Estimation and back extrapolation of CO_2 emissions from the road transport sector: emissions in Ireland, 1990 to 2013

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Abstract

The estimation of CO_2 emissions is an important information process in the assessment of climate impacts, mitigation policy development, and assessment of the impacts of previous interventions in various polluting sectors. This investigation comprised the estimation of CO_2 emissions from the road transport sector in Ireland using a previously unavailable level of data disaggregation for vehicle mileage as well as using vehicle class specific data and an improved estimation methodology. Estimates of CO_2 emissions were carried out for the recent years up to 2013 and these were also back extrapolated to 1990. CO_2 emissions were estimated using COPERT software. Historic vehicle fleet data were restructured, annual mileage data were estimated and back extrapolated using a linear regression approach.

The results of this investigation outline the distribution of CO_2 emissions across the transport sector in Ireland in 2013. These results also facilitate a comparison of the impacts of the new input data and improved estimation methodology over previous estimates of CO_2 emissions. Previous assessments (1990–2012) were shown to have under-estimated the contribution of diesel fuelled passenger cars by more than 38%. Diesel fuelled passenger cars were also shown to account for the majority of CO_2 emissions from road transport activities in Ireland in 2013.The results of this investigation highlight the impact of recent trends of increasing numbers of diesel car purchases in Ireland, which has been incentivised by government climate change policy.
Keywords: air pollution, transport, CO_2, emissions modelling, regression.

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1 Introduction

Greenhouse gases (GHG) such as carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) are naturally present in the atmosphere as part of the Earth's carbon and nitrogen cycles. These gases build the atmosphere around the earth and trap heat inside. CO_2 is the primary GHG as the amounts of CH_4 and N_2O released by anthropogenic activities are not as high (US EPA [1]). The IPCC [2] reported that CO_2 contributed at least 78% of the total greenhouse gas emissions from 1970 to 2010. Anthropogenic activities are the primary source of these pollutants. The United Nations Environment Programme (UNEP), [3] noted that the energy sector (35%), industry sector (18%), and transport sector (13%) were the top three sources of GHGs globally in 2010. In the EU, CO_2 emissions from transport increased by 25% in 2007 compared to 1990 and had a share of 23.1% of the EU27 CO_2 emissions (EC [4]). More than 71% of these emissions in 2007 originated from road transport (EU, 2012). Road transport is responsible for approximately one-fifth of the EU's total CO_2 emissions (Hill *et al.* [5]).

In Ireland, the transport sector was found to be the 3rd highest contributing sector (19.1%) for GHG emissions, behind energy (19.6%), and road transport is responsible for approx. 95.8% of the total CO_2 from transport sector (EPA [6]). Ireland's provisional 2013 GHG emissions for non-Emissions Trading Sectors (non-ETS) are 42.122 Mt CO_2 eq. Agriculture and Transport accounted for 70.5% of total non-ETS emissions in 2013 and both showed an increase in emissions in 2013 (EPA [6]). An emissions inventory was prepared for Ireland in order to ensure compliance with the Kyoto Protocol and the United Nations Framework Convention on Climate Change (UNFCCC).The UNFCCC sets binding obligations on industrialised countries to reduce GHGs, and yearly submission of the nation emissions inventory in order to assess the progress. Inventory preparation is a significant task and the accuracy primarily depends on the level of data availability and with improved data more accurate figures can be estimated. This task is crucial for assessing targets and compliance, and shaping national policies.

2 Methodology of the research

UNFCCC requires all countries to estimate mobile emissions from specific vehicle categories under the decision 24/CP.19-Annex I/II (UNFCCC [7]). As transport is a key category, Ireland has included a more disaggregated approach termed as a Tier 3 approach for estimating emissions from the transport sector. The tier 3 approach includes vehicle kilometre travelled (VKT) and vehicle technology data whereas tier 1 and tier 2 approaches is based on fuel consumption estimation. IPCC [8] guidelines suggested that VKT should be split into the vehicle and fuel categories required, and should consider that emissions and distance travelled each year vary according to the age of the vehicle.

