Analysis of actual emissions performance of the Flemish road vehicle park

Eindrapport

DEPARTEMENT OMGEVING

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TITEL STUDIE
Deze studie …
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1 INTRODUCTION

1.1 BACKGROUND

In Flanders, vehicle emissions contribute largely to health impacts of air pollutants such as nitrogen oxides (NOx, around 68%) and particle matter ($PM_{2.5}$, around 14%). Without specific targeted policy measures to reduce the vehicle emissions, Flanders will not be able to meet its long-term goals and targets with respect to local air quality.

Vehicle emissions are regulated on a European level through so called Euro standards. The latest Euro 6 (for light duty vehicles) and Euro VI (for heavy duty vehicles) standards theoretically have the potential to substantially reduce the emissions of both NOx and $PM_{2.5}$.

Over the years, vehicle manufacturers have improved engine combustion and developed additional exhaust after-treatment technologies to meet emissions standards. These include particulate filters for diesel engines (DPF) and selective catalytic reduction systems (SCR), which use urea to reduce NOx emissions.

The Volkswagen emissions scandal, widely known as “dieselgate”, broke out in September 2015, when the United States Environmental Protection Agency (EPA) formally accused Volkswagen of violating US emissions standards. Volkswagen subsequently admitted that a “defeat device” had been installed in 11 million diesel-fuelled vehicles worldwide. These devices were able to detect when a vehicle was being tested in a laboratory and activate its emissions control system for compliance with NOx emissions standards. However, outside a laboratory setting, the device would switch off the emissions control system, and the vehicle would produce emissions well above the US legal NOx limit. Even before this development, it was widely known that a vehicle’s NOx emissions on the road exceeded those measured in a laboratory. The scandal revealed that one of the reasons for this difference was the use of defeat devices.

The use of defeat devices, not only by vehicle manufacturers (original equipment manufacturers or OEM), but also vehicle owners and/or operators, means that a large portion of the emission reduction potential of the Euro standards is lost.

In response to the Dieselgate scandal, the EU has accelerated initiatives to improve emissions legislation and strengthen surveillance. Most notably, the new RDE-tests were introduced with in service conformity testing. A new framework for type-approval comes into force starting in September 2020 and requires member states to organize market surveillance tests.

With the sixth state reform in Belgium, Flanders has become competent for the approval and inspection of vehicles and, together with the already existing powers related to environment and mobility. The government of Flanders is responsible for organizing the market surveillance tests as required by Regulation (EU) 2018/858. As such, Flanders has an important role to play to limit vehicle emissions and fraud.

1.2 OBJECTIVES

In order to gain a more reliable insight into the actual real-world emissions of vehicles in Flanders and better understand how regional policy measures could help assuring respecting the emission limits during normal use, the Flemish government ordered an extensive study consisting of 4 parts:

- Legal investigation: understanding the legal context and what legally the Flemish Region can and cannot do
- Policy measures: developing suggestions for policy measures to tackle fraud by the OEMs and vehicle owners/operators
- Flemish vehicle fleet analysis: prioritisation of vehicle categories according to the impact of possible fraud
- Measurement campaign: measuring real world emissions in Flanders by means of remote sensing technology

This report presents the outcome of the third part, the Flemish vehicle fleet analysis, performed by Emisia and aims at identifying a priority list of different vehicle types (models, ages, technical characteristics, etc.) selected according to their occurrence and usage on Flemish roads and to the extent to which increased emissions occur under actual driving conditions.

In order to make maximum use of the reduction potential of the existing emission management systems, it is important not only to check which vehicles are most common (in sales), but also which vehicles are most frequently used (distance driven in Flanders).

Prioritising the vehicles to be considered in developing measures to prevent emission fraud, boils down to making a classification based on a combination of the following three elements: fraud potential, number of vehicles and intensity of use.

Since the context described above refers to the health impact of air pollution and the emission ceilings of the National Emissions Ceilings (NEC) Directive (European Commission 2016), the analysis focuses mainly on the emissions of NOx and $PM_{2.5}$ but other regulated pollutants, namely carbon monoxide (CO) and hydrocarbons (HC), are also examined. For $PM_{2.5}$ it is especially the “exhaust PM” that is important since the “non-exhaust PM” (mainly PM_{10}) are not regulated, and therefore fall outside the scope of the analysis on emissions fraud.

Further to this introductory part this report is structured as follows:
Chapter two analyses data from the Flemish emissions inventory in an attempt to identify the vehicle classes having the greatest impact on the emissions of the regulated pollutants.
Chapter three describes the methodology suggested for the identification of potential high emitters.
Finally, **chapter four** summarises the main findings and conclusions from the analyses in chapters two and three.

2 EMISSIONS INVENTORY OF FLANDERS

2.1 ABOUT THE EMISSIONS INVENTORY

2.1.1 Institutional arrangements

In Belgium, the emission inventory is a regional competency. The Vlaamse Milieumaatschappij (VMM[1]) has created the emission inventory for Flanders and updates it on a yearly basis. Because the international and European reporting needs to take place on the Belgian national level, the Belgian Interregional Environment Agency (IRCEL – CELINE[2]) is responsible for adding up the 3 regional emission inventories and the creation of the single national emission inventory for international reporting.

Due to the division of powers among different authorities in the environmental field, good dialogue is vital. The Coordination Committee for International Environmental Policy (CCIEP[3]) regroups all relevant strategic bodies involved in environmental matters in Belgium and was set up in 1995 to meet the need for dialog and coordination. The committee has a group of experts that deals specifically with the road transport emission inventory. The group aims at keeping the regional emission inventories as coherent as possible and developing a common methodology so that adding up the numbers of the regional inventories makes sense.

2.1.2 Methodology and data sources

The road transport emission inventory calculation is done using the COPERT[4] model which is part of the EMEP/CORINAIR Emission Inventory Guidebook[5] for the calculation of air pollutant emissions and is consistent with the 2006 IPCC Guidelines for the calculation of greenhouse gas emissions. The use of a software tool to calculate road transport emissions allows for a transparent and standardized, hence consistent and comparable data collecting and emissions reporting procedure, in accordance with the requirements of international conventions and protocols and EU legislation.

COPERT estimates emissions from all relevant road vehicle operation modes:
- thermal stabilised engine operation (‘hot’ emissions);
- the warming-up phase (‘cold start’ emissions);
- non-exhaust emissions (from fuel evaporation, tyre and brake wear emissions).

COPERT contains emission factors for more than 450 individual vehicle types including for:
- passenger cars;
- light commercial vehicles;
- heavy duty vehicles (including trucks and buses);
- L-category vehicles (including mopeds, motorcycles, quads and mini-cars).

COPERT is often classified as an ‘average speed’ model; this refers to specific parts of the software, primarily hot emission factors (g/vkm), which are a function of the mean travel speed. However, other detailed sub models are included that are not a function of average speed (e.g. evaporative

[1] https://www.vmm.be/over-vmm/organisatie
[2] https://www.irceline.be/en
[3] https://www.health.belgium.be/en/cciep-coordination-committee-international-environmental-policy
[4] https://www.emisia.com/utilities/copert/
[5] https://www.eea.europa.eu/themes/air/air-pollution-sources-1/emep-eea-air-pollutant-emission-inventory-guidebook

emissions). In general, the model is based on comprehensive laboratory emission tests over various drive cycles (hot running/cold start) or test procedures (evaporative) or derived from other methods (e.g. 'apparent' metal emissions, non-exhaust PM emissions).

To date the emission factors of COPERT have been largely based on large empirical test programs. In this approach, numerous vehicles are driven over real-world drive cycles on a chassis dynamometer with simultaneous modal or 'bag' emission measurements[6]. These "baseline" emission factors correspond to a fleet of average mileage (30.000 – 60.000 km) and a degradation factor is therefore inherent. For petrol cars and light commercial vehicles, further emission degradation — due to increased mileage — occurs, which is taken into account by applying additional degradation factors. Over the last 4-5 years PEMS tests are increasingly being used for complementing the emission factors development. Mean emission factors (g/km) are then related to the average speeds of (predefined) cycle segments through model fitting procedures. It is noted that other approaches (SHED test, near-road air quality measurements, literature review etc.) are used for specific sub models in the software such as evaporative emissions, non-exhaust PM emissions (tyre, brake, road) and heavy metal emission factors.

