Evaluating the Impact of Energy Efficiency and CO_2 Emissions Measures on Private Car Transport Using a Stock Model

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ABSTRACT

EU emission reduction targets are ambitious, but on a Member State level it is as yet unclear how legislation will affect each sector and subsector and where savings will come from. This paper addresses the role of Irish private car transport policy in the context of these targets, but the approach can be applied to other countries. This paper builds an energy demand model for private cars using a stock model derived from historical data and uses this to project baseline energy and CO_2 demand to 2020. Scenario analysis is then used to quantify the impact of three technologically driven policy measures on the composition of the vehicle fleet and appraise these measures in terms of their contribution to two EU targets for Ireland: Decision 406/EC/2009, mandating the reduction of emissions from non-ETS sectors by 20% on 2005 levels by 2020, and Directive 2009/28/EC, requiring 10% of (non-aviation and maritime) transport fuels to come from renewable sources by 2020. Results indicate that the three measures combined have the potential to reverse the upward trend in emissions caused by increased activity, giving an emissions decrease of 12% compared to the private car baseline and a 1.4% reduction on non-ETS emissions in 2020. With transport currently representing 30% of non-ETS emissions and private cars being the most significant subsector, robust policy evaluation methods such as those presented in this paper are crucial for forming evidence based policy and determining Ireland's ability to reach these targets.

1. Introduction

Transport energy demand has grown at a rate of 2.2% per annum since 1972, at a rate faster than overall energy demand (IEA, 2009a). Transport is 95% dependent on oil (IEA, 2009b) therefore this growth has consequences for emission reductions and for energy security. Policies aimed at reducing emissions from transport have targeted the energy intensity of travel, firstly by encouraging less energy intensive travel through public transport investment, and secondly, by reducing the intensity of individual modes.

The focus of this paper is on modelling the impacts of the latter policies aimed at private car transport in Ireland. The authors

1. demonstrate a methodology for estimating the impact of technologically driven policy measures on energy consumption in private cars;
2. evaluate the impact of three specific Irish and EU measures on the composition of the Irish car fleet using this methodology, and
3. assess these measures for their contribution towards national emissions and renewable energy targets as compared to a baseline scenario.

Ireland is an interesting case study for this type of evaluation for a number of reasons. Transport energy demand has not decoupled from economic growth as it has in other sectors, having grown by 181% in the period 1990 – 2007 and increased its share of total demand from 28% to 43% in the same period (Howley et al., 2009a). In 2007, private cars accounted for 43% of all transport energy (excluding fuel tourism), making it the most significant mode. In the future, Ireland's transport energy demand is forecast to grow by 1.5% per annum in a baseline scenario (Walker et al., 2009). Transport and, in particular, private cars are disproportionately dependent on fossil fuel imports and therefore policies implemented in this sector will have an important role in determining Ireland's future energy security and CO_2 emissions.

1.1 Policy Targets and Measures

The projected growth in transport energy will have implications for Ireland's ability to reach particular EU targets by 2020, namely

1. Decision 406/EC/2009 which requires a reduction in Ireland's GHG emissions in non emissions trading sectors (ETS) by 20% relative to 2005 levels, and
2. EU Directive 2009/28/EC, which obliges each EU country to source 10% of (non-aviation or maritime) transport fuel from renewable sources by 2020.

The following three measures are assessed in terms of their impact on private car emissions and their subsequent contribution to meeting the above targets:

1. In late 2008, the Government in the Republic of Ireland set a target that 10% of all vehicles in its transport fleet are to be powered by electricity by 2020;
2. Legislation has been put in place by the EU through Regulation 443/2009 to achieve mandatory new-car emissions of 130g CO_2/km through vehicle technology improvements by 2015; and
3. Ireland's 2010 Biofuels Obligation Bill requires all fuel sold to contain 4% of biofuel by volume from July 2010.

The paper does not specify or predict the mechanisms for how these three measures are to be achieved, but quantifies the individual emissions savings and contribution to renewable energy targets from these three measures under generalised scenarios and also the savings resulting from the successful implementation of all three compared with a baseline projection.

1.2 Methodological Approach

This approach focuses on the on-road fuel economy of the vehicle fleet and the emissions intensity of transport fuel, and how trends in these variables effect total fuel consumption and emissions. The methodology used to calculate the fleet emissions intensity is derived from a bottom-up stock model which calculates the on-road energy consumption and activity of cars in different categories (Daly and Ó Gallachóir, 2010). For examining technological effects, bottom-up modelling, focussing on a detailed description of the technological composition of energy end-use, has certain advantages over top-down methods, which aggregate consumption over a sector and derive relationships between energy consumption and explanatory variables, such as the price of oil or national income. While income and price influence purchasing patterns and travel behaviour, these econometric methods don't have the ability to model non-linear changes in the technological specification of the car fleet which may be brought about by policy, and don't reflect the potential of 'disruptive' technology such as electric vehicles (Barkenbus, 2009).