In order to do this, national vehicle statistics were required to be split into more disaggregated categories. Estimation of mileage, as well as other parameters were required to be segregated according to those categories. The age and technological impact on emissions of different vehicle classes were accounted for considering the pre-EURO and EURO class emissions band defined by European Union directives. For the vehicle fleet, this was conducted considering the age of the vehicle and the year of introduction of the vehicles. The most disaggregated level of vehicle mileage data were included by from the National Car Test (NCT) (passenger mileage data from 2000 to 2013, and goods vehicle data from 2008–2013) (SEAI [9]). In addition, public transport data under state owned companies were also available in recent years (mileage and fleet since 2006, and passenger journeys since 1999). Motorcycle/scooter data were also available since 2000 (CSO [10, 11]). These data were modelled for back-extrapolation using linear regression models in order to estimate historical emissions from road transport. In order to deal with the detailed vehicle classification which were not present in national statistics, vehicle scrappage distribution were estimated. Similarly, for mileage degradation, the ratio of the average mileage to different class according to the age and vehicle technology was determined and these trends were applied to data in previous years.

These data were fed into the COPERT 4.version 11.0 model. For emissions estimation at the national level using such disaggregated data, countries use different software platforms. As an EU member state Ireland uses the COPERT software which is popular in the EU and freely available to the member states. COPERT, as any other software, requires additional information for emissions estimation. Other parameters like vehicle share, air conditioner use, VKT according to urban, rural and highways were applied using the previous year's inventory data (Duffy *et al.* [12]). Similarly, the speed on these three road categories was not possible to determine accurately because these are subject to variation both spatially and temporally in the time series. Speeds were estimated for different classes of vehicle in different road categories using the most recently data available from the Road Safety Authority (RSA) [13, 14]. This estimation caused uncertainty and inaccuracy which was addressed by fuel balancing, as per IPCC, 2006 guidelines (i.e. comparing the fuel consumption data for transport with that calculated by COPERT) (IPCC [8]). The process of activities is reported below in Figure 1.

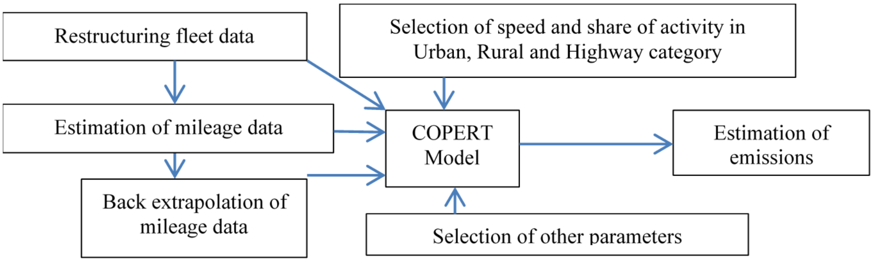

Figure 1: Emissions estimation activity from road transport.

Detailed QA/QC procedures were applied to the fleet data reconstruction and mileage estimation process. The historic vehicle fleet was recalculated from the year 1990 to 2013 from national statistics – Vehicle Bulletin of Driver Statistics (DOE, DELG, DEHLG, DOT, DOTTS [15]). In the case of vehicle mileage estimation, there were many missing data points observed. For instance, detailed information for 19,657 vehicle tests (LDV and HDV) from the year 2008–2012, were missing, representing a total of 1.15% missing values. Software such as SPSS, R, and MS excel were applied for data analysis, cross checking and regression modelling.

3 Vehicle fleet

The primary fuel types for the fleet are: Gasoline (leaded and unleaded), Diesel, LPG and biofuels. At a glance the road transport sector in Ireland could be subdivided into the following sub categories: passenger car (PC), light duty vehicle (LDV), heavy duty vehicle (HDV), buses, coaches, mopeds and motorcycle. Buses and coaches are similar; however, buses run in the urban area and thus the speed and operation characteristics differ from coaches. From the national statistics some categories of vehicles were excluded which constitute either a very small percentage of the fleet or these are included in emissions estimations in other sectors, e.g. tractors in agriculture.

The total number of vehicles was available from 1990 for each taxation class for different fuels types in the national statistics. The total vehicle fleet registered in a year under a category were also reported in successive years up to 2013. In addition, unladen weight ranges for commercial vehicles and engine capacity for passenger cars were also available. Furthermore, the total remaining number of these vehicles, such as passenger car and good vehicles after scrappage in the vehicle fleet were reported yearly for the first 15–16 years. However, the remaining total number of the vehicles/surviving vehicles that are older than 16 years were reported in a single category. Vehicles in this single category cannot be classified according to their year of introduction or age. A similar problem occurred for goods vehicles that were above a weight of 15,241 kg. All good vehicles above 15,241 kg were reported in a single category. These single categories were required to be split following a distribution so that these vehicles could be put into appropriate emissions classes/emission bands.

