How additional actions in the road transport sector could improve air quality in Europe — an extension of the Concawe urban air quality studies

Introduction

Over the years, emission reduction measures have resulted in significant improvements in overall air quality in Europe. However, air quality continues to be an issue of policy and public concern at European, national and city levels, as non-compliance with air quality limit values (AQLVs) still remains a challenge in many urban areas, especially for nitrogen dioxide (NO_2), particulate matter (PM) and ozone (O_3). Based on the latest official data, NO_2 and $PM_{2.5}$[1] concentrations were above the annual AQLV[2] at 8% and 4% of all measuring stations in Europe, respectively, while for O_3, more than 40% of all stations showed concentrations above the EU target value.[3] [1]

Road transport is considered a major source of air pollution, especially in urban areas, with 40% of total NO_x emissions in Europe being attributed to road transport emissions.[1] In addition, despite the fact that recent advances in PM treatment techniques have proven to significantly reduce the relative contribution of road transport to primary particulate matter emissions, road transport remains a contributor to PM concentrations, in particular with regard to $PM_{2.5}$. Targeting emissions from road transport is therefore considered to be one of the primary mechanisms for reducing urban concentrations of pollutants, with the more recent focus being on diesel passenger cars.

In response to this, the European Commission (EC) has traditionally utilised a number of regulatory initiatives to control the exhaust emissions of road transport, including setting increasingly stringent emissions standards for its fleet segment as well as introducing testing procedures which more closely reflect the actual vehicle emissions on the road. These initiatives have proven to be successful in reducing emissions of pollutants over the years. For example, NO_x and $PM_{2.5}$ emissions from road transport in Europe decreased by 50% and 60% respectively in 2018 compared to 2000 levels.[1] In addition, as the ongoing revision of the EU's Ambient Air Quality Directives aims to ensure close alignment of the EU AQLVs with the (lower) WHO air quality guideline values that have also been recently revised,[2] it is expected that there will be increased focus on the sources of these emissions, which are believed to be major contributors to non-compliance. The new draft regulatory proposals for the next iteration of vehicle emission standards (i.e. Euro 7/VII) that the EC has started to prepare is an example of this direction.

Concawe has recently undertaken two urban air quality studies[3,4] that aimed to better understand the contribution of road transport emissions to overall air quality in European urban areas, with a particular focus on the concerns over non-compliance with the annual AQLVs for NO_2 and PM. In the first study, the contribution of each element of the road transport fleet was explored. In the second study, the focus was largely on diesel passenger cars and concerns over the 'under-delivery' of legislated Euro 6 emission limits under real driving conditions.

A modelling study has been undertaken to provide insight in potential additional actions that may be considered to improve compliance with air quality limit values in the future. The study was based on a scenario sensitivity analysis, focusing primarily on road transport emissions but also taking into account emissions from other sectors to provide context. This article summarises the results of the study.

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1 $PM_{2.5}$ = particulate matter with an aerodynamic diameter of less than 2.5 µm

2 EU annual AQLVs: $PM_{2.5}$ = 25 µg/m^3, NO_2 = 40 µg/m^3

3 EU target value: maximum daily 8-hour O_3 mean = 120 µg/m^3 (not to be exceeded on more than 25 days)

In particular, using modelling and the results of an earlier study that focused on determining the actual and expected real driving emissions for multiple classes of Euro 6 vehicles (Euro 6b, Euro 6c, Euro 6d temp, Euro 6d)[5] as input, Concawe assessed the impact that a fleet turnover to the latest Euro 6 diesel passenger cars would have on NO_2 and PM compliance during the period 2020–2030 throughout the EU-27 + UK. Several emissions scenarios were examined, including a scenario where all new passenger cars are replaced with zero-emission vehicles. The results show that, with a turnover of the vehicle fleet from older vehicles to new vehicles, the latest Euro 6d diesel vehicles will be as effective as zero-emission vehicles in helping cities become compliant with the AQLVs. In addition, the study showed that there is almost no difference in population exposure to NO_2 concentrations above the limit value when replacing the diesel passenger car fleet with zero-emission vehicles or with Euro 6d-compliant diesel passenger cars.

Building on the findings of Concawe's earlier UAQ studies, this study aims to give insights into the important policy question of what additional actions can be undertaken to significantly improve air quality in Europe. In this context, Concawe used the same methodology as that used in the analyses that underpinned each of the previous UAQ studies, and explored in more detail the effects of various rates of substitution of diesel-powered road transport vehicles (e.g. passenger cars, light-duty commercial vehicles and heavy-duty vehicles) with electric-powered vehicles undertaking the same level of activity. Although road transport emissions were the primary focus of the study, additional scenarios were explored which examined emissions reductions from other sectors so that the contribution of road transport to improving compliance could be considered in context with other sources. The study covered all of the EU-27 + UK with a detailed focus on the same 10 cities used in the earlier Concawe UAQ studies, namely Berlin, Bratislava, Brussels, London, Madrid, Milan, Munich, Paris, Vienna and Warsaw. For brevity, the article uses illustrative examples from the analysis to demonstrate the results of the study.

