The Influence of Passenger Car Population and Their Activities on NO_X and PM Emissions (Data from Croatia)

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Introduction

For the past few years special attention has been given to harmful road transport emissions, nitrogen oxides (NO_X) and particulate matter (PM). Exposure to increased concentrations of NO_X and PM emissions is known to cause respiratory ailments, heart diseases, stroke and can be the cause of premature death (Guttikunda and Goel, 2013; Li et al., 2017; Stockfelt et al., 2017). The time series results of real driving emission measurements have shown a significant difference in NO_X emissions of diesel cars compared to the type approval limit values. However, this does not apply to petrol cars (Chen and Borken-Kleefeld, 2014). Remote sensing measurements indicate that NO_X emissions from Euro 5 petrol cars are about a factor of 20 lower than Euro 0 cars. However, there has not been a significant change in NO_X emission reduction for diesel cars from Euro 0 to Euro 5 (Carslaw and Rhys-Tyler, 2013). Particulate matter emissions are rising in many of the world's populated cities and exceeding World Health Organization guidelines (Guttikunda and Goel, 2013; Ma and Jia, 2016). However, the emission control policies implemented in the last decade could result in noticeable reduction in PM emissions (Wang et al., 2017). Not only policy measures, but also the implementation of DPF (Diesel Particulate Filter) technology on vehicles enabled a large reduction in PM emissions (Tzamkiozis et al., 2010). However, some countries like Croatia have an aged vehicle fleet and exhaust PM emissions have a significant role in total emissions. The most severe problem is found in urban areas with high traffic density. One of the methods to reduce NO_X and PM emissions in urban areas is to introduce a low emission zones. The study from the University of Sydney shows the impact of London's low emission zone on NO_X and PM10 emissions (Ellison et al., 2013). Not only tailpipe exhaust emissions but also non-exhaust PM emissions (road dust resuspension, road surface wear, abrasion of tyres, brakes and clutch) have a significant impact on air quality in urban areas (Amato et al., 2016; Pant and Harrison, 2013). Although electric vehicles are not included in this study, exploitation of such vehicles also results in non-exhaust emissions. Because of the significantly larger mass of electric vehicles in comparison to vehicles equipped with an internal combustion engine, electric vehicles generate more non-exhaust emissions than conventional vehicles (Timmers and Achten, 2016).

Most popular vehicle emission models such as COPERT (Computer Programme to calculate Emissions from Road Transport), HBEFA (The Handbook Emission Factors for Road Transport) and VERSIT+ are used for estimating road transport emissions (Borge et al., 2012; Smit et al., 2007). By applying these emissions models, it is possible to estimate emissions generated on a defined geographic area in a given time period. Air pollutant emissions from on-road vehicles in China for the time period from 1999 to 2011 were estimated using COPERT emission model (Lang et al., 2014). Considering that NO_X RDE from Euro 6 diesel cars exceed emission levels used in COPERT by two times, it was necessary to update NO_X emission factors (EFs) (Ntziachristos et al., 2016). In Croatia, an emissions study has already been made, which, among other things, provided NO_X and PM emissions of passenger cars (PCs) for the period from 2007 to 2016 (Resetar et al., 2017). In order to apply COPERT model, a significant amount of input data must be acquired. Therefore, a top-down approach is used in order to determine national emissions and the most important data, along with emission factors, is precisely related to the PC fleet structure and activity data.

Based on the above-mentioned information it is obvious that NO_X and PM emissions present a major problem today with diesel cars as the major source of the above pollutants. Therefore, the study focused on the influence of PC population and their activities on NO_X and PM emissions in the Republic of Croatia. For relevant PC subcategories, emissions and implied emission factors for pollutants NO_X and PM for the year 2016 were calculated using COPERT 5 computer program.