The information regarding the number of goods vehicles according to unladen weight were known, helping to divide the data into light and heavy duty vehicles. However the information regarding HDV fuel technology was unknown. Similarly, the segregation of buses and coaches were not reported, while their fuel technologies were also unknown. Since 2008 the reported categories of vehicles has changed, and the categories of ‘petrol and electric’, as well as ‘petrol and ethanol’ have arrived replacing previous categories for ‘petrol and gas’ (dual fuel vehicles). In the same year, additional information regarding passenger cars according to fuel type, age, and engine capacity became available. These led to a more refined methodology for restructuring the vehicle fleet according to the emissions class. Vehicles in a class were first divided according to the fuel technology, then to engine size and finally according to emissions band. Some assumptions were taken into account for this fleet distribution:

- Segregation of total vehicles in a category (e.g. passenger car that use petrol) into emissions band was based on the year of the vehicles registration and the year of enactment of laws relating to those emissions bands.
- Due to absence of data no <1.4l diesel vehicle category was assumed to be present in the Irish fleet/or in small public service vehicles until 2007 (in 2008 diesel vehicle less than 1.4l was about 5% of the total diesel category), and a 50–50 split between rest of the two categories (1.4–2.01L and >2.0L) was considered for small public service vehicle.
- No LPG vehicles were included in the model except where historic evidence of their introduction was observed. A vehicle scrappage distribution (similar to petrol) was used on LPG vehicles to estimate the number of remaining vehicles in each year.
- Petrol and gas, petrol and electric, and petrol and ethanol powered vehicles were included in the petrol category.
- Small public service vehicles were included in the passenger car category for the distribution.
- It was assumed that all goods vehicle <3.5tonnes or 3556 kg were Diesel and Gasoline LDV, and >3.5l petrol Large Public service vehicles were HDV Gasoline, >3.5l were Diesel HDV.
- HDV vehicles are fuel powered, except where otherwise mentioned in the national statistics.
- National statistics for motorcycles were classified into four categories as: up to 75cc, 76–150cc, 151–250cc, and >250cc. 50% of the first categories were classified as mopeds, and rest as two stroke motorcycles.

3.1 Vehicle technology

Vehicles were not reported in the national bulletins based on their emissions standard. In order to segregate the vehicle fleet at this level, an approximation (see Table 1) was applied from corresponding regulations regarding the EURO emissions band, their actual effective date, commencement of each vehicle class in the Irish fleet from historic evidence, available bus fleet information, and good practice guidance from the Danish National Inventory Report 2014 (Nielsen *et al.* [16]).

3.2 Fleet distribution and survival rate

The surviving vehicles that were first registered since 1965 were reported in the 1987 National Bulletin of vehicle statistics, and all the surviving vehicles before 1972 were reported in a single category. In order to split that single category the historic survival rate from 1972 to 1984 was calculated (see Figure 2) which was found to be unaffected by import vehicle numbers. This survival rate was applied to data from 1965.

Table 1: EURO class vehicle commencement years.

Technology	PC	LDV	HDV	Buses/Coaches	Moped/Motorcycle
Pre-ECE	Up to 1969				
ECE 15/00-01	1970–1978				
ECE 15/02	1979–1980	--			
ECE 15/03	1981–1985				
ECE 15/04	1986–1991				
Conventional	--	Up to 1993	Up to 1994	Up to 1993	Up to 1994
Euro-I	1992–1996	1994–1997	1995–1997	1994–1996	1900–2003
Euro-II	1997–2001	1998–2001	1998–2001	1997–2001	2004–2006
Euro-III	2002–2005	2002–2005	2002–2005	2002–2006	2007 to date
Euro-IV	2006–2010	2006–2010	2006–2010	2007–2009	--
Euro-V	2011 to date	2011 to date	2011 to date	2010 to date	--

