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NAEI ROAD TRANSPORT INVENTORY

Implementation of COPERT 5.6 Factors into the NAEI Road Transport Model

Report for: Department for Environment Food and Rural Affairs

Ricardo ref. ED15103155 Issue: 01 September 2023

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Date:
6th September 2023

Ricardo reference:
ED15103155

CONTENTS

1. FOREWORD

This report is the result of improvement work that was done in 2023 and implemented into the NAEI published in 2024 which covered up to the calendar year 2022. This report has been published to ensure that the methodology of the NAEI is as clear and transparent as possible. After this improvement work was completed, further updates on COPERT were released (and will continue to be released). The latest update as of January 2025 (COPERT v5.8) has been implemented into the inventory for publication in 2025 and the methodology will be described in the Informative Inventory Report published in 2025.

The proposed changes for the COPERT 5.7 were implemented as described in section 6.

2. GLOSSARY

BEV – Battery Electric Vehicle

CH_4 – Methane

CO – Carbon monoxide

COPERT – Calculation of Emissions from Road Transport

DfT – Department for Transport

ICE – Internal Combustion Engine

GDI – Gasoline Diesel Injection

HDV – Heavy-Duty Vehicles

HGV – Heavy-Goods Vehicles

LDV – Light-Duty Vehicles

LGV – Large Goods Vehicle

LPG – Liquefied petroleum gas

NAEI – National Atmospheric Emissions Inventory

NH_3 – Ammonia

NMVOCs – Non-methane volatile organic compounds

NO_x – Nitrogen dioxides

PCM – Pollution Climate Mapping

PFI – Port Fuel Injection

PHEV – Plug-in Hybrid Vehicles

PM – Particulate Matter

RDE – Real Driving Emissions

SCR – Selective Catalytic Reduction

TFEIP – Task Force on Emission Inventories and Projections

TSP – Total Suspended Particulates

WLTC – The Worldwide harmonized Light vehicles Test Cycles

3. INTRODUCTION

The UK's National Atmospheric Emissions Inventory (NAEI) estimates emissions from road transport using a methodology and set of vehicle specific emission factors from the EMEP/EEA air pollutant emission inventory Guidebook and the COPERT model. The Guidebook was updated in December 2022 in line with a new version of COPERT v5.6.

A summary of the main changes made to the factors was provided in a short report to Defra in February 2023, but at that time a full implantation of the new factors into the NAEI road transport emissions model had not been undertaken showing the impact these changes have on the overall inventory for both historic years and the projections. This document describes the updates to the emissions model which have now been made and shows the changes in UK emissions that occur as a result by comparison with the UK emissions in the 2021 NAEI reported in March 2023 which used factors from a previous version of the Guidebook and COPERT 5.4

In summary, the updates between COPERT 5.4 and COPERT 5.6 were to the:

- Non-exhaust emission factors for particulate matter (PM)
- Relationships for the degradation of hot exhaust emissions with vehicle mileage
- Cold start emission factors
- Revisions to emission factors for LPG cars
- Updates to PM exhaust emission factors

Emissions results are provided to visualise the effect of these changes on key pollutant emissions. The focus for these comparisons is on the pollutants NO_x, PM (exhaust and non-exhaust), and NMVOCs. Emission factors for NH_3 were also investigated however there were no changes for NH_3 in the update from COPERT 5.4 to COPERT 5.6.

In March 2023, we became aware that a further update to the factors in the Guidebook was being proposed. This would also be implemented in a new version of COPERT 5.7 which was not available at the time this comparison work was done. These updates were presented at the TFEIP meeting held in Oxford in April 2023, and have since been formerly adopted in the Guidebook, but not in time for completion of this work and incorporation into the 2022 version of the NAEI. The proposed changes to the emission factors are relatively minor compared with the changes made for COPERT 5.6, but this report provides a summary of the changes and their likely impacts on the inventory should they be adopted.

4. UPDATES TO COPERT 5.6

4.1 EMISSION DEGRADATION

The EMEP/EEA Inventory Guidebook provides correction factors that should be applied to baseline emission factors to account for the increase in emissions as vehicles age due to increased mileage. Degradation functions are provided to simulate the deterioration of emissions of NO_x, CO and NMVOCs. COPERT 5.4 and earlier versions of COPERT provided deterioration functions for Euro 1 to Euro 4 petrol cars and LGVs only, but not for more recent Euro standards. The following updates were introduced in COPERT 5.6:

- Degradation functions for Euro 1-4 petrol cars and LGVs were revised.
- New degradation functions were introduced for Euro 5 and 6 petrol cars and LGVs and Euro 1-6 diesel cars and LGVs. No degradation rates had previously been applied to these vehicle types

The functions reflect the deterioration in performance of engines and aftertreatment systems such as three-way catalysts fitted to petrol cars and vans and catalysts and technologies used to abate emissions from diesel cars and vans. The deterioration functions were updated or introduced based on evidence from European remote sensing data and from vehicle measurements of Euro 6 vehicles performed under WLTC, RDE and non-RDE test cycles.

The mileage correction functions in COPERT 5.4 and COPERT 5.6 take the same overall form of a linear function, with coefficients for each vehicle fuel type, Euro standard and pollutant provided in the Guidebook. However, some simplifications were made to the updated mileage correction functions in COPERT 5.6:

- COPERT 5.4 assumed a speed dependence to the correction functions, providing correction factors under urban (<19 kph) and rural (>63 kph) driving modes, whereas the correction functions in COPERT 5.6 assume there is no speed dependence.
- COPERT 5.4 provided different correction functions for different engine sizes of petrol car and LGV, whereas COPERT 5.6 provides a single correction factor that should be used for all engine sizes.
- In COPERT 5.6 the degradation of emissions is assumed to start after 50,000 km and remains stable after 200,000 km. In COPERT 5.4 the correction functions do not have a lower limit and it is assumed that emissions from Euro 1 and 2 vehicles do not degrade further after 120,000 km and emissions from Euro 3 and 4 petrol vehicles do not degrade further above 160,000 km.

4.1.1 Emissions Changes

The following two figures show the hot exhaust emissions by vehicle type and fuel type for each of NO_x and NMVOCs. The emissions changes shown here are due to the effects of degradation only. Degradation only affects petrol and diesel fuelled cars and LGVs, so only emissions from these vehicle types are shown in the figures. There are no degradation rates available for heavy duty vehicles, nor are there any for PM exhaust emissions.

4.1.1.1 NO_x

For NO_x, Figure 2-1 shows that the degradation method changes have a relatively small effect on emissions, as the emissions results for COPERT 5.6 and COPERT 5.4 are similar. Emissions from COPERT 5.6 are larger than those from COPERT 5.4 as COPERT 5.6 includes the application of new degradation functions for diesel LDVs and Euro 5 and 6 petrol LDVs. The largest difference between COPERT 5.6 and COPERT 5.4 is in the early timeseries.

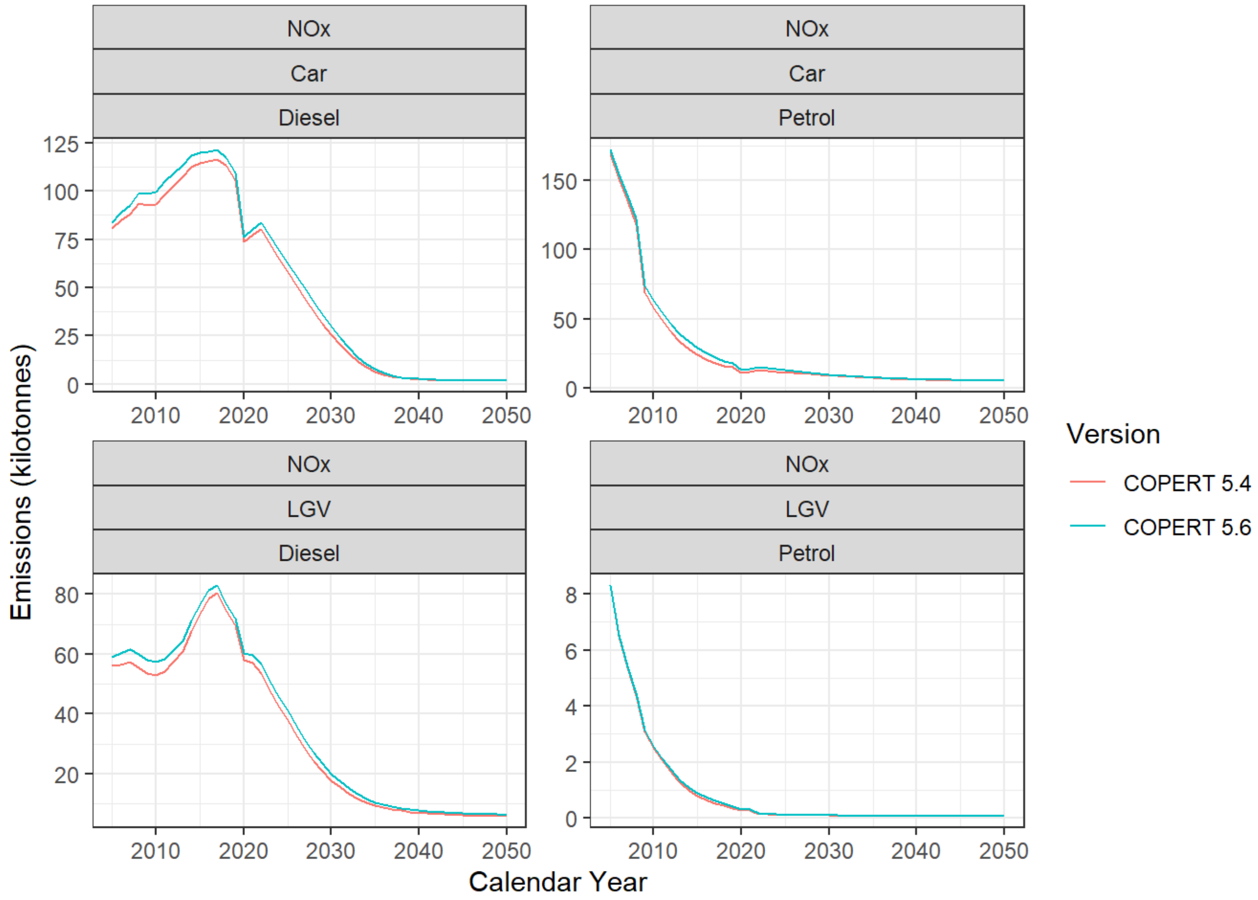

Figure 2-1: Hot exhaust NO_x emissions compared between COPERT 5.6 and COPERT 5.4 using different degradation approaches

4.1.1.2 NMVOCs

For NMVOCs, Figure 4-2 shows a large relative increase for diesel LDVs in COPERT 5.6 compared to COPERT 5.4, due to the introduction of degradation for diesel LDVs. NMVOC emissions are dominated by petrol vehicles, however. For petrol cars, emissions from COPERT 5.6 are lower than COPERT 5.4 in the early timeseries, reflecting the methodological changes for degradation introduced in COPERT 5.6. In the later timeseries, emissions are similar between COPERT 5.6 and COPERT 5.4, as emissions reductions from the methodological changes are offset by emissions increases due to the introduction of degradation for Euro 5 and 6 cars. Emissions for petrol LGVs are similar between COPERT 5.6 and COPERT 5.4.

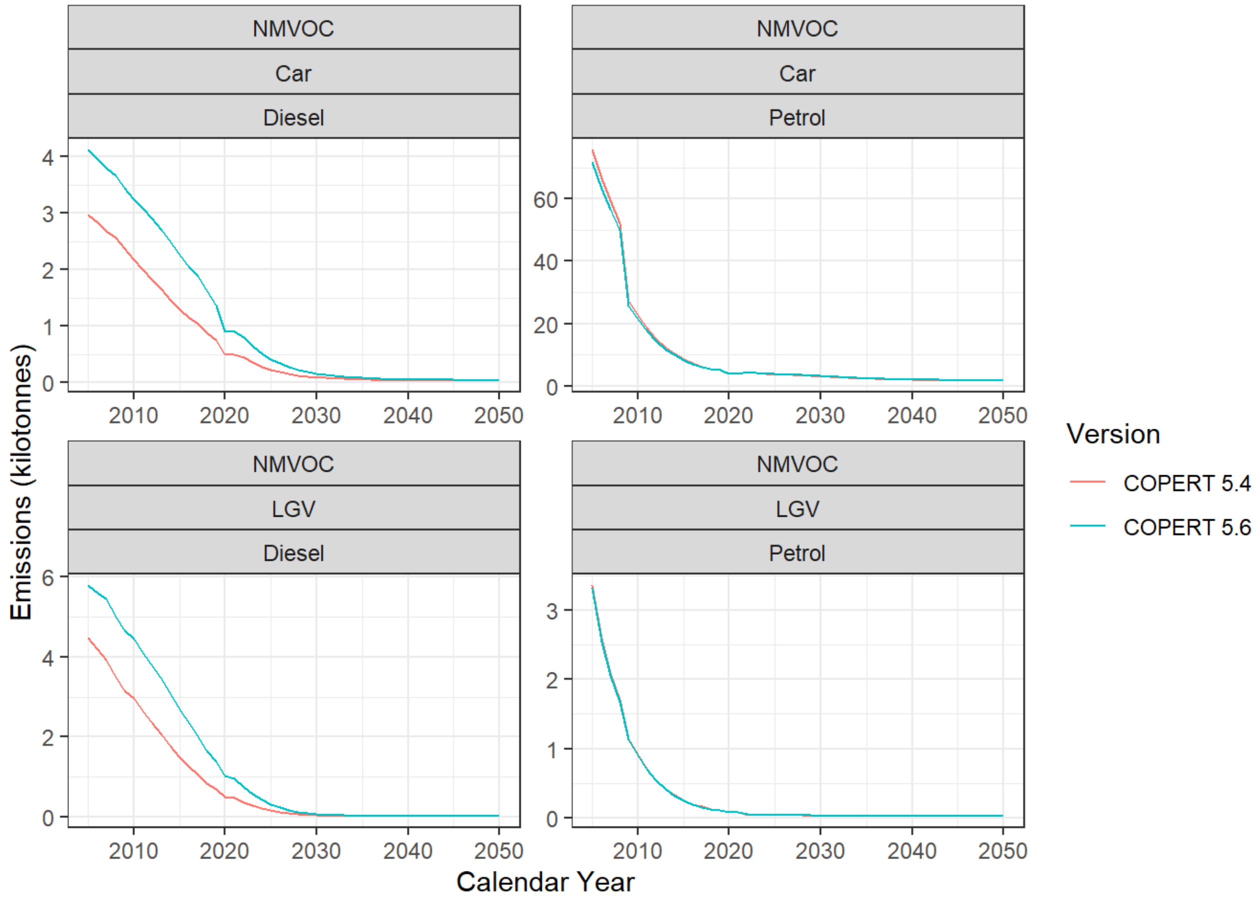

Figure 4-2: Hot exhaust NMVOC emissions compared between COPERT 5.6 and COPERT 5.4 using different degradation approaches

4.2 NON-EXHAUST EMISSIONS OF PM

Non-exhaust emission factors for brake wear, tyre wear and road surface wear were revised in COPERT 5.6.

