morgenrath (2001).

In scientific literature many studies have explored the benefits of EVs and report that a net reduction in greenhouse (GHG) emissions can be achieved by replacing internal combustion engine vehicles (ICEV) with EVs. The Electrical Power Research Institute (EPRI) and the Natural Resources Defence Council (NRDC) compared plug-in hybrid vehicles (PHEV) to hybrid vehicles (HEV) and ICEVS using specific electricity generating technologies. The results concluded that regardless of the electricity supply, PHEVs and HEVs would result in a net decrease in GHG emissions (between 28-67%) relative to ICEVs (EPRI, 2007). Litienthal and Brown (2007) estimated the potential carbon dioxide (CO<sub>2</sub>) emissions reduction through the introduction of PHEVs into individual states in North America. It was determined that use of PHEVs would provide CO<sub>2</sub> emissions reductions in 49 states and on average a CO<sub>2</sub> reduction of 42% per mile driven. However, the author note that majority of the U.S

electrical generation comes from coal, which implies that greater reductions would be possible if a higher proportion of the fuel mix came from renewable sources. In the Irish context, Smith (2010) examined the potential benefits of PHEVs in terms of reducing the primary energy requirement (PER) and CO<sub>2</sub> emissions of passenger cars in Ireland. The analysis found that the electricification of the Irish passenger car fleet could reduce the PER and CO<sub>2</sub> emissions by 50% for each km travelled in electric mode.

## **2. Data and Methodology**

### **2.1 Fleet emission calculation**

The details of regular work trips were sourced from the Place of work Census of Anonymised Records (POWCAR) (Central Statistics Office, 2007b). It derives from the data gathered in the 2006 Irish census and details information on 1,834,472 regular work trips of the entire population. It is the only source of disaggregate origin-destination travel to work data in Ireland.

The ISus private car stock model, developed by the Economic and Social Research Institute (ESRI) of Ireland (Hennessy and Tol, 2010), was used to make assumptions about the future composition 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 passenger car sales, which has been calibrated to recent data on the actual stock (Hennessy and Tol, 2010). The model distinguishes cars by fuel type, engine size and age. The current composition of the Irish private car fleet in terms of diesel/gasoline, percentage weight and engine size distribution is presented in Table 1.

**Table 1. Current Irish private car fleet composition.**

Engine Size (L)	Fuel	# Vehicles	% Total private car fleet
<1.4	Gasoline	963,044	49.9
1.4-2.0		543,080	28.1
>2.0		53,251	2.8
<2.0	Diesel	320,073	16.6
>2.0		50,571	2.6
Total		1,930,019	100

The potential reduction in tailpipe GHG emissions was calculated using the COPERT 4 computer model. 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 (Kousoulidou et al., 2008). Over twenty European member states including Ireland use the COPERT 4 model.

The COPERT 4 methodology is based on average speeds and corresponding average speed emission factors to calculate vehicle emissions (Gkatzoflias et al., 2007). 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 (14% of total distance), rural (9% of total distance) and highway (76% of total distance) driving was considered with average speeds of 40 km/hr (rural), 60 km/hr (urban) and 100 km/hr (highway). The vehicles were allocated to different European emission standards on the basis of their age and application dates of the standards in Ireland.

The temperature data required for the COPERT models was sourced from the European Climate Assessment & Dataset (ECA&D, 2010). 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 1987 were utilized instead (Irish Statute Book, 2003). The only difference being that the 2009 stage fuel specifications, has 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.

### **3.2 Employment and Passenger Car kilometres (PCkm) in the GDA**

In 2006, it is estimated that 223,578 individuals travelled to work in Dublin by car. Based on the Central Statistics Office (CSO) employment statistics for the nation over the period 2006-2009 (Central Statistics Office, 2010) and future employment projections by the ESRI (Bergin et al., 2010), the number of individuals who will potentially travel to work by car to Dublin in 2020 was forecast. Under a low growth scenario, the ESRI predict that annual employment will increase by 1.9% and 0.9% over the periods 2011-2015 and 2015-2020 respectively. By applying the national employment statistics to the GDA, we estimate that approximately 226,300 individuals will travel to work by car to Dublin in 2020, of which approximately 156,800 will belong to households with two or more cars.

