Work Package 4 – Examining the emission reductions from changes in the Private Car Fleet and Public Transport Bus Fleet

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List of Abbreviations

BaU = Business as Usual

BEV = Battery Electric Vehicles

CH_4 = Methane

CNG = Compressed Natural Gas

CO = Carbon monoxide

CO_2 = Carbon dioxide

COPERT = Computer Programme to calculate Emissions from Road Transport

EEV = Enhanced Environmental Vehicle

EV = Electric Vehicle

GHG = Greenhouse Gas

HEV = Hybrid Electric Vehicles

ICEV = Internal combustion engine vehicle

kmph = Kilometre per hour

kt = Kilo tonnes

LPG = Liquefied Petroleum Gas

Mt = Mega tonnes

N_2O = Nitrous oxide

NMVOC = Non-methane volatile organic compound

NO = Nitric oxide

NO_2 = Nitrogen dioxide

NOx = Oxides of Nitrogen

PC = Private Car

PHEV = Plug-in Hybrid Vehicles

PM_{10} = Particulate matter less than 10 microns

$PM_{2.5}$ = Particulate matter less than 2.5 micron

PT = Public Transport

SO_2 = Sulphur dioxide

TTW = Tank-to-Wheel

VOC = Volatile organic compound

WTT = Well-to-Tank

WTW = Well-to-Wheel

Executive summary

This report provides a summary of emission reductions from changes in the private car fleet and the public transport bus fleet in Ireland. The greenhouse gas and other exhaust pollutants discharged from the passenger car fleet were calculated for the 2015 fleet which was considered as the baseline scenario. Different electric vehicle options, such as battery electric vehicles, hybrid electric vehicles, plug-in hybrid vehicles were examined in terms of their potential in reducing emission levels from PCs. The car ownership for the future years was estimated based on National Transport model (2014). Private car composition in the future fleet was calculated using Systra's rolling fleet model (v. 7.0) with business as usual situation (DTTaS, 2016). The model predicts that electric vehicle market penetration will not be significant until 2030. The annual average mileages were forecasted using multiple regression analysis. Changes in emission levels with BaU scenario were calculated for the years, 2020, 2025, 2030, 2040 and 2050. In 2015, 6.1Mt CO_2 were exhausted from PC fleet alone, which is estimated to increase by 39% in 2030. The results showed a huge increase in emission levels under BaU condition. Three hypothetical scenarios were designed considering low, medium and high BEV market penetration in 2025 and emissions were calculated in 2030 based on these scenarios. Even though this assumption results in a huge reduction in emission levels but is not enough to meet Ireland's emissions target.

For public transport bus fleet, which includes Dublin bus and bus Éireann, alternative fuel and technology options were examined. Four alternative scenarios which consider electric buses, CNG buses and bio-CNG buses, were evaluated. In addition to these, euro 6 and EEV buses were studied in terms of their potential in reducing emission levels. It was found that if urban public transport bus fleets in Dublin, Cork, Galway, Limerick and Waterford (i.e. where Dublin bus and bus Éireann run) are replaced by electric buses the emission levels can be reduced by more than 90% compared to 2015 levels, if renewable based energy is used for electricity production. However, with the use of bio-CNG for the entire PT bus fleet CO_2 emissions can be reduced by 57%. Emissions from public transport bus fleet in 2030 and possible reductions with designed scenarios were calculated. Only public transport bus fleets were considered as consideration of other modes of public transport was outside the scope of the report.

Ireland's target was to have 10% EVs in the PC fleet by 2020 (Brady and O'Mahony, 2011), the target has been revised as to have 10,000 EVs in the fleet by 2020. Changes in emission levels of all the major air pollutants, namely CO_2, CO, NO, NO_2, $PM_{2.5}$, PM_{10}, N_2O, VOC and NMVOC in 2020 with the current target were calculated and the difference with respect to the base year have been reported. Ireland's target for 2030 is to reduce GHG emission level by 30% relative to 2005 levels (European commission, 2017). The 2030 target has been estimated from 2005 GHG levels and the target emission levels were backcasted to suggest breakdowns of PC and PT fleet compositions which is required to meet the 2030's GHG target. It has been estimated that 14%, 13%, 50%, 23% of BEV, PHEV, HEV, ICEV are required to be in the PC fleet to reduce emission levels by 30%, relative to 2005 levels.

Chapter 1: Introduction

This report presents the emissions information related to the private car and public transport bus fleets in Ireland. In addition to having 10% EVs in the PC fleet in 2020, Ireland's target is to derive 16% of the final energy use and 10% of the transport energy use from renewable sources (SEAI, 2016). However, transport emissions are projected to show a strong growth over the period 2015-2020 resulting in 10% to 12% increase in GHG emissions compared to 2015 levels. This reflects the strong economic growth forecasted over the upcoming period (EPA, 2017). The 12% increase is estimated based on the measures which are already in place (i.e. with existing measures), such as, VRT (vehicle registration tax) and motor tax (introduced in 2008), carbon tax imposed on fuels since 2010, improvements to the fuel economy of the private cars etc. With the additional measures scenario, which includes 8% of the transport energy demand will be drawn from renewables by 2020 and 10000 electric vehicle deployment by 2020, emissions from transportation sector is expected to increase by 10% to 13Mt CO2eq. GHG emissions from road transport alone are expected to increase by 14% relative to 2005 levels with the existing measures. The GHG emissions over 1990 and the current year along with the projected GHG till 2035 are shown in Figure 1 (EPA, 2017). The graph shows an increasing trend till 2020 and then decreases with a slower rate.

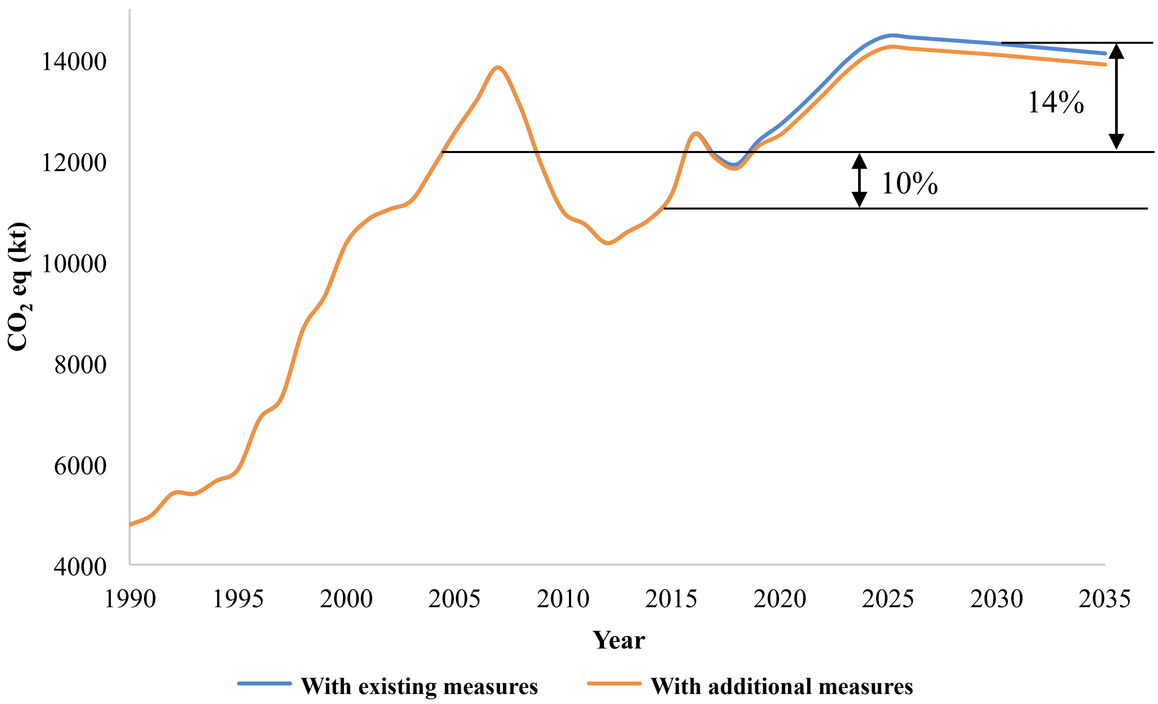

Figure 1: GHG emissions trend from road transport over 1990-2035

COPERT is a road transportation emissions modelling tool developed for European countries. COPERT 5 which is the most updated version of COPERT, has been used in this study to calculate exhausted pollutant levels from PC and PT bus fleets. Due to dieselgate where it was found that, apparently, all euro 5 Light Duty Vehicles are not obeying the emission standards and COPERT underestimates the NOx emission factors (g/km) (Ntziachristos et al., 2016), it was pointed out that COPERT needs revision to match the emission factors. In COPERT 5, the diesel NOx emission factors have been revised. In addition to calculating emission, COPERT 5 can calculate fuel consumption in terms of energy.

Next sections describe the analysis and findings of the research, conclusion, and plan for the next work package. Chapter 2 presents emission reductions from changes in private car fleet. Chapter 3 presents emission reductions from changes in public transport bus fleet. Alternative fuel/technology percentages required to be in the private car and bus fleets to meet 2030 target have been described in Chapter 4.

Chapter 2: WP4.1- Examining the emission reductions from changes in the private car fleet

2.1. Introduction

In 2008, it was announced that of 10% of the private car fleet (approximately 230,000 vehicles) to be electric by 2020 (SEAI, 2014). The electrification of the transportation sector has become necessary considering the growth in transport demand, resulting greenhouse gas, urban air pollution and fossil fuel depletion (Weldon et al., 2016). Electric vehicles have zero tailpipe emissions which is particularly important in densely urban areas. It is the most promising alternative to internal combustion engine vehicles towards a cleaner transportation sector (Casals et al., 2016). The net emissions savings from EV use have always been a concern as it largely depends on the fuel the electricity is produced from. Thus, while evaluating the environmental benefits of electric vehicles over conventional vehicles, one must consider the emissions resulted from the energy production. The Well-to-Wheel methodology is commonly used to estimate fuel efficiency of a vehicle in its use phase, which can be considered as a combination of the Well-to-Tank and the Tank-to-Wheel (Campanari et al., 2009; Hawkins et al., 2012). The WTT phase comprises of the emissions resulted while fuel extraction, refining and distribution activities needed to fill the vehicle tank. The TTW emissions include the emissions produced by fuel combustion to generate traction power. The environmental impact of ICEV mostly depends on the TTW phase. Whereas, in case of EVs, the TTW emissions are zero. Thus, in the carbon footprint assessment of EVs, WTT i.e., the emissions resulted from the electricity generation is analysed (Nicolay, 2000). It is very difficult to determine the electricity consumed by EVs as it depends on many factors, such as, driving behaviour, use of auxiliaries, weather conditions (Badin et al., 2013; De Vroey et al., 2013). Therefore, a wide range of electricity consumption, varying from 0.10 kWh/km to 0.24 kWh/km, has been reported by the researchers (Campanari et al., 2009; De Vroey et al., 2013; Hawkins et al., 2012; Helms et al., 2010; Strecker et al., 2014). In addition to the consumption variability, the emissions from the electricity production and distribution were also assessed by the researchers (Helms et al., 2010). Thus, unlike ICEVs, the environmental impacts of EVs are largely variable depending on the source of electricity and electricity consumption while in use (Campanari et al., 2009). But, the air pollution caused by electricity production is comparable to other conventional vehicles, however, the batteries are associated with environmental problems (Vreugdenhil, 2016).

The advantages of electric cars depend on the primary source of electric supply and the efficiency of the power stations. In electricity production, higher the use of coal lower is the advantage in CO_2 reduction. There would be no advantage if the electricity is produced entirely from coal (Engerer and Horn, 2010). If BEVs are fuelled with electricity produced from coal power then the per kilometre CO_2 emissions are higher than that of ICEVs (Wolfram and Lutsey, 2016). For PHEVs, the emission behaviour is less clear but if 50-50 distribution is assumed, i.e. 50% of the time fuel is used as power and 50% of the time electricity is used (Stewart et al., 2015) then the GHG emission behaviour is similar as BEV.