The main revisions were:

- Revisions to brake wear emission factors for cars and light goods vehicles (LGVs)
- New brake, tyre and road surface wear emission factors for hybrid, plug-in hybrid (PHEV) and battery electric (BEV) cars.

Non-exhaust emission factors were updated to take account of the latest research and measurements of non-exhaust emission factors. The new non-exhaust emission factors for hybrid, PHEV and BEV cars account for the impact of regenerative braking and the higher average mass of hybrid, PHEV and BEV cars compared to internal combustion engine (ICE) cars. In the absence of specific non-exhaust emission factors for hybrid, PHEV and BEV cars in COPERT 5.4, these vehicles were previously assumed to have the same non-exhaust emission factors as ICE cars.

COPERT 5.6 has not differentiated non-exhaust factors for hybrid, PHEV, BEV and ICE LGVs. The relative effect of powertrain on non-exhaust emissions from LGVs might be expected to be the same as passenger cars. Because of this, we have used the relative difference in the non-exhaust emission factors for cars by powertrain type to adjust the non-exhaust emission factors for LGVs.

4.2.1 Road Abrasion

PM emission factors from road surface wear are provided by vehicle type and are speed independent. Table 4-1 summarises Total Suspended Particulates (TSP) emission factors from road surface wear in COPERT 5.4 and COPERT 5.6 and the absolute and percentage changes to the emission factors. New emission factors for hybrid, PHEV and BEV passenger cars were introduced. The new emission factors were between 6.0 and 12.7% greater than the emission factor for ICE cars and account for the higher average vehicle weight of hybrid, PHEV and BEV cars compared to ICE cars. These relative differences have also been applied for LGVs.

Table 4-1: TSP emission factors from road surface wear (g/km)

Vehicle category	COPERT 5.4	COPERT 5.6	Change	Change (%)
Two-wheel vehicles	0.006	0.0060	0.0000	0.0
Passenger cars - ICE	0.015	0.0150	0.0000	0.0
Passenger cars - Hybrid	0.015	0.0159	0.0009	6.0
Passenger cars - PHEV	0.015	0.0161	0.0011	7.3
Passenger cars - BEV	0.015	0.0169	0.0019	12.7
Light Goods Vehicles - ICE	0.015	0.0150	0.0000	0.0
Light Goods Vehicles – Hybrid[1]	0.015	0.0159	0.0009	6.0
Light Goods Vehicles - PHEV[1]	0.015	0.0161	0.0011	7.3
Light Goods Vehicles - BEV[1]	0.015	0.0169	0.0019	12.7
Heavy-duty trucks & buses	0.076	0.0760	0.0000	0.0

[1] The relative change in factors for different power trains assumed to be the same for LGVs as for passenger cars

4.2.1.1 Emissions Changes

COPERT and the guidebook provide scaling factors to convert TSP emissions to mass emissions of PM_{10} and $PM_{2.5}$. The scaling factors are less than 1 and decrease with smaller particle size ranges reflecting the fact that a significant fraction of the particle mass is emitted in the coarse size range.

As shown in Table 4-1, the only vehicle types affected by the change in road abrasion emission factors are cars and LGVs (collectively referred to as LDVs). Figure 4-3 shows the road abrasion PM_{10} and $PM_{2.5}$ emissions for LDVs. Road abrasion emissions are now higher for LDVs from COPERT 5.6 than COPERT 5.4 in recent years due to these more modern technologies entering the fleet with higher emission factors and this gap will widen in future years as the proportions of these vehicle types continue to grow.

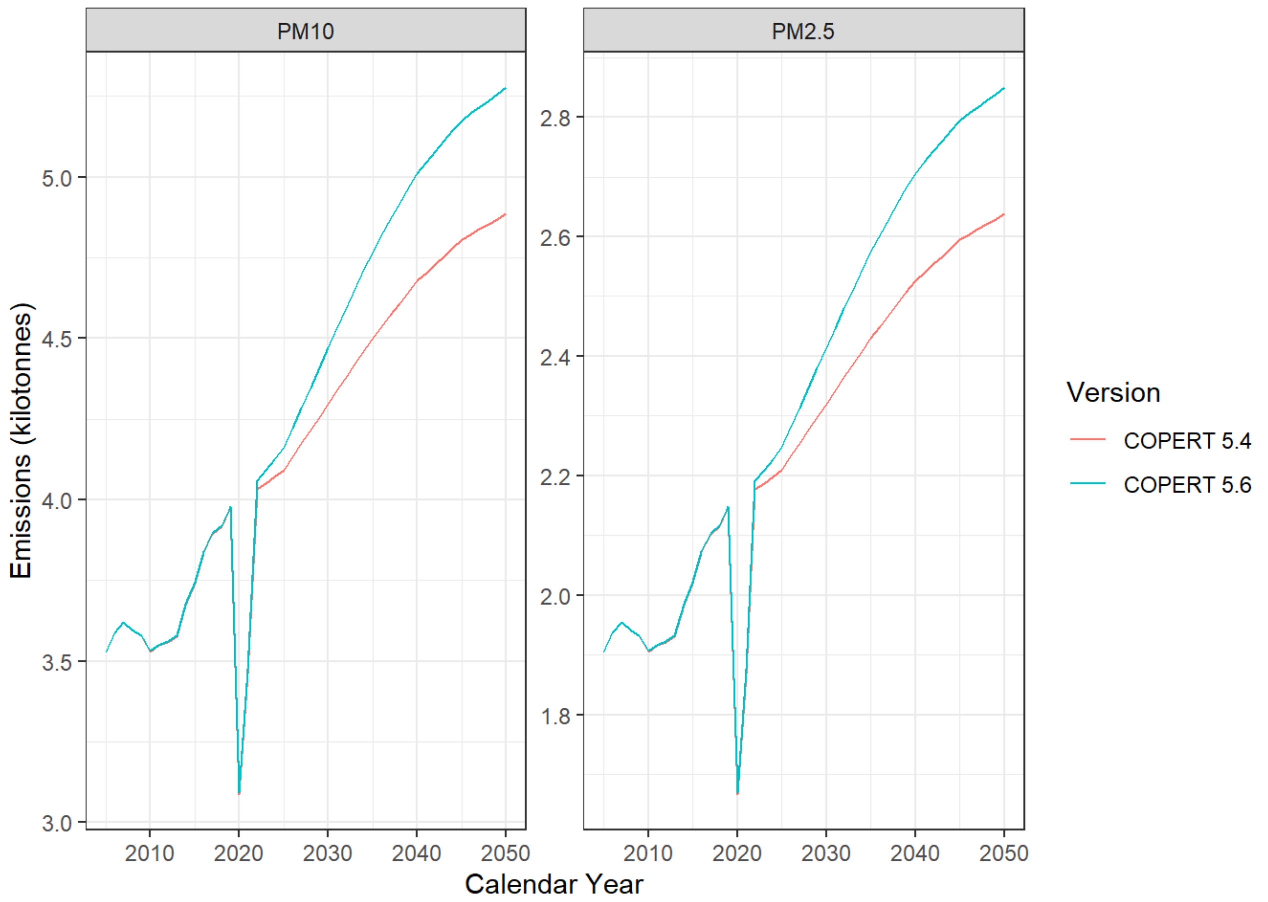

Figure 4-3: Road abrasion PM_{10} and $PM_{2.5}$ emissions for LDVs. The negative spike in emissions in 2020 shown by the NAEI is a consequence of reduced traffic in that year due to Covid-19 restrictions

For context, the road abrasion PM_{10} and $PM_{2.5}$ emissions for all vehicle types is shown in Figure 4-4.

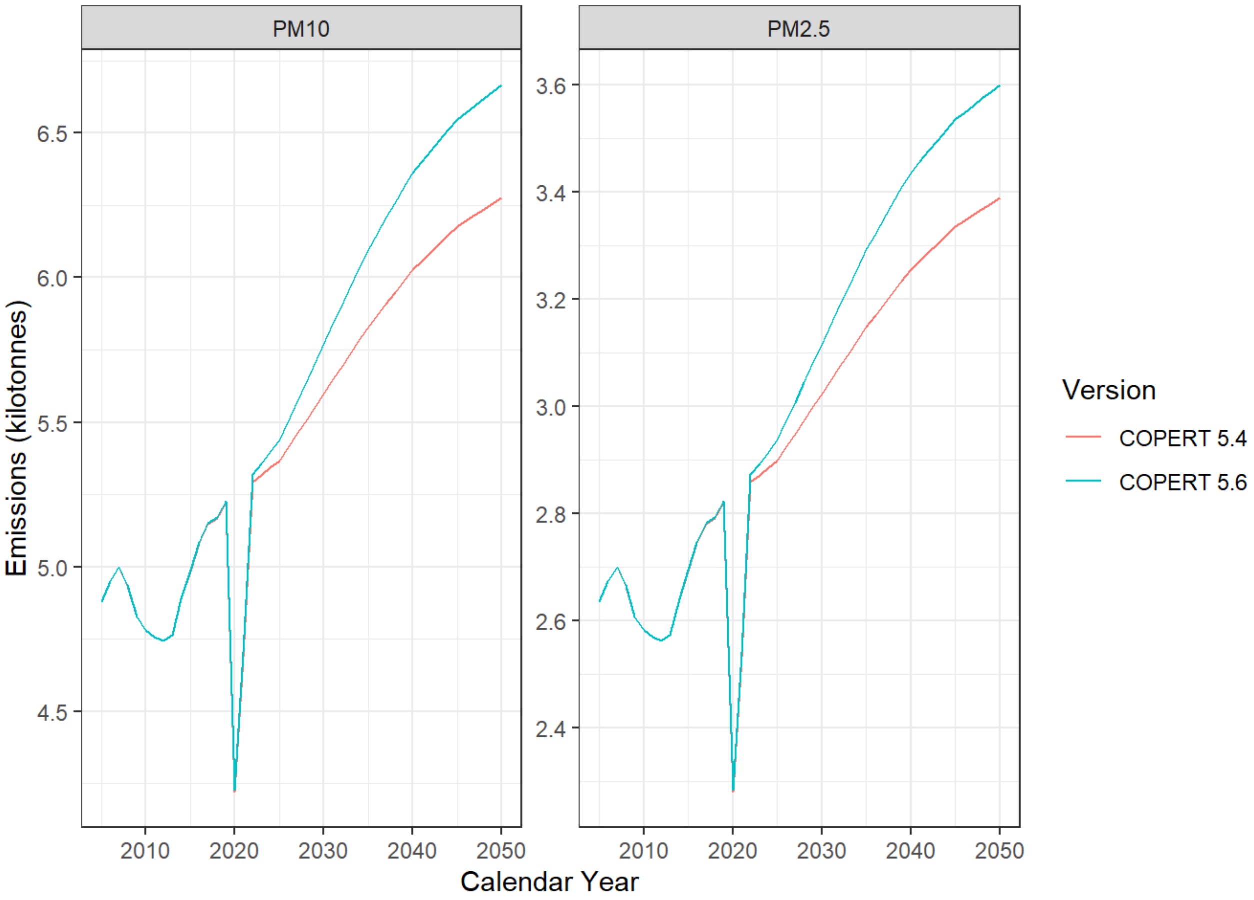

Figure 4-4: Road abrasion PM_{10} and $PM_{2.5}$ emissions for all vehicle types

4.2.2 Brake Wear

The EMEP/EEA inventory Guidebook provides non-exhaust emission factors for brake wear as a set of total suspended particle (TSP) base emission factors and speed dependent correction factors that account for variations in emission factors with different average trip speeds. Brake wear decreases as the mean speed increases, accounting for a higher frequency of braking in urban driving compared to motorway driving. Table 4-2 presents the base TSP brake emission factors for cars and LGVs in COPERT 5.4 and 5.6 at an illustrative speed of 65 kph and provides the absolute and percentage changes to the emission factors. In summary, the main revisions in COPERT 5.6 were:

- Emission factors for ICE cars and LGVs were increased significantly in COPERT 5.6 compared with COPERT 5.4
- The LGV category was split into two size categories for small (N-I) and medium/large LGVs (N1-II, III); small LGVs are assigned the same emission factor as cars while emission factors for medium/large LGVs are greater and are higher than emission factors from brake wear in COPERT 5.4
- New emission factors for hybrid, PHEV and BEV cars are lower than from ICE cars in COPERT 5.6. This is due to the effects of regenerative braking.