2. Energy Demand Model

Private car emissions are a product of fleet activity, average energy efficiency and the emissions intensity of transport fuel. The fleet activity variable, the product of the number of cars and average mileage, is determined using top-down methods and is exogenous to this model, and therefore fleet activity is the same for each policy scenario. From total fleet activity, the fleet size each year is determined, and a stock model is derived from sales scenarios to determine the composition of the fleet for each year between 2008 and 2020. The stock model is used to project the effect of different policy driven sales scenarios on the fleet energy efficiency and fuel content, and hence emissions.

2.1 Stock Model

In order to project baseline energy demand from private cars we firstly use a *stock model* to determine the composition of the car fleet for each year in the future in terms of vintage and technological category (defined by fuel type and engine size). Firstly, the total fleet size and annual sales are projected using top-down methods, then historical scrappage and import rates are used to calculate stock turnover each year.

Step 1: Stock, sales and imports.

The total fleet activity (in km/year) and car sales are projected to 2020 using Ireland's Gross National Product (GNP) and petrol price as explanatory variables. Historical values for GNP from the Central Statistics Office (CSO, 2009a), the price of petrol (CSO, 2009c) and total private car activity (determined from fleet size (CSO, 2009b) and average mileage (Howley et al., 2009a)) and sales (CSO, 2009d). Price and income elasticities with respect to activity and sales, respectively δP_{Act}, δI_{Act} δP_S and δI_S, are calculated as the best fit of the following points to the observed data according to least squares for years T = 1992 to 2008:

$$Act_T = Act_{T-1} * (1 + Dw_T * \delta I_{Act}) * (1 + Dp_T * \delta P_{Act}) \quad (1)$$
$$Sales_T = Sales_{T-1} * (1 + Dw_T * \delta I_S) * (1 + Dp_T * \delta P_S), \quad (2)$$

where Dw_T and Dp_T are the rates of change of wealth (GNP) and fuel price in between year T and $T\text{-}1$. Table 1 shows results from this analysis. It is not intended that these figures represent econometric results, but rather provide a reasonable grounding for estimating future vehicle activity based on historic trends.

Table 1: Fuel price and income elasticities of new car sales and fleet activity (km/year).

	Activity	*Sales*
Fuel price elasticity (PE)	-0.1	-0.80
Income elasticity (IE)	0.35	0.78

Projections of GNP (FitzGerald et al., 2008) and fuel prices, assumed to grow in line with projected oil price (Capros et al., 2008), are used to project total activity and sales; forecasts are generated using equations (1) and (2), and shown in Figure 1. The car stock is determined from activity: average mileage is assumed to stay constant at 2008 levels and therefore stock grows at the same rate as activity.

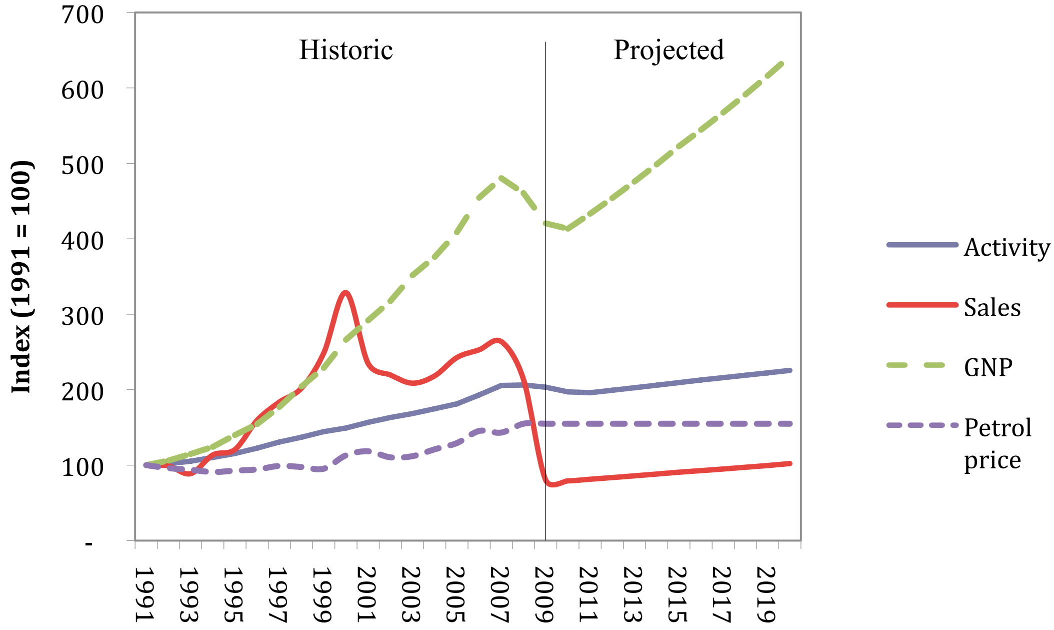

Figure 1: Historical and projected GNP, petrol price and private car activity and sales, indexed on 1991 levels