If wind energy is used as the source of energy, then there is huge scope of GHGE savings with WTW emissions being 6 g CO_2 e per km.

Davies and Kurani (2013) explored the actual implications for energy and emissions impacts of plug-in hybrid vehicles based on observation rather than assumption. Unlike electric vehicles plug-in hybrid vehicles allow the flexibility to be run by gasoline when there is not chance to charge the vehicle. But with this flexibility comes the uncertainty in estimating the shares of electricity and fuel consumption and resulting emissions, as it largely depends on may factors associated with charging and driving behaviour. Lorf et al. (2013) studied energy consumption and CO_2 emissions from HEV, PHEV, EV and ICEV presented results from 40 vehicles and the results show that depending on the source of primary energy WTW CO_2 emissions could be lower in PHEV and HEV than BEV.

Smith (2010) examined the potential benefits of plug-in hybrid vehicles in reducing primary energy use and CO_2 emissions in Ireland. It was concluded that PHEVs have potential to reduce PER (primary energy requirement) and CO_2 by more than 50% per kilometre. The author also reported that PHEV operating in EV mode will account for approximately 10% passenger car kilometre in 2020 and 50% in 2030. PHEV mitigate the tailpipe emission which contributes to the local air pollution and climate change (Ralston and Nigro, 2011; Sharma et al., 2013). Wu et al. (2015) pointed out that significant reduction in CO_2 and NOx in HEV is possible compared to the conventional gasoline and diesel vehicles. It was also reported in the study that even though the purchase cost is higher for HEV, but with time the total costs of vehicle purchase and fuel consumption of diesel and petrol cars exceed that of HEV in less than 3 years. Ke et al. (2017) report that by 2030 the WTW CO2 by BEV should approach 100g/km due to a decrease in fossil electricity. Though the NOx emissions from BEV are higher than conventional gasoline vehicles by 66% it is expected that by 2020 there would be reduction benefit of 41%. This study concludes that BEV and PHEV could significantly reduce the WTW CO_2 by 32% and 46% respectively compared to MPFI (multiport fuel injection). This is due to the rapid switch from coal to natural gas in electricity production.

Hydrogen Fuel Cell Electric Vehicles are also free from tailpipe emissions except for water vapor. Use of Hydrogen Fuel Cell Electric Vehicles can lead to lowest GHG emissions if wind-powered electrolysis is used to produce the hydrogen but this currently very expensive to be considered as a viable option. Currently, the hydrogen is produced by reforming the natural gas where the WTW GHGE is 177 g CO_2eq per km. whereas use of natural gas in producing electricity can result in 90 g CO_2eq per km. With average European electricity sources, BEVs provide an about 40%–50% GHG benefit compared with average vehicles (Wolfram and Lutsey, 2016).

Brady and O'Mahony (2011) studied the potential emission reduction with high (25%), medium (15%) and low (10%) market penetrations of EVs to be used in the work trips in Dublin to meet Ireland's EV target for 2020 which was to have 10% EVs in the fleet in 2020. The EV purchase rate in Ireland is very low even by providing incentives to increase uptake. Figure 2 shows the new car registration pattern with respect to engine type over past 10 years

(SIMI, 2016). It's worth commenting here on how low the EV and Hybrid numbers are SEAI offers a grant of up to €5,000 for every BEV or PHEV purchase.

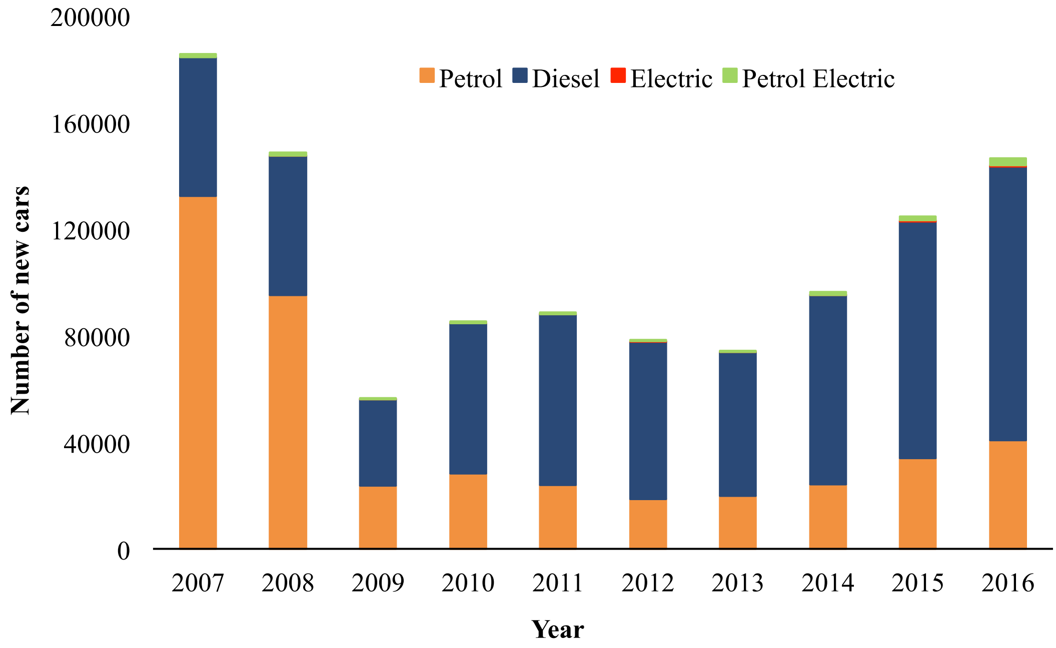

Figure 2: New car registration pattern over 2007-2016

In addition to the grant, there are VRT relieves of €5,000 for BEV and €2,500 for PHEV (SEAI, 2017). The annual motor tax for EV is €120. Even after all these measures, the EV uptake is significantly low in Ireland. There are very limited number of EV models available in Ireland at this moment with only 85 fast charging stations. The financial incentives that would reduce the emissions are, financial subsidy on low emission vehicles, subsidies on retrofit programmes when feasible, financial bonus (cash for replacement) to encourage early scrappage, increase local parking fees or increase in congestion pricing (Hao et al., 2006). Valeri and Danielis (2015) studied the market penetration of cars with alternative fuel powertrain technologies in Italy. The authors considered 5 scenarios, such as, introducing a state subsidy on purchasing low emission cars, 20% increase in fossil fuel price, a €5,000 price decrease in BEVs, a threefold range increase for BEVs and the last one is all those previous scenarios together. It was found that only when all the incentives were implemented together, i.e. in the fifth scenario the BEV market penetration can be increased significantly, about 15%. Nanaki and Koroneos (2016) designed different alternative fuel penetration scenarios and found that maximum emission saving is possible with 10% natural gas, 10% biodiesel, 10% electricity resulting in 49%-78% savings in CO, NOx, OM, HC and 21% in CO_2. Main components of electric mobility are vehicles, batteries, charging points, and services. Table 1 provides a list of NOx and PM emission factors, WTW CO_2 emissions, TTW fuel consumptions and TTW electricity requirements of the available fuel/technology options for PCs (European Commission, 2007).

Table 1: Passenger car energy consumption and emission factors for different fuel types

Technology	Dimension	NOx (g/km)	PM (g/km)	WTW CO_2 (g/km)	TTW FC (MJ/km)	TTW Electricity (MJ/km)
Conventional gasoline – Euro VI	1.4-2.0 t	0.029	0.001	193,490	2,240	0
Conventional diesel – Euro VI	<2.0 t	0.207	0.001	159,792	1,830	0
Hybrid	Mean	0.120	0.002	139,655	1,168	0.292
Electric	Mean	0	0	154,800	0	1200
CNG stoich. 2017	Mean	0.009	0	120,920	1,880	0
Biofuel 20	Mean	0.411	0.016	140,028	1,770	0
Ethanol 15	Mean	0.399	0.011	158,733	1,900	0
Biofuel 100	Mean	0.447	0.011	87,491	1,880	0
Ethanol 100	Mean	0.399	0.009	108,810	1,900	0

The electric vehicle uptake rate is very low in Ireland. Total GHG emissions have increased by 6.7% in 2015 to 1990 levels. The greenhouse gas emission share of transportation was 9.1% in 1990 which has increased to 19.8% in 2015. The share is expected to be 21.6% in 2020 and 23.1% in 2030 (EPA, 2017).

Emission levels from the 2015 PC fleet and reduction in emission levels with the current 2020 target are presented in this study. Time series results in terms of emission levels of the air pollutants in the years 2020, 2025, 2030, 2040 and 2050 have also been presented. Potential reduction in emissions from the PC fleet from hypothetical scenarios was calculated. Three hypothetical scenarios were designed with the assumptions that EV market penetration will increase to 10%, 15% and 25% in 2025 and reach to 50% in 2030.

2.2. Methodology and data

This section describes the methodology used to assess the emission levels and data used with their sources. Emission levels of the pollutants were calculated using COPERT 5 which is the recommended road transportation emission model developed for European countries. This transportation emission modelling tool follows tier 3 methodology which requires a detailed level of environmental information, fleet data, activity data in addition to requiring trip information and annual fuel consumption for different fuel types. Table 2 presents the input data, needed to calculate vehicular emissions using COPERT, with their respective sources.

Table 2: Input data and their respective sources

Data type	Source
Fuel consumption	Sustainable Energy Authority of Ireland (SEAI, 2015)
Fleet data	- Motorstats: The official statistics of the Irish Motor Industry (2016) - Department of Transport, Tourism and Sport (2016)
Fuel Information	- Motorstats: The official statistics of the Irish Motor Industry (2016) - Department of Transport, Tourism and Sport (2016)
Mileage	- CSO (2014) - SEAI (2013)
Relative Humidity	- MET Éireann: The Irish Meteorological Service Online (2016) - World Weather & Climate Information (2016)
Temperature	MET Éireann: The Irish Meteorological Service Online (2016)
Speed	Road Safety Authority (2015)
Trip length	CSO (2014)
Mileage share	Brady and O'Mahony (2011)

The breakdown of the fleet for 2015 is shown in Figure 3 (DTTaS, 2016). The monthly average minimum and maximum temperatures and relative humidity values are presented in Figures 4 and 5 respectively.