The speed dependent correction factors that should be applied to the base emission factors were not revised in COPERT 5.6. Particle size distributions were also not adjusted: PM_{10} remains 98% mass fraction of TSP, and $PM_{2.5}$ is 39% mass fraction of TSP.

Table 4-2: TSP emission factors from brake wear at 65 kph (g/km) for cars and LGVs

Vehicle category	COPERT 5.4	COPERT 5.6	Change	Change (%)
Two-wheel vehicles	0.0037	0.0037	0.0000	0.0
Passenger cars - ICE	0.0075	0.0122	0.0047	62.7
Passenger cars - Hybrid	0.0075	0.0097	0.0022	29.3
Passenger cars - PHEV	0.0075	0.0066	-0.0009	-12.0
Passenger cars - BEV	0.0075	0.0034	-0.0041	-54.7
LGV (N1 - I) - ICE	0.0117	0.0122	0.0005	4.3
LGV (N1 - I) - Hybrid	0.0117	0.0097	-0.0020	-17.1
LGV (N1 - I) - PHEV	0.0117	0.0066	-0.0051	-43.6
LGV (N1 - I) - BEV	0.0117	0.0034	-0.0083	-70.9
LGV (N1 - II, III) - ICE	0.0117	0.0173	0.0056	47.9
LGV (N1 - II, III) - Hybrid	0.0117	0.0138	0.0021	17.9
LGV (N1 - II, III) - PHEV	0.0117	0.0094	-0.0023	-19.7
LGV (N1 - II, III) - BEV	0.0117	0.0048	-0.0083	-59.0

The Guidebook provides a simple scaling factor to calculate brake wear emissions from heavy duty vehicles (HDVs) that is applied to the passenger car emission factor in order to fit heavy-duty vehicle experimental data. The scaling factor includes a correction factor to account for vehicle load, i.e. leading to higher emission factors for vehicles of heavier load. The latest Guidebook for COPERT 5.6 has provided a different brake wear scaling factor for HDVs from that provided with COPERT 5.4 which is then applied to the new COPERT 5.6 brake wear emission factor for passenger cars, but it retains the same load correction factor as provided in COPERT 5.4.

To illustrate this, the scaling factor equations taken from the Guidebook are:

COPERT 5.4: $EF_{TSP,B,HDV,COP5.4} = 3.13 * LCF_B * EF_{TSP,B,C,COP5.4}$

COPERT 5.6: $EF_{TSP,B,HDV,COP5.6} = 1.956 * LCF_B * EF_{TSP,B,C,COP5.6}$

$EF_{TSP,B,C}$ refers to the TSP emission factor for cars, LCF_B refers to the load correction factor for HDVs and the *COP5.4* and *COP5.6* subscripts refer to the versions of COPERT.

The net result of the changes in car emission factors and scaling factor for HDVs is that the brake wear emission factors for HDVs from COPERT 5.6 are just 1.65% higher than the factors derived from COPERT 5.4 at all speeds. There are no brake wear emission factors for HDVs with hybrid or electric powertrains. The relative impact these technologies will have on HDV brake wear emissions is likely to be different to that for light duty vehicles so cannot be estimated.

4.2.2.1 Emissions Changes

Figure 4-5 shows the brake wear PM_{10} emissions by vehicle type compared between COPERT 5.6 and COPERT 5.4. Motorcycles are not shown as there has been no change for motorcycle brake wear emission factors. As the $PM_{2.5}$:PM_{10} ratio has not changed between COPERT versions, $PM_{2.5}$ has the same trends as shown in Figure 4-5 for PM_{10}.

For Light-Duty Vehicles (LDVs: cars & LGVs), emissions are significantly higher in COPERT 5.6 pre-2021. This is because ICE cars were especially dominant in those years and from Table 4-2, it can be seen that the brake wear emission factors for ICE LDVs are notably higher in COPERT 5.6 compared to COPERT 5.4. The emissions from COPERT 5.6 decline sharply from around 2021 however and are lower than from COPERT

5.4 from around 2035. This is because COPERT 5.6 considers emission factors that vary by powertrain. Emission factors from modern BEVs and PHEVs are notably lower than ICE LDVs and so as the fleet becomes increasingly dominated by those vehicles, the fleet-weighted LDV brake wear emission factor decreases. Emissions from HGVs and buses using COPERT 5.6 are very similar to the emissions derived from COPERT 5.4.

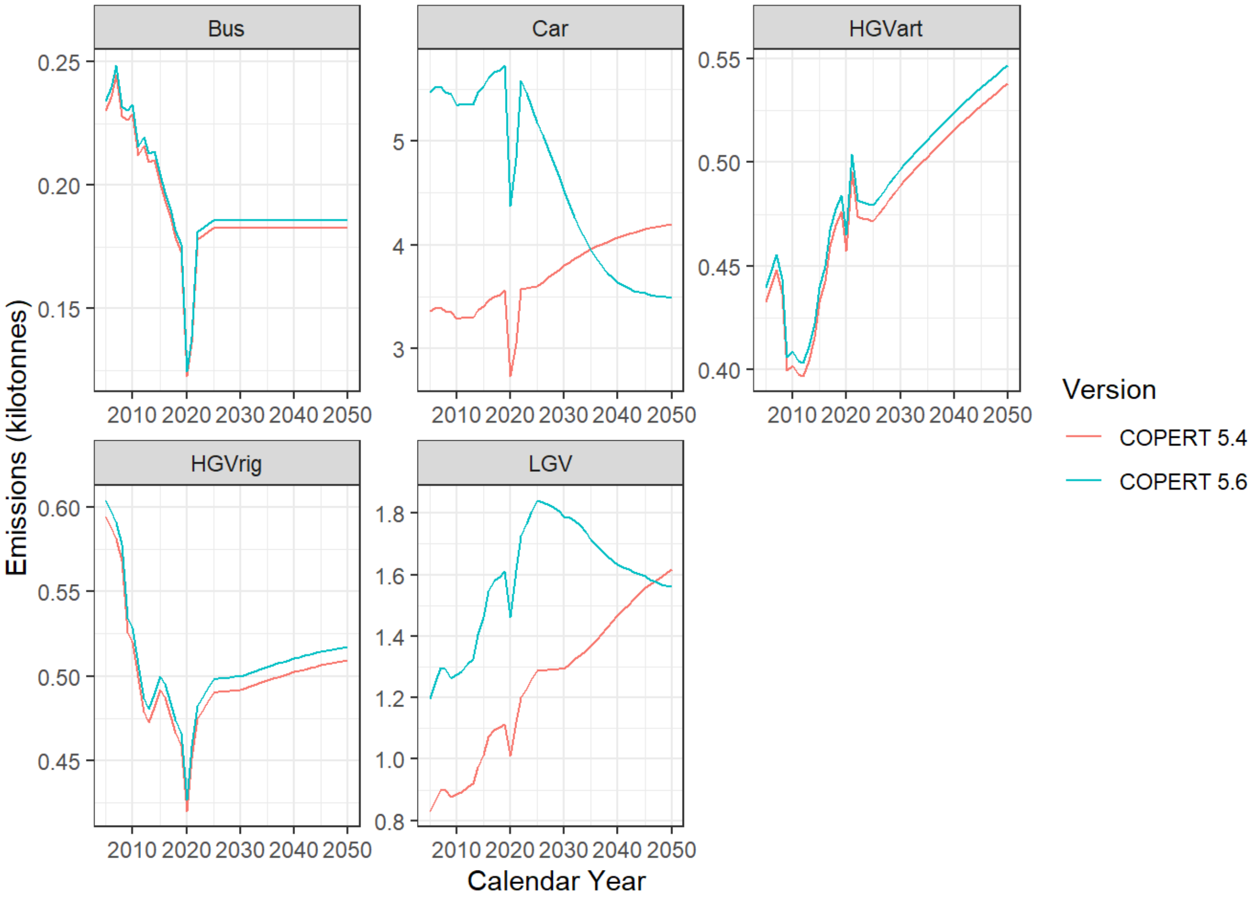

Figure 4-5: Brake wear PM_{10} emissions by vehicle type compared between COPERT 5.6 and COPERT 5.4. The negative spike in emissions in 2020 shown by the NAEI is a consequence of reduced traffic in that year due to Covid-19 restrictions.

For context, Figure 4-6 shows the brake wear emissions for $PM_{2.5}$ and PM_{10} across all vehicle types, compared between COPERT 5.6 and COPERT 5.4. As mentioned previously, the pattern for PM_{10} and $PM_{2.5}$ is the same. Overall, emissions are significantly larger using COPERT 5.6 in historic years and in most projected years. The difference between COPERT 5.6 and COPERT 5.4 decreases in later years as the fleet-weighted car emission factor drops significantly over time in COPERT 5.6 due to the increased electrification of the LDV fleet and the reduction in brake wear emission factors.

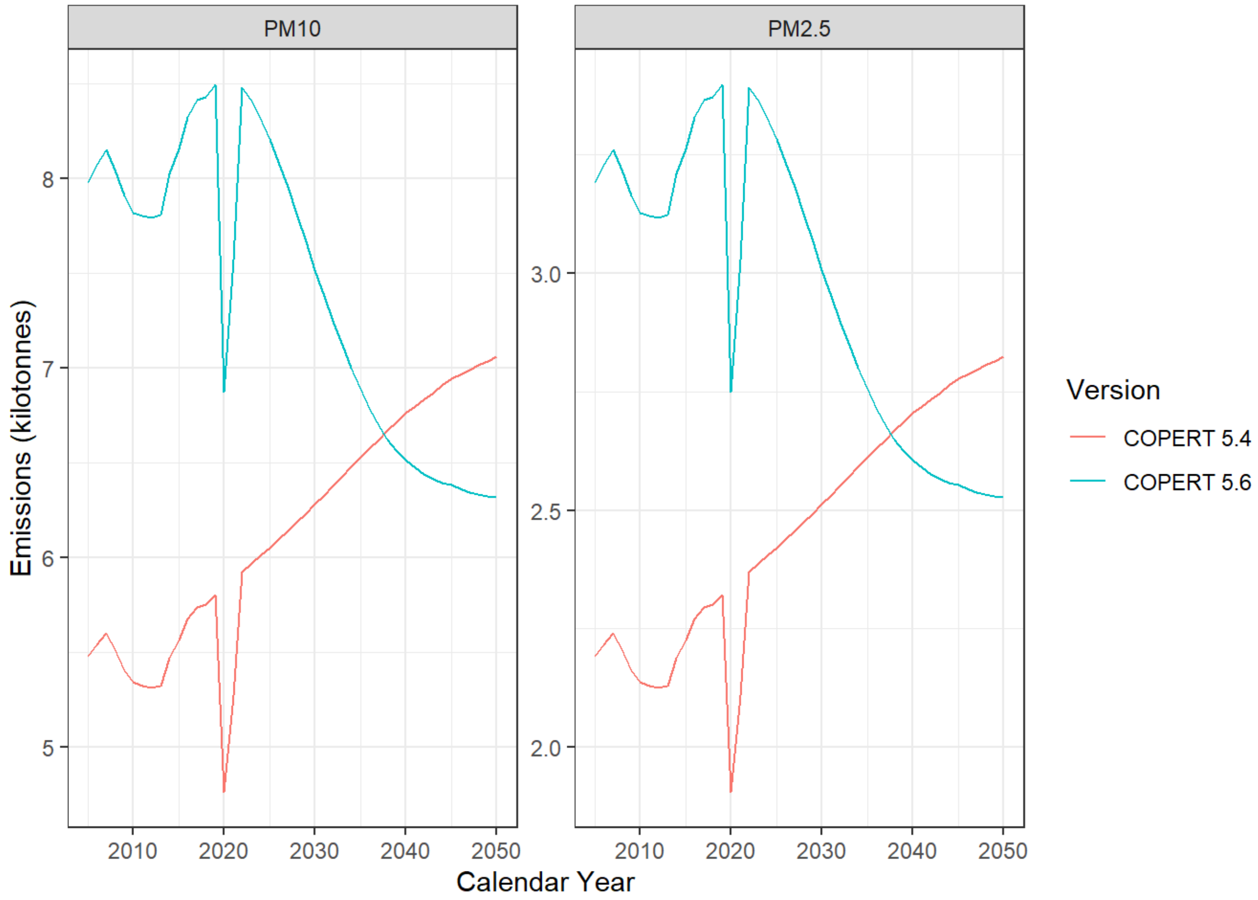

Figure 4-6: Brake wear emissions for $PM_{2.5}$ and PM_{10} across all vehicle types, compared between COPERT 5.6 and COPERT 5.4

4.2.3 Tyre wear

Tyre wear emission factors are provided as a set of TSP base emission factors and a speed dependent correction factor, similar to the form of brake wear emission factors. Table 4-3 provides the base TSP emission factors from tyre wear for cars and LGVs in COPERT 5.4 and COPERT 5.6 at an illustrative speed of 80 kph, and the absolute and percentage changes to the emission factors. New emission factors for hybrid, PHEV and BEV passenger cars were introduced. The new emission factors were between 3.7% and 14% greater than the emission factor for ICE cars and account for the higher average vehicle weight of hybrid, PHEV and BEV cars compared to ICE cars. The speed dependent correction factors that are applied to the base emission factors were not revised in COPERT 5.6. Particle size distributions were also not adjusted: PM_{10} remains 60% mass fraction of TSP, and $PM_{2.5}$ is 42% mass fraction of TSP.