The main data source for establishing the Flemish vehicle fleet inventory is the data from the federal vehicle registration database (Federale Overheidsdienst Mobiliteit en Vervoer, Dienst Inschrijving van Voertuigen, DIV). The allocation of vehicles to a regional fleet is done using the postal code of the owner of the vehicle. The DIV data is cross-checked and augmented with other sources of statistical data such as the national vehicle manufacturers association FEBIAC for mopeds, the regional public transportation company De Lijn for city buses. Based on the detailed DIV data augmented with the information from the certificate of conformity (CoC), the vehicles are allocated to the different COPERT vehicle classes.

The activity data for Flanders comes from the Flemish Traffic Institute (Vlaams verkeerscentrum). The institute uses a mathematical model that uses information from various sources such as traffic counting stations, ad hoc counting surveys and other information to determine the overall activity in Flanders split over the COPERT driving modes urban, rural and highway. This activity is then allocated to the different COPERT vehicle categories using other sources such as the annual mileage from the technical inspection (CarPASS data) and various statistical surveys considering the age of the vehicles (older vehicles drive on average less miles per year).

It is to be noted that the calculation based on the activity data from the Flemish Traffic Institute is a bottom-up approach, referred to as "fuel used" (FU). The Emission Inventory Guidebook advises to calibrate the activity data to the quantities of fuel sold within the country, referred to as "fuel sold" (FS) approach. Because the statistical data on the quantities of fuel sold is the responsibility of the Belgian Federal Government, the FS data is not available on the regional level. As such, the FU/FS calibration is done by IRCEL – CELINE on the national level. The so called "surplus" of emissions is then attributed to the different regions following the relative FU contributions. Because the FU/FS difference is a scaling factor, it only impacts absolute numbers and has little impact on this study that mainly focusses on relative numbers.

2.1.3 Importance of road transport emissions in Flanders

Road traffic accounts for a large portion of air pollutant emissions in the transport sector. Inland shipping and rail traffic emissions contribute less to total emissions. The use of passenger cars

[6] All vehicles selected for testing are well maintained, with no obvious defects or modifications.

contributes more than 50% to the emission of air pollution from road traffic. New passenger cars are more economical and environmentally friendly, reducing their pollutant emissions. Nevertheless, the total mileage driven is the dominating parameter. Freight transport by road continues to grow.

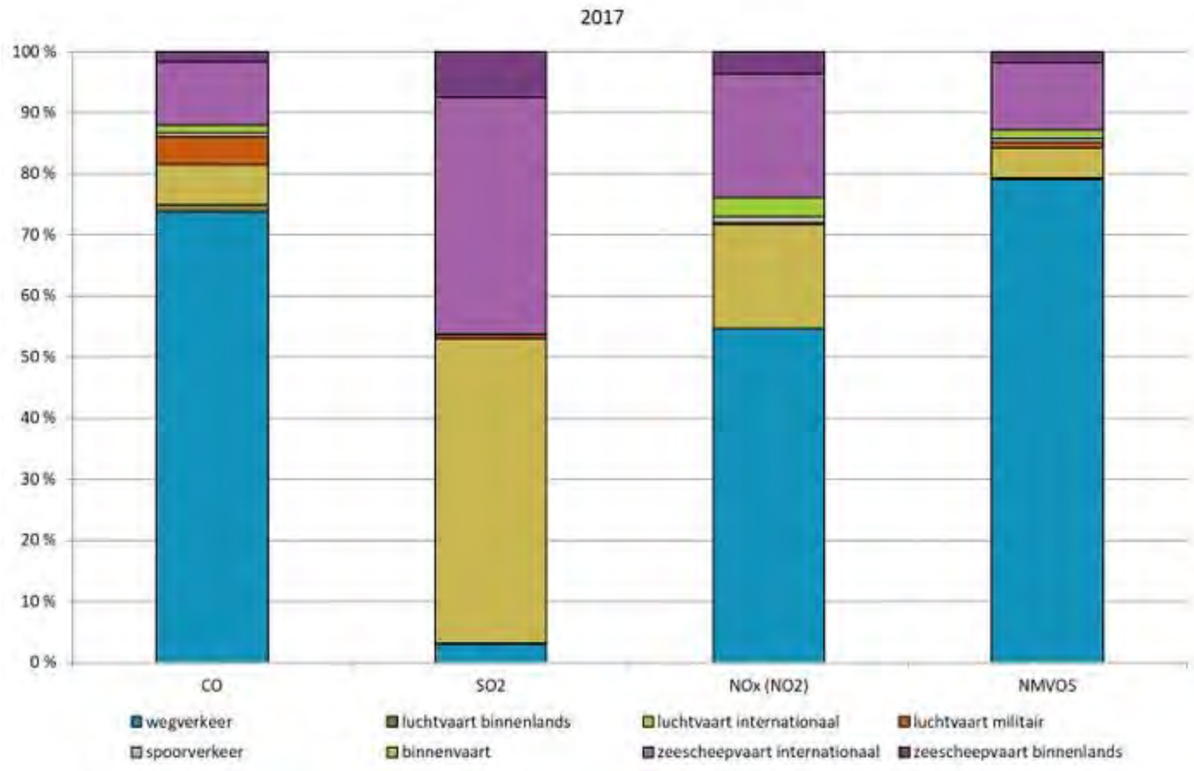

Figure 1: Air pollutant emissions per sector in Flanders

A complete review of the air pollutant emission inventory can be found on the VMM annual report[7].

2.2 METHODOLOGY

The analysis of the Flanders emissions inventory presented in the following sections aims to identify the vehicle categories and technologies that have the greatest impact on the total emissions in the Flemish region. The four regulated pollutants are examined in this study:

- Nitrogen oxides (NOx)
- Particulate Matter below 2.5 µm (PM2.5)
- Carbon monoxide (CO)
- Hydrocarbons (HC)

The emissions inventory includes detailed emissions calculations for all vehicle categories, including:

- Passenger cars (PC)
- Light commercial vehicles (LCV)
- Heavy duty trucks (HDT)
- Buses (BUS)
- Mopeds and motorcycles (L-cat)

[7] https://www.vmm.be/publicaties/lucht-2019/uitstoot-2000-2017-en-luchtkwaliteit-2018-in-vlaanderen-samenvatting

The above vehicle categories are further distinguished by fuel (petrol, diesel, other), and size, based on engine capacity for passenger vehicles or based on gross vehicle weight for freight vehicles.

Finally, all the above subsectors are further distinguished in technology classes based on the Euro emission standard:
– Pre Euro, Euro 1 through Euro 6 for light duty vehicles (PC, LCV, L-cat)
– Pre Euro, Euro I through Euro VI for heavy duty vehicles (HDT, BUS)

For each pollutant, the analysis is performed in two steps. In the first step, the total emissions from each vehicle category and fuel (e.g. petrol PCs, diesel, LCVs, HDTs, etc.) are extracted and ranked based on their share in total emissions. Then, for the three vehicle classes with the largest shares, the emissions are allocated to technology classes (e.g. petrol Euro 4 PCs, diesel Euro 5 LCVs, etc.).

For the identification of the vehicle classes having the largest contribution to total emissions two criteria are used:
– The absolute emission levels of each class
– The relative emission levels compared to the regulated emission limit of the class

For the comparison to emission limits, the average implied emission factor in grams of pollutant per vehicle-kilometre travelled (for light-duty) or in grams of pollutant per kilowatt-hour mechanical power output (for heavy-duty) is computed for each vehicle class. The total vehicle-kilometres for each class are computed as the product of vehicle population and mileage of that class. The total kilowatt-hours are calculated from the total fuel consumption, converted from tons to kilowatt-hours, and an assumed overall efficiency for converting the energy content of the fuel to mechanical power.

2.3 RESULTS

Data for the year 2017, the most recent year in the Flemish emissions inventory, were extracted and used as input for the analysis following the methodology described previously. In the following sections the results are presented separately for the four regulated pollutants.

2.3.1 NOx emissions

It is inherently known that diesel vehicles are responsible for the majority of NOx emissions from road transport. In Flanders this share exceeds 95%, as depicted in Figure 2. Diesel passenger cars are responsible for 44% of total NOx emissions, heavy duty trucks are responsible for 29% and diesel light commercial vehicles for 20%. All other vehicle classes contribute to the rest 7% of the total NOx emissions.