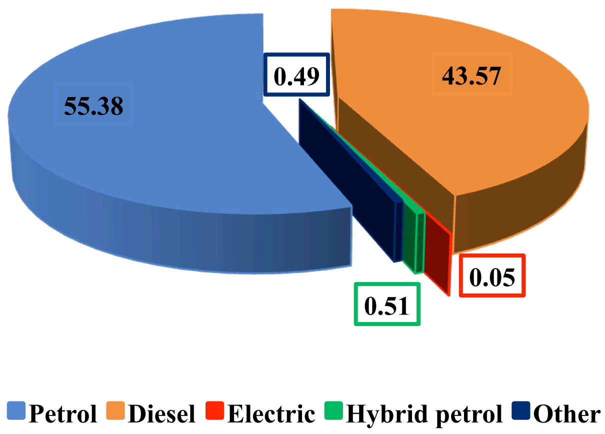

Figure 3: Percentage breakdown of 2015 fleet

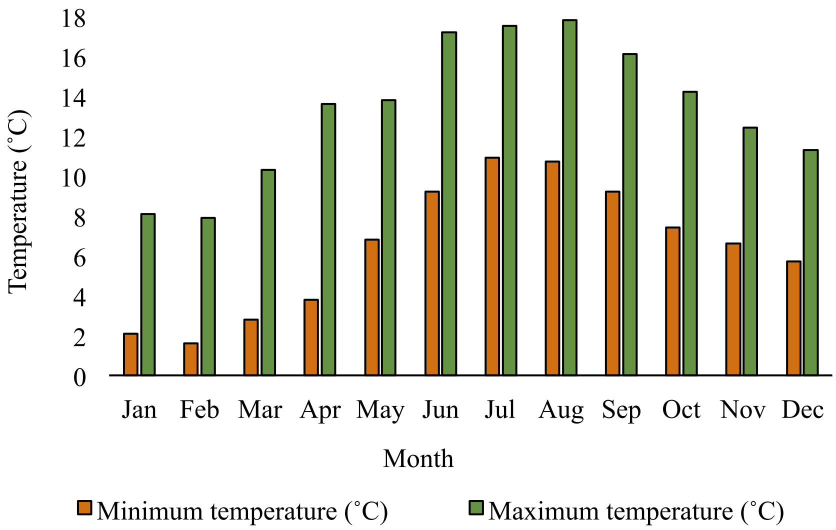

Figure 4: Monthly average minimum, maximum and mode of the temperature differences at the base scenario

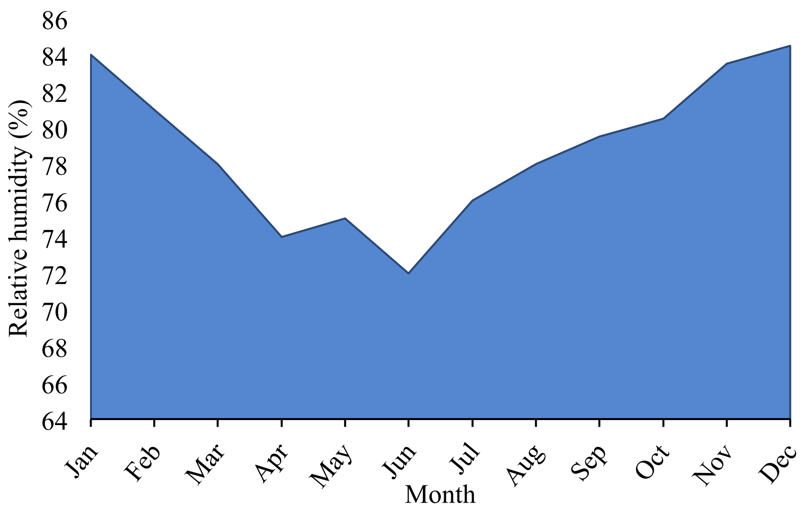

Figure 5: Monthly average relative humidity (%) at the base scenario

The fleet data for 2015 were extracted from the Society of Irish Motor Industry (SIMI, 2016) and DTTaS (2016). The detailed classification of fleet data as required for COPERT 5 with respect to engine classes i.e. Small (<1.4 L), medium (1.4-2.0 L) and large (>2.0L), fuel type and technology classes (Euro 1, Euro 2 etc.) have been shown in Figure 6.

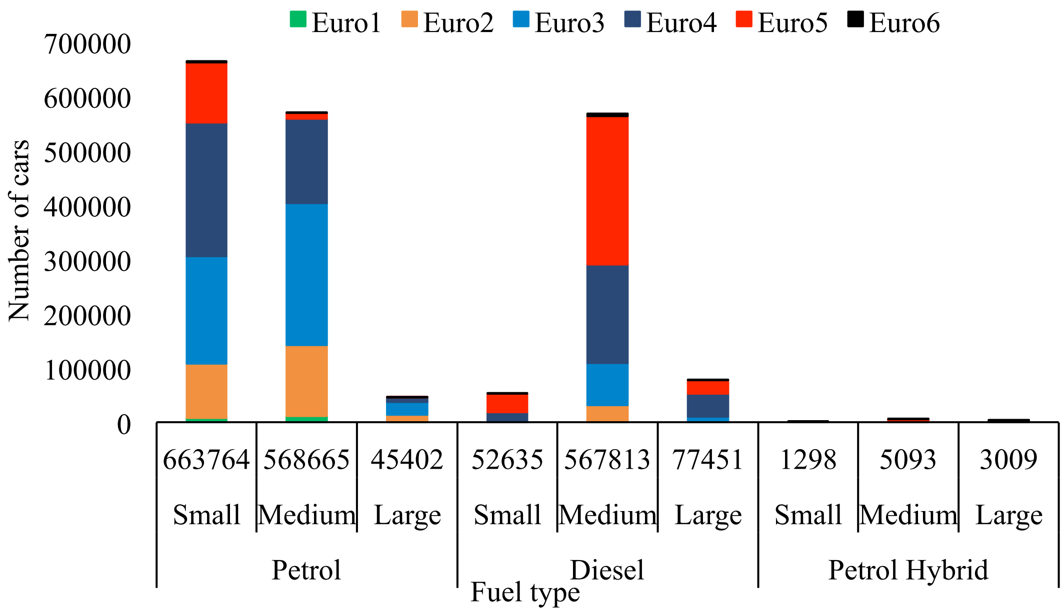

Figure 6: Passenger car fleet composition for 2015

Average speed for on urban roads, rural roads and highways were taken as 40kmph, 60kmoh and 100kmph respectively (RSA, 2015) and the driving mode shares as 30% (Urban), 50% (Rural), 20% (Highway). The emission levels from the PC fleets in 2020, 2025, 2030, 2040 and 2050 with respect to business as usual situation have been calculated using COPERT 5. The BaU scenarios are named as BaU_2020, BaU_2025, BaU_2030, BaU_2040 and BaU_2050. In order to calculate emissions for the future fleet, the car ownerships were estimated by Gompertz and Logistic models (NTA, 2014). Table 3 shows the forecasted car ownership in the future years for which the emission levels have been calculated.

Table 3: Prediction of car ownership

Year	Population (million)	Percentage change (%)	Car population	Percentage change (%)
2015	4.677		1,985,130	
2016	4.773	2.1	2,023,752	1.9
2020	4.80	2.6	2,132,532	7.4
2025	4.91	5.0	2,312,610	16.5
2030	5.07	8.4	2,555,280	28.7
2040	5.30	13.3	2,906,264	46.4
2050	5.41	15.7	3,062,060	54.2

It can be observed that the percentage increase in population compared to 2015 level is 5.07% in 2030 but the percentage increase in car population is 28.7%. Whereas, in 2050 the predicted population increase in Ireland is 5.41% with the car ownership increase by 54.2%. Car compositions for future years under BaU were calculated using Systra's_rolling_fleet_v7 model. The predicted compositions are shown in Figure 7. Systra's rolling fleet model predicts that the new car registration share of BEVs and PHEVs will have only 1.6% share in

2025 and 2030, however, it will increase to 50.8% in 2040 and in 2050 the new registration share of EVs will be 100%.

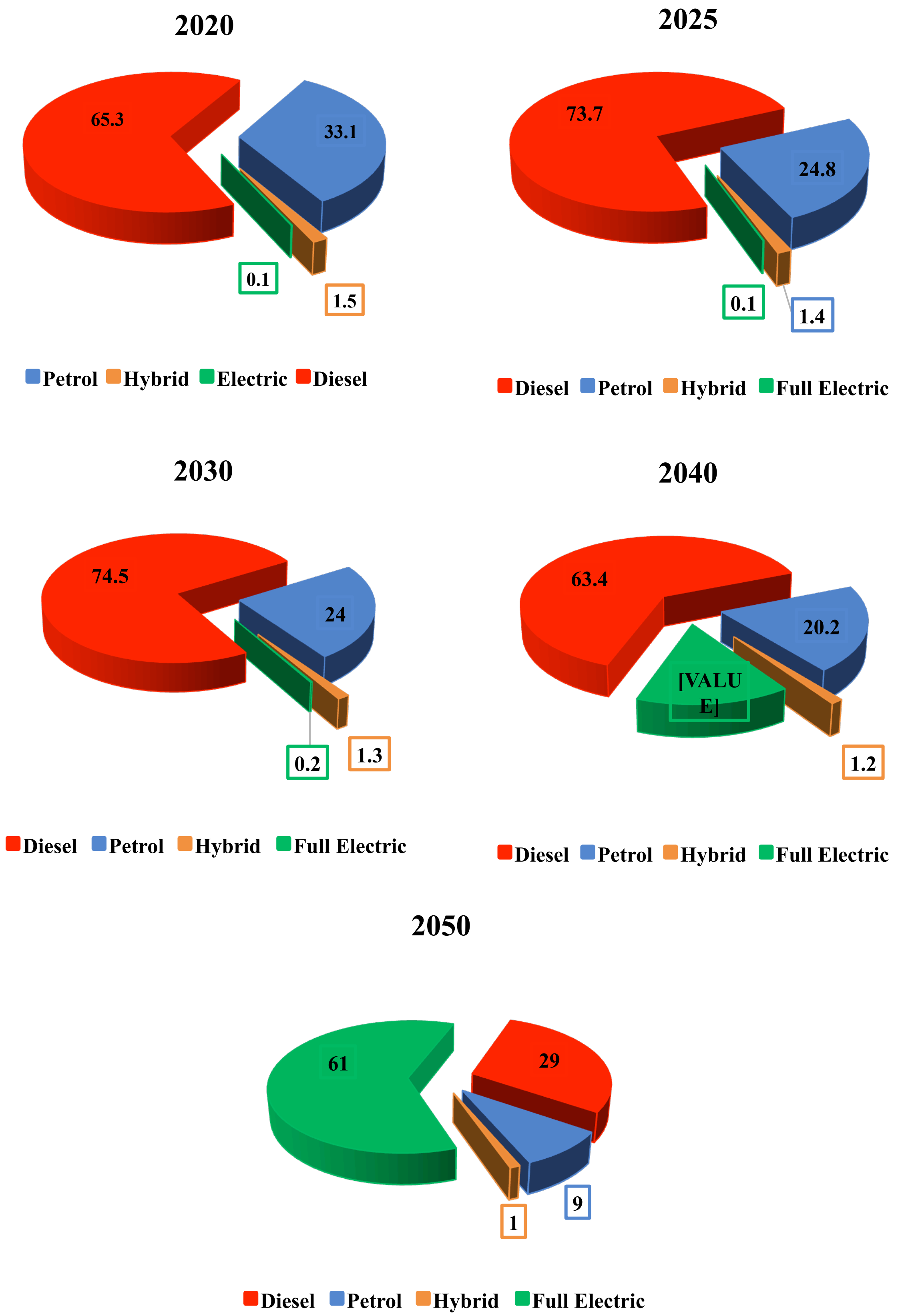

Figure 7: Private car fleet compositions with business as usual scenario

The average annual future fleet mileages have been calculated by multiple regression based on the population, a number of private cars and past 12 years weighted average annual mileage data. Table 4 to 6 show the results and statistical significance of the modelled mileages.

Table 4: Regression Statistics

Multiple R	0.992753
R Square	0.985558
Adjusted R Square	0.982349
Standard Error	92.7079
Observations	12

Table 5: ANOVA (Analysis of Variance) results

Parameter	df	SS	MS	F	Significance F
Regression	2	5278874	2639437	307.0986	5.23E-09
Residual	9	77352.79	8594.755		
Total	11	5356227			

Table 6: Summary output

Parameter	Coefficient	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	29221.8	22.1	3.75E-09	26230.9	32212.8	26230.9	32212.8
Population	-1975.9	-3.19	0.011	-3374.9	-576.913	-3374.9	-576.91
Number of Private cars	-0.001	-0.71	0.493	-0.002	0.001	-0.002	0.001

R^2 or co-efficient of determination is a measure of how well observed outcomes are replicated by the model while the adjusted-R^2 calculates R^2 from only those variables whose inclusion in the model is significant. It is always recommended to calculate adjusted-R^2 in multiple regression. The R^2 and adjusted R^2 values of the mileage prediction model are significantly high which indicates the goodness of fit. Figure 8 shows the available annual average mileage data and modelled mileages.