No changes have been made to the tyre wear emission factors for HGVs and buses. The method for estimating tyre wear emissions from HDVs is similar to the method for brake wear, using a scaling factor applied to the factors for ICE passenger cars combined with a load correction factor. An additional factor takes into account the number of wheel axles on the vehicle. Since neither the tyre wear emission factors for ICE passenger cars nor the HDV tyre wear scaling factor and load correction factors have been changed, there is no overall change in the HDV emission factors.

Table 4-3: TSP emission factors from tyre wear at 80 kph (g/km) for cars and LGVs

Vehicle category	COPERT 5.4	COPERT 5.6	Change	Change (%)
Two-wheel vehicles	0.0046	0.0046	0.0000	0.0
Passenger cars - ICE	0.0107	0.0107	0.0000	0.0
Passenger cars - Hybrid	0.0107	0.0111	0.0004	3.7
Passenger cars - PHEV	0.0107	0.0112	0.0005	4.7
Passenger cars - BEV	0.0107	0.0116	0.0009	8.4
LGV - ICE	0.0169	0.0169	0.0000	0.0
LGV - Hybrid	0.0169	0.0175	0.0006	3.7
LGV - PHEV	0.0169	0.0177	0.0008	4.7
LGV - BEV	0.0169	0.0183	0.0014	8.4

4.2.3.1 Emissions changes

For tyre wear, only the emission factors for LDVs have changed. Figure 4-7 shows the PM_{10} emissions from LDVs compared between COPERT 5.6 and COPERT 5.4. As the $PM_{2.5}$:PM_{10} ratio has not changed between COPERT versions, $PM_{2.5}$ has the same trends as shown in Figure 4-7 for PM_{10}.

The emissions from COPERT 5.6 are higher than from COPERT 5.4 as COPERT 5.6 considers higher emission factors for modern hybrid and electric powertrain technologies due to their larger weight. This effect is minimal in historic years but becomes more pronounced in later years. Different factors by technology were not considered in COPERT 5.4.

For context, Figure 4-8 shows the tyre wear emissions for $PM_{2.5}$ and PM_{10} across all vehicle types, compared between COPERT 5.6 and COPERT 5.4. As mentioned previously, the pattern for PM_{10} and $PM_{2.5}$ is the same.

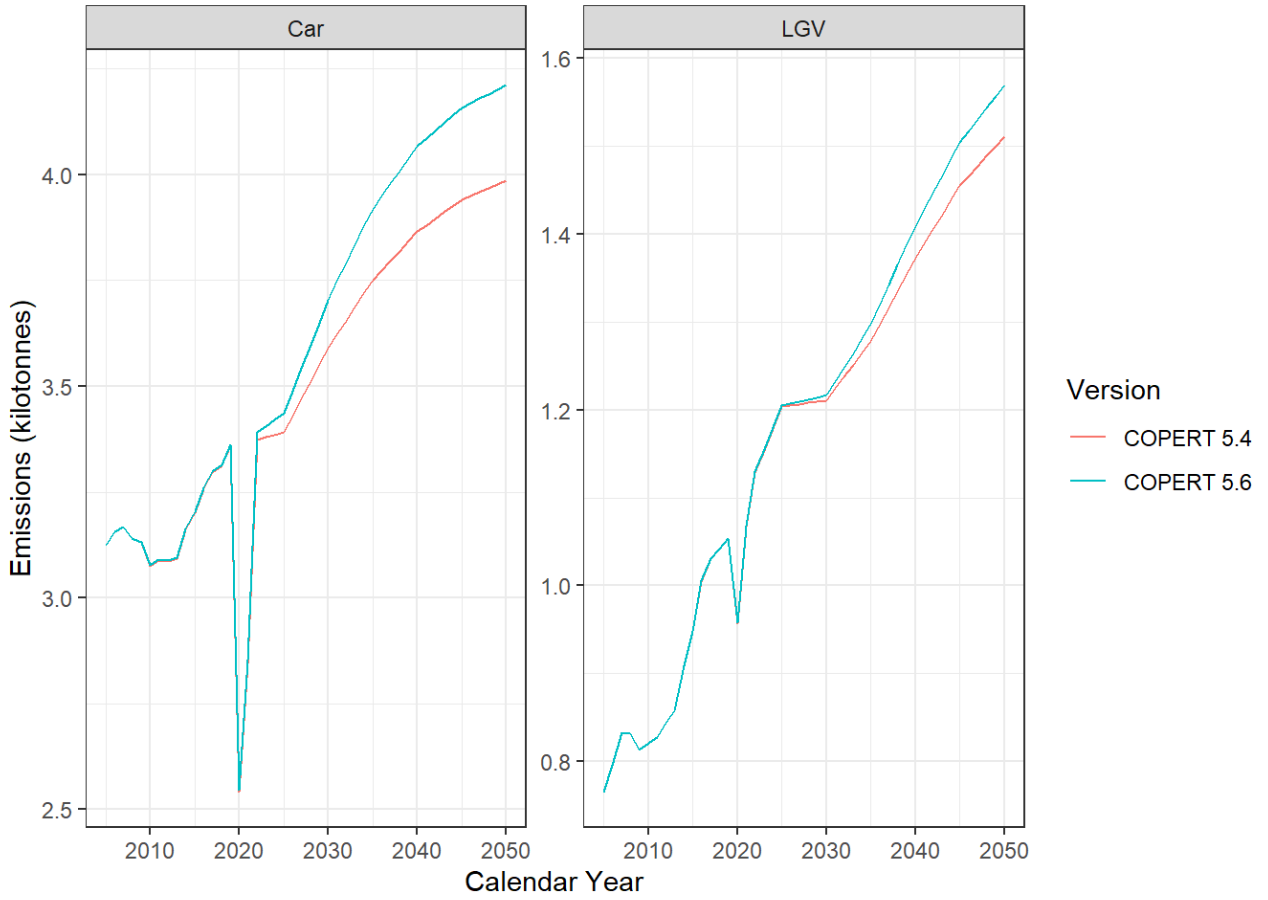

Figure 4-7: Tyre wear PM_{10} emissions from cars compared between COPERT 5.6 and COPERT 5.4. The negative spike in emissions in 2020 shown by the NAEI is a consequence of reduced traffic in that year due to Covid-19 restrictions

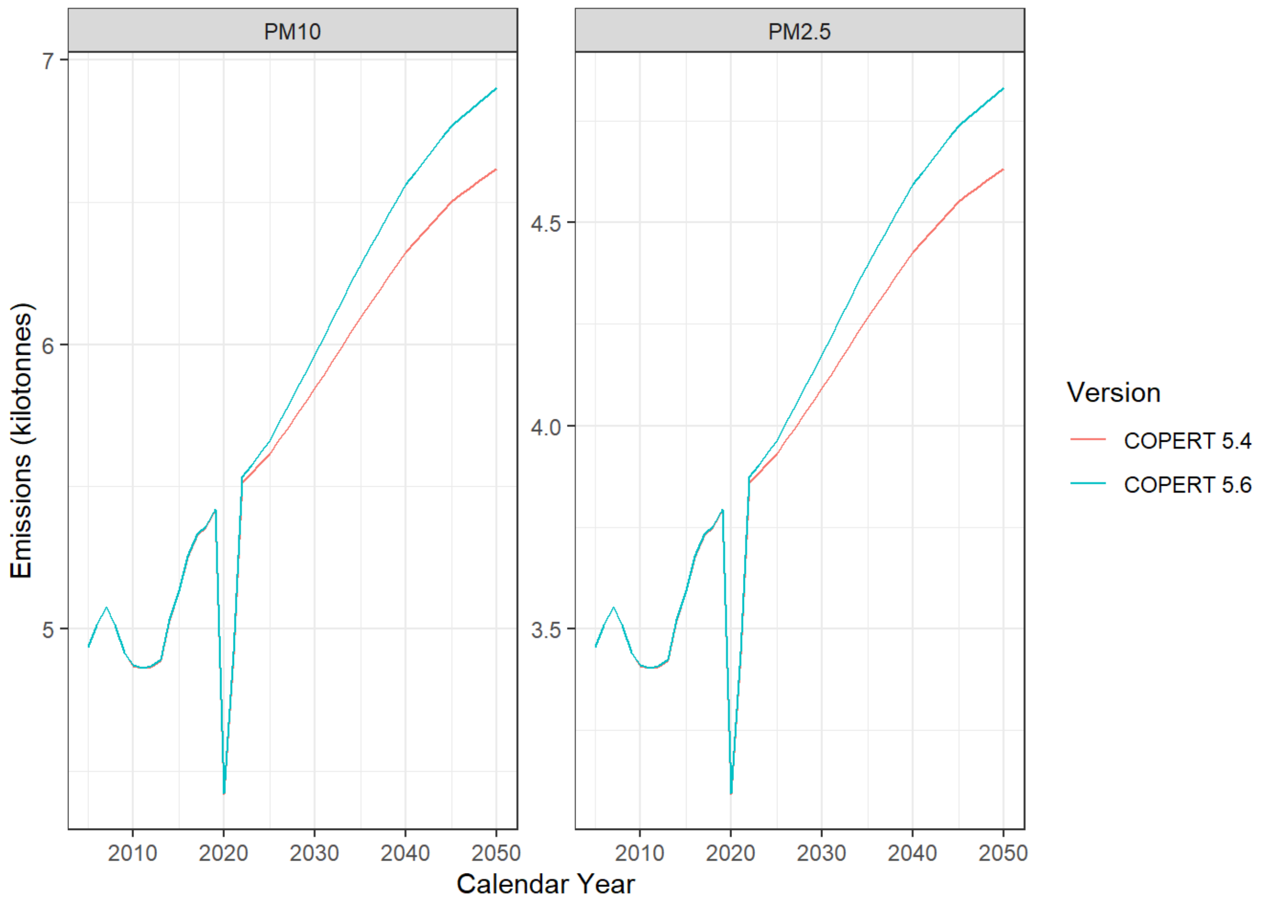

Figure 4-8: Tyre wear emissions for $PM_{2.5}$ and PM_{10} across all vehicle types, compared between COPERT 5.6 and COPERT 5.4

4.3 COLD START

Cold start emissions are the excess emissions that occur when a vehicle is started with its engine below normal operating temperatures. The excess emissions occur from petrol and diesel vehicles because of the lower efficiency of the engine before it has warmed up. Excess emissions also occur because catalysts, such as the three-way catalysts fitted to petrol cars and oxidation and SCR catalysts fitted to modern diesel vehicles, do not function effectively until they reach a minimum operating temperature. Cold start emissions provide quite an important contribution to total road transport emissions of CO, hydrocarbons and NO_x, for example NAEI21 (published in 2023) estimated that cold start emissions from petrol and diesel cars and LGVs made up approximately 34% of total CO, approximately 10% of NMVOC and approximately 6% of NO_x emissions from road transport sources in 2021. COPERT 5.4 provided a methodology to calculate excess cold start emissions from petrol and diesel cars and LGVs.

The cold start methodology was revised in COPERT 5.6 based on recent evidence on cold start emissions for newer vehicles. The key revisions were:

- Updates to cold start emissions of CO, NO_x and VOC from Euro 6 petrol and diesel cars and LGVs
- Introduction of a new method for cold start emissions of CO, NO_x and VOC from Euro V and VI diesel heavy duty vehicles.

Smaller revisions were made to the cold start emission factors for earlier Euro standards of cars and LGVs and a set of simplified factors for PM were also provided for petrol cars and LGVs for the first time in COPERT 5.6.

4.3.1 Temperature Data

The ambient temperature is an input parameter in the cold start emissions calculation in the Guidebook. Historically, and in NAEI21, ambient temperature data from the Met Office Central England Temperature source has been used for the UK. As part of this project, new temperature data from the Met Office has been sourced that provides temperature values for each Devolved Administration and also separately for London (using the "England SE/Central S" for London) (here). This allows the model to account for regional variability in ambient temperature.

Historically, and in NAEI20, projected ambient temperature data was estimated to be the average of the most recent five historic years across all projected calendar years. As part of this project, climate projections data from the Met Office has been used, to now account for the likely temperature impacts of climate change in the UK. On average, UK temperatures increase by around 0.8°C from the mid-2020s to 2050.

4.3.2 LDVs

There was an update to cold start emissions of CO, NO_x and VOC from Euro 6 petrol and diesel cars and LGVs (collectively referred to as light duty vehicles, LDVs). Also, the latest method from the 2022 Update of the Guidebook has been applied which affects post-Euro 1 petrol and diesel LDVs.

4.3.2.1 NO_x

Figure 4-9 shows LDV cold start NO_x emissions by year, pollutant, vehicle type, and fuel type compared between COPERT 5.6 and COPERT 5.4.

For diesel cars, emissions are similar between COPERT 5.6 and COPERT 5.4 up to around 2025. From 2025, emissions from COPERT 5.6 tend to be larger than from COPERT 5.4. For diesel LGVs, emissions from COPERT 5.6 are slightly higher than COPERT 5.4 in the early timeseries and significantly higher than COPERT 5.4 emissions in the later timeseries. The reason that the LGV emissions in COPERT 5.6 are much higher than in COPERT 5.4 in the later time-series is because the over-emission ratios for Euro 6d and Euro 6d-temp have increased significantly compared to COPERT 5.4 and these are acting on higher hot exhaust emission factors for Euro 6 diesel LGVs.

For petrol LDVs, emissions from COPERT 5.6 are lower than COPERT 5.4 up to around 2008 and higher in later years, due to the updated methodology and how the over-emission ratios for later Euro standards relate to older Euro standards.

4.3.2.2 NMVOCs

Figure 4-10 shows LDV cold start NMVOC emissions by year, pollutant, vehicle type, and fuel type compared between COPERT 5.6 and COPERT 5.4.