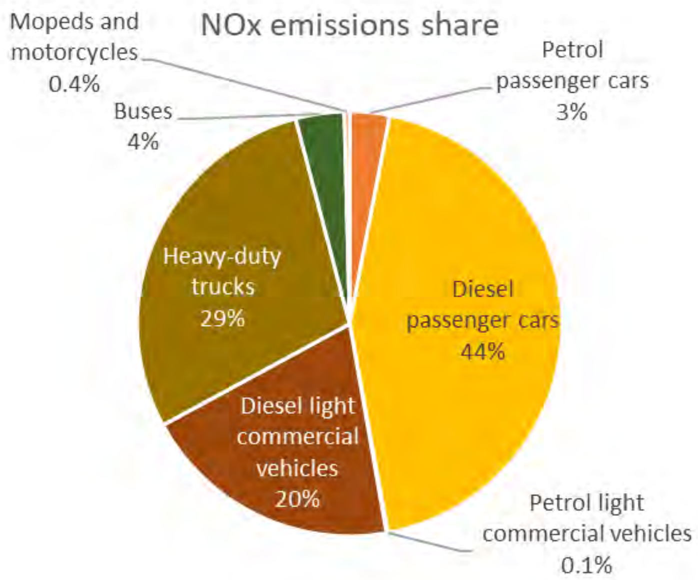

Figure 2: Contribution of the different vehicle and fuel types to the total NOx emissions from road transport in Flanders

2.3.1.1 Diesel passenger cars

Euro 6 and Euro 5 vehicles make up for more than 60% of the emissions from diesel passenger cars, whereas Euro 4 vehicles contribute about a quarter and Euro 3 about 10% of the emissions, as illustrated in Figure 3.

The colour scaling in the pie chart denotes the level of exceedance of calculated average emission factors compared to the respective emission limit. The dark blue colour denotes an exceedance of more than three times, whereas the light blue colour shows an exceedance up to two times and the intermediate blue colour shows exceedance between two and three times. The green light shows emission levels within the emission limit and hence no exceedance. The exact ratios of emissions relative to the respective emission limit for each Euro technology class are summarised in Table 1. It is noted that the average emission factors in the table reflect emissions in actual driving conditions representative for Flanders, as described in section 2.1.2.

On average, Euro 6 vehicles emit more than six times their respective emission limit (80 mg/km). This is due to the well-known diesel scandal revealed in 2015, which has affected the early stages of Euro 6 vehicles. The high emission levels can be attributed to the limited use of SCR, the main exhaust aftertreatment device to control NOx emissions, in real-world driving conditions. Euro 5 vehicles are also high emitters, with emission levels being on average more than three times the limit (180 mg/km).

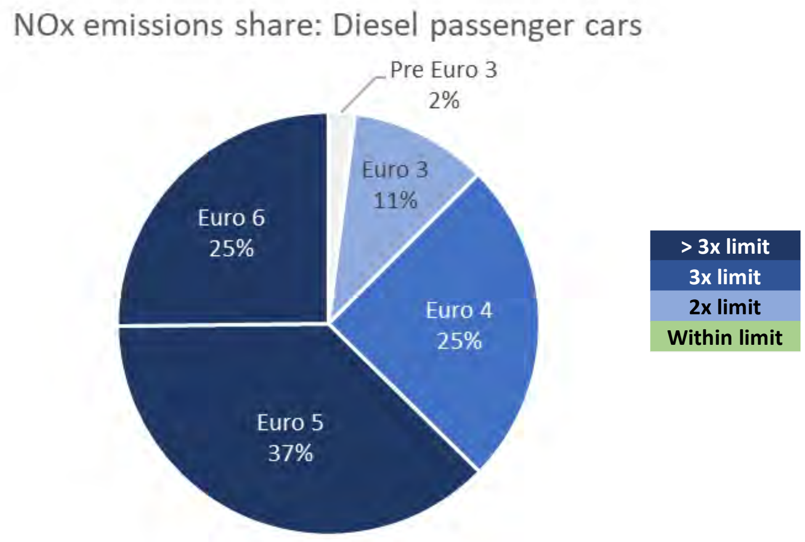

Figure 3: Contribution of the different Euro classes to the total NOx emissions from diesel passenger cars

Euro 4 vehicles emit about 2.5 times the emission limit (0,25 g/km), whereas Euro 3 emit somewhat closer to the emission limit, however they also exceed it (0,5 g/km). For these technologies emissions where controlled almost entirely by the three-way catalyst installed, without the need for any additional more sophisticated aftertreatment device.

Table 1: Average NOx emission factors of diesel passenger cars and comparison to emission limits

Euro class	Average emission factor (g/km)	Emission standard (g/km)	Exceedance ratio
Euro 3	0,79	0,50	*1,6*
Euro 4	0,61	0,25	*2,4*
Euro 5	0,62	0,18	*3,4*
Euro 6	0,51	0,08	*6,4*

2.3.1.2 Diesel heavy-duty trucks

Euro V is the largest contributor to NOx emissions, followed by Euro III and Euro IV. These three technologies combined have a share of almost 85% of NOx emissions from heavy-duty trucks. The Euro V standards required a substantial reduction of 60% over Euro II levels. In view of these strict requirements, real-world emissions reduced proportionally from Euro III to Euro V and these reductions were achieved with engine tuning and SCR systems.

As a result, Euro V trucks emit on average only slightly above the emission limits. Similar to Euro V, Euro III and Euro IV trucks also emit very close to their certification levels and hence are indicated with a light blue colour in Figure 4.

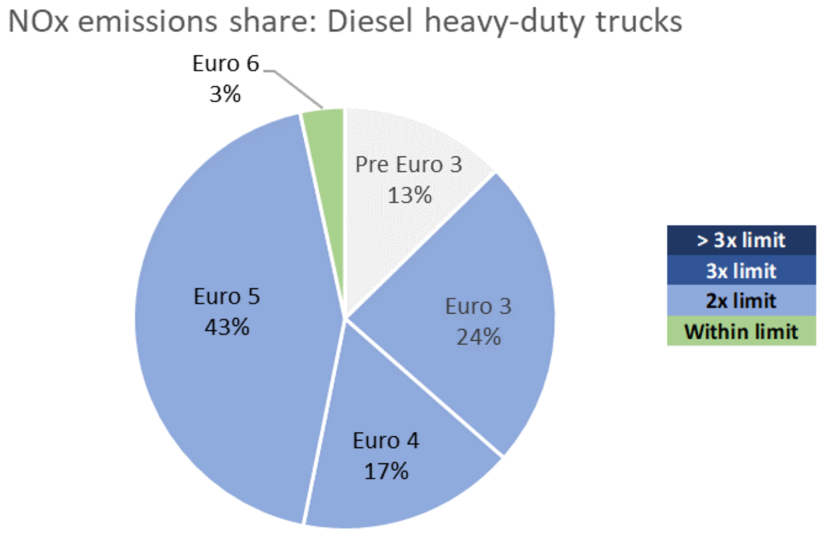

Figure 4: Contribution of the different Euro classes to the total NOx emissions from diesel heavy-duty trucks

Euro VI trucks have only a very small 3% share of the NOx emissions. This is due to the combined effect of their small population in the trucks fleet and the very low (compared to previous Euro technologies) emission levels, much lower than the Euro VI limit (Table 2). This finding is also confirmed by an ICCT study (ICCT, 2016) which concludes that, in contrast to Euro 6 cars, Euro VI trucks do not systematically emit more NOx in real-word everyday operation than they are certified to.

Table 2: Average NOx emission factors of diesel heavy-duty trucks and comparison to emission limits

Euro class	Implied emission factor (g/kWh)	Emission standard (g/kWh)	Exceedance ratio
Euro III	5,67	5,00	*1,1*
Euro IV	4,04	3,50	*1,2*
Euro V	2,36	2,00	*1,2*
Euro VI	0,16	0,40	*0,4*

2.3.1.3 Diesel light commercial vehicles

An almost identical to diesel passenger cars picture is observed for diesel light commercial vehicles, as illustrated in Figure 3. Euro 5 and Euro 6 vehicles dominate NOx emissions with a more than 70% share, and they are emitting several times above the respective limits. This is expected as they share to a very large extent the same technology – and the same problems that come with it – with diesel cars.