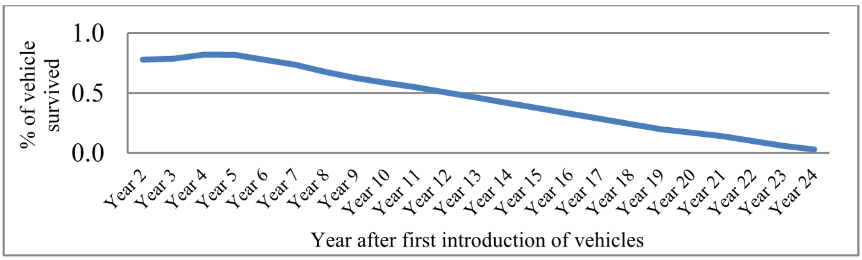

Figure 2: Historical trend for vehicle survival rate 1972–1984.

This survival rate enabled the estimation of the number of different vehicles registered in different years (in relation to EURO class) from the aggregated national statistics. This resulted in the production of a consistent distribution of the fleet as shown in Figure 3.

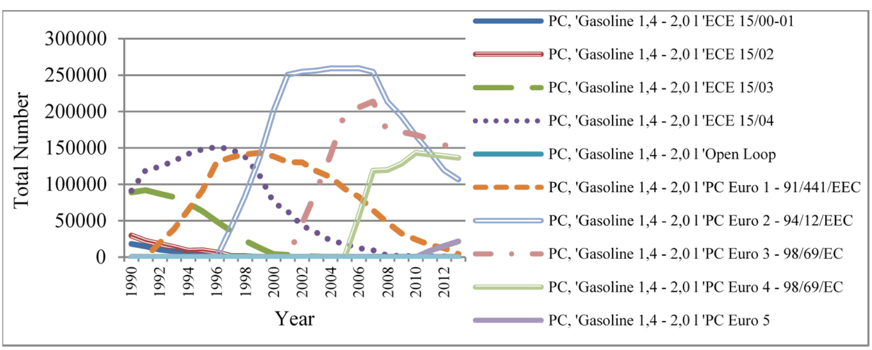

Figure 3: New trend for PC (petrol)-entering and leaving the fleet 1987–2013.

A similar approach was applied for LDV and HDV up to 15 t. The year of introduction of vehicles more than 15 tonnes were distributed using historic Irish evidence of first market penetration. Based on this, vehicles >20 t and articulated trucks < 50t penetrated in the Irish market in 2002 whereas articulated trucks 50–60 t started in 2005. HDVs >15 t were equally distributed in five Euro classes.

Although national statistics reported large public service vehicles and community buses separately. There were no actual divisions of buses and coaches that run in the entire country. This separation may be a difficult statistics to obtain, however, such classification is important for COPERT as vehicle operational characteristics are vital for the emissions estimation process.

The largest operator in Ireland for the bus industry is Dublin Bus, a state owned company. In addition, the state also owns the largest coach operator, Bus Éireann. The total number of buses and coaches and their most segregated information was collected from the annual reports from the bus industries, reports from the consultants (Goodbody [17, 18]), government agency CSO [10], and national driver statistics (NRA [19]). The split between public and private buses (public bus and coaches (around 30%) and the split between the public coaches and public buses (around 60%) were applied to the national statistics. An approximate split or assumption cannot be made for such segregation of private bus and coach industry. The available data from these sources also provides total passenger Journeys, total mileage since 1999, and fleet size since 2006 for all public buses and coaches. In order to estimate fleet sizes from 1999 to 2006 for public buses and coaches a regression model was developed for the fleet against passenger journeys. The adjusted R^2 of the regression models for public Bus were 0.52 and 0.64 for public coaches respectively. The Variable influential factor (VIF) was <4.

In order to derive statistics for urban buses, either private bus or private coach statistics were required along with the above public bus and coach data. From the data, 0.85 buses per 1000 people in 2011 can be observed for Dublin Bus Company. Normally, the urban buses lie between 0.5 and 1.2 per 1,000 (World Bank Group [20]). However, data accumulation under this study found that only 14 of the top 25 populated towns/cities in Ireland to have urban bus services. Of these services, only six private urban bus services can be observed serving one to several routes. Observing this information about the population served by the Dublin fleet and population served by number of buses/routes in the other cities, it can be understood that the number of private urban buses should be lower than that of the Dublin bus number (the population of the 24 town/cities is about 80% of the total population of Dublin).