Cold start NMVOC emissions for petrol cars and LGVs from COPERT 5.6 are similar to COPERT 5.4 except in the years between 2010 and 2030. Emissions in the later timeseries from 2030 are relatively small. Between 2010 and 2030, cold start NMVOC emissions are higher in COPERT 5.6 than they are in COPERT 5.4. This is due to methodological changes in COPERT 5.6 leading to significantly larger over-emission ratios for Euro 3 to Euro 5 vehicles. The changes are relatively small for diesel cars and LGVs.

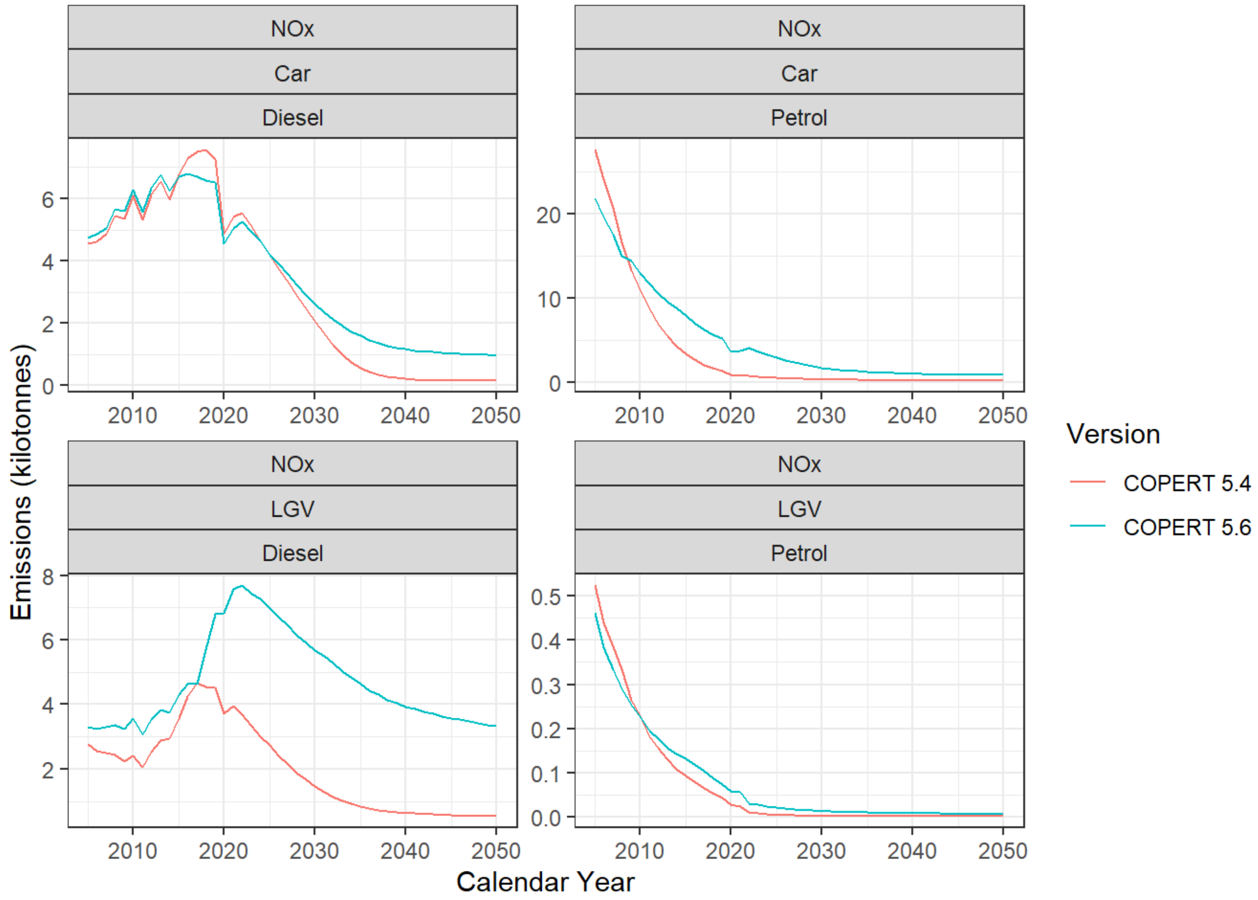

Figure 4-9: LDV cold start NO_x emissions by year, pollutant, and vehicle type, compared between COPERT 5.6 and COPERT 5.4

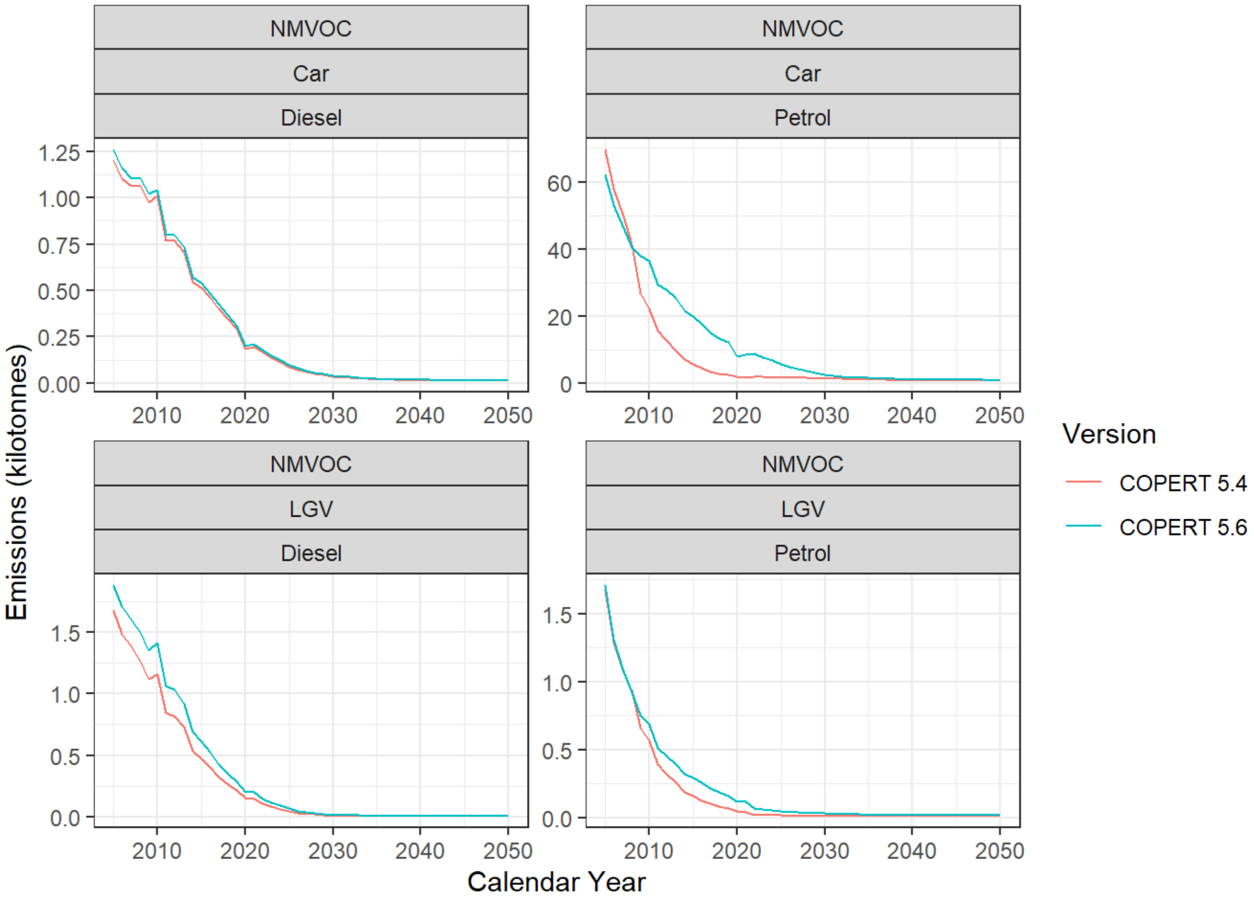

Figure 4-10: LDV cold start NMVOC emissions by year, pollutant, and vehicle type, compared between COPERT 5.6 and COPERT 5.4

4.3.2.3 PM

Figure 4-11 shows LDV cold start PM emissions by year, pollutant, vehicle type, and fuel type compared between COPERT 5.6 and COPERT 5.4.

For petrol LDVs, there were no PM cold start emissions estimated in the previous COPERT 5.4 method used in NAEI21. COPERT 5.6 now provides a set of cold start factors for petrol cars and LGVs and these are shown in Figure 4-11.

For diesel cars, the emissions from cars are marginally higher in COPERT 5.6 relative to COPERT 5.4 up to around 2015, and marginally lower in COPERT 5.6 from around 2015. For diesel LGVs, the emissions from cars are typically marginally higher in COPERT 5.6 relative to COPERT 5.4. This is due to updated cold start emission factors in COPERT 5.6.

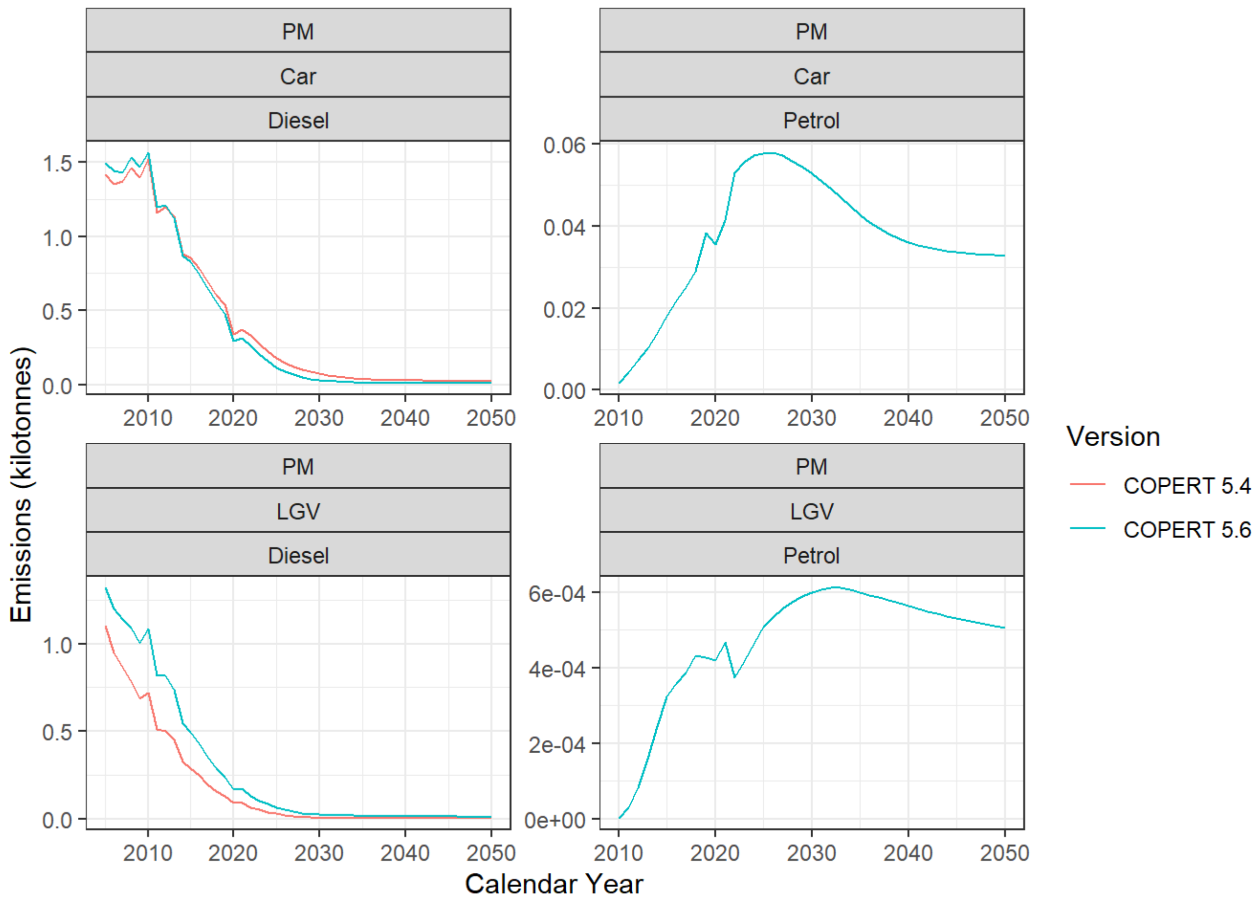

Figure 4-11: LDV cold start PM emissions by year, pollutant, and vehicle type, compared between COPERT 5.6 and COPERT 5.4

4.3.3 HDVs

Cold start emissions from HGVs and buses have historically assumed to be negligible and were not considered in previous versions of the Guidebook and COPERT. However, Euro V and VI HGVs and buses are fitted with more complex engine control technologies and SCR and oxidation catalysts that do not function effectively below a minimum operating temperature. Recent evidence from vehicle measurements has allowed cold start emissions from Euro V and VI HGVs and buses to be quantified. COPERT 5.6 sees the introduction of cold start emissions of CO, NO_x and VOC from Euro V and VI diesel heavy duty vehicles.

4.3.3.1 Trip Lengths

Vehicle trip length is an input parameter for the cold start emissions methodology in the Guidebook. The longer the vehicle trip length, the lower the cold start emissions are as a fraction of hot exhaust emissions. To accommodate the new method in COPERT 5.6, new data was required to use for HDV trip lengths.

HGVs

For HGVs, data from DfT publication RFS0108 was used. This gives the average length of haul separately for rigids and artics over the most recent 12 months (December 2022 in this case). These values were 60 km and 137 km for rigids and artics, respectively, which are much longer than the average trip length for passenger cars. It is known that artics tend to do more long-distance haulage.