Methodology and input data

The processed data on the PC fleet that underwent technical inspection in 2016 was collected from the database of Centre for Vehicles of Croatia (CVH), the company whose primary activity is performing periodical technical inspections on vehicles in Croatia. This is a unique database that contains data on all vehicles registered in Croatia, including periodical technical inspection data and annual vehicle activity data. These data have the greatest impact on the calculation of emissions and as such were used as COPERT 5 input data. Activity data taken into account means annual mileage along with mean lifetime cumulative mileage, whereas the assumed circulation data taken into account means the speed and the percentage of mileage driven by vehicles of each emission level per driving mode (urban/rural/highway). In addition to the above data, input data also included environmental information with monthly values of average minimum and maximum temperatures as well as relative humidity. Tier 3 methodology, which is described in *EMEP/EEA air pollutant emission inventory guidebook*, was applied in the scope of this research (Ntziachristos and Samaras, 2016). A simplified form of COPERT emissions calculation model is shown in Figure 1.

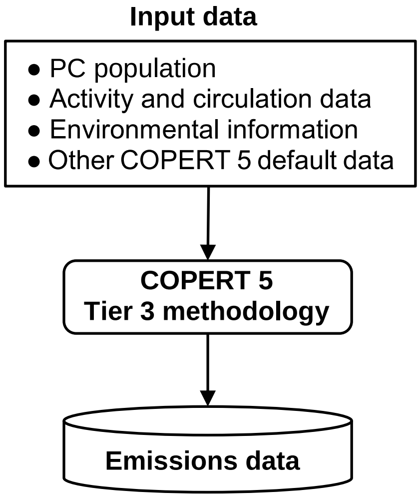

Figure 1: COPERT emissions calculation model.

Passenger car population and their activity data for the year 2016 were processed and prepared for COPERT calculation. Figure 2 shows PC population, mean annual activity and total annual activity for petrol and diesel PCs in 2016, according to each of the European emission standards. Over 779,000 petrol and over 718,000 diesel cars were registered in Croatia in 2016. Almost 61,000 other vehicles included hybrid, LPG bi-fuel and CNG bi-fuel cars, while 224 registered cars were electric. If we look at the top-left chart in Figure 2, it can be noted that there is a numerically small difference between the total number of petrol and diesel cars. Older cars, up to Euro 4, are mainly petrol, while newer cars, Euro 5 and Euro 6, are mainly diesel. There are roughly twice as many Euro 2 petrol cars as there are Euro 2 diesel cars. The top-right chart in Figure 2 indicates that diesel cars are exploited much more than petrol cars. When comparing all petrol and diesel PCs, diesel cars drive 6,750 km a year more than petrol cars. It is also apparent that newer vehicles, both petrol and diesel, are exploited much more than older vehicles. In order to calculate emissions on an annual basis, it was necessary to consider total annual activity (bottom chart in Figure 2). Total annual activity is the product of PC population and mean annual activity. This data is very useful because it shows a fleet's activity in a broader sense. Although the number of petrol cars is greater than the number of diesel cars, due to considerably greater exploitation of diesel cars compared to petrol cars, diesel cars drive 1.53 times more kilometres a year then petrol cars. The main causes of significantly higher activity of diesel cars are lower fuel consumption and lower fuel costs when compared to petrol cars.