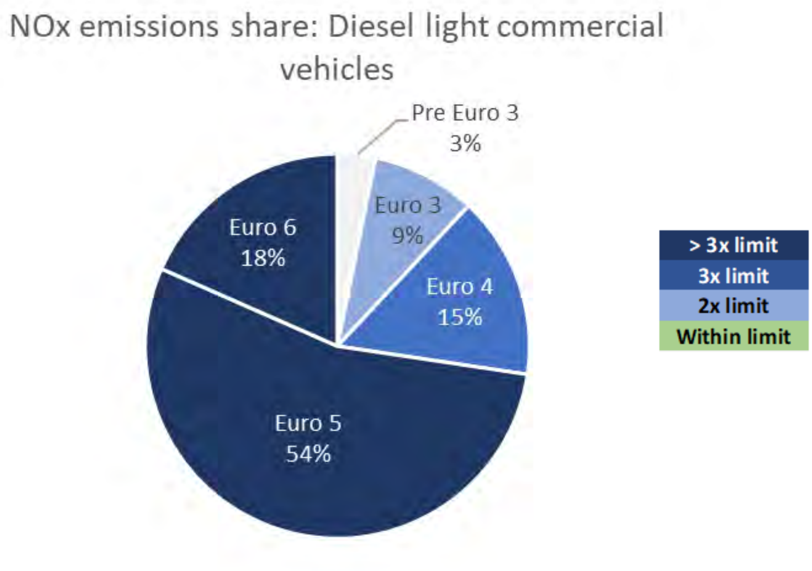

Figure 5: Contribution of the different Euro classes to the total NOx emissions from diesel light commercial vehicles

The contribution of Euro 4 and Euro 3 is much lower, on the order of 25%, mainly due to the gradual phase-out of these technologies from the Flemish vehicle fleet. Moreover, the emissions performance is also substantially better for the same reasons explained previously for passenger cars.

Table 3: Average NOx emission factors of diesel light commercial vehicles and comparison to emission limits

Euro class	Implied emission factor (g/km)	Emission standard (g/km)	Exceedance ratio
Euro 3	1,09	0,78	*1,4*
Euro 4	0,88	0,39	*2,3*
Euro 5	1,59	0,28	*5,7*
Euro 6	1,28	0,125	*10,3*

2.3.2 PM emissions

Diesel vehicles are responsible for the majority of PM emissions, contributing to more than 90% of total emissions. Diesel passenger cars are responsible for 47% of total $PM_{2.5}$ emissions in Flanders, as illustrated in Figure 6. Heavy-duty trucks are responsible for 26% and light commercial vehicles for 16%. All other vehicle classes contribute to the rest 10% of total $PM_{2.5}$ emissions.

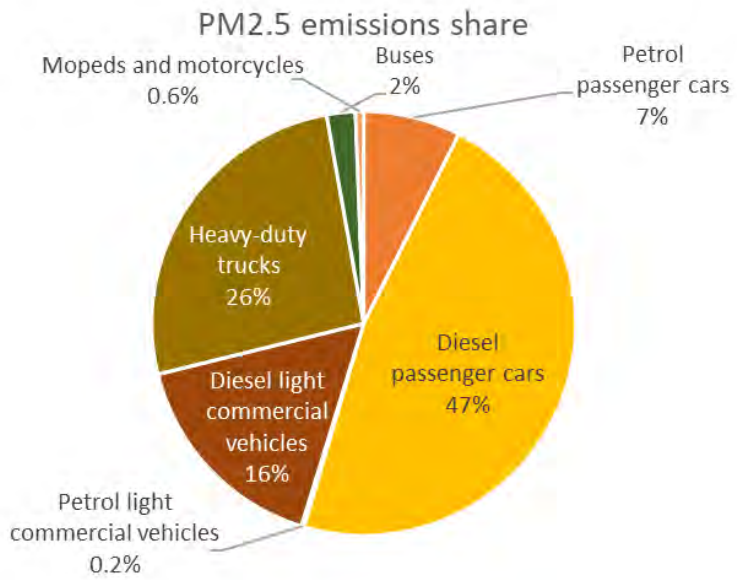

Figure 6: Contribution of the different vehicle and fuel types to the total PM emissions from road transport in Flanders

2.3.2.1 Diesel passenger cars

Euro 3 and Euro 4 vehicles, despite their decreasing population, still make up for more than 60% of the $PM_{2.5}$ emissions from diesel passenger cars (Figure 7). Euro 3 cars emit on average very close to the legislative limit of 0.05 g/km. Although the emission limit was reduced by half at the Euro 4 step, the emission levels improved only slightly.

For Euro 5 and Euro 6 vehicles the emission limit was reduced drastically, by 80% compared to Euro 4, down to 5 mg/km. In response to these much stricter limits most of the new vehicles were equipped with a diesel particle filter (DPF) which resulted in the emissions of Euro 5 and Euro 6 diesel cars to be also reduced by about 80%. However, these reductions were not sufficient for Euro 5 and Euro 6 cars to comply with their respective emission limits which they exceed by more than 100% as summarised in Table 4.

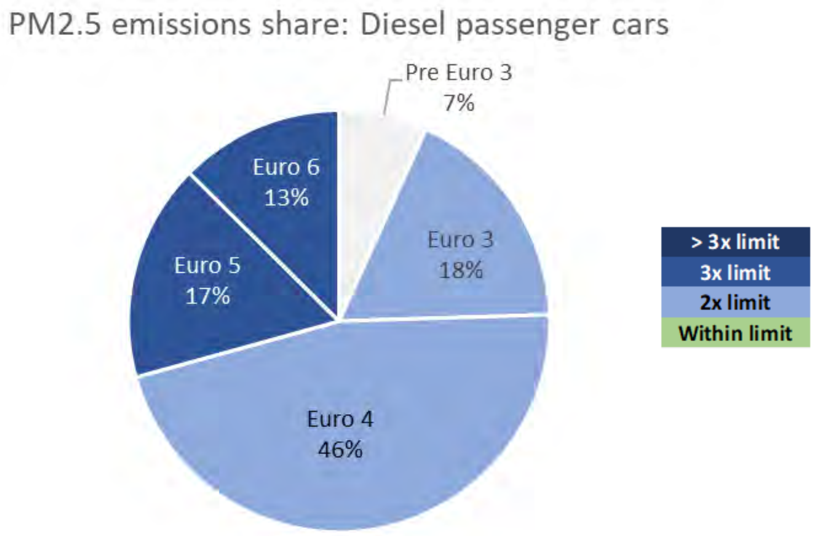

Figure 7: Contribution of the different Euro classes to the total PM emissions from diesel passenger cars

Table 4: Average PM emission factors of diesel passenger cars and comparison to emission limits

Euro class	Implied emission factor (g/km)	Emission standard (g/km)	Exceedance ratio
Euro 3	0,051	0,050	*1,0*
Euro 4	0,043	0,025	*1,7*
Euro 5	0,010	0,005	*2,2*
Euro 6	0,010	0,005	*2,2*

2.3.2.2 Diesel heavy-duty trucks

Heavy-duty vehicles largely follow the trend of passenger cars with Euro III trucks emitting closer to the emission limit and Euro IV and later vehicles emitting substantially higher than the respective limits (Figure 8 and Table 5). Whereas an 80% reduction in the emission limit was brought by the Euro IV standards, actual emissions only reduced by about 60%. As a result, post Euro III vehicles emit, on average, about two times above the PM emission limit and they are responsible for nearly 70% of the PM emissions from diesel trucks.