As an optimistic case, an assumption was made that private bus numbers were 50% of the Dublin bus. This assumption provided a figure of total 2954 urban buses in 2011 (approx. 30% of the total buses and coaches). The split between Euro classes (assumed same for bus and coaches) was conducted based on the large public service vehicle data from national statistics and developed scrappage distribution.

For the Euro class distribution in mopeds and motorcycle, Table 1 was considered and for single category reported in national statistics, a modified survival rate distribution (from MOVES 2010a) applicable for Irish fleet was applied (US EPA [21]).

4 Mileage estimation

This part of the task involved estimation of the average mileage from the available NCT data, and secondly, back extrapolation of this mileage data to 1990. Figure 4 shows that there is a distinctive pattern of average mileage from the earlier EURO class (e.g. EURO-I, or E-I) vehicles which show a reduction in mileage with age. More recent classes of vehicle do not show that pattern clearly. The mileage degradation pattern was also found for Diesel PC, and in all LDVs (e.g. Figure 5) and HDVs.

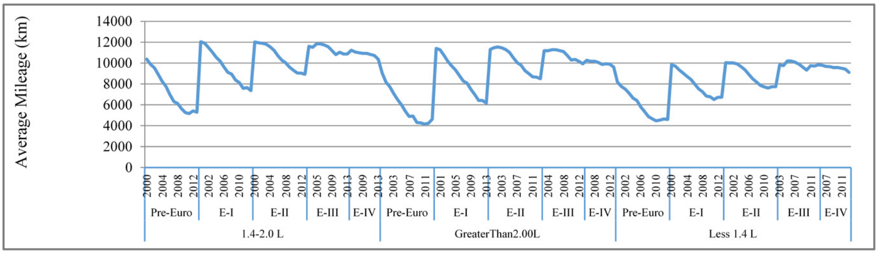

Figure 4: Average vehicle mileage data for petrol PC (2000–2013).

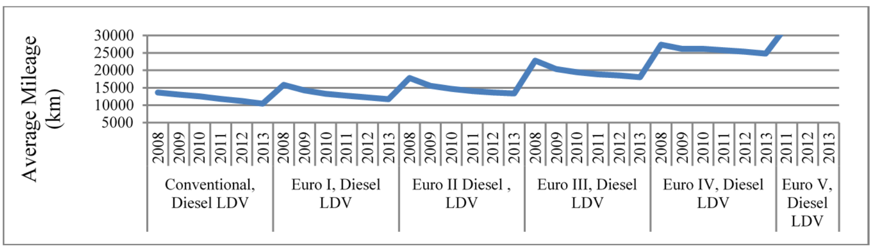

Figure 5: Average Vehicle mileage data for Diesel LDV (20082013).

For back extrapolation of the average PC mileage data, vehicle mileages for each passenger car vehicle class were estimated and assessed against 25 relevant predictor variables which were selected from World Development Indicators (WB [22]). Mileage was found to be highly correlated with variables such as GDP growth (annual %) and long-term unemployment (% of total unemployment). These can be included in regression models for each category of vehicle classes (see Figure 6). The model fitting R^2 and validation R^2 were acceptable (see legend in Figure 6) in most of the cases, however, not for the Diesel >2L vehicle category (Max. VIF<8). In general, Diesel passenger cars did not show high co-relations with economic activity data, which may be because of more diesel powered vehicle use in recent years due to introduction of incentivising tax policy in Ireland.

The mileage degradation observed in Figure 4 for petrol powered PC was applied on the extrapolated data from the % calculated data from the year 2000–2013. This was also conducted for the rest of the PC classes mentioned in Figure 6. This was done carefully considering the vehicle fuel technology, EURO class introduction year, vehicle type and the arrival of the next EURO class.

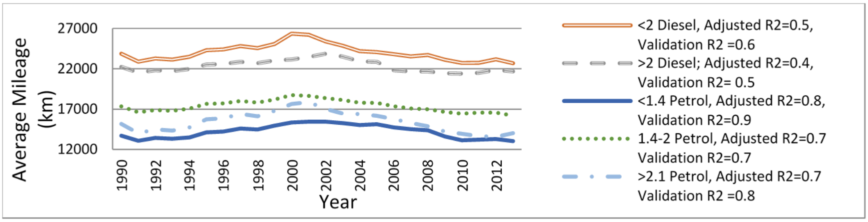

Figure 6: Average vehicle mileage split for petrol vehicle (1990–2013).