As this paper is concerned with annual emissions, the daily trip kilometres are calculated on an annual level, assuming that an individual completes a daily return work trip in a 220 day year. The average distance travelled to work in Dublin was 15.3 km in 2006, which equates to an average annual distance of 6,732 km per individual.

### **3.3 Potential electric vehicle market penetration**

The main uncertainty of the study is without any doubt the estimation of the future market penetration of EVs into the motor industry. The accurate prediction of market penetration includes great uncertainties and depends on a multitude of influencing factors (i.e. fossil fuel price, national incentive schemes and new developments in EV technology). In this study the rate of market penetration was estimated using a logistic S-curve. This methodology is in keeping with other studies, which have used S-curves to predict the market penetration of new technologies. These include Draper et al. (2008), who employed S-curves to predict the economic impact of EV adoption in the

United States and Smith (2010), who utilized S-curves to predict the penetration of PHEVs into the Irish car market.

The shape of the curve is determined by specifying two years and the expected market penetration of EVs at those particular years. Assuming that EV sales commence in 2011 and that 90% market penetration is achieved by 2035 we explore the reduction in emissions under three different market penetration scenarios, 'high', 'medium' and 'low' (Figure 2). In this case, market penetration refers to the penetration of annual sales - penetration of the entire car fleet would take significantly longer. Under the 'high' penetration scenario it is assumed that EVs will achieve 25% market share by 2020; under the 'medium' and 'low' scenarios, a share of 15% and 10% respectively. A Business as Usual (BAU) or baseline scenario was also investigated.

Insert Figure 2 here.

Figure 2. Projected EV market penetration under three scenarios 'high', 'medium' and 'low'.

From the analysis of the Society of Irish Motor Industry's (SIMI) new vehicle registration statistics over the period 2000-2007, an average of 79,512 new cars were registered in the GDA per annum. Due to the deterioration of the economy, new car registrations significantly decreased to 63,557 (-8%) and 26,265 (-59%) in 2008 and 2009 respectively. Early indications for 2010 (June) suggest a recovery in the industry with a 42% increase in sales (30,040) on the same period in 2009 (SIMI, 2010). 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 79,500 new cars registered in the GDA each year up to and including 2020.

Numerous studies have shown that the proportion of households with at least two cars is considerably higher in rural areas than in the urban areas largely due to the fact the individuals living in urban areas have better access to a more frequent public transport system (Commins & Nolan, 2009; Scottish Executive, 2005). Only 65% of households own two or more

vehicles in the GDA. Based on the technical features such as the driving range achievable by current EV models it is likely that EVs will only be purchased with the intention of becoming a household's secondary vehicle. Therefore we assume that only households with two or more cars would consider purchasing an EV. This reduces the potential market to approximately 51,700 sales per year.

Due to the extended driving range achievable by PHEVs, we assume that PHEVs are viable substitutes for all ICEVs with an engine size between 1.4 and 2.0 litres, but that battery electric vehicles (BEV) will only replace ICEVs with an engine size less than 1.4 litres, which have a lower than average annual mileage (Howley et al., 2009a). In the case of PHEVs, the fraction of the trip completed in all electric driving (ED) mode is difficult to determine. According to Smith (2010) and Parks et al., (2007) the fraction of the trip completed in ED mode is dependent on the trip length, the kinematic profile, driving habits and the PHEV operational mode. Smith (2010) reports that some current PHEV models such as the Chevrolet Volt and the Volkswagen VW -twindrive<sup>□</sup> have 100% performance capacity in ED mode and are capable of travelling 40 km or more in ED mode (Tate et al., 2008; Volkswagen AG, 2008). It is expected that in the future all PHEV models will have 100% performance capacity in ED mode and that the combustion engine will only serve as a means of extending the driving range (Smith, 2010). In 2006, 93% of commuters travelled less than 40 km to work in Dublin. Therefore for simplicity it is assumed that all trips to work are completed in ED mode and hence produce no tailpipe emissions.