The difference between sales and total stock in a year is made up of the previous year's stock plus second-hand imports (I_T), which between 2000 - 2008 have constituted 10 - 30% of new registrations in Ireland (Howley et al., 2009a), minus retirements (R_T) as a result of scrappage. To find the values of imports and retirements for cars of each vintage, the vintage profiles of cars registered in Ireland between 2000 and 2008 from licensing data were used. If there was a net average growth in cars manufactured in a given year between year T and year T+1, it is not revealed in the licensing data whether this growth was purely due to second-hand imports or due to a combination of imports and scrappage. Therefore, imports and retirements are aggregated in the model each year and are calculated by:

$$Stock_T = Stock_{T-1} + Sales_T + (I - R)_{T.}$$

This formula is not intended to describe the relationship between sales, imports, retirements and stock size per se, as all variables are dependent on eachother and on outer economic factors. See, for example, Greenspan & Cohen (1996) for a discussion of this type of modelling. Which technological categories and vintages imports and retirements are attributed to is dealt with in the next steps.

Step 2: Technology profile.

The second step in projecting the stock model is to specify the number of cars in each technological category, C, in each year T. $Stock_{T,C}$, the number of vehicles in category C, year T, is calculated using the following formula:

$$Stock_{T,C} = Stock_{T-1,C} + Sales_{T,C} + (I - R)_{T,C},$$

where

$$(I - R)_{T,C} = (I - R)_T * \frac{Stock_{T-1,C}}{Stock_{T-1}}$$

In other words, $(I-R)_T$ found in the last step is attributed to each category C depending on the number of cars in C relative to the whole fleet in year $T-1$. $Sales_{T,C}$ is scenario-specific, and in the baseline projection we assume the same sales profile as 2009.

Step 3: Age profile.

The final step is to find the vintage profile of cars in each category. We use vehicle licensing data to find an average 'scrappage curve', $\Phi_C(v)$:

$$\frac{\Phi_C(v)}{\Phi_C(v-1)} = \underset{T}{Avg}\left(\frac{Stock_{T-1,C,v-1} - Stock_{T,C,v}}{Stock_{T-1,C,v-1}} + 1\right),$$

where $\Phi_C(0) = 1$.

The scrappage curve is shown in Figure 2 aggregated for petrol and diesel cars $(I-R)_T$. It should be noted that the graph of Figure 2 is an average scrappage and import curve for cars between 2000 and 2008, and that the rate of imports depends heavily on economic factors, specifically currency exchange rates between the Euro and UK Sterling. The method for deriving the vintage profile of cars in each technological category is contained in Appendix 1.

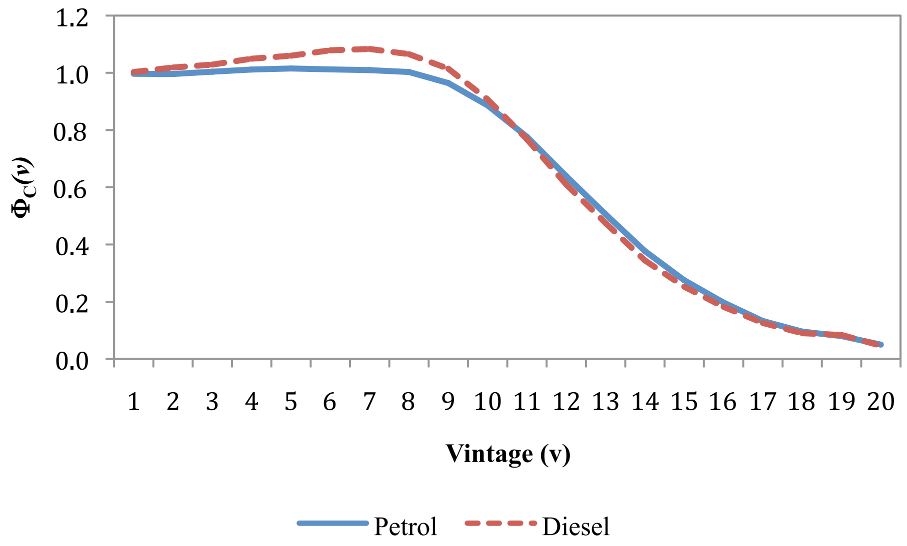

Figure 2: Profile of scrappage by car age; F > 1 indicates net imports

Figure 3 shows the stock profile of the 2010 private car fleet in terms of vintage and technological categories (engine cc and fuel). This profile is projected to 2020 using a baseline sales profile equal to sales in 2009.