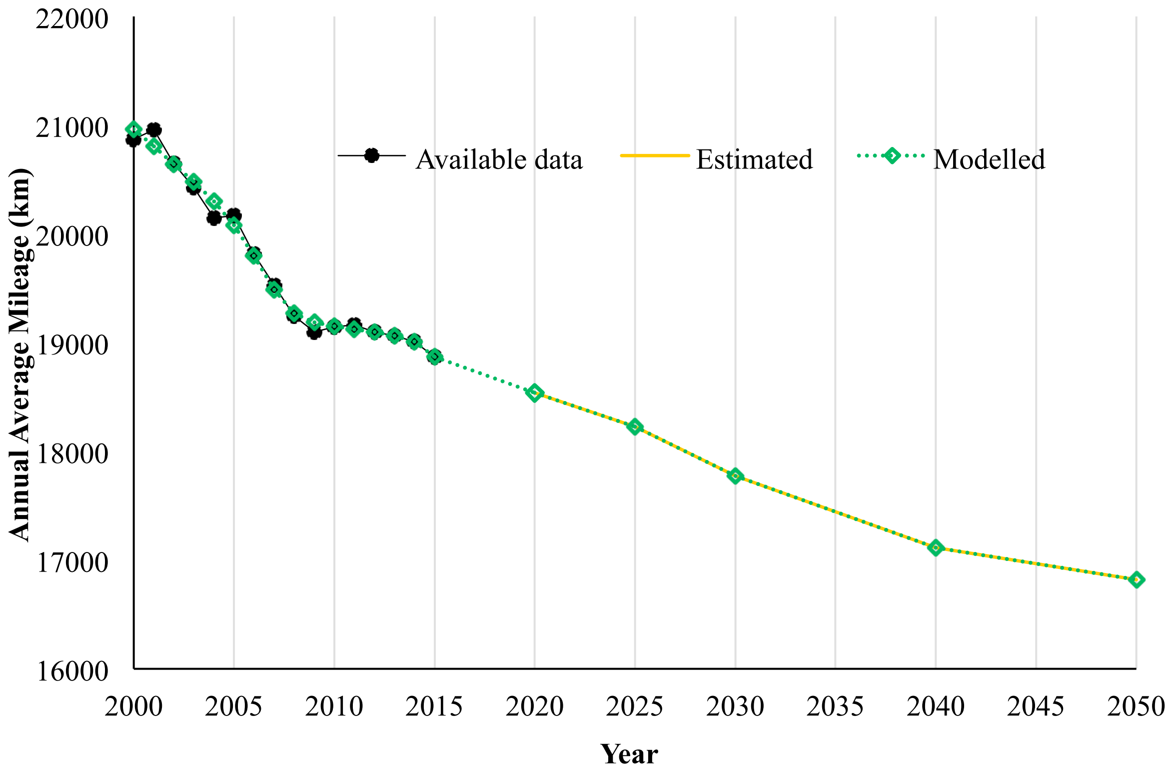

Figure 8: Annual average mileage (km)

It can be observed that the average mileage has a decreasing trend which is due to the increase in car ownership.

Three additional scenarios were designed to examine the possible reduction in emission levels. These alternative scenarios, namely 2030_low, 2030_medium and 2030_high, calculate emission levels in 2030 based on the assumptions that,

- 2030_low: 10% of total new PC registration in 2025 are EVs and 50% in 2030
- 2030_medium: 15% of total new PC registration in 2025 are EVs and 50% in 2030
- 2030_high: 25% of total new PC registration in 2025 are EVs and 50% in 2030

These scenarios consider implementing additional incentives and/or measures, which will be examined in next work package, to encourage EV uptake. It has been assumed that the uptake will follow Logistic S-curve (Brady and O'Mahony, 2011; Smith, 2010). Here it has been assumed that 50% of the market penetration will be achieved in 2030. And three scenarios have been assumed as 10%, 15% and 25% market penetration in 2025. The number of new car registration each year has been taken as 110000 based on past years data (SIMI, 2016).

$$\text{Market penetration} = 1/(1+\exp(-\alpha*(Y_i - Y_0))) \quad (1)$$

$$\alpha = (\ln(1/P_1-1) - \ln(1/P_2-1))/(Y_2-Y_1) \quad (2)$$

$$Y_0 = \ln(1/P_1)/\alpha+Y_1 \quad (3)$$

Y_i is the required year

Y_1 is the first year defined

Y_2 is the second year defined

P_1 is the expected penetration defined for Y_1

P_2 is the expected penetration defined for Y_2

The S-curves showing the EV market penetration under the three hypothetical scenarios are presented in Figure 9.

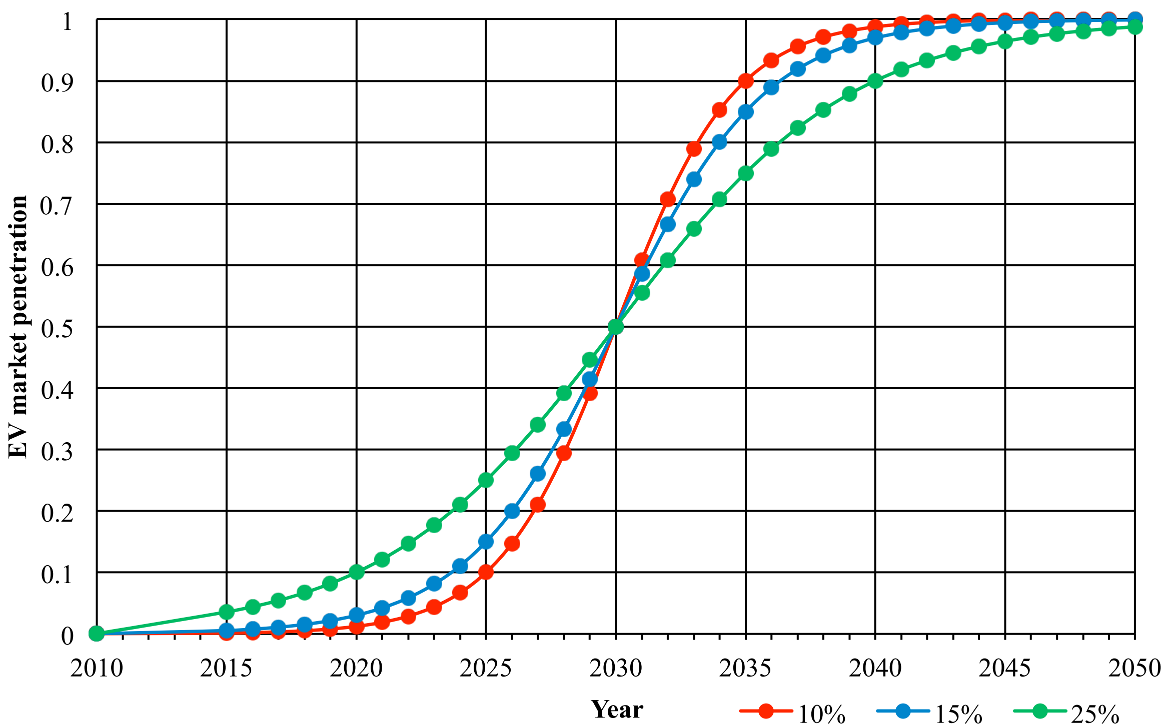

Figure 9: Market penetration pattern of electric car

In 2030, with the low penetration scenario the EV will comprise about 10% of the overall car fleet and with medium and high penetration scenarios the overall percentage share will be 11.5% and, 16.4% respectively. Additionally, emissions were calculated for 2020 with the current Irish target which is to have 10,000 EVs in the PC fleet by 2020. The emissions were calculated under these scenarios and emission reductions were compared to 2015 level.

2.3. Results and discussion

2.3.1. Emissions from the current PC fleet (2015)

This section presents the emissions resulted from the existing PC fleet in Ireland as calculated using COPERT 5. Table 7 shows the total emissions from the private car fleet and disaggregated emission levels with respect to fuel type and engine class.

Table 7: Total Emissions for different pollutants (tonne) for the current fleet (2015)

Pollutant	Fuel type / Engine Size	Petrol	Diesel	Hybrid Petrol	Total
		Emissions (t)			
CO_2	<1.4L	1,087,881	212,876	1,601	6,095,743
	1.4-2.0L	1,512,624	2,690,937	8,647	
	>2.0L	130,530	446,053	4,595	
CO	<1.4L	15,294	66	11	35,558
	1.4-2.0L	17,829	1,109	59	
	>2.0L	1,031	137	22	
NOx	<1.4L	713	752	0.5	13,766
	1.4-2.0L	1,049	9,986	2.6	
	>2.0L	72	1,189	1.3	
$PM_{2.5}$	<1.4L	70	31	0.1	772.1
	1.4-2.0L	83	510	0.6	
	>2.0L	6	73	0.3	
PM_{10}	<1.4L	120	41	0.2	1,039
	1.4-2.0L	142	635	1.2	
	>2.0L	10	88	0.6	
N_2O	<1.4L	16	9	0.02	182.18
	1.4-2.0L	23	118	0.11	
	>2.0L	2	15	0.05	
NMVOC	<1.4L	986	6	1	2,717
	1.4-2.0L	1,470	139	7	
	>2.0L	76	28	4	
VOC	<1.4L	1,123	6	1	3,058
	1.4-2.0L	1,649	150	7	
	>2.0L	89	29	4	

It can be observed that passenger cars alone contribute to about 6.1 Mt of CO_2 and 13.8 kt of NOx which has a severe impact on human health, especially in urban areas.

2.3.2. Emission levels in 2020, 2025, 2030, 2040, 2050 from PC fleet with BaU situation

This section presents time series results for the years 2020, 2025, 2030, 2040 and 2050 under BaU situation. The changes in emission levels of all the major air pollutants in the future years with respect to 2015 have been presented in Table 8. The CO_2 emission from electricity generation was taken as 582 gCO_2/kWh and electricity requirement per kilometre was taken as 0.15 kWh (SEAI, 2017). Thus, WTT emissions for BEVs is 87.30g/km. Taking into account the combined measures of increasing the share of renewable generation and improvements in the overall efficiency of the electricity supply, if it is assumed that the carbon intensity of the electricity supply will be 393 g CO_2/kW h in 2020. In this case, the

WTT emissions will be 58.95g/km. WTT emissions for BEVs for both the cases were calculated and the differences in CO_2 emission levels have been reported (table 8).

Table 8: Emission changes in future year with business as usual scenario

Pollutant	2015 emissions (tonnes)	Percentage change from 2015				
		BaU_2020	BaU_2025	BaU_2030	BaU_2040	BaU_2050
TTW CO_2	6,095,743	22	28	39	28	-39
WTW CO_2		22	28	39	41	13
WTW CO_2 (with renewable electricity)		22	28	39	37	-4
CO	35,558	-49	-65	-63	-67	-84
NO	8,858	28	52	65	54	-27
NO_2	4,908	53	44	35	23	-42
$PM_{2.5}$	772.1	4	-19	-22	-28	-66
PM_{10}	1,039	10	-5	-4	-11	-58
N_2O	182.18	28	36	41	30	-38
NMVOC	2,717	-50	-66	-65	-68	-84
VOC	3,058	-49	-64	-63	-66	-84

It can be observed from the results that in 2020, CO_2 emissions from private car fleet is expected to increase by 22% under BaU situation, whereas, it is expected to increase by 39% in 2030. Even with the renewable electricity production, emission levels are not expected to decrease due to increase in car ownership and no significant increase in electric vehicles. Thus, three hypothetical scenarios are designed to examine the difference in emission levels if the EV purchase trend does not follow Systra's prediction and there is an increase in electric vehicle uptake.

2.3.3. Emission levels in 2020 and 2030 from PC fleet with alternative scenarios

Three alternative scenarios were designed, with low, medium and high market penetration of EVs, which assumes 10%, 15%, 25% new EV registrations in 2025 respectively and 50% new EV deployment in 2030. Then the emission levels were calculated in 2030 under these three scenarios and percentage differences from the baseline were calculated. Emission levels with the current target which is to have 10,000 EVs in the car fleet by 2020 were also calculated. Table 9 shows the potential emission reductions from increased EV uptake, compared to the BaU emissions in 2020 and 2030.