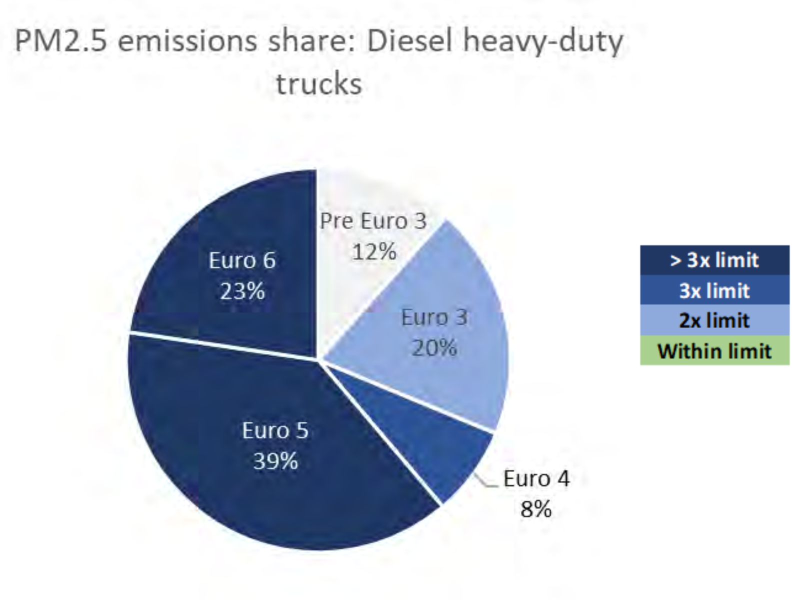

Figure 8: Contribution of the different Euro classes to the total NOx emissions from diesel heavy-duty trucks

Table 5: Average PM emission factors of diesel heavy-duty trucks and comparison to emission limits

Euro class	Implied emission factor (g/kWh)	Emission standard (g/kWh)	Exceedance ratio
Euro III	0,152	0,10	*1,5*
Euro IV	0,060	0,02	*3,0*
Euro V	0,066	0,02	*3,3*
Euro VI	0,033	0,01	*3,3*

2.3.2.3 Diesel light commercial vehicles

For diesel light commercial vehicles similar observations to diesel cars and trucks can be made (Figure 9 and Table 6). Euro 3 and Euro 4 vehicles have a 65% share in PM emissions, but they generally comply with the legislative limits. The gap between emission limit and real-world performance increases drastically for the latest Euro 5 and Euro 6 technologies, despite the extensive use of DPFs. Even though the two Euro classes do not yet have a big contribution to the total emissions, with the gradual phase out of older technologies, a large part of the emissions reduction potential might be lost if emission levels are not further reduced.

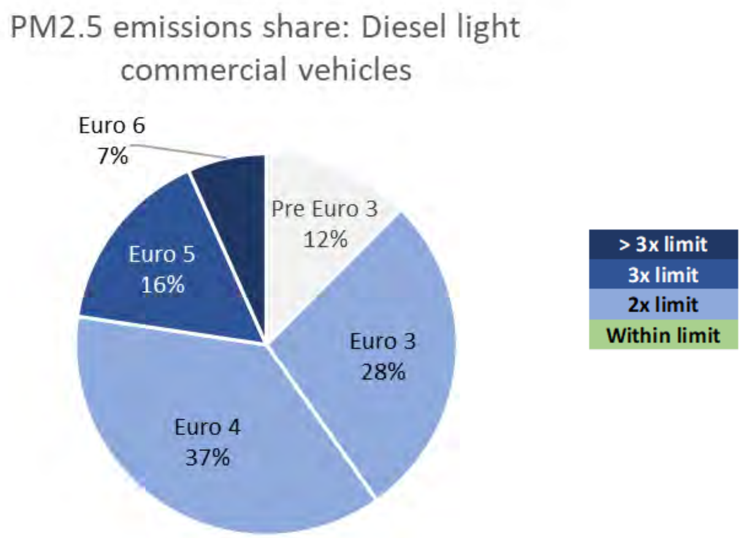

Figure 9: Contribution of the different Euro classes to the total PM emissions from diesel light commercial vehicles

Table 6: Average PM emission factors of diesel light commercial vehicles and comparison to emission limits

Euro class	Implied emission factor (g/km)	Emission standard (g/km)	Exceedance ratio
Euro 3	0,101	0,100	*1,0*
Euro 4	0,062	0,060	*1,0*
Euro 5	0,014	0,005	*2,7*
Euro 6	0,015	0,005	*3,0*

2.3.3 CO emissions

Petrol vehicles contribute by more than 70% to total CO emissions in Flanders. Figure 10 shows that petrol passenger cars are by far the largest contributor, being responsible for 54% of total emissions. Heavy duty trucks are responsible for 16% and mopeds and motorcycles for 14%. All other vehicle classes contribute to the rest 16% of total CO emissions.

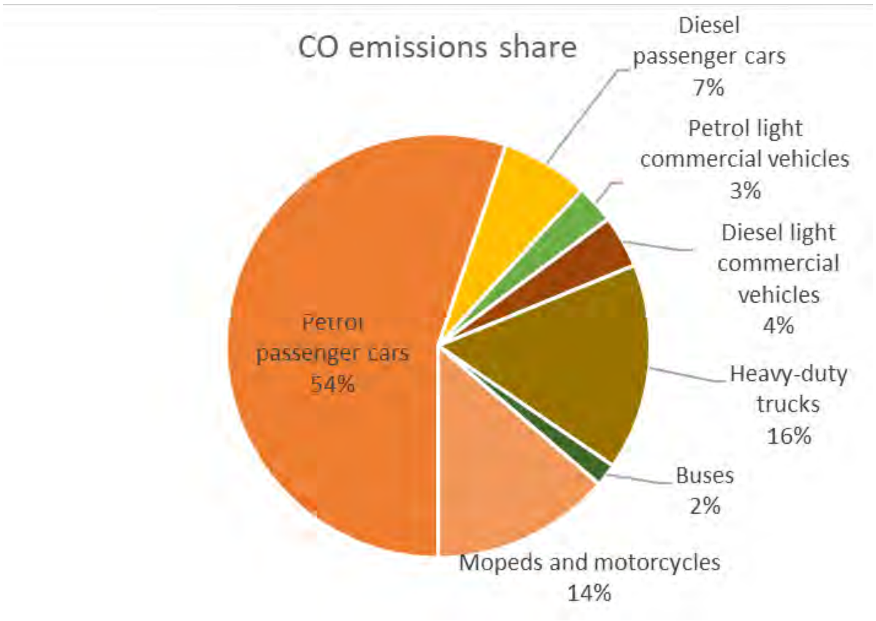

Figure 10: Contribution of the different vehicle and fuel types to the total CO emissions from road transport in Flanders

2.3.3.1 Petrol passenger cars

Petrol cars generally comply with the emission limits across all Euro standards with real-world emissions performance following the emission limits as illustrated in Table 7. The introduction and continuous improvement, in terms of emissions control efficiency and monitoring, of the three-way catalyst since the early Euro stages has resulted in the real-world emission levels being kept within the respective legislative limits.

Figure 11 shows that pre-Euro 3 cars still have a high share of 35% in CO emissions. This is due to the combined effect of originally higher emissions, yet within the limit, and the degradations of their catalytic converters with accumulated mileage.

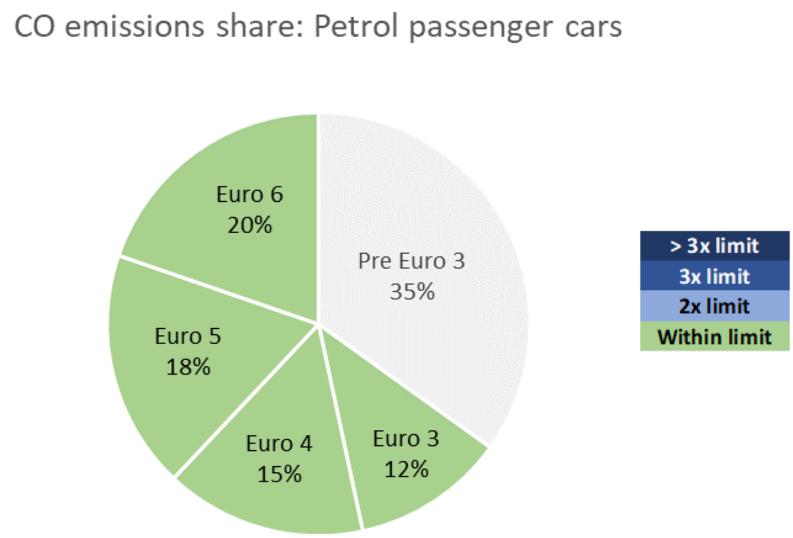

Figure 11: Contribution of the different Euro classes to the total CO emissions from petrol passenger cars

Table 7: Average CO emission factors of petrol passenger cars and comparison to emission limits

Euro class	Implied emission factor (g/km)	Emission standard (g/km)	Exceedance ratio
Euro 3	2,1	2,3	*0,9*
Euro 4	0,8	1,0	*0,8*
Euro 5	0,8	1,0	*0,8*
Euro 6	0,7	1,0	*0,7*

2.3.3.2 Mopeds and motorcycles

Euro 3 mopeds and motorcycles dominate the emissions of CO, accounting for almost 60% of the total emissions. Despite the improvement over Euro 2, largely due to the use of more efficient catalysts and the replacement of carburettors by fuel injection systems to almost all motorcycle models, their emission levels are about 40% above the limit of 2 g/km.