In the reviewed studies the range of conceivable market penetration scenarios varies widely (Hadley and Tsvetkova, 2008; Simpson 2006; Clement et al., 2008). 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 penetration 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 Ireland

will consist of 70% PHEVs and 30% BEVs (Mulvaney, 2010). Table 2 presents the projected composition of the commuter fleet in 2020 under each of the investigated scenarios.

**Table 2. Projected composition of the commuter fleet.**

Technology	BAU	High	Medium	Low
ICEV	226,300	161,398	193,037	206,186
BEV	0	19,471	9,979	6,034
PHEV	0	45,431	23,284	14,080
Total	226,300	226,300	226,300	226,300

### **3.4 Electrical energy requirement of electric vehicles and the emission intensity of the national grid**

In estimating the potential GHG and urban air quality benefits from the deployment of EVs, it is necessary to account for the emissions impact of electricity generation. 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 (2010) 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  $\text{Wh km}^{-1}$ , of a range of vehicles representative of the Irish PC fleet, operating over a selection of legislative and real-world drive cycles. A MER of  $105 \text{ Wh km}^{-1}$  for a PHEV on an Irish drive cycle was calculated. Allowing for inefficiencies between the wall socket/tyre-road interface (75%) and efficiency gains through regenerative braking (60%), this increases to  $140 \text{ Wh km}^{-1}$  and is referred to as the wall socket electrical energy requirement (WSER). Losses that occur during the generation, transmission and

distribution of electricity must also be taken into account. The Irish electricity supply efficiency is expected to be 67% in 2020 (Smith, 2010). We therefore expect the WSER to translate to a primary energy requirement (PER) of  $0.209 \text{ kWh km}^{-1}$ .

In a review of transport options to alleviate the effects of climate change, urban air pollution and oil dependence, Thomas (2009) reports that under optimum conditions, the average fuel economy of a BEV is 2.6 times greater than that of an ICE engine, giving a specific energy consumption of  $0.26 \text{ kWh km}^{-1}$ . However, Foley et al. (2010) 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 PHEV and a BEV is  $0.209 \text{ kWh km}^{-1}$  and  $0.25 \text{ kWh km}^{-1}$  respectively.

In 2008 the carbon intensity of the Irish electricity supply was  $582 \text{ g CO}_2/\text{kWh}$  (Howley et al., 2009b). Wind generation is steadily growing and accounted for 10% of electricity generation in 2009 and overall, the share of electricity generated from renewable energy sources accounted for 14.4% (Dennehy et al., 2010). This suggests that Ireland has surpassed the mandatory EU interim target of 13.2% for 2010 as outlined in the EU Directive (2009/28/EC). The high levels of growth in wind generation are expected to continue into the next decade as the Irish government have set a national target of deriving 40% of electricity from renewable resources by 2020. Taking into account the combined measures of increasing the share of renewable generation and improvements in the overall efficiency of the electricity supply, we assume that the carbon intensity of the electricity supply will be  $393 \text{ g CO}_2/\text{kWh}$  in 2020.

#### **4.0 Results and analysis**

Current emissions levels for 2010, and projected emissions under three EV market penetration scenarios and a BAU scenario for the year 2020 were estimated in this study. Table 3 presents both the estimated tailpipe emissions and the emissions due to electricity generation for each of the scenarios investigated. The results show that each of the EV scenarios examined would realise a net reduction in  $\text{CO}_2$  emissions and tailpipe air pollutants. BAU or baseline  $\text{CO}_2$  emissions for 2020 are projected to be 319 Kt  $\text{CO}_2$  (a 5% reduction on 2010 levels), of which households with at least 2 cars account for 69% (221 Kt). The 'high' and 'medium' market penetration scenarios demonstrate that a net reduction in  $\text{CO}_2$  emissions of 10% (287 Kt) and 5% (303 Kt) respectively could be achieved. Under the most likely scenario of 10% market penetration, the findings show that a net reduction of 3% (309 Kt) in  $\text{CO}_2$  emissions could be achieved.