Table 9: Emission reductions in future year with incentivized optimistic scenario

Pollutant	2015	Percentage change from 2015			
		2020_10000 EVs	2030_low	2030_medium	2030_high
TTW CO_2	6,095,743	21	27	24	19
WTW CO_2		33	32	29	22
WTW CO_2 (with renewable electricity)		31	29	26	22
CO	35,558	-50	-72	-76	-81
NO	8,858	28	60	63	61
NO_2	4,908	53	31	35	35
$PM_{2.5}$	772.1	4	-28	-29	-32
PM_{10}	1,039	10	-12	-13	-17
N_2O	182.18	28	36	38	37
NMVOC	2,717	-50	-74	-78	-83
VOC	3,058	-49	-72	-77	-82

It can be observed from both the tables (Table 8 and Table 9) that with the BaU, the CO_2 emission levels are expected to increase by about 39% in 2030 relative to 2015 but with the high market penetration, the increase in emission levels can be brought down by 20%. However, it is expected to increase by 19% compared to 2015 CO_2 levels. This also indicates that it is important for people to use sustainable mode of transport and public transport so that car ownership levels reduce and help Ireland to move towards its emissions goals. It can be noticed that due to technological improvements of ICEV engines (i.e. more euro 6 in the fleet) other pollutant levels have reduced, however, there is no reduction in NO and NO_2 because of the increase in a number of diesel cars in the overall fleet.

Chapter 3: WP4.2- Examining alternative fuel options and potential emission reductions from changes in public transport bus fleet in Ireland

3.1. Introduction

Road transport constitutes a major source of air pollution. This has a huge impact on human health, especially in urban areas where the population and vehicle densities are high. Road transport contributed to 18.5% greenhouse gas emissions in 2015 (EPA, 2017). The greenhouse gas emissions from the transport sector have increased by 130.3% and from road transport alone by 136.7% compared to 1990 emission levels (EPA, 2017). Ireland's target is to draw 10% of all transport energy from renewable sources by 2020. Ireland has an overall target to reduce the GHG by 20% and 30% by 2020 and 2030 respectively relative to 2005 levels. Alternative fuel options such as LPG, CNG, bio-CNG are available for buses and they have significant potential in reducing emissions. Public transport bus fleet allows the introduction of alternative fuel options and reduction of emissions on a large scale.

The most effective measure to reduce emission levels is fleet renewal with potential to reduce emissions on an average by 16.04% for all major pollutants, CO, CO_2, NOx, SO_2, $PM_{2.5}$, PM_{10}, CH_4 (Lumbreras et al., 2008). Several researchers have studied the potential of alternative fuels such as natural gas, fuel cell in reducing emission levels (Cohen, 2005; Karlstrom, 2005, Goncalves et al., 2009). Bio-CNG, electric buses are successfully being used by other European countries. Since 2002, there have been 9000 tonnes of CO_2 reduction per year from buses after implementing biogas use produced from organic waste in Sweden (IEA, 2013). It has been estimated that, in 2020, 18% of the total EU buses will be CNG, LPG powered and 30% will be a hybrid, electric and fuel cell powered (Mahmoud et al., 2016). CNG has 113% fuel cost savings over gasoline and 57% over diesel buses (Khan et al., 2015). Biomethane is one of the most indigenous nonresidue European transport biofuels and has potential to reduce emissions by 75% (Korres, 2010). Ryan and Caulfield (2010) examined optimal fuel type for urban bus operations in Dublin and concluded that only renewing the fleet with better technology will not be enough measure to reduce the emission levels significantly, therefore, incorporation of alternative fuel options is necessary. Biomethane is renewable and offers a reduction of around 80% CO_2 compared to diesel if produced from municipal waste (Baldwin, 2008). Electric buses have zero TTW emissions but the WTT emissions need to be considered. If the electricity is produced from renewable sources then the WTT emission for battery electric buses is as low as 20 gCO_2eq/km (Mahmoud et al., 2016).

In this study, alternative fuel and technology options that are currently available for bus fleet and their potential in reducing greenhouse gas and exhaust air pollutants are examined. This task has been achieved by designing hypothetical alternative scenarios and calculating emission levels corresponding to each designed scenario. The buses that are currently in use are of Euro 3, 4 and 5 technology classes which have different emission standards. The scenarios are designed by considering replacement of the present bus fleet with different percentages of available technology options (e.g. euro 6, EEV) and fuel alternatives such as CNG, bio-CNG and battery electric. The emission levels of all the major air pollutants, namely, CO, CO_2, NO_2 (Nitrogen dioxide), NO (Nitric oxide), $PM_{2.5}$, PM_{10}, VOC (Volatile organic compound), N_2O (Nitrous oxide), NMVOC (Non-methane volatile organic compound) emitted by the current public transport bus fleet as well as for the alternative scenarios were estimated using COPERT 5. COPERT is developed to calculate emissions from road transport in European countries (EMISIA, 2014). Researchers have used COPERT to calculate emissions from buses (Ryan and Caulfield, 2010; Alam et al., 2015) in Ireland.

The findings of this study will report the possible emissions savings from the alternative fuel and technology uptake which will reflect their potential in reducing emissions from public transport bus sector. This study considers Dublin bus and bus Éireann which are the main public service bus operators in Ireland with total 1,441 buses in the current fleet (NTA, 2016). The emission levels from CNG, Bio-CNG, electric buses were modelled and the emission savings were compared to the conventional diesel fuelled buses. The final energy consumptions in these scenarios have been reported. With urban public service buses being replaced by electric buses can reduce the CO_2 emissions by 94% followed by bio-CNG which offers 57% savings in emission levels.

The next section describes the methodology, followed by results, discussion, and conclusion of this research.

3.2. Methodology and data

This section presents the methodology followed to calculate the emission levels from public transport bus fleet and possible reductions with the use of alternative fuel options and technology, also, the resulting damage costs and feed stock required for bio-CNG. This study considers the entire Dublin bus and bus Éireann fleet. The potential of public transport bus fleet in reducing emissions has been assessed by designing four alternative scenarios in addition to the base scenario which uses diesel and older engine technology classes for the entire bus fleet. The emission levels of CO_2, CO, NOx, $PM_{2.5,}$ PM_{10}, N_2O, VOC, NMVOC were calculated in tonnes using COPERT which follows top down approach. Emission calculation using COPERT requires detailed input data (Dey et al., 2017) in terms of fuel consumption, trip information (trip length, trip duration), activity (speed, mileage and mileage share), fleet configuration (number of buses of each fuel type and technology class) and environmental information (monthly average relative humidity and monthly average minimum and maximum temperature). COPERT can calculate emissions from diesel, biodiesel and CNG buses for the all euro technology classes. Table 10 presents a summary of the five scenarios that were examined in this study. The scenarios are described as follows,

- Scenario 1 (S1): In this scenario emissions were calculated for the base year fleet. 2015 was taken as the base year. Public transport bus fleet in Ireland is diesel powered and of older euro technology classes which have higher emission factors. Dublin bus and bus Éireann being the dominant public service bus operators in Ireland have been considered in this study. The fleet data were obtained from Dublin Bus (2016) and National Transport Authority (NTA, 2016). The present fleet composition corresponding to euro class has been shown in Figure 10. For Dublin bus, the mileage share was taken as 100%, whereas, the mileage shares were taken as 15% rural and 85% urban (NTA, 2016).

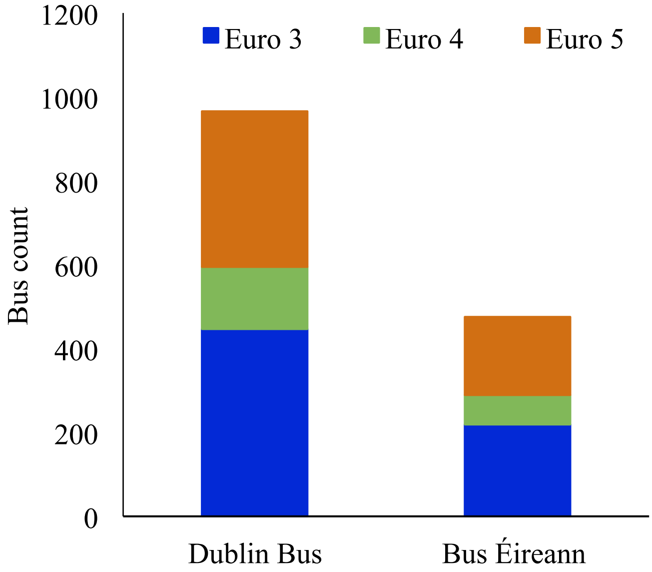

Figure 10: Public transport bus fleet composition in 2015 as per technology class

COPERT 5 provides the scope of specifying the peak and off-peak driving percentages and corresponding speeds separately. The urban share was further split into 50% for peak and 50% for off-peak hours with average peak hour speed taken as 13 kmph and average off-peak hour speed as 26.5 kmph (CSO, 2014; Ryan and Caulfield, 2010; Alam et al., 2015; RSA, 2015). For Bus Éireann, average rural speed was assumed to be 40 kmph. Annual average mileages were taken as 57288 km and 71074 km for Dublin bus and bus Éireann respectively (NTA, 2016).

- Scenario 2 (S2): This scenario presents the emission levels considering if all the buses are replaced by Euro 6 diesel buses. Euro 6 has improved technology, especially in terms of lower emission factors for NOx, PM, and VOCs. Emissions in this scenario were calculated using COPERT 5 with the entire fleet to be euro 6, whereas, the rest of the input parameters were taken as described in scenario 1.
- Scenario 3 (S3): This scenario presents the emission levels resulted from the public transport bus fleet if all the buses are replaced by EEV/Euro 6 CNG. It was found that EEV and euro 6 have the same emission factors. This scenario tests the emissions reduction by replacing both fuel and technology. Emissions levels in this scenario were also calculated using COPERT 5 with other input parameters than fuel and technology considered to be same as scenario 1.
- Scenario 4 (S4): In this scenario emissions were calculated assuming if all public transport buses are replaced by Bio-CNG euro 6/EEV buses. Therefore, this scenario also assumes replacement of both fuel and engine as considered in S3. Grass silage was chosen to be the optimum feedstock to produce bio-CNG in Ireland and carbon neutrality of bio-CNG was taken as 60% (Ryan and Caulfield, 2010).
- Scenario 5 (S5): This scenario evaluates the possible emission savings by replacing urban bus fleets by electric buses. In this scenario, the WTT emissions i.e. the emission due to

electricity generation was calculated for two cases. The first case assumes the energy source to be electricity generated from renewable sources which has WTW emissions of 20 gCO_2eq/km and the second case assumes that the required electricity comes from EU-mix with GHG emission rate 720 gCO_2eq/km (Mahmoud, 2016).

Table 10: Scenario descriptions for PT bus fleet

Scenario	Technology class	Fuel type	Number of Buses
1	Euro 3	Diesel	666
	Euro 4	Diesel	218
	Euro 5	Diesel	557
2	Euro 6	Diesel	1,441
3	Euro 6/EEV	CNG	1,441
4	Euro 6/EEV	Bio-CNG	1,441
5	Euro 6	Diesel	72
	Electric		1,369

3.3. Results and discussion

This section presents the emission levels resulted from the existing public transport bus fleet in Ireland and potential emissions savings from changing to alternative fuel and technology. Table 11 presents the emissions from the status quo and percentage change in the designed scenarios with respect to the base scenario.

Table 11: Emissions (tonnes) from the designed scenarios and their differences over base scenario

Pollutants	Emissions (t)	Difference with base (%) in each scenario			
	S1	S2	S3	S4	S5
CO	244.86	-88	-61	-61	-97
CO_2	99,185.35	-5	8	-57	-94* (-35**)
NO	786.31	-94	-53	-53	-97
NO_2	114.26	-96	-87	-87	-97
N_2O	1.47	137	-100	-100	-100
VOC	29.71	-85	216	216	-97
NMVOC	25.46	-84	-42	-42	-97
$PM_{2.5}$	16.07	-77	-74	-74	-99
PM_{10}	19.44	-64	-61	-61	-98

*Percentage decrease in CO_2 levels when renewable source of electricity is used; ** Percentage decrease in CO_2 emissions when electricity from EU-mix is used as source of electricity

Table 12 presents the energy consumption in the scenarios under this study. Electricity requirements for buses in scenario 5 were calculated taking the WTW energy consumptions as 18.66 MJ/km and 10.33 MJ/km for the energy sources being electricity from EU-mix and renewables respectively.