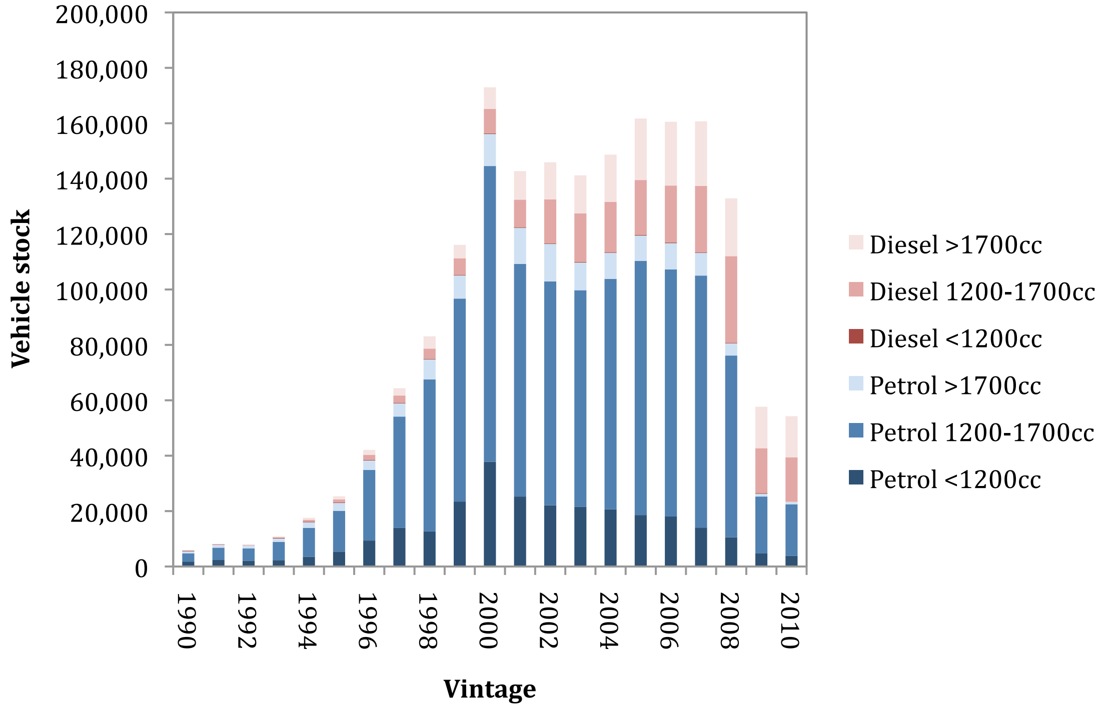

Figure 3: 2010 stock by fuel, engine cc and vintage

2.2 Baseline Energy and Emissions Calculations

For every year's car fleet, mileage (average kilometres driven in a year) and on-road specific energy consumption (*SEC* measured in MJ/km) are calculated for cars in each vintage (*V)* and technology category (*C*). Average mileage for cars in each technological category was gathered from odometer readings from the National Car Test (NCT) and profiled from 2000 – 2008 by the Sustainable Energy Authority of Ireland (SEAI) (Howley et al., 2007). These were then modelled on the trend of mileage over vintage to reflect the declining mileage of cars as they age (Kwon, 2006) according to methods described in (Daly and Ó Gallachóir, 2010). New-car SEC of cars in each category was also gathered by the SEAI from official fuel consumption test data from the UK's Vehicle Certification Agency (VCA). The total private car energy consumption in year *T* is calculated using the formula:

$$Energy_T = \sum_{C,V} Stock_{T,C,V} * Mileage_{T,C,V} * SEC_{T,C,V}$$

For the baseline calculations, the mileage profile and new-car SEC in each category are assumed to stay constant at 2008 levels.

Total private car CO_2 tailpipe emissions can be calculated from energy consumption using the emission factor 68g CO_2/MJ for petrol and diesel.

3. Policy Scenarios

Variations in the sales profile of the stock model and in the fuel mix is now used to evaluate three policy measures, named here *EMR*, *BIO* and *EV,* in terms of their projected impact on emissions compared to the baseline, above. The individual impact of each policy scenario is quantified firstly, and then all three are integrated into a *successful policy* scenario. This section presents the data inputs for each scenario: *EMR* and *EV* affect the fleet-average fuel economy; *EV* and *BIO* change the fuel mix.

3.1 EU New-Car Emissions: *EMR*

In this scenario, it is assumed that new-car average emissions reaches 130g CO_2/km in Ireland by 2015, the year in which car manufacturers are required to reach full compliance by EU Regulation 443-2009. Although it is not required that this target be met in each member state, but rather the community as a whole, the Irish Government has stated its commitment to reaching this target (DoT, 2009).

The average energy intensity of cars in each category is assumed to improve at the rate of average change between 2000 and 2008, with figures calculated by the Sustainable Energy Authority of Ireland (Howley et al., 2009a). Given the assumed efficiency improvement, the 130gCO_2/km target is met in the model by a change in the new-car profile. The 2015 sales profile is determined as that which results in the smallest change from 2009 (minimising the sum-of-squares difference between sales profiles of the two years). Figure 4 shows the sales share by aggregated engine size and fuel type and resulting average new-car emissions for this scenario. 2008 and 2009 profiles and emissions are measured: the significant shift towards diesel and reduction in emissions was largely as a result of a shift to an emissions-based vehicle registration tax; this change has been explored in detail elsewhere (Howley et al., 2009a; Rogan et al., in review).