**Table 3. Emission results.**

Pollutant	2010 (t)	BAU 2020 (t)	% Change from 2010	High (t)	% Change from BAU 2020	Medium (t)	% Change from BAU 2020	Low (t)	% Change from BAU 2020
Tailpipe CO <sub>2</sub>	337,102	318,759	-5	249,475	-22	283,241	-11	297,275	-7
Grid CO <sub>2</sub>	-	-	-	37,999	-	19,475	-	11,776	-
Net CO <sub>2</sub>	337,102	318,759	-5	287,474	-10	302,716	-5	309,051	-3
CH <sub>4</sub>	28.54	13.39	-53	11.69	-13	12.51	-7	12.86	-4
N <sub>2</sub> O	5.24	9.04	73	6.15	-32	7.56	-16	8.14	-10
CO	3,385	834.91	-75	718.00	-14	774.96	-7	798.64	-4
VOC	376.71	115.11	-69	95.73	-17	105.17	-9	109.1	-5
NO <sub>x</sub>	283.79	201.27	-29	149.40	-26	173.06	-14	182.90	-9
NO <sub>2</sub>	41.46	13.4	-68	13.26	-1	13.33	-1	13.36	0
PM <sub>2.5</sub>	29.93	21.27	-29	15.87	-25	18.50	-13	19.60	-8
PM <sub>10</sub>	42.31	35.09	-17	25.73	-27	30.29	-14	32.19	-8

**Note all values are in tonnes.**

The results for the BAU scenario suggest that there will be significant reductions in CO, VOC, PM, NO<sub>2</sub> and NO<sub>x</sub> emissions in 2020, without the introduction of EVs to the fleet. These reductions can be attributed to two factors, the introduction of Euro 5 and Euro 6 emissions standards, which have stricter limits on pollutant emissions and the retirement of older higher pollutant emitting vehicles from the fleet. The highest reduction is, consequently, predicted for CO (75%) and VOCs have a similar expected evolution (69%). The results also showed considerable reductions of 68% and 53% for NO<sub>2</sub> and CH<sub>4</sub> emissions respectively. The Euro 5 and Euro 6 emissions standards will require NO<sub>x</sub> emissions to be reduced by 25-50%. Therefore a 29% reduction in NO<sub>x</sub> emissions is as expected.

The introduction of EVs exhibits superiority in further reducing all road traffic related emissions. A comparison between the EV adoption scenarios examined demonstrates that the 'high' adoption scenario would result in the largest decrease in overall emissions. Under the most probable scenario (10% market penetration by the year 2020) the results indicate a modest reduction in emissions. A further 8% reduction on the BAU scenario for PM<sub>2.5</sub> and PM<sub>10</sub> is observed. Globally, VOCs contribute to the formation of ozone (O<sub>3</sub>) which can lead to the production of photochemical smog in urban areas. Whilst Ireland does not experience smog pollution, the introduction of EVs could further reduce emissions by 69%. By 2020, NO<sub>x</sub> emissions are expected to decrease by a further 9% relative to the BAU scenario. Projected reductions in CO and NO<sub>2</sub> emissions are the lowest at 4% and <1% respectively.

## **5.0 Conclusions**

The results show that the introduction of EVs presents an advantage over the BAU case in every aspect of their emissions. Under the most likely scenario (10% market penetration by the year 2020) the results indicate a net reduction of 3% (309 Kt) in CO<sub>2</sub> emissions relative to the BAU case could be achieved. These results are mildly encouraging as this reduction in CO<sub>2</sub> emissions will most likely only account for approximately 1.93% of the CO<sub>2</sub> emissions from the transport sector in 2020. Urban air pollutants are individually projected to decrease in the range 1-10% under the most likely 'low' market penetration scenario. Due to the displacement of tailpipe emissions from densely populated areas to remote electricity generation sites, moderate pollution exposure benefits could be realised. As a conclusion of this study, the results obtained indicate that the time required for electric vehicles to acquire a significant share of the fleet, suggests that they will have a limited impact on climate change and urban air quality for at least the next decade but supports existing evidence that EVs are a realistic alternative to ICEVs in the long term and can contribute to emissions reductions.

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Figure 1



Figure 2