Table 12: Energy consumption

Scenarios	S1	S2	S3	S4	S5	
Fuel consumption (TJ)	1,875	1,809	2,602	3,411	75	
Electricity consumption (TJ)	-	-	-	-	EU-mix	Renewable
					1,568	868

It can be seen that CNG buses have highest energy requirement, whereas, a substantial reduction in energy consumption is possible in S5 for renewable based electricity. Scenario 4, which considers the alternative fuel option as bio-CNG and technology class as euro 6/EEV for public transport bus services, is a very suitable option for Ireland by utilizing the agricultural grass silage as feedstock in producing biomethane (Smyth et al., 2009).

The cost of health and other (biodiversity, crop, buildings) damages caused by the pollutants discharged by the bus fleet were calculated by multiplying the quantity of pollutants (tonne) with unit damage cost per tonnes of the pollutant as obtained from Handbook on External Costs of Transport (2014) and DTTaS (2016). Damage costs per tonne of pollutant were taken as €13.22, €5,851, €19,143, €1,438, €1,398, €200,239, €48,779, €16,985 for CO_2, NOx, PM_{10}, VOC, NMVOC, $PM_{2.5}$ (Urban), $PM_{2.5}$ (Suburban), $PM_{2.5}$ (Rural) respectively.

The damage costs caused by the emissions (Table 11) have been shown in Table 13 along with the possible savings if alternative fuel and technology options are implemented.

Table 13: Damage costs from the pollutants in the base scenario and possible savings in alternative scenarios

Pollutants	Cost of emissions (€)	Potential cost savings relative to damage costs in S1 (€)			
	S1	S2	S3	S4	S5
CO_2	1,311,230	63,688	+105,172	744,669.2	1,259,118
NOx	5,269,213	4,968,777	3,017,719	3,017,719	5,108,574
VOC	42,719.81	36,101	+92,288.5	+92,288.5	41,479.65
NMVOC	35,593	29,789	15,084	15,084	34,388
$PM_{2.5}$	3,055,587	2,354,735	2,272,714	2,272,714	3,020,654
PM_{10}	372,206.2	236,862	228,596	228,595.8	365,193.5
Total (Mil€)	10.09	7.69	5.34	6.19	9.83

It can be observed that the pollutants from the public transport bus fleet alone have caused damage worth 10.09 million euro in 2015. Scenario 5 offers highest annual saving in damage costs and scenario 3 offers the lowest possible savings.

Chapter 4: WP4.3- Emission projections and compliance with EU's 2030 targets

4.1. Introduction

There is no separate target for road transport sector in Ireland, therefore, this study assumes the target for road transport as same as the overall which is to reduce emission levels in 2030 by 30%, relative to 2005. The emissions in 2005 were obtained from EPA (2017), and 30% of that was calculated to determine the target in 2030. Then the emissions were back casted to suggest a fleet composition with percentages of BEV, HEV, PHEV and ICEV shares that are required to meet this target. Two separate approaches were taken,

- Approach 1: Car and bus fleet composition to meet the target combinedly with the estimated car ownership and buses in 2030.
- Approach 2: Car and bus fleet composition to meet the target separately.

In the first approach, the proposed car and bus fleet compositions will jointly reduce 30% CO_2 emissions. While in the second approach, required car and bus fleet composition to reduce CO_2 emissions individually by 30% were evaluated.

4.2. Emission projections and proposed fleet compositions

4.2.1. Approach 1- Meeting target combinedly

This section presents the PC and PT fleet compositions which together will help to meet the 2030 emission goal. It was found that the desired car fleet to meet the EU 2030 emissions target should be as shown in figure 11.

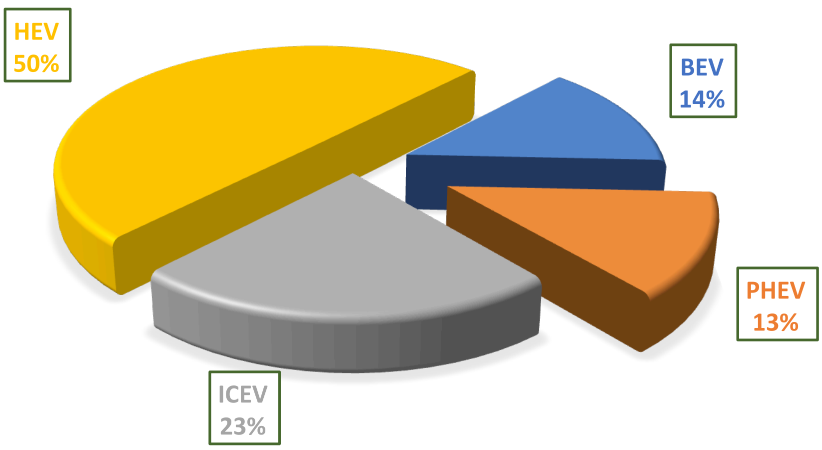

Figure 11: Desired passenger car fleet composition to meet 2030 target

It has been assumed that, in 2030, there will 15% increase in number of public transport buses. Assuming the life of a public service bus as 15 years the fleet composition for 2030 was estimated. Figure 12 shows projected 2030 public transport bus fleet (Dublin Bus and

Bus Éireann) composition with respect to technology class. It was estimated that in order to reduce the combined emissions from PC and PT bus fleets by 30%, urban bus fleet should be replaced by electric buses.

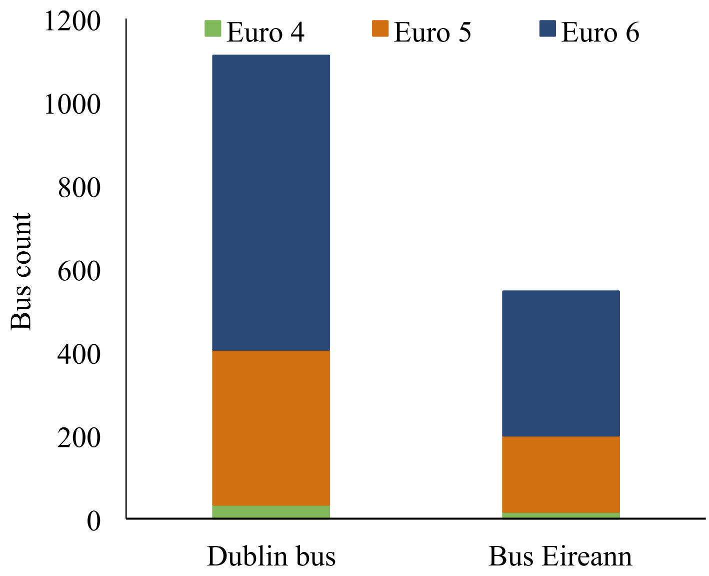

Figure 12: Public transport bus fleet composition in 2030 as per technology class

CO_2 emission levels in 2005, target emission levels in 2030 and potential reductions in GHG emissions from PC and PT bus fleets are presented in Table 14. The passenger car CO_2 emission share was taken as 67.5% of the total road transport emissions share and the same for Dublin bus and bus Éireann fleets was taken as 1% (Alam et al., 2015).

Table 14: Emission levels (tonnes) and potential reductions in 2030 relative to 2005 with the proposed fleet composition

Road Transport Mode	2005	Target year: 2030	
	CO_2 emissions (t)	CO_2 emissions (t)	% decrease relative to 2005 levels
Car	8,474,539	5,982,034	-29
Bus	118,330	7,913	-93
Total	8,592,869	5,989,947	-30

It can be observed that a huge number of electric vehicles are to be deployed to reduce the GHG emission levels by 30% in 2030.

4.2.2. Approach 2- Meeting target separately

This section presents the required PC and PT fleet compositions that will be required to reduce the CO_2 emissions individually from PC and PT sector by 30% in 2030, compared to the CO_2 emission levels in 2005.

Passenger car fleet:

The results presented in the previous section shows that with the increase in car ownership levels, the only way to achieve the emissions goals is a high level of electrification in the PC fleet. This section examines the reduced car ownership level that will result in fulfilling the target and a more practical PC fleet breakdown. To estimate the EV share, this scenario assumes high EV market penetration as estimated using S-curve (see section 2.2). Then the desired CO_2 emission levels were backcasted to determine the desired car ownership and fleet composition. Table 15 shows the estimated fleet composition and car ownership.

Table 15: Desired car ownership and fleet composition to meet 2030 target

Engine size / Fuel type	<1.4L	1.4-2.0L	>2.0L
Petrol	191,312	66,328	3,917
Diesel	61,860	993,535	78,751
Petrol Hybrid	17,653	222,486	93,080
Electric vehicle		351,710	
Total		2,080,632	

The emission levels, as calculated using COPERT 5 based on the fleet composition shown in table 15, are presented in Table 16. The CO_2 emissions in 2005 from PC fleet and target for 2030 are also presented in Table 16 along with the potential reduction in 2030, relative to 2005.

Table 16: Emission levels (tonnes) and reduction in 2030 relative to 2005 with the proposed PC fleet

Pollutants	Emissions in 2005 (t)	Emissions (t) in 2030			Emissions target 2030 (t)	Reduction (%)
		WTT	TTW	WTW		
CO_2	8,474,539	374,005	5,506,600	5,880,605	5,932,177	-30.6
CO		0	37,857	37,857		
NO		0	9,010	9,010		
NO_2		0	4,055	4,055		
$PM_{2.5}$		0	399	399		
PM10		0	670	670		
N_2O		0	164	164		
NMVOC		0	924	924		
VOC		0	1,004	1,004		

Public transport bus fleet:

The required PT bus fleet to and possible emissions reduction have been presented in this section. As mentioned in section 3.2, depending on the source and method of electricity production TTW emissions can vary from 20 gCO2/km to as high as 720 gCO_2/km. Therefore, two cases were designed, case-1 considers determination of PT bus fleet composition if the produced electricity is renewable based (TTW CO_2 is 20 gCO_2/km) and case-2 considers calculation of PT bus fleet breakdown if the source of electricity is EU-mix (TTW CO_2 is 720 gCO_2/km). Table 17 presents the desired fleet composition in 2030 to meet the emissions target.

Table 17: Bus fleet composition (%) to meet 2030 target

Fuel type / Euro class	Case 1			Case 2		
	Diesel	Bio-CNG	Electric (Renewable)	Diesel	Bio-CNG	Electric (EU-mix)
Euro 4	2	-	-	1	-	-
Euro 5	22	-	-	15	-	-
Euro 6	41	25	10	29	30	25
Total	65	25	10	45	30	25

Based on the fleet estimated in case-1 and case-2, emissions were calculated using COPERT 5. Table 18 lists the separate emission levels from diesel, bio-CNG and electric buses for the proposed fleet (Table 17).

Table 18: Emission levels (tonnes) in 2030 with the proposed PT bus fleet

Fuel type / Pollutants	Case-1			Case-2		
	Emission levels (t)					
	Diesel	Bio-CNG	Electric (Renewable)	Diesel	Bio-CNG	Electric (EU-mix)
CO	79.21	27.74	-	54.70	33.22	-
CO_2	70,038	12,343	205	48,454	14,782	18,477
NO	206.62	106.40	-	142.69	127.42	-
NO2	23.60	4.43	-	16.30	5.31	-
N2O	2.38	0.00	-	1.64	0.00	-
VOC	3.90	27.04	-	2.70	32.38	-
NMVOC	3.57	4.23	-	2.47	5.06	-
PM2.5	4.19	1.19	-	2.90	1.42	-
PM10	6.72	2.16	-	4.64	2.59	-

Table 19 presents the CO_2 emission levels from PT bus fleet in Ireland in 2005, CO_2 emission levels from the proposed fleets and the possible reductions under both the cases.