Figure 12 shows that pre-Euro 2 mopeds and motorcycles still have a high share of more than 30% of CO emissions. This is due to their relatively high share in the fleet and the fact that only few vehicles are equipped with catalysts to control emissions.

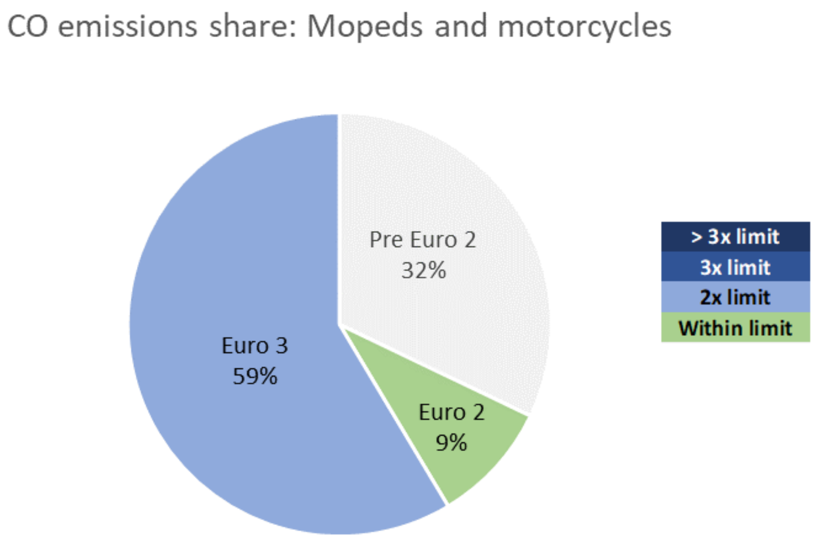

Figure 12: Contribution of the different Euro classes to the total CO emissions from mopeds and motorcycles

Table 8: Average CO emission factors of mopeds and motorcycles and comparison to emission limits

Euro class	Implied emission factor (g/km)	Emission standard (g/km)	Exceedance ratio
Euro 2	4,3	5,5	*0,8*
Euro 3	2,7	2,0	*1,4*

2.3.3.3 Diesel heavy-duty trucks

CO emissions from heavy-duty trucks are well below the emission limit across all Euro standards as illustrated in Figure 13. Euro 5 vehicles dominate the trucks fleet in Flanders and hence also the CO emissions having a share of about 60%. The emissions of CO (and HC as well) are effectively controlled by the diesel oxidation catalyst installed in all trucks.

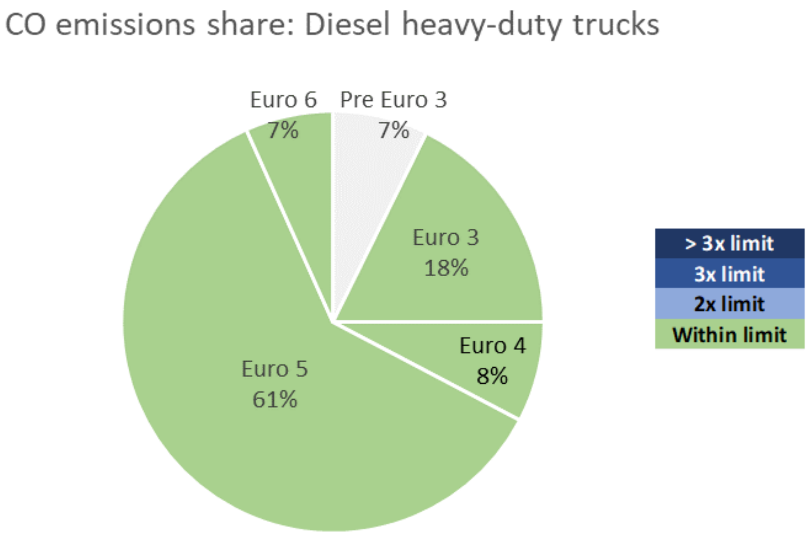

Figure 13: Contribution of the different Euro classes to the total CO emissions from diesel heavy-duty trucks

Table 9: Average CO emission factors of diesel heavy-duty trucks and comparison to emission limits

Euro class	Implied emission factor (g/kWh)	Emission standard (g/kWh)	Exceedance ratio
Euro III	1,51	2,10	*0,7*
Euro IV	0,68	1,50	*0,5*
Euro V	1,16	1,50	*0,8*
Euro VI	0,11	1,50	*0,1*

2.3.4 HC emissions

Similar to CO emissions, petrol vehicles are the largest producer of HC emissions, contributing more than 80% to total emissions in Flanders. Figure 14 shows that petrol passenger cars are by far the largest contributor, being responsible for 60% of total emissions in Flanders. Mopeds and motorcycles are responsible for 18% and heavy-duty trucks for 9%. All other vehicle classes contribute to the rest 13% of total HC emissions.

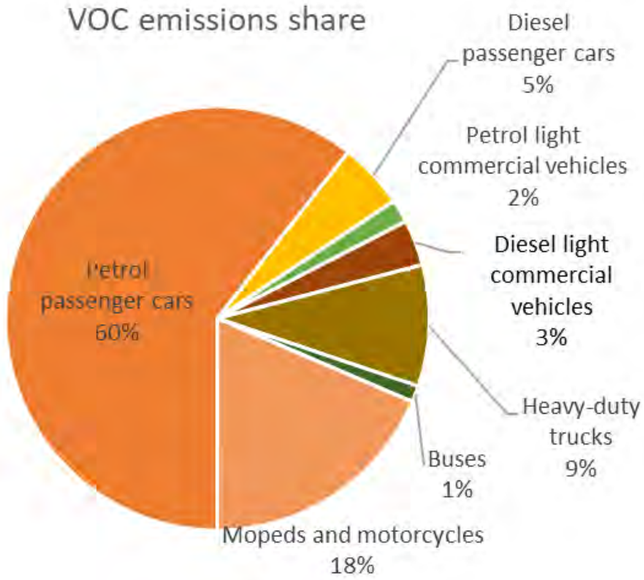

Figure 14: Contribution of the different vehicle and fuel types to the total HC emissions from road transport in Flanders

2.3.4.1 Petrol passenger cars

HC emissions of petrol passenger cars are generally close to the respective emission limits across all Euro standards, yet they exceed the limit by 20 to 50%. Emissions levels were reduced from the Euro 3 to the Euro 4 step following a tightening of the limit and they remained nearly constant afterwards as the emission limit were not further reduced. As described previously for CO emissions, the introduction and continuous improvement of the three-way catalyst since the early Euro stages has resulted in the real-world HC emission levels being kept at reasonably low levels.

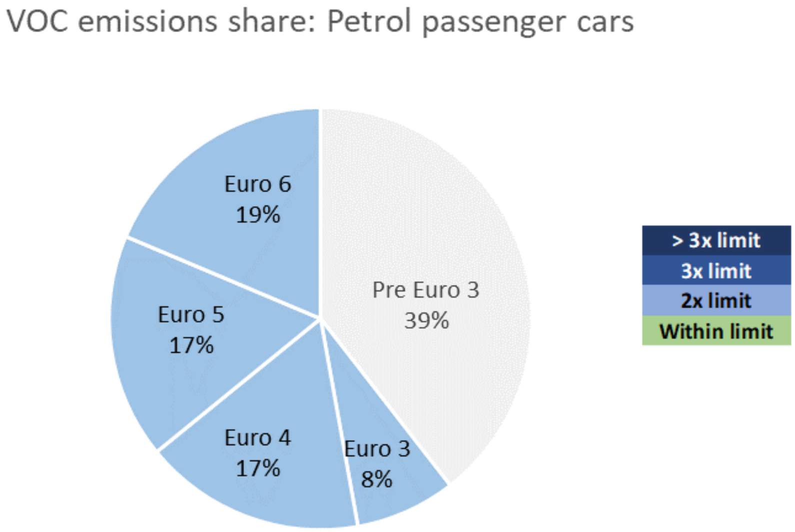

Figure 15: Average HC emission factors of petrol passenger cars and comparison to emission limits

Table 10: Average HC emission factors of petrol passenger cars and comparison to emission limits

Euro class	Implied emission factor (g/km)	Emission standard (g/km)	Exceedance ratio
Euro 3	0,25	0,2	*1,2*
Euro 4	0,16	0,1	*1,5*
Euro 5	0,13	0,1	*1,3*
Euro 6	0,12	0,1	*1,2*

2.3.4.2 Mopeds and motorcycles

Euro 3 mopeds and motorcycles dominate the emissions of HC, accounting for almost 65% of the total emissions. Mopeds and motorcycles are shown separately in Figure 16 and in Table 11 as they have different emission limits. Motorcycles emissions were reduced drastically from Euro 2 to Euro 3, however they still emit twice the emission limit. The emissions performance of mopeds on the other hand has improved going from Euro 2 to Euro 3.