Buses

For buses, similar length of "haul" information was not available from DfT. The average trip length was calculated as Total bus vkm / (Total no. buses * 365 days) on the assumption that a bus makes only one trip per day starting with a cold engine, i.e., any other stops that a bus makes are not with the engine turned off long enough for it to cool down. Note that this is different to the higher emissions that might result from the cooling down of aftertreatment SCR systems when idling as this is already reflected in the speed-emission curves provided for buses in COPERT. DfT publication BUS06 was used for the stock of vehicles and DfT publication BUS02 was used for the vehicle kilometres travelled. The average trip length was calculated separately for London and the four Devolved Authorities. The average trip length from 2004-2021 ranged from 144 km for London, to 203 km for Scotland.

Coaches

For coaches, similar length of "haul" information was not available from DfT. The average trip length was calculated as Total coach vkm / (Total no. coaches * 365 days). DfT publication BUS06 was used for the stock of vehicles and the coach vehicle kilometre data from NAEI21 was used for the vehicle kilometres travelled. The average trip length from 2004-2021 was calculated as 429 km. This is significantly higher than the other vehicle types, though it is reasonable as coaches tend to do a lot of long distance travel on motorways.

4.3.3.2 Emissions Results

Figure 4-12 shows HDV cold start emissions by year, pollutant, and vehicle type in COPERT 5.6. Note that there were no cold start HDV emissions estimated in COPERT 5.4 and NAEI21. As HDV cold start emissions only apply from Euro V, emissions are low in the early timeseries, as the fleet is dominated by pre-Euro V vehicles in those years. Emissions rise from the early timeseries to the mid-2020s, after which they stabilise and plateau.

Emissions from rigid HGVs are noticeably larger than those for artic HGVs. This is because of the significantly shorter average trip length of rigid HGVs (as shown in section 4.3.3.1), meaning a larger proportion of the rigid vehicle kilometres is done under cold start conditions relative to artic HGVs. Cold start emissions from buses and coaches are lower than those of artic or rigid HGVs due to their significantly lower vehicle kilometres travelled and relatively large daily trip lengths.

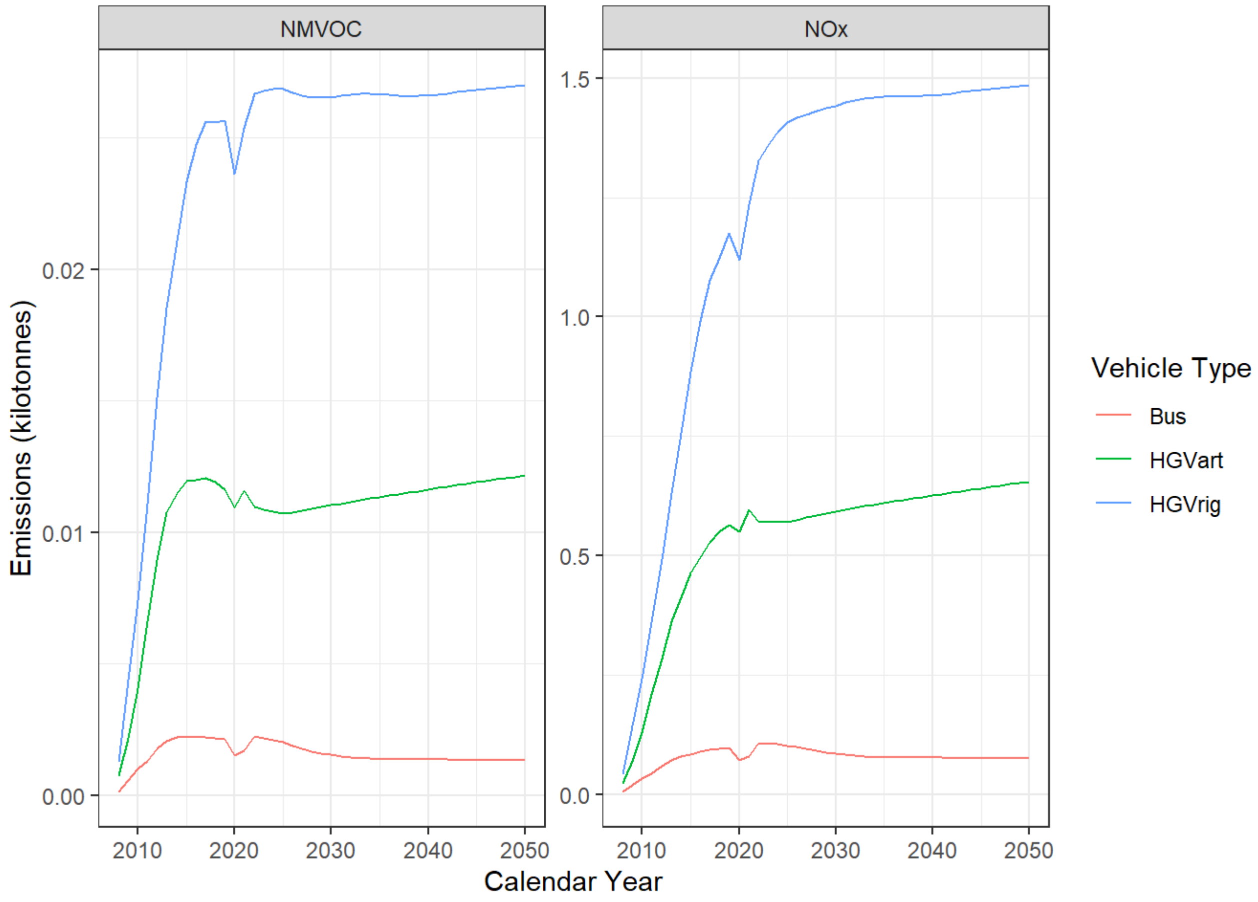

Figure 4-12: HDV cold start emissions by year, pollutant, and vehicle type in COPERT 5.6

Figure 4-13 shows HDV cold start and hot exhaust emissions by year and pollutant in COPERT 5.6 from 2020. This is shown for context, to see the relative importance of the newly introduced HDV cold start emissions against the hot exhaust emissions.

It is clear from Figure 4-13 that hot exhaust emissions dominate over cold start emissions. The largest relative contribution for cold start emissions is in the later time-series for NO_x. In 2040, HDV cold start NO_x emissions are estimated to be 2.2 kt and HDV hot exhaust NO_x emissions were estimated to be 7.0 kt. Prior to 2020, the cold start emissions were even lower and showing those years in the plot would make it harder to see the differences clearly in later years.

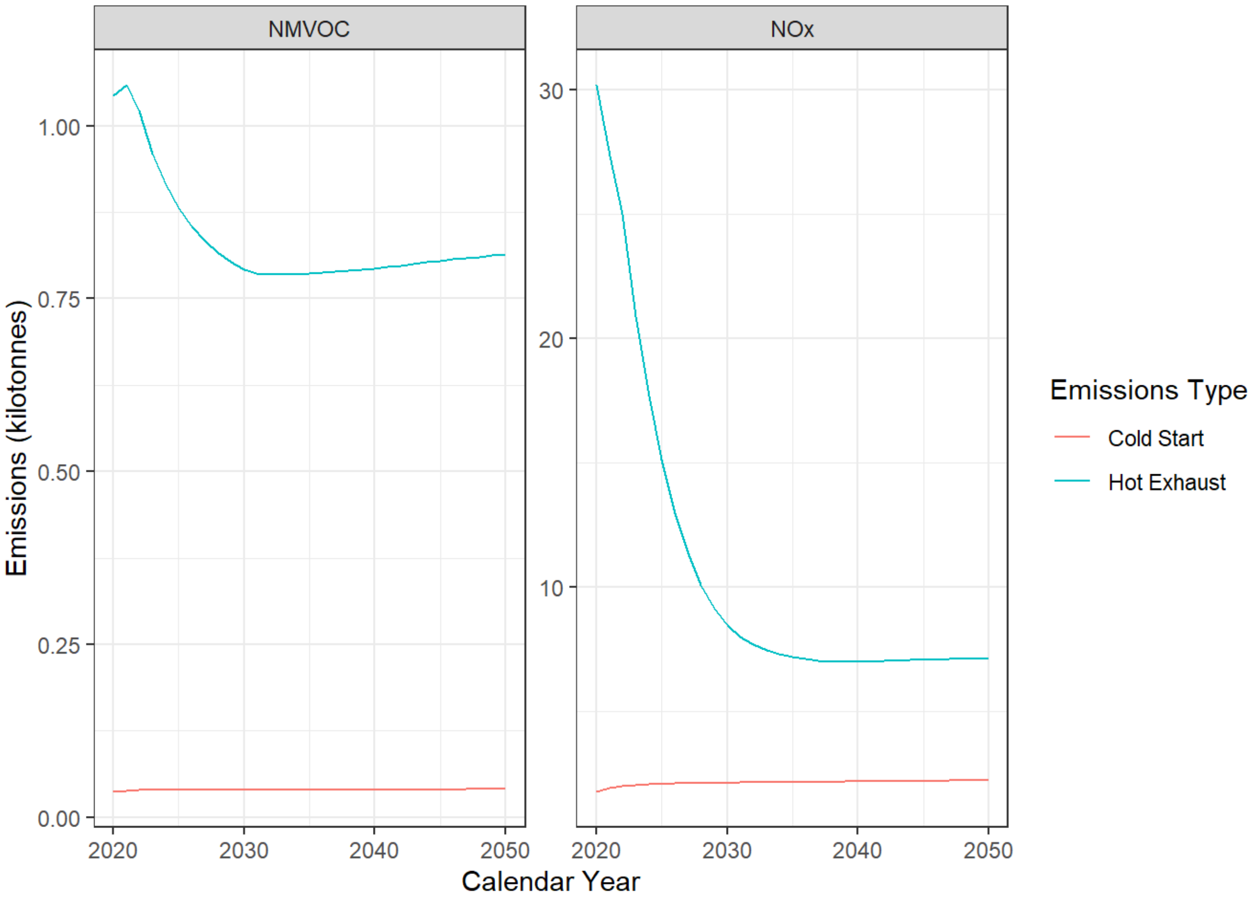

Figure 4-13 HDV cold start and hot exhaust emissions by year and pollutant in COPERT 5.6 from 2020

4.3.4 All Cold Start Emissions Results

Figure 4-14 shows the overall impact of the revisions to cold start across all vehicle types. The most significant absolute difference in the cold start emissions for NO_x overall occurs in the later part of the time-series and is due to changes in the estimates made for diesel LGVs and HDVs, although the changes for petrol cars also have an impact in years up to 2020. The changes in cold start emissions for NMVOCs overall are mainly due to the changes made for petrol cars for most of the time-series.

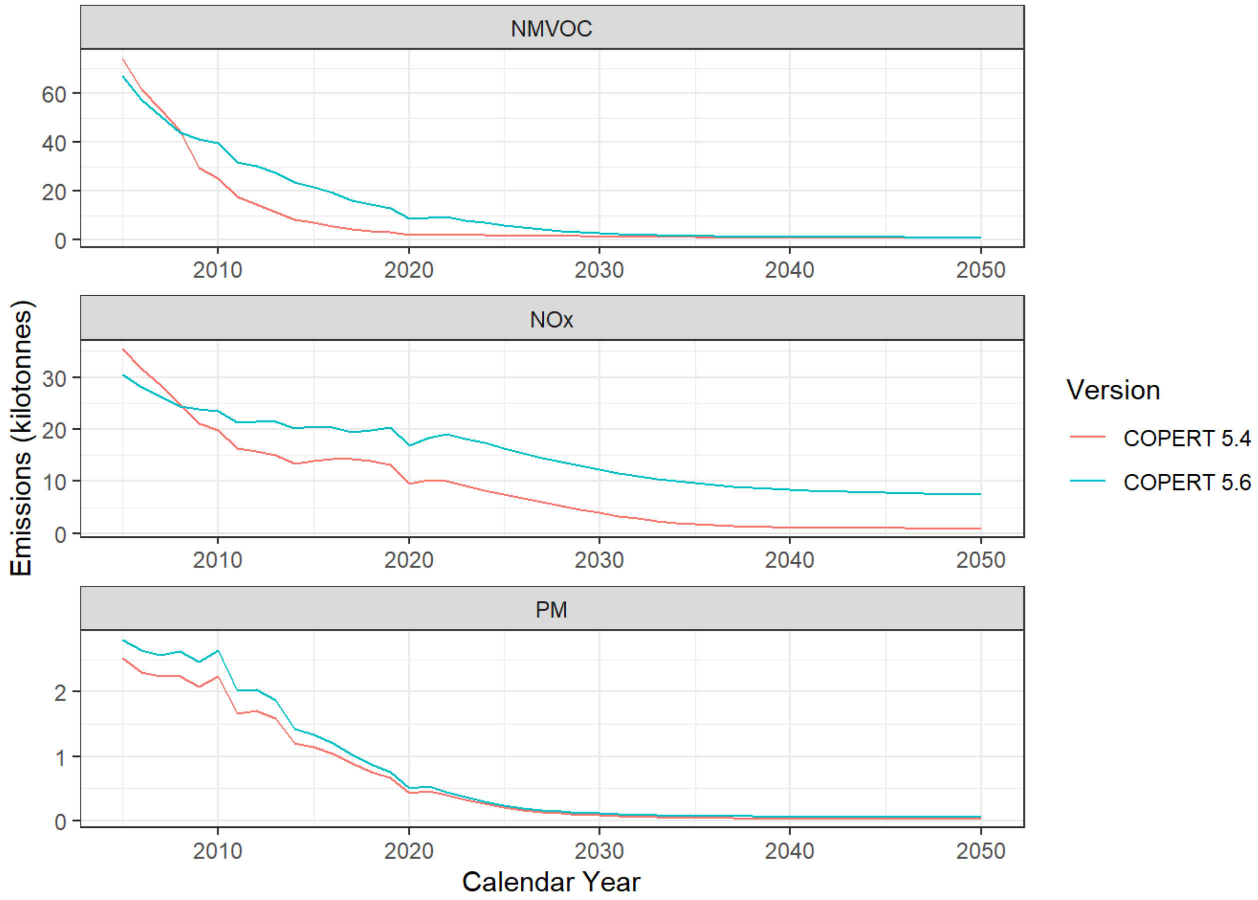

Figure 4-14: Overall impact of the revisions to cold start across all vehicle types

4.4 PM HOT EXHAUST EMISSION FACTORS

The implementation of COPERT 5.6 requires a few changes to the hot exhaust emission factors for PM, most notably in the way factors are presented for petrol cars/LGVs and for Euro V and VI HGVs and buses. Updates have also affected diesel LDVs and motorcycles due to changes across COPERT 5.5 and COPERT 5.6, relative to COPERT 5.4.