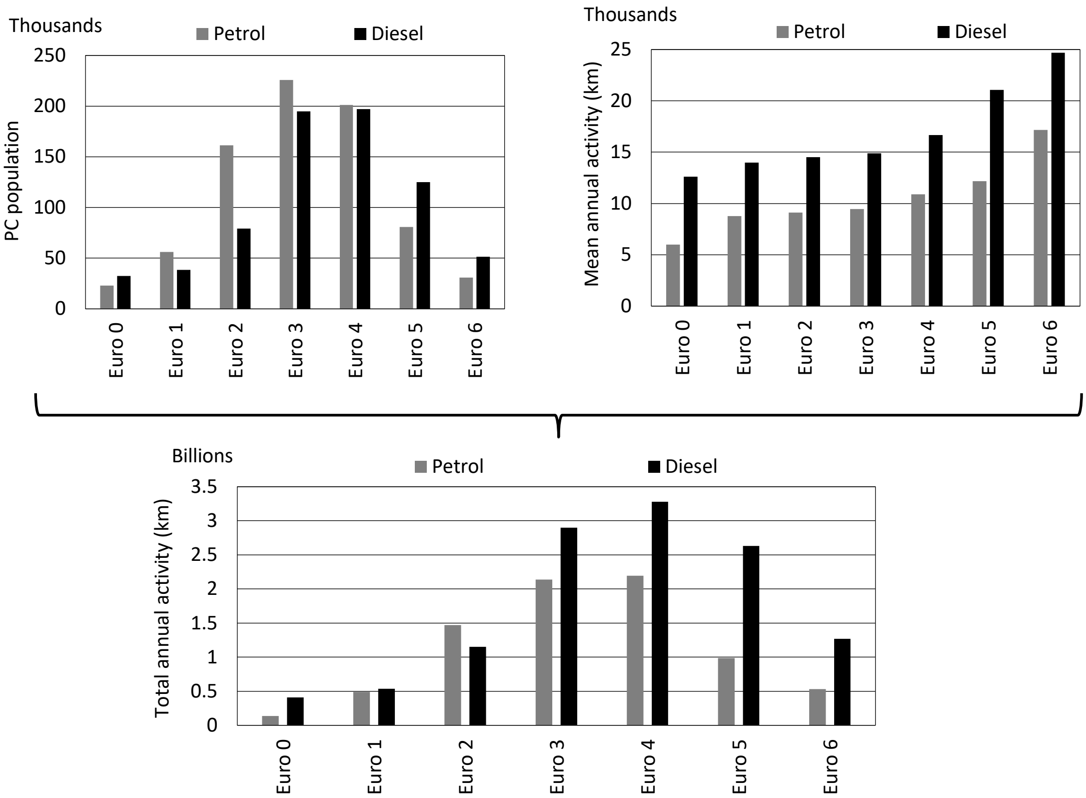

Figure 2: Population, mean annual activity and total annual activity for petrol and diesel PCs in 2016, according to European emission standards.

As mentioned above, circulation data were taken as an assumption. Therefore, the distribution of emissions generated in separate driving modes (urban/rural/highway) has not been considered. This paper presents total emissions generated in all mentioned driving modes. Table 1 shows the mean speed and the percentage of mileage driven by vehicles per driving mode (urban/rural/highway).

Table 1: The mean speed and percentage of mileage driven by vehicles per driving mode.

DRIVING MODE	MEAN SPEED (km/h)	SHARE (%)
Urban Off Peak	38	20
Urban Peak	28	20
Rural	60	35
Highway	110	25

Environmental information includes monthly values of average minimum and maximum temperatures as well as relative humidity. The data were taken from *The GLOBE Program of Croatia* and are shown in Table 2 (Jurić et al., 2012).

Table 2: Monthly values of average minimum and maximum temperatures as well as relative humidity (data for Zagreb, 2012).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Min Temp (°C)	0.7	-0.2	4.5	10	12.5	16.9	18.1	19	16.4	8	2.2	2.1
Max Temp (°C)	5.6	6.4	13	20.4	24.1	27.5	28.6	30.3	26.8	16.1	7.1	7.9
Relative Humidity (%)	68	56	44	48	49	52	49	45	47	56	75	70

Results

Total (hot and cold) NO_X emissions from both petrol and diesel PCs in 2016 according to each Euro emission standard (Euro 0 to Euro 6) are calculated and presented in the top-left chart in Figure 3. Emissions are expressed in kilotons (kt). The top-right chart in Figure 3 shows implied NO_X EFs for petrol and diesel cars. Implied NO_X EFs are defined as total NO_X emission produced by cars with the relevant Euro standard, divided by the total annual activity of these cars. Nitrogen oxides EFs are provided in grams per kilometre (g/km). The comparison between implied NO_X EFs and type approval limit values for both petrol and diesel cars are presented in the bottom charts in Figure 3.