Table 19: Emissions reduction in 2030 relative to 2005 from PT bus fleet

CO_2 emissions (t) in 2005	CO_2 emissions (t) in 2030		Decrease (%) in 2030 relative to 2005 levels	
	Case-1	Case-2	Case-1	Case-2
118,330	82,587	30.21	81,713	30.94

Chapter 5: Conclusion

This research has examined, through a comprehensive analysis, the potential emissions reduction from changes in private car fleet and public transport bus fleet in Ireland. In 2015, the CO_2 emission levels from PC fleet alone was 6.1 Mt of CO_2, whereas, NOx and $PM_{2.5}$ levels were 13.8 kt and 772 tonnes respectively. NOx and $PM_{2.5}$ have been linked to series of health effects such as stroke, lung cancer, chronic and acute respiratory diseases, including asthma (WHO, 2016). NOx, which is comprised of NO_2 and NO, is a key air pollutant which contributes to atmospheric levels of NOx, fine particulate matter, and ground-level ozone (USEPA, 2016) which is currently one of the air pollutants of most concern in Europe (WHO, 2016). Diesel cars is one of the major sources of these deadly pollutants. Ireland has the highest share (72% of the total new registration in 2015) of newly registered diesel cars in Europe. As calculated in the previous section, in 2020, with 10,000 EVs in the fleet CO_2 emissions are estimated to increase by 31-33% depending on the source and efficiency of electricity production and supply. Whereas, resulting NO_2 emissions are expected to increase by 53%. In 2030 with BaU and with high EV deployment, the CO_2 emission levels are expected to increase by 39% and 19% respectively, compared to 2015 levels. Thus, looking at the solution, substantial electrification of the car fleet is imperative to satisfy Ireland's sustainable goals. Despite the fiscal incentives provided by the Irish government towards EV purchase, the uptake is not significant. Therefore, it is necessary to look into the existing policies and consider needful revision and also, implementation of new policies and measures.

The potential of alternative fuel options available for public transport bus fleet in reducing emissions were evaluated. The results showed that all the scenarios offer a significant reduction in emission levels. Euro 6, being the clearer technology shows a considerable reduction in CO, PM, NO, NO_2, VOCs emissions but does not significantly reduce the CO_2 emissions. This indicates that alternative fuels must be incorporated in order to move towards meeting Ireland's GHG target for 2020 and 2030. From this view, CNG is also not a suitable option as the results show that use of CNG as bus fuel will increase the CO_2 emissions by 8%. But when the emission levels resulting from the use of Bio-CNG are compared, 57% CO_2 emissions reduction was observed with CO, NO_2, $PM_{2.5}$ reductions being 61%, 87%, and 74% respectively. Looking at the availability of grass land in Ireland, Bio-CNG offers a convenient and feasible option as an alternative fuel for public transport buses. Scenario 5, which examined the emission reductions from only replacing the urban bus fleets by battery electric buses, shows the highest potential in reducing both GHG and other harmful pollutants. Emission levels of all the pollutants can possibly be reduced by more than 90%. With the electricity source being renewable energy based which has high energy efficiency, the energy demand can be reduced by 49% relative to base scenario.

It can be concluded that electric buses offer the most attractive option. The public transport bus services studied in this study mainly operates in cities like Dublin, Cork, and Galway where the population density is higher. Renewal of the fleet will not only reduce the emission levels but also will improve public health. Thus, replacing the urban public service bus fleets with electric buses is highly recommended, given the electricity is produced from renewable energy sources.

The PC and PT bus fleet compositions as proposed in chapter 4, indicate that reduction in estimated future car ownership is essential to feasibly help Ireland to move towards its 2030 GHG emissions target. Also, increased use of renewable energy and improved efficiency in electricity production play a major role in reducing emissions.

Chapter 6: Next task

Analysing policies are very important in emissions mitigation. As mentioned earlier, Irish government provides grants and other financial incentives to increase the EV uptake rate. But the purchase pattern is not as desired. Norway is known to be the electric vehicle capital of Europe. In a survey conducted in Norway to find the reason for the people to prefer EVs over ICEVs, 54% have reported the reason as cheapness followed by 25% as EVs are environmentally smart. The incentives (Aasness and Odeck, 2015) which resulted in rapid increase in EV uptake in Norway are,

- Temporary Exemption from on-off registration tax
- Exemption from annual vehicle tax
- Exemption from road tolls
- Temporary use of transit lanes
- Exemption from VAT
- Further reduction in company car tax
- Exemption from parking fees on municipal owned parking facilities
- Reduced company car tax
- Permanent use of transit lanes
- Exemption from paying car ferry fees

Thus, the next task will examine the policies taken up by other European countries to encourage the purchase of the zero emission vehicles and divert from ICEVs. Different policies will be analysed and their applicability in Ireland will be evaluated. Tax scenarios that will shift the attention from ICEVs will also be examined. Damage costs caused by the exhaust pollutants on health, crops, biodiversity, material, and buildings will be evaluated. The cost of fiscal incentives, revenues from tax changes and damage costs will be compared to evaluate the financial benefits. Cost of car ownership will also be reported.

In addition to this, land area required to fulfil the biogas demand of public transport bus fleet will be analysed. A cost analysis, which includes manufacturing, maintenance, running and infrastructure costs, will be performed for electric buses. Damage costs from the pollutants discharged by the ICE buses and alternative fuel powered buses will also be reported and compared with the cost analysis results to report the financially favourable alternative option.

References

1. A. H. Kakaee and A. Paykani. Research and development of natural-gas fueled engines in Iran. Renewable and Sustainable Energy Reviews, Vol. 26, pp. 805–821, 2013. http://dx.doi.org/10.1016/j.rser.2013.05.048
2. A. Manjunath and G. Gross. Towards a meaningful metric for the quantification of GHG emissions of electric vehicles (EVs). Energy Policy, Vol. 102, pp. 423-429, 2017. http://dx.doi.org/10.1016/j.enpol.2016.12.00
3. A. Stewart, A. Hope-Morley, P. Mock, and U. Tietge. Quantifying the impact of real-world driving on total CO 2 emissions from UK cars and vans. Final report for The Committee on Climate Change prepared by The International Council on Clean Transportation, 2015. Accessed: 29.05.2017. Available at: https://www.theccc.org.uk/wp-content/uploads/2015/09/Impact-of-real-world-driving-emissions-for-UK-cars-and-vans.pdf
4. ACEA (European Automobile Manufacturers association). Differences Between Diesel and Petrol. 2016. http://www.acea.be/news/article/differences-between-diesel-and-petrol
   Available at: http://www.cso.ie/multiquicktables/quickTables.aspx?id=tha10_3
5. B. M. Smyth, J. D. Murphy and C. M. O'Brien. What is the energy balance of grass biomethane in Ireland and other temperate northern European climates? Renewable and Sustainable Energy Reviews, Vol. 13, pp. 2349–2360, 2009. doi:10.1016/j.rser.2009.04.003
6. B. Strecker, A. Hausmann and C. Depcik. Well to wheels energy and emissions analysis of a recycled 1974 VW Super Beetle converted into a plug-in series hybrid electric vehicle. J. Clean. Prod., Vol. 68, 93-103, 2014. http://dx.doi.org/10.1016/j.jclepro.2013.04.030.
7. C. Lorf, R. F. Martínez-Botas, D. A. Howey, L. Lytton and B. Cussons. (2013). "Comparative analysis of the energy consumption and CO2 emissions of 40 electric, plug-in hybrid electric, hybrid electric and internal combustion engine vehicles". Transportation Research Part D, Vol. 23, pp. 12–19, 2013. http://dx.doi.org/10.1016/j.trd.2013.03.004.
8. CSO (Central Statistics Office). Average kilometres travelled by road traffic. 2014. Accessed: 27.02.2017. Available at: http://www.cso.ie/px/pxeirestat/statire/SelectVarVal/Define.asp?Maintable=THA10&PLanguage=0
9. CSO (Central Statistics Office). National Travel Survey: key findings, 2014. Accessed: 05.06.2017. Available at: http://www.cso.ie/en/releasesandpublications/ep/p-nts/nationaltravelsurvey2014/keyfindings/
10. CSO (Central Statistics Office). Transport Omnibus 2015: Public transport. 2015. Accessed: 05.06.2017. Available at: http://www.cso.ie/en/releasesandpublications/ep/p-tranom/to2015/pt/

11. D. Dineen, M. Howley and M. Holland. Energy in Transport. SEAI (Sustainable energy authority of Ireland). 2014.
12. DTTAS (Department of Transport, Tourism and Sport). Appraisal. 2016.
13. DTTAS (Department of Transport, Tourism and Sport). Irish Bulletin of Vehicle and driver Statistics DTTAS, February 16, 2016. Available at: http://www.dttas.ie/roads/publications/english/irish-bulletin-vehicle-and-driver-statistics-2015
14. Dublin Bus. Dublin Bus Fleet. 2016. Accessed: 23.11.2016. Available at: https://www.dublinbus.ie/About-Us/Dublin-Bus-Fleet/
15. E. A. Nanaki and C. J. Koroneos. Climate change mitigation and deployment of electric vehicles in urban areas. Renewable Energy, Vol. 99, pp. 1153- 1160, 2016. http://dx.doi.org/10.1016/j.renene.2016.08.006
16. E. Sadeghinezhad, S. N. Kazi, A. Badarudin, C. S. Oon, M. N. M. Zubir and M. Mehrali. A comprehensive review of bio-diesel as alternative fuel for compression ignition engines. Renewable and Sustainable Energy Reviews, Vol. 28, pp. 410–424, 2013. http://dx.doi.org/10.1016/j.rser.2013.08.003
17. E. Valeri and R. Danielis. Simulating the market penetration of cars with alternative fuelpowertrain technologies in Italy. Transport Policy, Vol. 37, pp. 44–56, 2015. http://dx.doi.org/10.1016/j.tranpol.2014.10.003
18. EMISIA. The popular, straightforward and simple to use emissions calculator. EMISIA: mission for environment, 2014. Accessed: 10.03.2017. Available at: http://emisia.com/products/copert
19. EMISIA: Mission for Environment. COPERT Version 5 download. 2017. http://emisia.com/products/copert/copert-5
20. EPA (Environmental Protection Agency). Ireland's Greenhouse Gas Emission Projections 2016-2035. April 2017.
21. EPA (Environmental Protection Agency). Ireland's Greenhouse Gas Emission Projections: 2016-2035. 2017. http://www.epa.ie/pubs/reports/air/airemissions/ghgprojections/
22. EPA (Environmental Protection Agency). Ireland's Greenhouse Gas Emissions in 2015, 2017. http://www.epa.ie/pubs/reports/air/airemissions/ghgemissions/
23. European Commission. Impact assessment on a new approach for the cleaner and more energy efficient vehicles directive proposal. Directive General Energy and Transport, 2007.
24. European Commission. Ireland's EU 2030 emissions targets published. Accessed 28.07.2017. Available at: http://ec.europa.eu/ireland/news/ireland-s-eu-2030-emissions-targets-published_en
25. F. Badin, F. Le Berr, H. Briki, J.-C. Dabadie, M. Petit, S. Magand and E. Condemine. Evaluation of EVs energy consumption influencing factors, driving conditions, auxiliaries use, driver's aggressiveness. In: Electr. Veh. Symp. Exhib. (EVS27), 2013 World. http://dx.doi.org/10.1109/EVS.2013.6914723.
26. F. Ryan and B. Caulfield. Examining the benefits of using bio-CNG in urban bus operations. Transportation Research Part D, Vol. 15, pp. 362–365, 2010. doi:10.1016/j.trd.2010.04.002