Figure 16 shows that pre-Euro 2 mopeds and motorcycles still have a high share of more than 25% of HC emissions. This is due to their relatively high share in the fleet and the fact that only few vehicles are equipped with catalysts to control emissions.

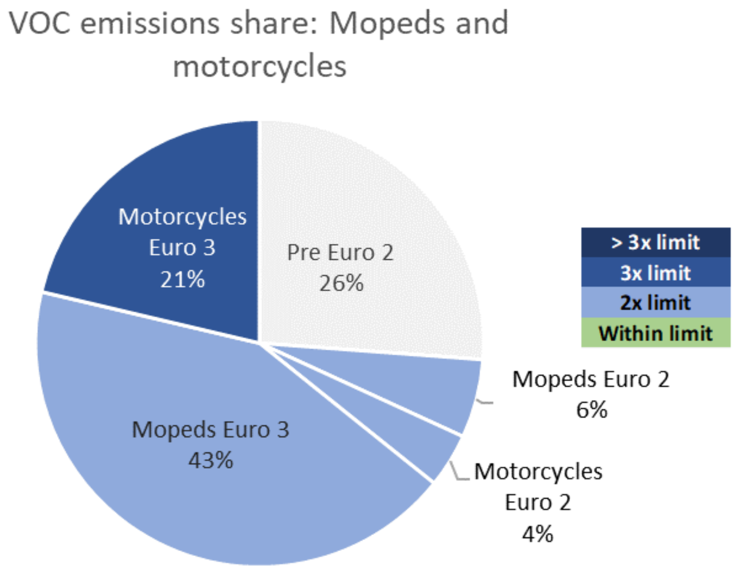

Figure 16: Contribution of the different Euro classes to the total HC emissions from mopeds and motorcycles

Table 11: Average HC emission factors of mopeds and motorcycles and comparison to emission limits

Euro class	Implied emission factor (g/km)	Emission standard (g/km)	Exceedance ratio
Mopeds Euro 2	2,01	1,20	*1,7*
Mopeds Euro 3	1,00	1,00	*1,0*
MC Euro 2	1,51	0,80	*1,9*
MC Euro 3	0,63	0,30	*2,1*

2.3.4.3 Diesel heavy-duty trucks

HC emissions from heavy-duty trucks are very low, well below the emission limit across all Euro standards as illustrated in Figure 17. Euro 3 vehicles still have an important share of about 35% which is due to the higher emission levels of trucks at this technology step, rather than their population. The emissions of HC (and CO as well) are effectively controlled by the diesel oxidation catalyst installed in all trucks already at the early Euro stages.

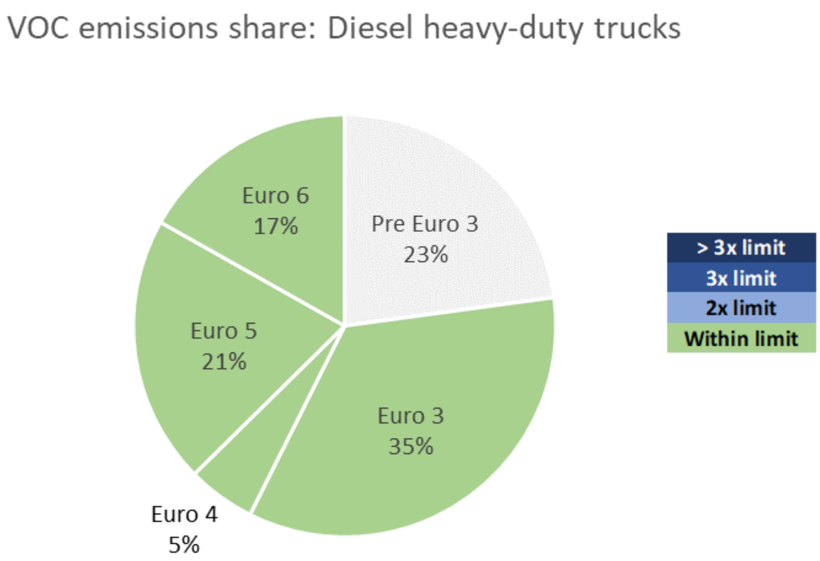

Figure 17: Contribution of the different Euro classes to the total HC emissions from diesel heavy-duty trucks

Table 12: Average HC emission factors of diesel heavy-duty trucks and comparison to emission limits

Euro class	Implied emission factor (g/kWh)	Emission standard (g/kWh)	Exceedance ratio
Euro 3	0,27	0,66	*0,4*
Euro 4	0,04	0,46	*0,1*
Euro 5	0,03	0,46	*0,1*
Euro 6	0,02	0,13	*0,2*

3 PROPOSED METHODOLOGY TO ORGANISE RISK-BASED MARKET SURVEILLANCE USING REMOTE SENSING DATA

3.1 USE OF REMOTE SENSING DATA

The first step includes collection of real-world emission data on RDE-ISC vehicles, with the use of remote sensing data. The vehicle models ranking methodology, based on a ranking of high emitting vehicle models obtained using remote sensing, is proposed for the detection of potential high emitters. According to this methodology, vehicle models are ranked based on the average emissions of all monitored vehicles belonging to the same model. The vehicle model is defined by its commercial name, fuel, and Euro standard. All vehicle models with average emissions 1,5 times above the average emissions of all monitored vehicles belonging to the same model are characterised as potential high emitters.

For the identification of vehicle models the occurrence of these models in Flanders based on annual sales must be also taken into consideration. To this aim, the number of new registrations for each vehicle model, by fuel, for the latest year for which data is available (usually the year before) must be extracted for Flanders from official statistics. As an example, the best-selling vehicle models in Belgium[8] are listed in Table 13, processed from the CO_2 emissions monitoring database managed by the European Environment Agency[9]. The top selling diesel and petrol cars (the VW Golf 1.6 diesel and the Citroen C3 1.2 petrol) account for 2,4% and 2,1% respectively of the total passenger cars registered in Belgium in 2018.

Table 13: Top 30 best-selling diesel and petrol passenger car models (Euro 6) in Belgium, in 2018

Vehicle model	Number of registrations	Vehicle model	Number of registrations
Diesel		Petrol	
VW Golf 1.6l	20.385	Citroen C3 1.2L	14.973
Peugeot 308 1.6l	15.986	Peugeot 2008 1.2L	14.941
Renault Clio 1.5l	15.019	Peugeot 208 1.2L	14.424
Audi A4 Avant 2.0l	13.904	Fiat 500 1.2l	14.136
Scoda Octavia 1.6l	13.745	VW Golf 1.2l	13.520
Volvo XC60 2.0l	12.810	VW Polo 1.0l	13.438
Citroen C4 Picasso 1.6l	12.409	Hyundai Tucson Ix35 1.6L	13.064
Renault Megane Scenic 1.5l	12.332	Opel Corsa 1.2L	12.179
Renault Megane 1.5l	12.296	Renault Megane 1.2l	11.906
Volvo V40 2.0l	12.116	Renault Clio 0.9l	11.399
Dacia Duster 1.5l	11.959	Dacia Sandero 0.9l	10.880
Hyundai Tucson 1.7L	11.043	Ford Fiesta 1.0l	10.533
Audi A3 Sportback 1.6l	10.771	Renault Captur 0.9l	9.772
BMW 318d 2.0l	10.505	Citroen C4 1.2l	9.660
VW Tiguan 2.0l	10.371	Opel Mokka 1.4L	8.566
VW Passat 1.6l	9.329	VW Tiguan 1.4l	8.465
Astra Sports Tourer 1.6l	8.726	Opel Corsa 1.4L	8.243
Mercedes A 180 Cdi	8.615	Nissan Qashqai 1.2l	7.966
Renault Captur 1.5l	8.542	Toyota Auris 1.8l	7.843