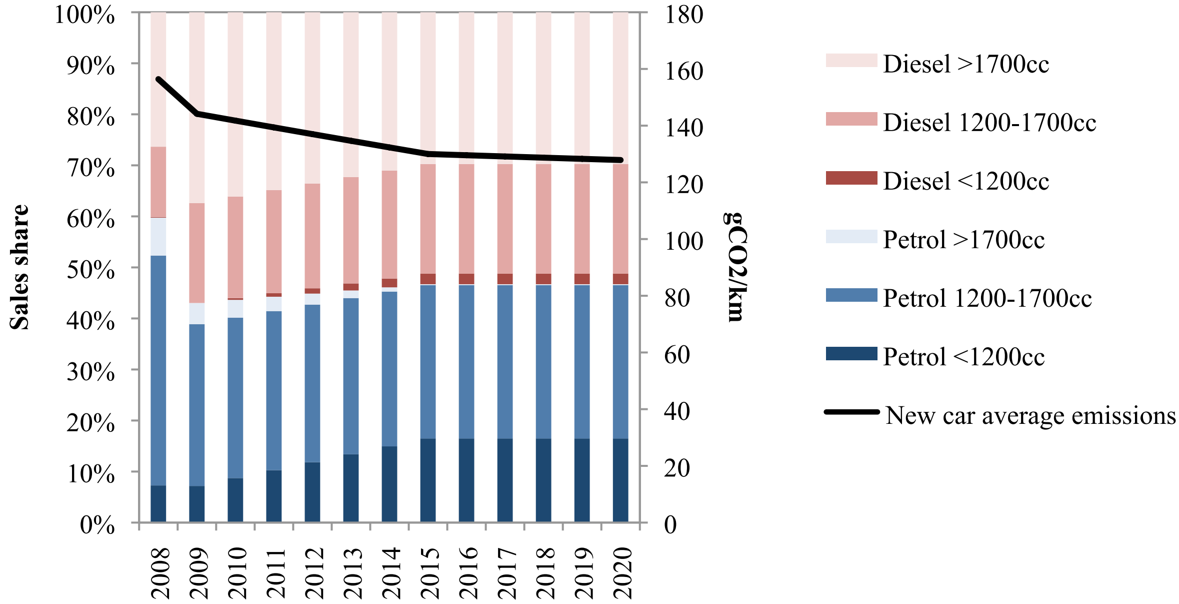

Figure 4: EMR scenario sales proportions by fuel and cc band; weighted average new car emissions

3.2 Electric Vehicles: *EV*

Deployment of electric vehicles is about to take place in Ireland, with 10% of the vehicle fleet targeted to be electric by 2020. The electricity from renewable sources used for transport has been encouraged by the EU by being given a weighting factor of 2.5 in calculations of renewable energy usage. In this scenario we examine the possibility of electrifying 10% of private cars, which made up 77% of the total vehicle fleet in 2008 (Howley et al., 2009a)[1].

[1] The 10% EV target is likely to be met from passenger cars (private and public service) as opposed to freight vehicles, which will necessitate a greater than 10% EV penetration for private cars.

The GHG effect of the introduction of electric vehicles (EVs) to a car stock is very sensitive to a number of factors, for example the replacement profile (Hennessey, 2010), the mileage and charging profiles of EVs (Foley A. M., 2009) and the type of technology (full electric or plug in hybrid) introduced. This paper does not explore scenarios surrounding the deployment of EVs but makes simplistic calculations in order to indicate the scale of energy demand. The following assumptions are used:

- EV purchasing starts in 2011 and the proportion of EVs bought accelerates each year in order to meet the 10% 2020 target, shown in Figure 5 along with the resulting overall EV penetration in the stock. Sales figures used are as those projected by ESB, the Electricity Supply Board, who have a key role in EV deployment (Mulvaney, 2010).
- A negligible number of EVs will be scrapped in their first 10 years, therefore all EVs bought between 2009 and 2020 will be in use in 2020.
- The baseline internal combustion engine (ICE) purchasing pattern by engine capacity and fuel type holds. This implies that EVs don't displace any particular technological category.
- Overall mileage isn't affected by EV introduction, and average EV activity is equal to average ICE activity.
- Average EV fuel economy is 2.6 times greater than that of the average conventional ICE engine in 2008 (Sandy Thomas, 2009), giving a specific energy consumption of 26 kWh/100km, or 0.95 MJ/km.