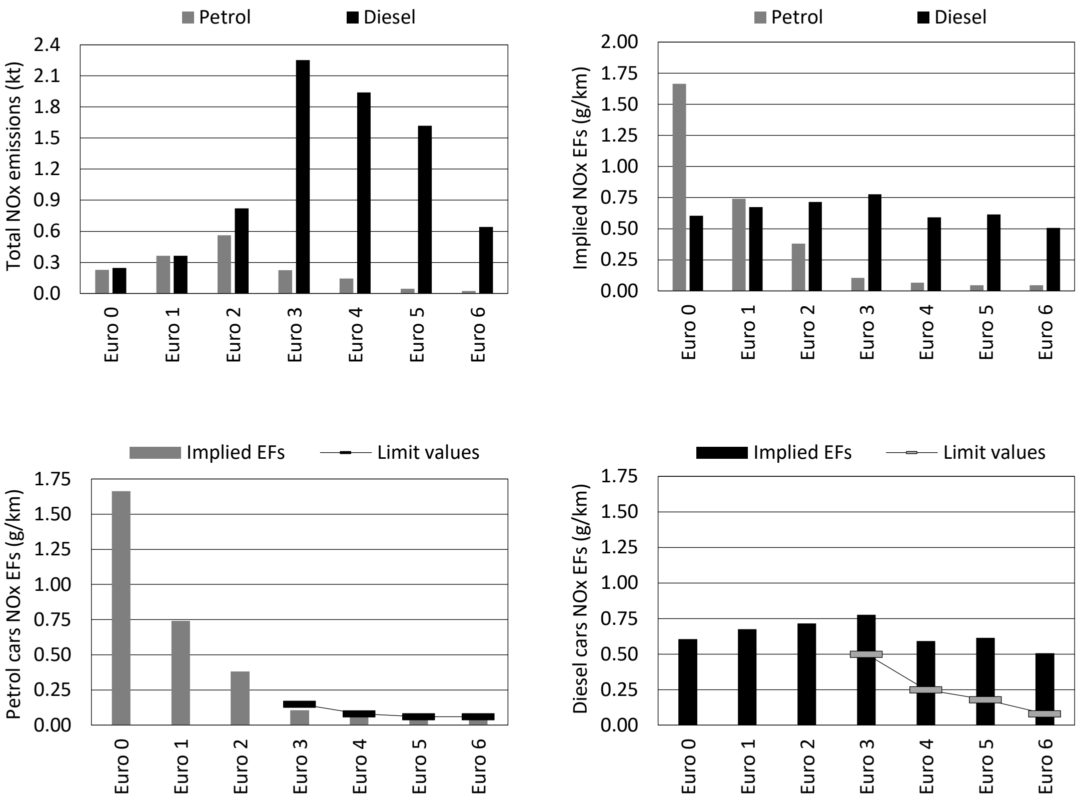

Figure 3: Total NO_X emissions, implied NO_X EFs and comparison of calculated NO_X EFs with type approval limit values.

Tailpipe emission of particulate matter PM10 from both petrol and diesel PCs in 2016 according to each Euro emission standard (Euro 0 to Euro 6) are calculated and presented in the top-left chart in Figure 4. Emissions are expressed in tons (t). The top-right chart in Figure 4 shows implied PM10 EFs for petrol and diesel cars. Implied PM10 EFs are defined as total PM10 emission produced by cars with the relevant Euro standard, divided by the total annual activity of these cars. Particulate matter EFs are provided in milligrams per kilometre (mg/km). The comparison between implied PM10 EFs and type approval limit values for both petrol and diesel cars are presented in the bottom charts in Figure 4.