27. G. Vreugdenhil. Electric vehicles. A small step towards improving air quality and mortality? European Journal of Internal Medicine, Vol. 37, pp. 9-10, 2017. http://dx.doi.org/10.1016/j.ejim.2016.10.015
28. H. Engerer and M Horn. Natural gas vehicles: An option for Europe". Energy Policy, Vol. 38, pp. 1017-1029, 2010.
29. H. Helms, M. Pehnt, U. Lambrecht and A. Liebich. Electric vehicle and plug-in hybrid energy efficiency and life cycle emissions. In: Transport and Air Pollution 18th International Symposium, pp. 113-124, 2010.
30. IEA (International Energy Agency). 100% Biogas for Urban Transport in Linköping, Sweden. IEA Bioenergy Task 37. 2013. Accessed: 16.04.2017. Available at: http://www.seai.ie/Renewables/Bioenergy/100_biogas_for_urban_transport_in_Linkoeping_IEA_Bio_Task_37.pdf
31. J. Baldwin. The renewable CNG option for carbon neutral transport. cng services ltd., 2008. Accessed: 15.04.2017. Available at: http://awbriefing.com/presentations/20080129_john_Baldwin.pdf.
32. J. Brady and M. O'Mahony. Travel to work in Dublin. The potential impacts of electric vehicles on climate change and urban air quality. Transportation Research Part D, Vol. 16, pp. 188–193, 2011. doi:10.1016/j.trd.2010.09.006
33. J. D. Murphy and N. M. Power. An argument for using biomethane generated from grass as a biofuel in Ireland. biomass and bioenergy, Vol. 33, pp. 504 – 512, 2009. doi:10.1016/j.biombioe.2008.08.018
34. J. Davies and K. S. Kurani. Moving from assumption to observation: Implications for energy and emissions impacts of plug-in hybrid electric vehicles. Energy Policy, Vol. 62. pp. 550-560, 2013. http://dx.doi.org/10.1016/j.enpol.2013.06.126
35. J. Hao, J. Hu and L. Fu. Controlling vehicular emissions in Beijing during the last decade. Transportation Research Part A, Vol. 40, pp. 639–651, 2006. doi:10.1016/j.tra.2005.11.005
36. J. Lumbreras, M. Valdés, R. Borge, and M. E. Rodríguez. "Assessment of vehicle emissions projections in Madrid (Spain) from 2004 to 2012 considering several control strategies." Transportation Research Part A, Vol. 42, pp. 646–658, 2008.
37. J. Scheer, M. Clancy and F. Gaffney. Ireland's Energy Target: Progress, Ambition & Impacts. Sustainable Energy Authority of Ireland, 2016.
38. J. T. Cohen. Diesel vs. compressed natural gas for school buses: a cost effectiveness evaluation of alternative fuels. Energy Policy, Vol. 33, pp. 1709–1722, 2005. http://dx.doi.org/10.1016/j.enpol.2004.02.010
39. L. C. Casals, E. Martinez-Laserna, B. A. García, N. Nieto. Sustainability analysis of the electric vehicle use in Europe for CO_2 emissions reduction. Journal of Cleaner Production, Vol. 127. pp. 425-437, 2016 http://dx.doi.org/10.1016/j.jclepro.2016.03.120
40. L. De Vroey, R. Jahn, M. El Baghdadi, J. Van Mierlo. Plug-to-wheel energy balance-results of a two years experience behind the wheel of electric vehicles. In: Electr. Veh. Symp. Exhib. (EVS27), 2013. World. http://dx.doi.org/10.1109/EVS.2013.6914803.

41. L. Ntziachristos, G. Papadimitriou, N. Ligterink and S. Hausberger. Implications of diesel emissions control failures to emission factors and road transport NOx evolution. Atmospheric Environment, Vol. 141, pp. 542-551, 2016. doi:10.1016/j.atmosenv.2016.07.036.
42. M. A. Aasness and J. Odeck. The increase of electric vehicle usage in Norway- incentives and adverse effects. European Transport Research Review, Vol. 7: 34, 2015.
43. M. Gonçalves, P. Jiménez-Guerrero and J. M. Baldasano. High resolution modeling of the effects of alternative fuels use on urban air quality: Introduction of natural gas vehicles in Barcelona and Madrid Greater Areas (Spain). Science of the Total Environment, Vol. 407, pp. 776 – 790, 2009.
44. M. Howley, M. Holland and D. Dineen. Energy in Ireland: Key Statistics 2015. Sustainable Energy Authority of Ireland (SEAI). 2015.
45. M. I. Khan, T. Yasmin and A. Shakoor. Technical overview of compressed natural gas (CNG) as a transportation fuel. Renewable and Sustainable Energy Reviews, Vol. 51, pp. 785–797, 2015. http://dx.doi.org/10.1016/j.rser.2015.06.053.
46. M. I. Khan, T. Yasmin and A. Shakoor. Technical overview of compressed natural gas (CNG) as a transportation fuel. Renewable and Sustainable Energy Reviews, Vol. 51, pp. 785–797, 2015. http://dx.doi.org/10.1016/j.rser.2015.06.053.
47. M. Karlström. Local environmental benefits of fuel cell buses – a case study. Journal of Cleaner Production, Vol. 13, pp. 679 – 685, 2005.
48. M. Mahmoud, R. Garnett, M. Ferguson and P. Kanaroglou. Electric buses: A review of alternative powertrains. Renewable and Sustainable Energy Reviews, Vol. 62, pp. 673–684, 2016. http://dx.doi.org/10.1016/j.rser.2016.05.019
49. M. Ralston and N. Nigro. Plug-in electric vehicles: literature review. Center for Climate and Energy solutions, American Association of state highway and transportation officials (AASHTO): The voice of Transportation, 2011.
50. M. S. Alam, P. Duffy, B. Hyde and A. McNabola. Estimation and back extrapolation of CO_2 emissions from the road transport sector: emissions in Ireland, 1990 to 2013. Air Pollution XXII, Vol. 198, pp. 63-75, 2015. doi:10.2495/AIR150061
51. MET eireann. Irish Weather reports for the year 2015. 2016. Accessed: 25.11.2016. Available at: http://www.met.ie/climate/irish-climate-monthly-summary.asp .
52. MET eireann. Monthly Data. 2016. Accessed: 25.11.2016. Available at: http://www.met.ie/climate/monthly-data.asp
53. N. E. Korres, Singh, A., Nizami, A., S., and Murphy, J., D. Is grass biomethane a sustainable transport biofuel? Society of Chemical Industry and John Wiley & Sons, Ltd, 2010.
54. N. M. Power and J. D. Murphy. Which is the preferable transport fuel on a greenhouse gas basis; biomethane or ethanol?. Biomass and bioenergy, Vol. 33 , pp. 1403 – 1412, 2009. doi:10.1016/j.biombioe.2009.06.004
55. NTA (National Transport Authority). Bus Statistics for Ireland. Statistical Bulletin Number:03/2016, 2016.
56. NTA (National Transport Authority). National Transport Model, Volume 3, Demographic and Economic Forecasting Report, 2014.

57. P. Weldon, Patrick Morrissey, John Brady, Margaret O'Mahony. (2016). An investigation into usage patterns of electric vehicles in Ireland. Transportation Research Part D. v. 43. pp. 207-225. http://dx.doi.org/10.1016/j.trd.2015.12.013
58. P. Wolfram and N. Lutsey. Electric vehicles: Literature review of technology costs and carbon emissions. International Council on Clean Transportation. 2016.
59. R. F. Britto Júnior and C. A. Martins. Emission analysis of a Diesel Engine Operating in Diesel–Ethanol Dual-Fuel mode. Fuel, Vol. 148, pp. 191–201, 2015. http://dx.doi.org/10.1016/j.fuel.2015.01.008
60. R. Sharma, C. Manzie, M. Bessede, R. H. Crawford and M. J. Brear. Conventional, hybrid and electric vehicles for Australian driving conditions. Part 2: Life cycle CO2-e emissions. Transportation Research Part C. Vol. 28. pp. 63-73, 2013. http://dx.doi.org/10.1016/j.trc.2012.12.011
61. Road Safety Authority (RSA). Free Speed Study: Survey Report 2015. 2015. Accessed: 02.03.2017. Available at: http://www.rsa.ie/en/RSA/Road-Safety/RSA-Statistics/Surveys--Consultations/Speed/
62. RSA (Road Safety Authority). Free Speed Study: Survey Report 2015, 2015.
63. S. Campanari, G. Manzolini, F. G. de la Iglesia. Energy analysis of electric vehicles using batteries or fuel cells through well-to-wheel driving cycle simulations. J. Power Sources, Vol. 186, pp. 464-477, 2009. http://dx.doi.org/10.1016/j.jpowsour.2008.09.115.
64. S. Dey, B. Caulfield and B. Ghosh. The potential health, financial & environmental impacts of *dieselgate* in Ireland. Journal of Transportation Planning and Technology, 2017. (Accepted)
65. S. Nicolay. A simplified LCA for automotive sector - comparison of ICE (diesel and petrol), electric and hybrid vehicles, Vol. 95, 2000.
66. SEAI (Sustainable energy authority of Ireland). Average Fuel Consumption and Distance Travelled for Private Cars by Engine Capacity cc, Type of Fuel, Year and Statistic. 2013. Energy statistics databank. Accessed: 23.02.2017. Available at: http://www.cso.ie/px/pxeirestat/statire/SelectVarVal/Define.asp?Maintable=SEI07&PLanguage=0
67. SEAI (Sustainable Energy Authority of Ireland). Electric vehicle comparison calculator. 2017. Accessed: 15.07.2017. Available at: http://www.seai.ie/Grants/Electric_Vehicle_Grant_Scheme/EV_calculator/
68. SEAI (Sustainable Energy Authority of Ireland). Electric Vehicle Grants Overview. 2017. Accessed: 20.07.2017. Available at: http://www.seai.ie/Grants/Electric_Vehicle_Grant_Scheme/EV_Grants/Electric_Vehicle_Grants_Overview.html
69. SIMI: The Society of the Irish Motor Industry. Motorstats, The official statistics of the Irish Motor Industry, 2016. Accessed: 21.09.2016. Available at: http://www.beepbeep.ie/stats
70. T. R. Hawkins, O. M. Gausen, A.H., Strømman. Environmental impacts of hybrid and electric vehiclesda review. Int. J. Life Cycle Assess, Vol. 17, pp. 997-1014, 2012. http://dx.doi.org/10.1007/s11367-012-0440-9.

71. USEPA (United States Environmental Protection Agency). Frequent Questions about Volkswagen Violations. USEPA. 2016. Accessed September 16 2016. https://www.epa.gov/vw/frequent-questions-about-volkswagen-violations#health
72. W. J. Smith (2010). Plug-in hybrid electric vehicles—A low-carbon solution for Ireland?. Energy Policy. v. 38. pp. 1485-1499. doi:10.1016/j.enpol.2009.11.031
73. W. Ke, S. Zhang, X. He, Y. Wu and J. Hao. Well-to-wheels energy consumption and emissions of electric vehicles: Mid-term implications from real-world features and air pollution control progress. Applied Energy, Vol. 188, pp. 367–377, 2017.
74. X. Huang, Y. Wang, Z. Xing and K. Du. Emission factors of air pollutants from CNG-gasoline bi-fuel vehicles: Part II. CO, HC and NOx. Science of the Total Environment. Vol. 565. pp. 698-705, 2016. http://dx.doi.org/10.1016/j.scitotenv.2016.05.069
75. X. Wu, S. Zhang, Y. Wu, Z. Li , W. Ke, L. Fu and J. Hao "On–road measurement of gaseous emissions and fuel consumption for two hybrid electric vehicles in Macao". Atmospheric Pollution Research. v. 6, pp. 858-866.
76. Y. Wang, Z. Xing, H. Xu and K. Du. Emission factors of air pollutants from CNG-gasoline bi-fuel vehicles: Part I. Black carbon. Science of the Total Environment, Vol. 572, pp. 1161-1165, 2016. http://dx.doi.org/10.1016/j.scitotenv.2016.08.027
77. WHO (World Health Organization). Ambient (outdoor) air quality and health. 2016. http://www.who.int/mediacentre/factsheets/fs313/en/