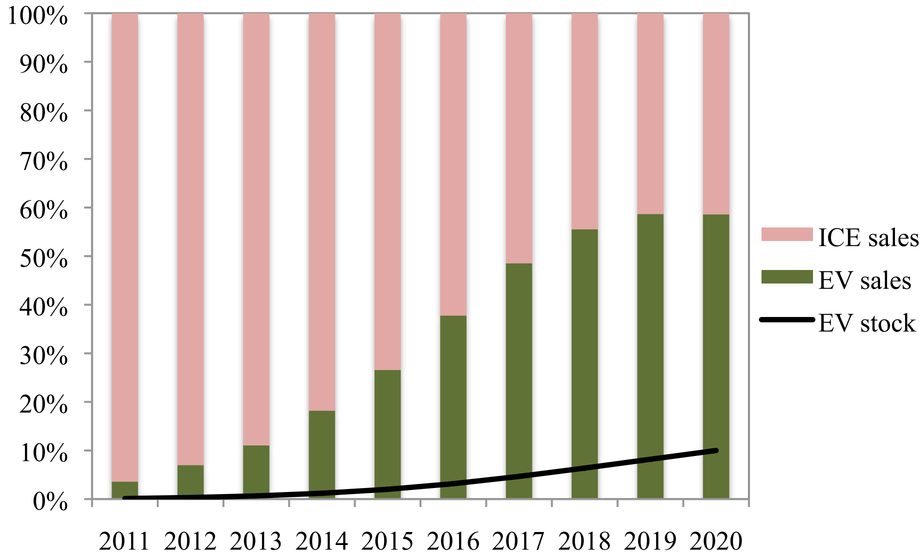

Figure 5: EV sales proportion required to meet 2020 10% target

The above assumptions are at best optimistic: it is likely that EVs will displace smaller ICE cars intended for city driving, and therefore are likely to have lower than average mileage than the fleet.

In calculating the emissions impact of electricity it is assumed that 40% of the electricity mix will come from renewables by 2020. The total energy-related CO_2 emissions associated with electricity generation in this scenario is projected by the All Ireland Grid Study to be 15.3 Mt CO_2 given a demand of 54 TWh in 2020 (Meibom et al., 2008). This results in an electricity emission factor of 78.7 gCO_2/MJ, falling from 161.5 gCO_2/MJ in 2008 (Howley et al., 2009b). Figures for interim years are linearly interpolated.

3.3 Biofuels Blending: *BIO*

According to Ireland's 2008 energy balance (SEI, 2008), 56 ktoe of 2181 ktoe consumed by private cars in 2008 came from liquid biofuel, a 2.6% mix by energy. In this scenario it is assumed that the biofuel content of Irish transport fuel will be as set down by the 2010 Biofuel Obligation Bill, compromising 4% by volume by July 2010. This target is assumed to be met by a 4% mix of biodiesel in diesel fuel and a 4% mix of bioethanol in petrol. The share of biofuel by energy content is calculated using the energy content by volume for each fuel as defined by Annex III of Directive 2009/28/EC and the overall petrol and diesel share as projected in the baseline scenario.

In calculating the CO_2 content of bioethanol and biodiesel the minimum sustainability criteria for biofuels is assumed as defined by Article 17 of Directive 2009/28/EC are met. In terms of GHG savings compared to petrol and diesel, they are as follows:

- 35% GHG saving 2009 – 2016.
- 50% GHG saving 2017.
- 60% GHG saving from 2018.

Table 2 summarises the total emissions savings as a result of these targets. However, although these figures represent a realistic CO_2 savings figure for biofuels, biofuels are assumed to be totally carbon neutral and 100% renewable when calculating CO_2 savings and renewability for the results below, as this is how both EU targets make the calculations.

Table 2: Projected biofuel content by volume and energy, and resulting projected CO_2 savings

	2010	*2011*	*2016*	*2017*	*2018*
Biofuel CO_2 saving	0.35	0.35	0.35	0.5	0.6
Biofuel content (vol)	3.3%	4.2%	4.2%	4.2%	4.2%
Biofuel content (energy)	2.9%	3.6%	3.8%	3.8%	3.8%
Total CO_2 Saving	0.8%	1.3%	1.3%	1.9%	2.3%

4. Results

4.1 Emissions

Figure 6 and Table 3 show the relative impact of each policy scenario on emissions from 2008 – 2020 compared to the baseline scenario.

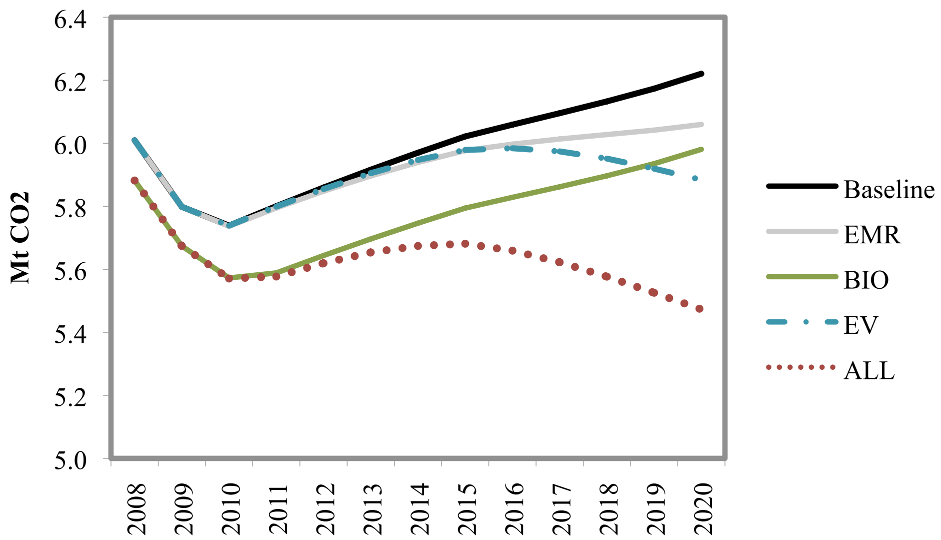

Figure 6: Projected private car emissions given baseline scenario, three individual policy scenarios, and all three together