While back extrapolation was attempted according to the smallest vehicle categories, or even LDV and HDV, no appropriate predictors were found to correlate with the mileage data. A model was generated with the average mileage data from all LDV and HDV against GDP (constant Local currency unit). This relationship somewhat explained the variation around the mean (R^2= 0.38, Validation R^2= 0.38; Max. VIF<5). It is expected that with the more NCT testing carried out in the next few years, more data will be available which may be more explainable than the current form. The current six years of data (2008-2013) may not be sufficiently long for back extrapolation to 1990.

Using the regression model built for average mileage for LDV and HDV, back extrapolation was conducted up to 1990. A ratio between the average of LDVs and HDVs, and different class of LDV and HDV was derived and applied to the extrapolated data. Due to lack of sufficient data for goods vehicle mileage, degradation followed the petrol and diesel passenger car distribution.

The available data sources show a very limited amount of mileage data for private bus and coach industry in Ireland (Table 2). On the other hand, as noted earlier the largest public sector bus and coach industry had a large amount of data to work with. However, average mileage from both public and private sector is required for input into the COPERT model. Using the estimated fleet mentioned earlier, the average fleet mileage for public bus and coaches are mentioned in Figure 7.

For back extrapolation, predictors applied earlier were assessed against the bus and coach mileage data. After the assessment, the best fitted models were developed for Dublin Bus and Bus Éireann in Table 3, and extrapolated results were found as shown in Figure 8.

The average mileage for motorcycles was obtained from CSO, and back extrapolated using a regression model where predictor variables were: length of the total road network (in km) and long-term unemployment (% of total

Table 2: Average vehicle mileage in kilometres for private sector buses and coaches/public sector buses and coaches under Public Service Obligation (PSO).

Average vehicle mileage in km	2004	2006	2010	2011	2012	2013
79 operators**	76576	67456				
Top 60 operators**	92054					
Bus Éireann – PSO Buses			95200	81174	84289	79338
Dublin Bus – PSO Buses			55230	57340	57002	55458

Source: Goodbody [17, 18]; NRA [19];**Private bus and coach-per vehicle.

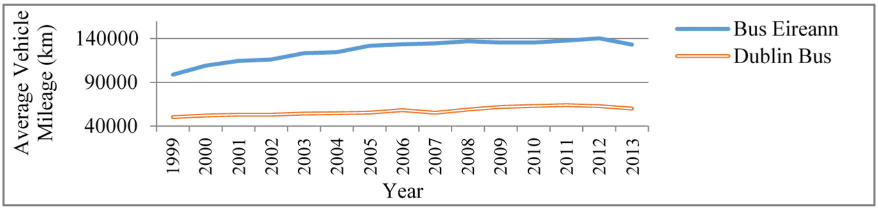

Figure 7: Mileage for bus and coach industry in public sector (1999–2013).

Table 3: Dublin bus and Bus Éireann mileage model.

Bus Éireann Model: Adjusted R^2: 0.89; VIF<5; Validation R^2:0.95		
Intercept	GDP (current US$)	Population (Total)
2.65E+04	1.06E-07	1.91E-02
Dublin Bus Model: Adjusted R^2: 0.95; VIF<2; Validation R^2:0.94		
Intercept	Road sector energy consumption (% of total)	Urban population (% of total)
-208524.6	-405.1	4558.8

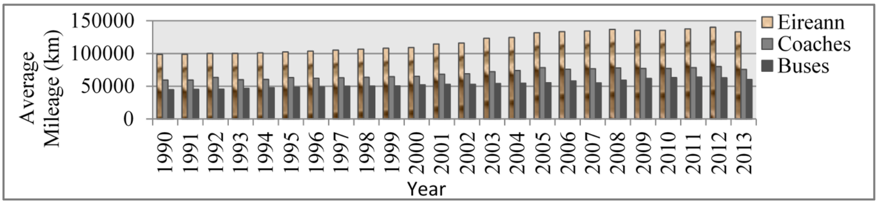

Figure 8: Average vehicle mileage for bus and coach industry (1990–2013).

unemployment). The result is presented in Figure 9. The model fitting R^2 was 0.59 and validation R^2 was 0.58 (Max. VIF<8). Due to insufficient data of vehicle segregation, the average mileage in each year was applied for all mopeds and motorcycles in the COPERT model.