4.4.1 GDI/PFI proportions

COPERT 5.6 introduced different PM exhaust emission factors for Gasoline Diesel Injection (GDI) and Port Fuel Injection (PFI). This applies to petrol cars from Euro 3 and petrol LGVs from Euro 6.

In order to use those emission factors in the inventory, estimates of the proportion of vehicle sales by GDI/PFI were required. There are no statistics available on the split from DfT, but information was available from consultation with vehicle engineering colleagues at Ricardo based on various European market searches and industry projections on gasoline engine production. Analysis of these searches suggested a growth in GDI car sales from a share of 2% in 2005 to 22% by 2010, 62% by 2020, then stabilising at 72% in 2030.

4.4.2 Euro V and VI HDVs

In COPERT 5.6, HDV PM Euro V and Euro VI emission factors were provided in units of g/kWh for the first time (previously they were provided as g/km). Although no reason is given for this, it may be because the factors have become so low, in line with the challenging emission limit values which are expressed in these units, with measurements possibly being restricted to the types of tests required to show compliance with the limit values under different load conditions. However, conversion to g/km was still possible using specific fuel consumption factors and fuel energy to energy output power assumptions.

4.4.3 Emissions changes

Figure 4-15 shows that Petrol LDV emissions are lower in COPERT 5.6 than in COPERT 5.4. This is driven by the GDI/PFI proportions introduced in COPERT 5.6, leading to lower average emission factors by Euro Standard. Diesel LDV emissions are also lower in COPERT 5.6 than in COPERT 5.4 due to revised emission factors in COPERT 5.6.

Euro 4 and 5 >750cm^3 motorcycle PM emission factors in COPERT 5.6 were 17.5% of what they were in COPERT 5.4, leading to lower emissions in COPERT 5.6 for motorcycles from around 2015.

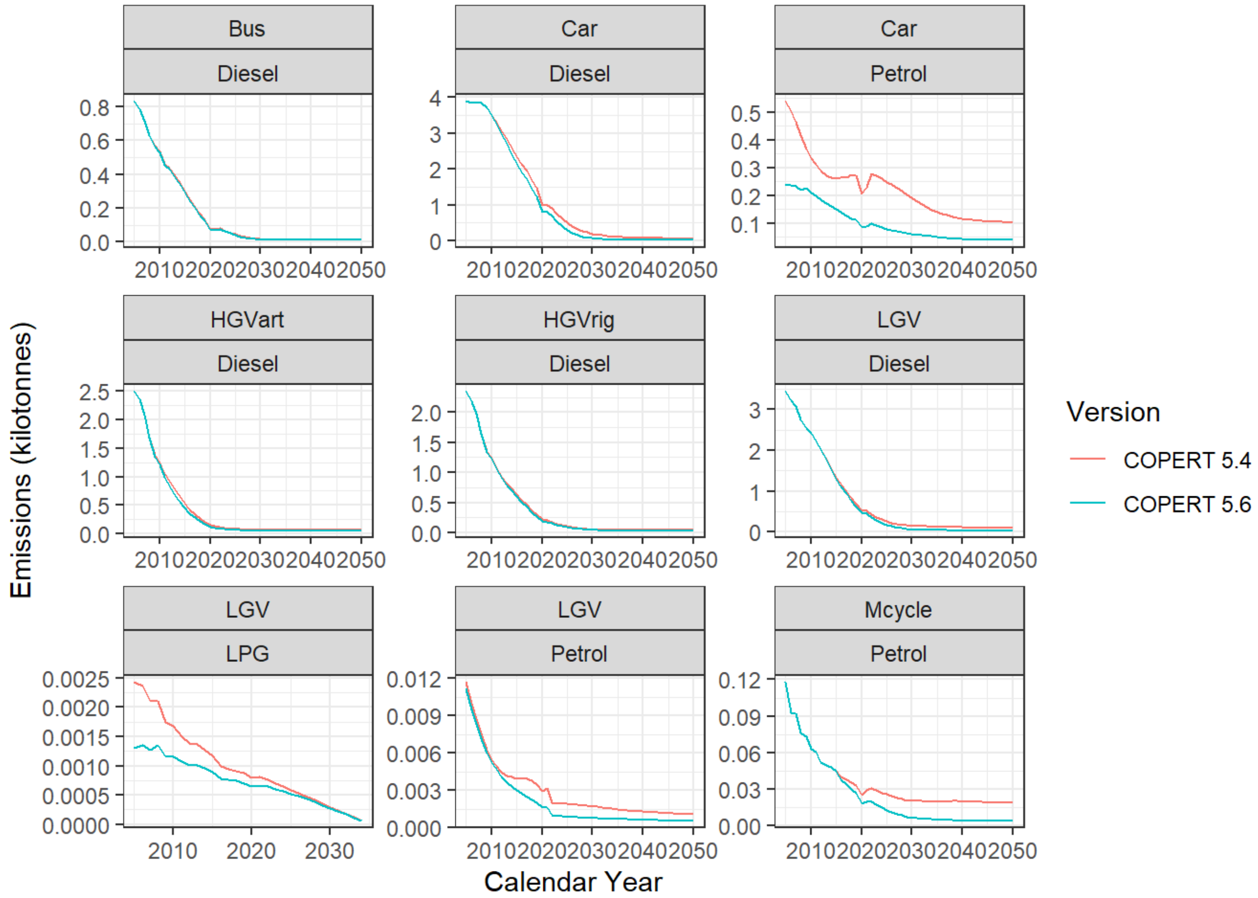

Figure 4-15: PM exhaust emissions by vehicle type and fuel type, compared between COPERT 5.6 and COPERT 5.4

4.5 UPDATED LPG EMISSION FACTORS

There are very few vehicles in the UK that use liquefied petroleum gas (LPG) as a fuel, but factors for LDVs using LPG were updated to align with COPERT 5.6. Emission factors for PM, NO_x, and VOCs for Euro 6 LPG passenger cars were revised downwards in COPERT 5.6, based on new evidence from vehicle test data.

It was noted that the total VOC emission factors for Euro 6 vehicles shown in the Guidebook for COPERT 5.6 were significantly lower than those for Euro 5, but most importantly, were significantly lower than CH_4 emission factors, which is nonsensical given that CH_4 is a subset of total VOCs[1]. This would appear to be an error in the Guidebook[2]. To address this, the VOC emission factors for Euro 5 LPG vehicles were used for Euro 6. This

[1] Emissions for NMVOCs are derived by subtracting CH_4 emissions from those calculated for total VOCs

[2] The authors of the Guidebook have since been notified of this and replied that this would be corrected in the next update of COPERT.

means there is no change in the Euro 6 LPG emission factors for total VOCs relative to COPERT 5.4 and NAEI21.

Figure 4-16 shows the LPG hot exhaust emissions by year and pollutant, compared between COPERT 5.6 and COPERT 5.4. Because there are very few LPG vehicles in the UK fleet, the impact of this revision on total road transport emissions of PM, NO_x and VOC emissions in the NAEI is very small.

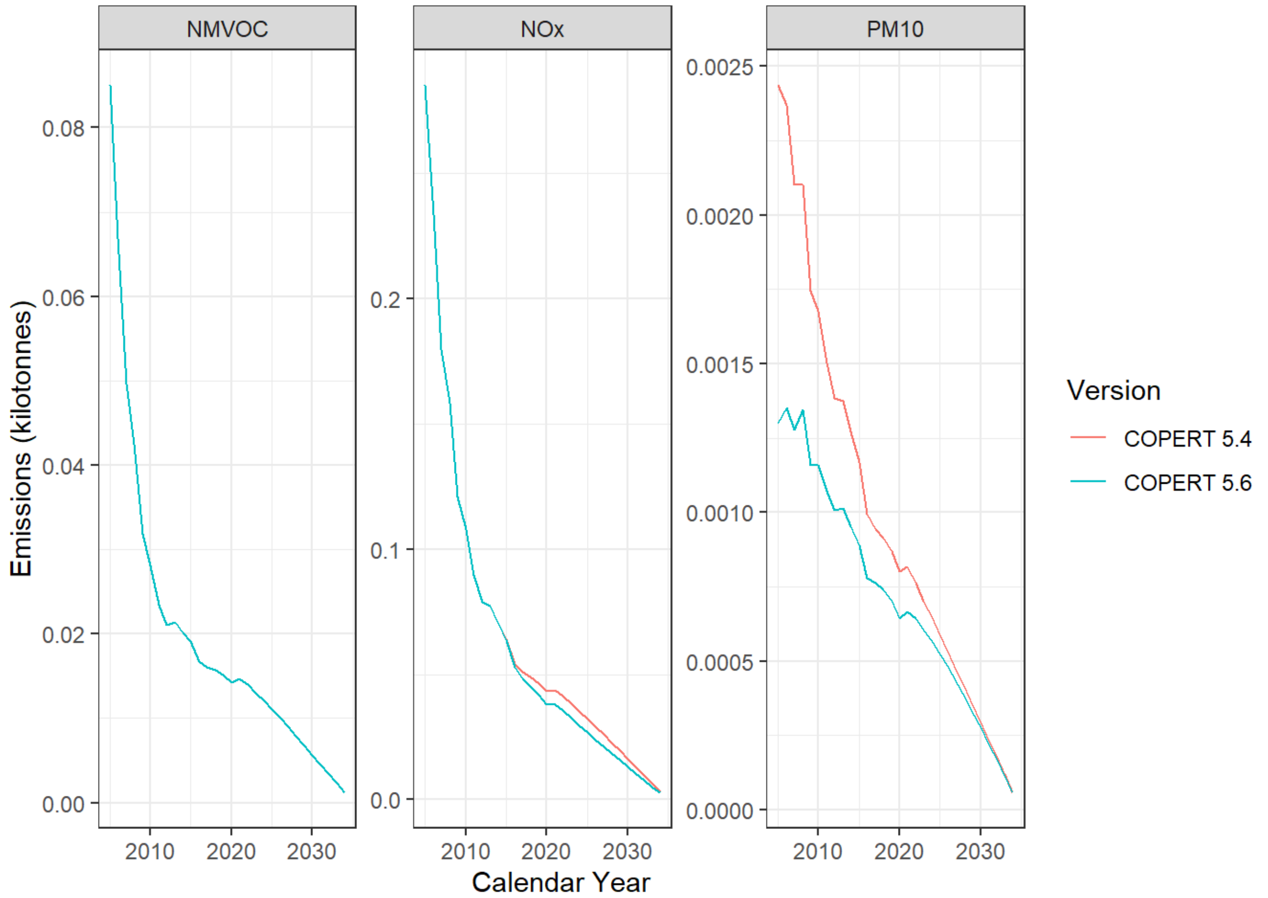

Figure 4-16: LPG emissions by year and pollutant, compared between COPERT 5.6 and COPERT 5.4

5. OVERALL CHANGES

Figure 5-1 and Table 5-1 shows changes across all vehicle types, fuel types and emissions sources (hot exhaust, cold start, non-exhaust etc.) compared between COPERT 5.4 and COPERT 5.6, by pollutant.

For NO_x, overall emissions are higher using COPERT 5.6 than using COPERT 5.4 across the time-series (historic and projections). From around 2008, emissions from COPERT 5.6 are slightly higher than from COPERT 5.4, but the difference increases by 2015 and then decreases again beyond 2020 in absolute terms, though in percentage terms the differences increase. The higher emissions from COPERT 5.6 are initially driven by changes to the degradation method in the early part of the time-series, but in the projections, changes to the cold start method become increasingly dominant. Initially the increase in cold start emissions is driven by changes to the method for diesel LDVs and petrol cars, but later in the projections changes to cold starts from diesel LDVs and HDVs are the dominant cause.

For PM, emissions from COPERT 5.6 are higher than from COPERT 5.4 across most of the timeseries. Until 2025, the change is largely driven by the increase in the brake wear emission factors for ICE LDVs but is partially offset by changes due to reductions in the hot exhaust emission factors. By 2040, brake wear emissions from COPERT 5.6 are reduced due to the lower emissions associated with electric and hybrid vehicles introduced in COPERT 5.6, with these vehicles having further penetrated the fleet by then, but the lower estimates from brake wear are offset by increases in tyre wear and road abrasion emission estimates from these vehicles also represented in COPERT 5.6.

For NMVOCs, emissions are notably higher in COPERT 5.6 compared to COPERT 5.4 between around 2010 and 2030. This is driven predominantly by the changes in cold start emissions introduced in COPERT 5.6.