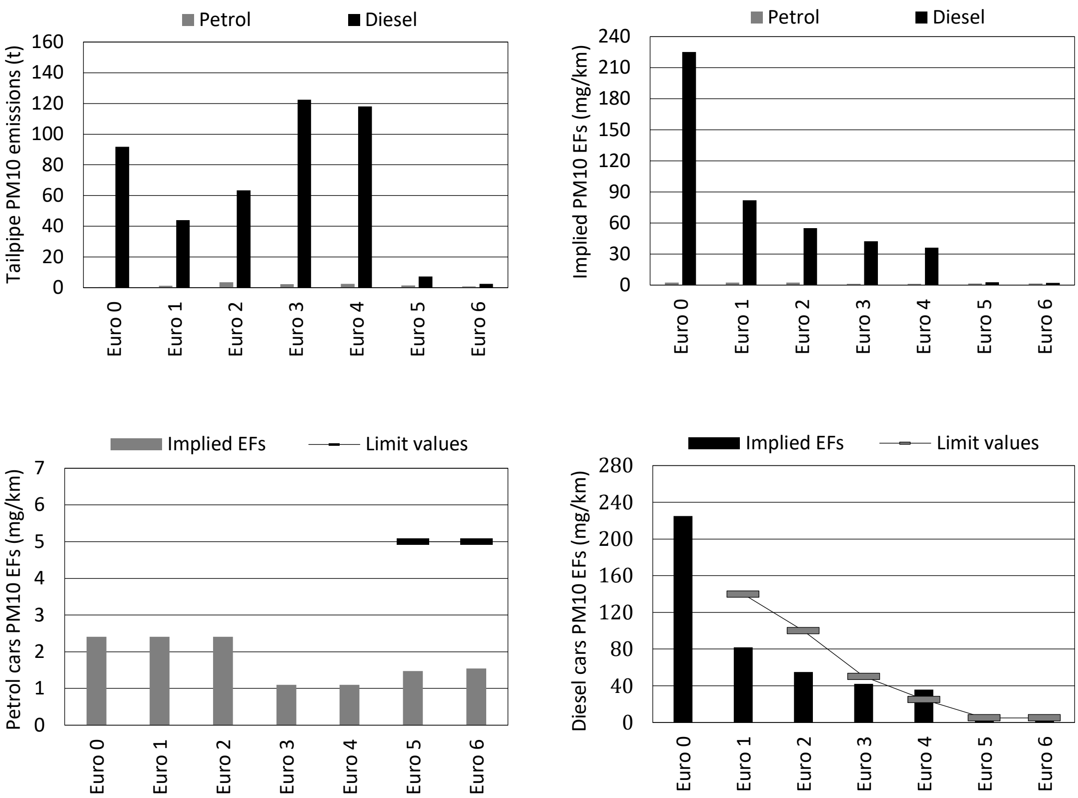

Figure 4: Tailpipe PM10 emissions, implied PM10 EFs and comparison of calculated PM10 EFs with type approval limit values.

Discussion and conclusions

The study investigated the influence of PC population and their activities on NO_X and PM emissions. As petrol and diesel PCs made up 96 % of the Croatian PC fleet in 2016, only these two PC subcategories were taken into account. Petrol cars make up 52 %, while diesel cars make up 48 % of the total number of vehicles considered. However, petrol cars drive 40 %, while diesel cars drive 60 % of the total annual mileage considered. Euro 3, Euro 4 and Euro 5 diesel cars are exploited much more than other PCs and these vehicles generated more than 60 % of total NO_X emissions of PCs. It is evident from Figure 3 that Euro 3/4/5/6 diesel cars exceed type approval limit values. Although diesel Euro 6 implied NO_X EF is the lowest in total diesel PC subcategory, its value exceeds Euro 6 emission limit by more than 6 times. Euro 0 petrol cars have the biggest implied NO_X EF, but the number of these vehicles is negligible compared to other PC subcategories. In addition, this subcategory is only marginally exploited. Regarding PM10 emissions, petrol cars do not play a significant role. Diesel cars Euro 0 up to, and including, Euro 4 emission standard produced 95 % of tailpipe PM10 emissions. It is only with the implementation of DPF technology on diesel Euro 5 and Euro 6 cars enabled that the PM emissions were significantly reduced. In order to reduce NO_X and PM emissions, it is necessary to lower the number of diesel PCs and/or their activity. The introduction of levies for diesel PCs is a method that would surely contribute to a reduced number of diesel vehicles and consequently to reduction of NO_X and PM emissions. In Croatia most levies are being considered through the carbon dioxide (CO_2) as a criterion. Diesel vehicles, due to lower fuel consumption compared to petrol cars, have the advantage when CO_2 EFs are taken as a criterion. But along with CO_2 as a criterion, it is necessary to introduce additional criteria related to harmful emissions, primarily NO_X and PM. Therefore, it is necessary to change the national policy measures. In order to decrease emissions, the vehicle fleet has to be renewed as well, by replacing older second-hand vehicles with new ones with low emissions. This would require definite national policy measures which would introduce tax cuts for new vehicles, while new tax levies would be redirected to older, mostly technically faulty and environmentally unfit vehicles, and specifically to the import of such vehicles.

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