Modelling approach

The AQUIReS+ model[3] been used to forecast the effect of emissions changes on atmospheric concentrations of NO_2, $PM_{2.5}$ and O_3 at all monitoring stations across the EU included in the European Environment Agency's (EEA's) Air Quality e-Reporting dataset.[6] This ensures that the modelling is directly related to the individual measuring stations used to monitor compliance with the AQLVs. The model uses a gridded emission inventory and source-receptor relationships[7] that relate a change in emission to a change in concentration. These derive from regional chemical transport models (EMEP,[8] CHIMERE[9]) used in air quality studies. The local environment, traffic and topographical characteristics of each station are also taken into account by the model during the predictions. Model predictions for each monitoring station are also compared with measured data from the EEA's Air Quality e-Reporting dataset to ensure that the model performs well in reproducing concentrations of pollutants over historic years. A detailed overview of the model evaluation and a description of the data sources and dataflows in the model are presented in earlier studies.[3,10]

Emissions scenarios

Base case

A base case emissions scenario was used as a starting point in the modelling, aligned with the January 2015 Thematic Strategy on Air Pollution Report #16 (TSAP16) Working Party for the Environment (WPE) Current Legislation scenario.[11,12] This emissions dataset was developed for the EU Air Policy Review process[13] and was generated by IIASA's GAINS model.[14] The Current Legislation scenario is an official EU projection of how emissions (based on multiple sector contributions) will evolve over time, and takes account of economic growth and the progressive introduction of European legislation currently in force. Projections are made in five-year steps (i.e. 2015–2020–2025–2030). The geographic distribution of emissions is accounted for at a fine scale, and national emissions for the EU Member States (EU-27 + UK) are calculated by spatial aggregation.

The base case road transport emissions calculations utilised the TREMOVE 3.3.2 alternative dataset and the COPERT 4 v11.8.5 emissions factors. For the purposes of this study however, the road transport emissions in the base case emissions scenario were updated to take into account the findings from the earlier Concawe-Ricardo study.[5] Under the study, it is assumed that all Euro 6 diesel passenger cars introduced in a specific year are assumed to conform to the median level of the Concawe-Ricardo results (Table 1), while all new diesel passenger car registrations from 2020 onwards are assumed to be Euro 6d compliant.

Table 1: NO_x median conformity factors[4][4] for diesel passenger cars used in the base case emission scenario

	Euro 6b, pre-2015	Euro 6b, post-2015	Euro 6c	Euro 6d (temp)
Median NO_X	5.41	1.90	1.21	0.76[5]

[4] The conformity factor is a simple coefficient of the legislated limit value (LLV); for example, a conformity factor of 1.5 is one and a half times the LLV. This was introduced in Commission Regulation (EU) 2016/427 of 10 March 2016.

[5] In any scenario where the conformity factor was measured as being less than 1, the modelling has assumed a conformity factor of 1, which serves to ensure that the model reflects the minimum effect that full compliance with the legislated emissions limits would have on air quality.

How additional actions in the road transport sector could improve air quality in Europe — an extension of the Concawe urban air quality studies

Figures 1 and 2 (below) provide an overview of the projected EU emissions[6] of NO_x and $PM_{2.5}$ used in the base case. Each source sector is shown separately so that the contribution of each sector to overall emissions can be clearly seen. Over the 15-year period from 2015 to 2030, NO_x emissions are projected to decline by approximately 50% (Figure 1). Road transport emissions have seen the greatest reduction of all sectors, amounting to approximately 80% by 2030, while for 2025 and beyond it is forecast that the road transport sector will no longer be the primary contributing sector, with energy production and industrial combustion accounting for 23% and 25% of NO_x emissions, respectively. The road transport contribution to total EU NO_x emissions is projected to fall from 43% in 2015 to 18% by 2030.

$PM_{2.5}$ emissions also show a downward trend over the 15-year period, with a 20% reduction by 2030. The $PM_{2.5}$ contribution from road transport is projected to stabilise from 2020 onwards as the non-exhaust fraction dominates the overall emissions of PM. Residential combustion is by far the most significant source of $PM_{2.5}$ emissions in all years shown (more than 40% in all years).