Table 3: Emissions growth and savings compared to baseline of scenarios

Scenario	*2020 emissions (Mt CO_2)*	*Growth from 2008*	*CO_2 Saving*
Baseline	6.2	3.5%	
EMR	6.1	0.8%	2.6%
EV	5.4	-2.1%	5.4%
BIO	6.0	1.7%	3.9%
All	5.5	-7.0%	12.0%

All three policy measures combined are projected to reduce CO_2 emissions in 2020 by 0.7 Mt CO_2, a 12% saving, compared to the baseline projection. To indicate the extent to which this reduction will contribute towards the target for 37.2 MtCO_2 by 2020, a reduction of 20% on 2005 non-ETS emissions (EPA, 2010), we assume that private cars have the same modal share in transport energy demand as 2007, 37.5% (Howley et al., 2009a). The Environmental Protection Agency (EPA) in their *With Measures* GHG emission scenario (EPA, 2010), which is based on SEAI's *Baseline* energy projection, projects that non-ETS emissions will be 49.5 MtCO_2e in 2020, leaving a gap of 12.3 MtCO_2e to the target[2]. Therefore, the 0.7 MtCO_2 saving from the three policies analysed here have the potential to reduce this gap by 7%, which translates into a reduction in baseline non-ETS emissions by 1.4%.

However, national energy and emissions projections include these policy measures to different degrees depending on the date of introduction. SEAI's *Baseline* energy forecast, for example, incorporates the *EMR* measure but estimates that the energy saving as a result of this is 5.5 PJ, over twice the saving calculated in this methodology, 2.4 PJ.

4.2 RE composition

In calculating the renewable energy contribution from EV measures it is assumed that the 40% national renewable electricity target is to be met, and the proportion of renewables online is to follow the SEAI Energy Forecast *White Paper Plus* scenario (Walker et al., 2009). Figure 7 shows the renewable energy contribution of each scenario as measured by Directive 2009/28/EC, with renewable electricity from electric vehicles being weighted by a factor of 2.5 in the "All (EV weight)" scenario.

[2] This is based on the non-inclusion of forest sinks into emissions calculations. The *With Measures* non-ETS emissions, in this case, are projected to be 44.7 MtCO_2e, overshooting the target by 7.5 MtCO_2e. Under the *With Additional Measures* scenario, assuming all relevant policies outlined in government documents are met fully and on time, the gap is projected to be 2.8 and 7.6 MtCO_2e, with and without including carbon sinks respectively.

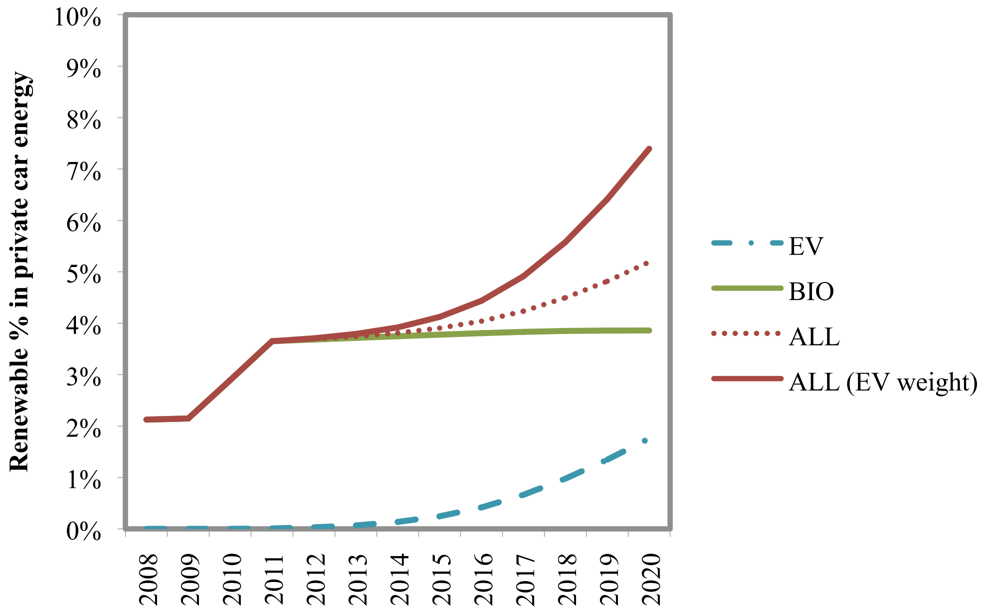

Figure 7: Private car renewable energy penetration resulting from Biofuel and EV measures individually and together, and with a weighting of 2.5 on renewable electricity

The 'best-case' scenario projects a share of 7.5% in meeting private car energy needs from renewables by 2020. This translates into a 4% contribution of these three combined policies towards renewables in (non-maritime and aviation) transport energy as a whole, assuming that private cars have the same modal share in 2020 as in 2007. With private car transport projected to represent 35% of transport energy needs by 2020, even with the ambitious targets of 10% fleet electrification and 40% renewable energy, it is likely that Ireland will need additional measures towards meeting its renewable energy in transport target.