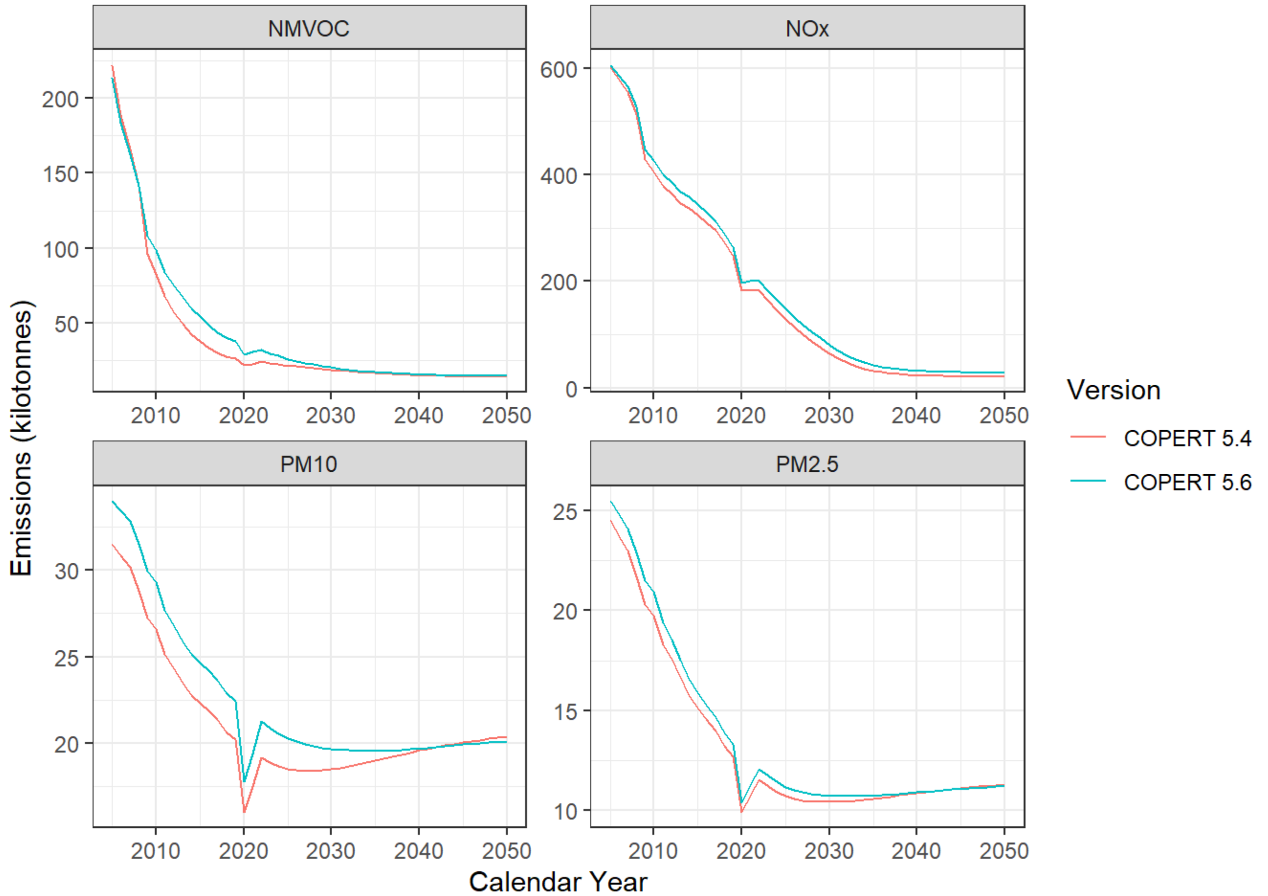

Figure 5-1: Changes across all vehicle types, fuel types and emissions sources (hot exhaust, cold start, non-exhaust etc.) compared between COPERT 5.4 and COPERT 5.6, by pollutant

Table 5-1 shows Emissions changes by pollutant, year, and COPERT version for reference.

Table 5-1: Emissions changes by pollutant, year, and COPERT version (ktonnes)

Table 3.1: Emissions changes by pollutant, year, and COPERT version (ktonnes)				
Pollutant	**Calendar Year**	**COPERT 5.4**	**COPERT 5.6**	**Difference (%)**
NMVOC				
NMVOC	2005	222.0	213.6	-4%
NMVOC	2015	37.7	54.3	44%
NMVOC	2021	22.8	30.6	34%
NMVOC	2025	21.6	26.1	21%
NMVOC	2030	18.8	20.4	9%
NMVOC	2040	15.1	15.7	4%
NMVOC	2050	14.2	14.6	3%
NOx				
NOx	2005	601.9	605.5	1%
NOx	2015	324.0	344.7	6%
NOx	2021	184.1	200.2	9%
NOx	2025	129.6	147.9	14%
NOx	2030	65.1	80.6	24%
NOx	2040	23.6	32.2	36%
NOx	2050	20.8	28.3	36%
PM10				
PM10	2005	31.5	34.0	8%
PM10	2015	22.3	24.6	10%
PM10	2021	17.5	19.4	11%
PM10	2025	18.5	20.3	10%
PM10	2030	18.5	19.7	6%
PM10	2040	19.6	19.7	1%
PM10	2050	20.4	20.1	-1%
PM2.5				
PM2.5	2005	24.5	25.5	4%
PM2.5	2015	15.1	15.9	5%
PM2.5	2021	10.7	11.2	5%
PM2.5	2025	10.7	11.2	5%
PM2.5	2030	10.4	10.7	3%
PM2.5	2040	10.9	10.9	0%
PM2.5	2050	11.3	11.2	-1%

6. PROPOSED CHANGES MADE IN THE LATEST VERSION OF THE GUIDEBOOK

Proposed updates to the latest version of the Guidebook 2023 (COPERT v5.7) were presented at the TFEIP meeting in Oxford in April 2023. A summary of the changes proposed for road transport (1A3b) compared to the previous version (Guidebook version 2022 (COPERT v5.6)) is presented below.

6.1 EXHAUST EMISSIONS

6.1.1 Diesel Heavy-Duty Buses

Recent measurements of emissions from Euro VI urban buses have led to proposed updates of the hot emission factors for CO and NO_x and in fuel consumption in COPERT 5.7. The changes to the Euro VI emissions factors in COPERT 5.7 (for zero road slope, 50% load and 50km/h) are summarised below.

6.1.1.1 Changes to the CO Emission factors

For all urban bus sizes in the NAEI, emission factors in COPERT 5.7 are around 2 times higher than they were in COPERT 5.6.

6.1.1.2 Changes to the NO_x emission factors

For midi buses (<15t), emission factors are around 5.6 times higher than they were in COPERT 5.6, for standard buses (15-18t) they are 5.1 times higher

6.1.1.3 Changes to the Fuel Consumption (FC) Emission factors

For urban buses (all sizes), fuel consumption factors increased by 21% in COPERT 5.7.

6.1.2 Hybrid Electric Urban Buses

Speed dependent fuel consumption factors for hybrid electric urban buses as well as their respective CO and NO_x emission factors have been updated through recent measurements. A summary of the proposed changes seen in the Euro VI emissions factors in COPERT 5.7 (for zero road slope, 50% load and 50km/h) is provided below.

6.1.2.1 Changes to the CO Emission Factors

For diesel hybrid buses, the CO factors increased by 12% in COPERT 5.7.

6.1.2.2 Changes to the NO_x Emission Factors

For diesel hybrid buses, the NOx factors are 5 times higher in COPERT 5.7.

6.1.2.3 Changes to the Fuel Consumption (EC) Emission Factors

For diesel hybrid buses, the fuel consumption factors decreased by 13% in COPERT 5.7.

6.2 NON-EXHAUST EMISSIONS OF PM

Guidebook version 2023 (COPERT 5.7) provides a differentiation of TSP tyre and brake and road surface wear emission factors among different sizes of passenger cars and light commercial vehicles for the first time. This differentiation will provide a better presentation of how the non-exhaust emissions vary with the vehicle size, i.e., smaller (thus lighter) size vehicles will have lower non-exhaust emissions than larger (heavier) vehicles. The emission factors for medium-size passenger cars have not changed significantly and the likely impact on PM emissions is expected to be small. Evidence is based on recent literature, and for road surface wear, the available information is limited and thus the factors are highly uncertain. Table 6-1, Table 6-2 and Table 6-3 show the Tier 2 TSP emission factors for road vehicle tyre and brake wear and road surface wear from Guidebook version 2022 (COPERT 5.6) and version 2023 (COPERT 5.7).

Table 6-1: Tier 2 TSP emission factors (g/km) for road vehicle tyre wear

Vehicle class	Guidebook version 2022-COPERT 5.6	Guidebook version 2023-COPERT 5.7
Passenger cars – ICE – Small	0.0107	0.0096
Passenger cars – ICE – Medium		0.0107
Passenger cars – ICE – Large		0.0118
Passenger cars – Hybrid – Small	0.0111	0.0100
Passenger Cars – Hybrid – Medium		0.0111
Passenger Cars – Hybrid – Large		0.0123
Passenger Cars – PHEV – Small	0.0112	0.0101
Passenger Cars – PHEV – Medium		0.0112
Passenger Cars – PHEV – Large		0.0124
Passenger Cars – BEV – Small	0.0116	0.0105
Passenger Cars – BEV - Medium		0.0116
Passenger Cars – BEV – Large		0.0127
Light-Commercial Vehicles (N1 – I)	0.0169	0.0107
Light-Commercial Vehicles (N1 – II, III)		0.0169

Table 6-2: Tier 2 TSP emission factors (g/km) for road vehicle brake wear

Vehicle category	Guidebook version 2022-COPERT 5.6	Guidebook version 2023-COPERT 5.7
Passenger cars – ICE – Small	0.0122	0.0102
Passenger cars – ICE – Medium		0.0122
Passenger cars – ICE – Large		0.0143
Passenger cars – Hybrid – Small	0.0097	0.0081
Passenger Cars – Hybrid – Medium		0.0097
Passenger Cars – Hybrid – Large		0.0114
Passenger Cars – PHEV – Small	0.0066	0.0055
Passenger Cars – PHEV – Medium		0.0066
Passenger Cars – PHEV – Large		0.0077
Passenger Cars – BEV – Small	0.0034	0.0030
Passenger Cars – BEV - Medium		0.0035
Passenger Cars – BEV – Large		0.0040

Table 6-3: Tier 2 TSP emission factors (g/km) from road surface wear

Vehicle category	Guidebook version 2022-COPERT 5.6	Guidebook version 2023-COPERT 5.7
Passenger cars – ICE – Small	0.0150	0.0127
Passenger cars – ICE – Medium		0.0150
Passenger cars – ICE – Large		0.0174
Passenger cars – Hybrid – Small	0.0159	0.0135
Passenger Cars – Hybrid – Medium		0.0159
Passenger Cars – Hybrid – Large		0.0183
Passenger Cars – PHEV – Small	0.0161	0.0137
Passenger Cars – PHEV – Medium		0.0161
Passenger Cars – PHEV – Large		0.0185
Passenger Cars – BEV – Small	0.0169	0.0145
Passenger Cars – BEV - Medium		0.0169
Passenger Cars – BEV – Large		0.0194
Light-Commercial Vehicles (N1 – I)	0.0150	0.0150
Light-Commercial Vehicles (N1 – II, III)		0.0210

7. SUMMARY AND CONSIDERATION OF LIKELY IMPACT ON THE POLLUTION CLIMATE MAPPING (PCM) PROGRAMME

COPERT 5.6 has implemented more changes to the emission factors than previous updates have made in recent years. The changes have covered several different aspects of the road transport inventory and each has affected emissions differently for each vehicle type, pollutant and year. In some cases the effect of the changes has been cumulative, each leading to changes in the same direction, in other cases they have shown opposing effects to a greater or lesser extent.

Overall, the changes have mostly led to an increase in emission estimates for NO_x, PM and NMVOCs. No changes have occurred for NH_3.

Emission estimates for NO_x have generally increased due to changes in cold starts and degradation effects. In relative terms, the increases have been larger in the projection years than in historic years.

For PM, the estimates have also increased, almost entirely due to changes in the non-exhaust sources. In relative terms, the changes have been smaller than for NO_x, but have tended to be larger in historic years than in projection years.

For NMVOCs, emissions are overall higher for COPERT 5.6 than COPERT 5.4, except in 2005 when they are slightly lower. The differences are mainly due to cold starts and tend to decrease going forward in years.

The Pollution Climate Mapping (PCM) programme is an important user of data from the NAEI's road transport inventory in air quality compliance assessment work for Defra. The PCM uses spatially-resolved inventory data developed from year-specific fleet-weighted emission factors for each vehicle type, fuel and road type which are combined with traffic census and vehicle km data. The process involved in developing these factors from a different version of COPERT is unchanged, though the factors themselves will change. It will be necessary to map cold start emissions from HGVs and buses for the first time as this is a new feature of COPERT 5.6 and to do this will require a suitable set of data that represents the location of trip starts for these vehicle types.

The increase in NO_x emissions in both current and projected years will be reflected in the higher fleet-weighted factors provided for diesel cars and LGVs in particular, and for cold starts which mainly occur in urban areas. As these are dominant sources of NO_x in most urban areas, these will have an impact on the PCM modelled NO_x and NO_2, generally leading to an increase in roadside concentrations in urban areas and in turn, altering the PCM calibration factor.

For PM, the changes are expected to have a small effect on roadside concentrations relative to background, but a small increase in $PM_{2.5}$ and PM_{10} concentrations will be expected due to increases in the non-exhaust emissions, particularly those arising from brake wear in recent model years.

As part of this project, we have looked to use for the first time regional ambient temperature data for the calculation of cold start emissions. This will allow for more accurate distribution of cold start emissions by Devolved Authority and London that takes account of these regional temperature differences, an improvement that will benefit the PCM modelling of concentrations.

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