[8] Belgium is used as a proxy for Flanders in this case.
[9] https://www.eea.europa.eu/data-and-maps/data/co2-cars-emission-18/co2-emissions-cars-2018-final

Peugeot 3008 1.6l	8.256	Peugeot 308 1.2l	7.607
Peugeot Partner 1.6l	8.227	Renault Captur 1.2l	7.229
Citroen Berlingo 1.6l	7.924	VW Polo 1.2l	6.854
BMW X1 Sdrive18d 2.0L	7.863	VW Golf 1.4l	6.571
Volvo V60 2.0l	7.813	Hyundai I20 1.2L	6.491
Audi Q5 2.0l	7.351	Skoda Fabia 1.2l	6.377
Peugeot 2008 1.6l	7.206	Seat Ibiza 1.0l	6.259
VW Passat 2.0l	7.186	Renault Twingo 1.0l	6.182
BMW 116d Efficient Dynamics 1.5L	7.010	Renault Clio 1.2l	5.960
Audi A6 Avant 2.0l	6.907	Toyota Aygo 1.0l	5.552
Nissan Qashqai 1.5l	6.781	Audi A1 1.0l	5.518

The vehicle selection list can be further refined to ensure a suitable range of manufacturers are covered.

3.2 MINIMUM SAMPLE SIZE

For the computation of average emissions of each vehicle model, a minimum number of emissions records in the remote sensing database must be ensured in order for this average value to be representative and not biased by very few high (or low) emission values. The exact number of records needed depends on the statistical characteristics of the monitored emissions (standard deviation, confidence level, etc.) and can be determined as described in the following.

There is a certain number of valid emissions records for any specific vehicle model included in a remote sensing dataset. The well-known formula for the calculation of the confidence interval of the mean of a population in order to determine the necessary sample size threshold (Montgomery and Runger, 2003) is suggested to be used. The formula calculates the size of the sample that is required to achieve a pre-defined level of accuracy for the estimation to be made, i.e. the estimation of the unknown mean emissions level of a specific model in this case.

To that end, the average and standard deviation values obtained from the remote sensing dataset for a given vehicle model are used to determine the respective coefficient of variation. The desired precision and the level of confidence of the estimation to be made must also be defined. The minimum sample size (n) is then calculated as follows:

$$n = \left(\frac{z_{a/2}}{e} * cv\right)^2$$

Where:

n the required sample size of measurements for a given vehicle model

α the type I error; (1-α) is the confidence level of the respective interval (e.g. given a value of α=0.05 or 5% type I error we calculate the respective (1-α) or 95% confidence interval)

$z_{a/2}$ the standard normal variable value that corresponds to the $(1-\frac{a}{2})$ cumulative probability of the respective standard normal distribution (e.g. for a given value of α=0.05, the respective cumulative probability is $\left(1-\frac{a}{2}\right) = 0.975$, and $z = 1.96$)

e the desired percentage error or the targeted precision for the estimated population mean, i.e. ±e% of the unknown population mean (μ) (e.g. e=0.1 for a precision of ±10%)

cv the population coefficient of variation, i.e. $cv = \frac{\sigma}{\mu}$ (with μ being the sample mean and σ being the standard deviation)

As application examples of the above method the two best-selling models in Belgium, the VW Golf 1.6 diesel and the Citroen C3 1.2 petrol (see also Table 13), were selected. The main data are summarised in Table 14, in which the number of emission records included in the remote sensing database is indicated in the first row, whereas the sample mean and standard deviation are calculated from this sample. The minimum number of emission records is calculated for an assumed confidence level of 95% and two different error values. It is evident that the minimum sample size reduces drastically by increasing the error, or the targeted precision for the estimated population mean, from 10% to 20%.

Another interesting observation is the effect of the measured emissions variability, expressed by the standard deviation. For the petrol vehicle, this variability is much larger (i.e. the standard deviation is much larger than the mean) compared to the diesel vehicle. As a result, the minimum number of samples required for the petrol car is about six times higher than for the diesel. Similar findings are observed for other petrol cars too. For reducing this number an even higher error and a lower confidence level would have to be selected.

Table 14: Calculation of minimum sample size for the two best-selling models

Cut-off point	VW Golf 1.6 diesel		Citroen C3 1.2 petrol	
Number of RS data	973		67	
Mean (μ)	7,39		1,14	
Std. deviation (σ)	7,79		3,03	
Confidence level (1-α)	95%		95%	
Error (e)	10%	20%	10%	20%
Minimum sample size (n)	427	107	2.737	684

3.3 FOLLOW-UP

The vehicle models identified with the above methodology must be then further investigated following an appropriate testing programme. This can include testing against WLTP and RDE requirements to assess the actual emissions performance under real-world conditions. The exact specifications, including testing scale and protocol, must be carefully designed for this purpose and the remedial actions clarified.

4 DISCUSSION AND CONCLUSIONS

Laboratory-based (including PEMS) emission factors used in emission models, such as in COPERT, provide a very good estimate of the actual emission levels of the circulating road vehicle fleet in any given geographic area at the national, regional or local level.

In the case of Flanders, the analysis of the emissions inventory has provided useful information on the real-world emissions performance of the vehicle fleet and the contribution of the different vehicle categories, fuels, and technology classes to the total emissions of the regulated pollutants. The most important findings of the analysis are:

- NOx emissions are dominated by diesel passenger cars and light commercial vehicles, with Euro 5 and Euro 6 vehicles emitting several times above the respective limits. Heavy duty trucks, despite being responsible for almost a third of the total NOx emissions, on average emit very close to the emission limits.
- Diesel vehicles are responsible for the majority of PM emissions, contributing to more than 90% of total emissions. All diesel vehicle categories of the latest Euro 5 and Euro 6 standards exceed the PM emission limits by up to two times.
- Petrol vehicles are the largest producers of CO and HC emissions, contributing more than 60% and 80% respectively to total emissions in Flanders. However, most vehicle classes comply with the respective emission limits, with very few exceptions.

Based on the previous analysis and findings, a methodology for vehicle fleet screening to identify potentially high emitting vehicle models is proposed. The main elements of the suggested methodology are:

- Collection of real-world emission data on RDE-ISC vehicles with the use of remote sensing data.
- The vehicle models ranking methodology is proposed for the detection of potential high emitters. Based on this, all vehicle models with average emissions 1,5 times above the average emissions of all monitored vehicles are flagged as potential high emitters.
- For the identification of vehicle models the occurrence of these models in Flanders based on annual sales must be also taken into consideration. To this aim, the number of new registrations for each vehicle model, by fuel, for the latest year for which data is available must be collected.
- A minimum number of emissions records is required for ensuring accuracy of the estimated average emission value. A mathematical formula based on basic statistical metrics for calculating this sample is provided.
- Further investigations for the detected vehicle models following an appropriate testing programme (e.g. WLTP and/or RDE) is required. The exact specifications, including testing scale and protocol, must be carefully designed for this purpose and the remedial actions clarified.

The analyses performed in this study provide significant insight on the actual emission levels of the Flemish vehicle fleet, indicating which are the vehicle categories and technologies contributing most to the high emissions observed for NOx. However, they can provide only indications on the likely extent and impact of tampering of emission control devices. A remote sensing measurement lasts for less than one second and hence any excess emissions measured for one vehicle cannot necessarily be attributed to tampering as the emissions control device in that specific moment might not operate properly for different reasons. For such applications, multiple measurements would be required.

Remote sensing offers a useful tool for fleet monitoring and collecting emission readings from a large number of vehicles. Using statistical analyses, it provides useful insight about the emission performance of specific groups of vehicles (e.g. vehicle models). Applied as such, the results provide insight into the in-service compliance of vehicles put on the market by manufactures. This way, remote sensing can play an important role in the market surveillance schemes which member states are required to set up starting in September 2020.

When remote sensing schemes are set up in Belgium for such applications, we recommend taking the opportunity to carry out further research into the possibilities and restrictions for future applications of the technique. A dedicated study targeting high emitters only could shed more light into the reasons of high emitting vehicles and quantify the impact of different effects, including tampering, emissions degradation and driving behaviour.