5. Conclusion

Projections show that the reduction in emissions to be achieved as a result of increasing energy efficiency and reduced carbon intensity from the three policy measures in question will reverse the upwards trend in emissions caused by increased private car activity. All three policies together result in an 12% reduction in CO_2 emissions compared to the private car baseline, which contributes to reducing the projected gap to the target by 7%. Despite the gains in efficiency resulting from these measures, the increasing baseline activity demand diminishes emissions savings. Projected to represent 36% of non-ETS emissions by 2020, the contribution from transport energy policies will be a strong determinant of Ireland's ability to reach its emissions reduction target, and it is evident from these results that demand management through investment in alternative transport modes will be required to make significant savings from private car transport, as even the ambitious efficiency measures are insufficient. Besides the energy question, the growing negative effects associated with private car activity – traffic congestion, air and noise pollution – are reasons to invest in alternative modes.

Almost entirely oil fuelled, the issue of energy security is especially pertinent to private car transport. We project that 40% of the renewable transport energy target is to be met by car electrification and biofuel mixing, but over a quarter of this comes from the weighting of renewable electricity by 2.5, and assumes that 40% of electricity will come from renewables by 2020, an ambitious target.

The purpose of the presented methodology is to demonstrate purely technological effects of policies on the carbon intensity of cars holding all other factors constant: it doesn't show, for example, rebound effects of greater fuel efficiency on travel demand, or fuel price and GDP effects on the baseline purchasing behaviour in terms of car technology. In this way, total travel demand is exogenous to the model, a simplification meriting further development. The EV sales scenario assumes that EVs will displace conventional ICE cars perfectly in mileage, unlikely given the limited range. Also, EVs are likely to replace urban driving which is less efficient than highway driving. The types of EVs introduced, the cars they displace and their mileage are unknown factors and will be important in determining their effect on emissions.

Despite these generalised assumptions, the use of the bottom-up car stock model is important and interesting in studying the evolution of the car stock, and shows for example the time lag between new-car policies and how this affects the whole car fleet over time.

While all projections are inherently uncertain, the results above show that technological "fixes", even ambitious visions for electrifying the car fleet and increasing engine efficiency, are not sufficient alone for significantly reducing emissions or our dependency on imported fuel: fundamental behavioural changes to do with mobility are also needed.

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Appendix: Vintage Profile

For a given technological category C in year T we have derived $Stock_{T,C}$. The profile of $Stock_{T,C}$ by vintage is derived given the vintage profile of the previous year's stock in category C, $Stock_{T-1,C}$, such that

$$\sum_{v=0}^{20} s_{T,C,v} = Stock_{T,C} \qquad (*)$$

where $s_{T,C,0} = Sales_{T,C}$ is given. We also have derived a scrappage curve shown in Figure 2, where $\Phi_{z}(v)$ is the probability that a car of vintage v has been scrapped. We introduce the probability curve

$$\sigma_C(v) = \frac{\Phi_C(v)}{\Phi_C(v-1)}$$

where $\sigma_C(v)$ is the probability that a car of vintage v has survived given that it survived to vintage $v-1$. The formula used for profiling vintage is as follows:

$$s_{T,C,v} = \underbrace{\left[s_{T-1,C,v-1} * \sigma_C(v)\right]}_{\text{Natural survival}} + \underbrace{\frac{\sigma_C(v)}{\sum_{w=0}^{20} \sigma_C(w)}}_{\text{Weight}} * \underbrace{\left[Stock_{T,C} - \sum_{w=0}^{20}\left(s_{T-1,C,w} * \sigma_C(w)\right) - Sales_{T,C}\right]}_{\text{Remainder}}$$

This essentially distributes the "Imports – Retirements" term across all vintages according to the historical scrappage profile. The requirement (*) is verified:

$$\sum_{v=0}^{20} s_{T,C,v} = Sales_{T,C} + \sum_{v=1}^{20}\left(s_{T-1,C,v-1} * \sigma_C(v)\right) + \frac{\sum \sigma_C(v)}{\sum \sigma_C(v)}\left[Stock_{T,C} - \sum_{w=0}^{20}\left(s_{T-1,C,w} * \sigma_C(w)\right) - Sales_{T,C}\right]$$

$$= Sales_{T,C} + \sum_{v=1}^{20}\left(s_{T-1,C,v-1} * \sigma_C(v)\right) + Stock_{T,C} - \sum_{w=0}^{20}\left(s_{T-1,C,w} * \sigma_C(w)\right) - Sales_{T,C}$$

$$= Stock_{T,C}$$