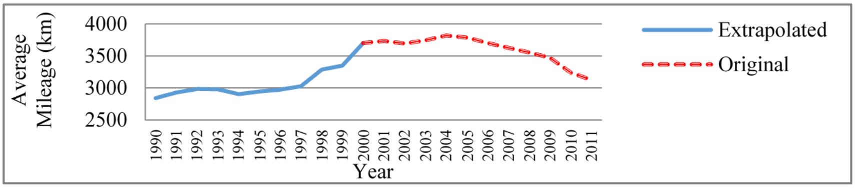

Figure 9: Average mileage for motorcycles (1990–2013).

5 Vehicle speeds

The reported speed data by RSA for different categories of roads were reclassified in Figure 10 below for use in COPERT based on the understanding of the road classification definition, mode classification and survey location.

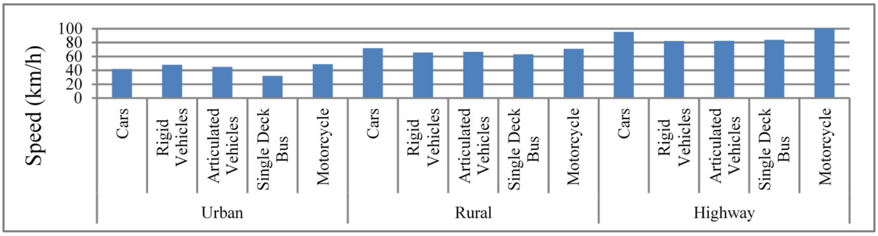

Figure 10: Speed of different vehicles in different kinds of roads.

6 Result and discussion

The modelled data has been applied in the COPERT model to estimate emissions and fuel balancing was conducted for every year to account for all fuels in Ireland. With this analysis, it would be possible to report emissions at the vehicle class level this year which has not been reported on previously. CO_2 estimation was previously reported based on the fuel consumption, multiplied by emissions factors.

The results for CO_2 are comparable with the recent reports (Duffy *et al.* [12], Dineen *et al.* [23]). As the fuel was balanced for both of the cases the total emissions for CO_2 from the road sector does not change, however, the distribution of the CO_2 from different vehicle classes has been changed significantly. The major trade off was observed between the diesel LDV and diesel PC. Diesel LDV had previously being over estimated. In addition, reductions in emissions from diesel powered HDV and buses and coaches were also observed.

As can be seen from the comparison in Figure 11, diesel fuelled passenger cars now represent the largest single contributor to CO_2 emissions in the road transport sector in Ireland and the use of the improved methodology developed here has shown a significant change in its previous estimation (3.34 million vs. 2.14 million tonnes of CO_2 in 2012, Duffy *et al.* [12]). This finding may have a major implication for the direction of CO_2 emission control policy in the transport sector in Ireland, whereby the growth of passenger diesel car numbers in recent years may need to be addressed.

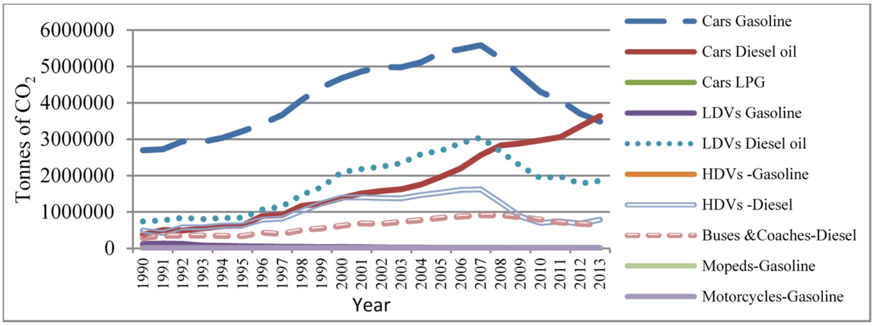

Figure 11: CO_2 emissions distribution from new methodology.

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