Figure 1: Sectoral NO_x emissions for Europe under the base case

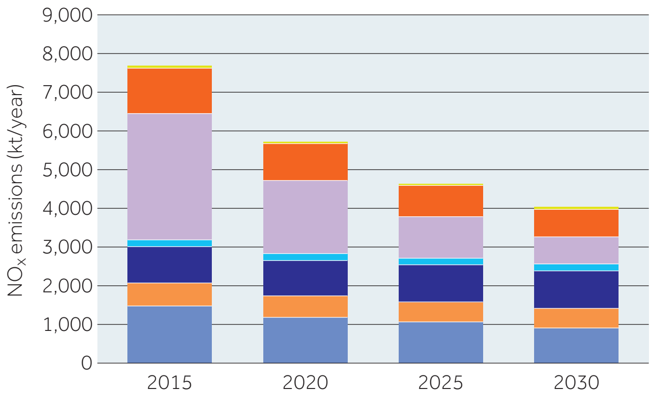
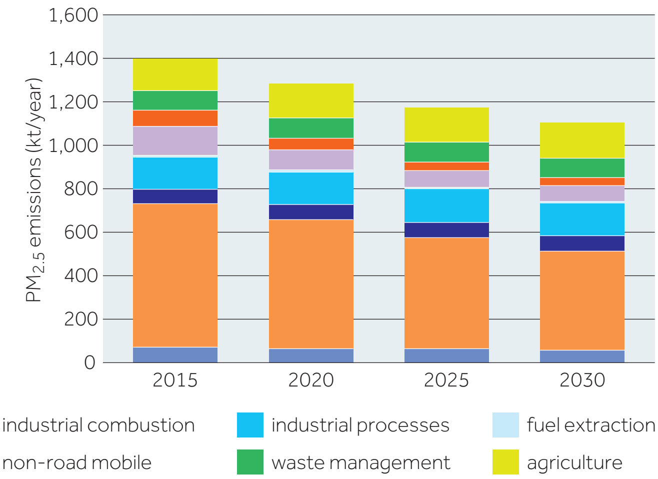


Figure 2: Sectoral $PM_{2.5}$ emissions for Europe under the base case



Source: IIASA TSAP #16/GAINS model, with updated road transport data based on the Concawe-Ricardo study[5]

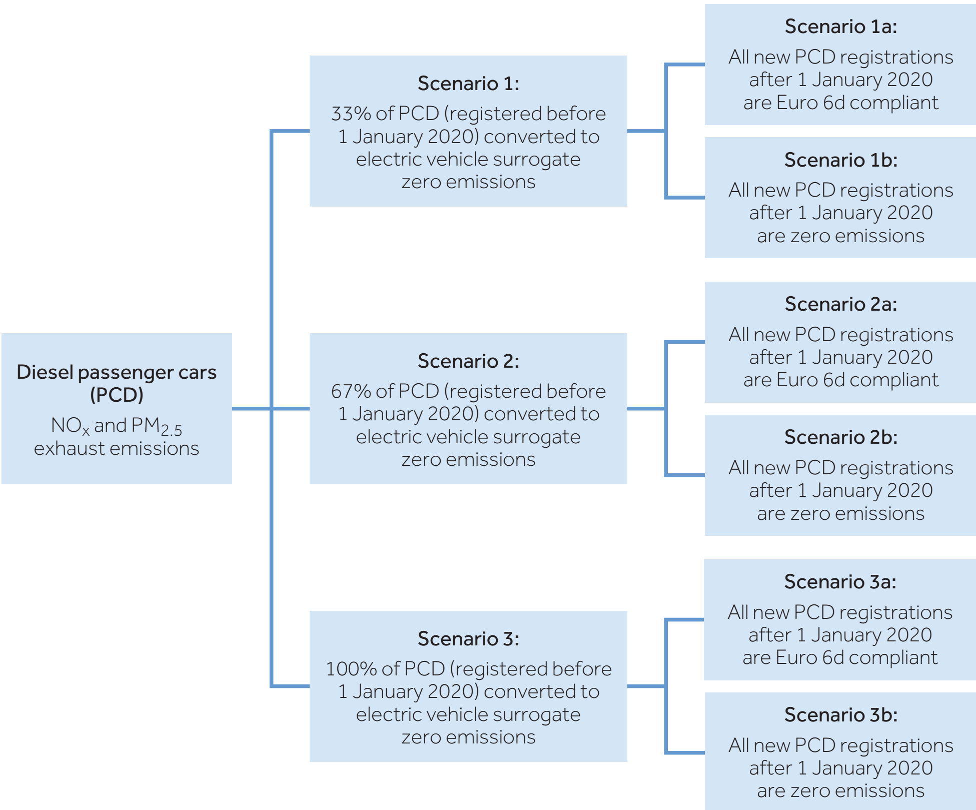
Road transport emissions scenarios

As road transport is the major focus of this study, the majority of the emissions scenarios explored targeted this sector and, in particular, the diesel-powered fleet segment. Nine different scenarios were designed that involved different rates of substitution of diesel-powered vehicles (i.e. passenger cars, light-duty commercial and heavy-duty vehicles) with electric-powered vehicles undertaking the same level of activity. The flow charts in Figures 3 to 5 on pages 35–37 describe the road transport scenarios examined under the study, and the graphs present the associated NO_x emissions considered in each scenario.

[6] The figures provide an indication of the trends and relative contributions of NO_x and $PM_{2.5}$ sectoral emissions, which is representative of all EU countries. The absolute values, however, are country-specific.

Figure 3: Diesel passenger car (PCD) scenarios examined in the study, and the associated NO_x emissions (note: emissions for Scenario 3b are zero)

a) Diesel passenger car scenarios



b) Diesel passenger car NO_x emissions

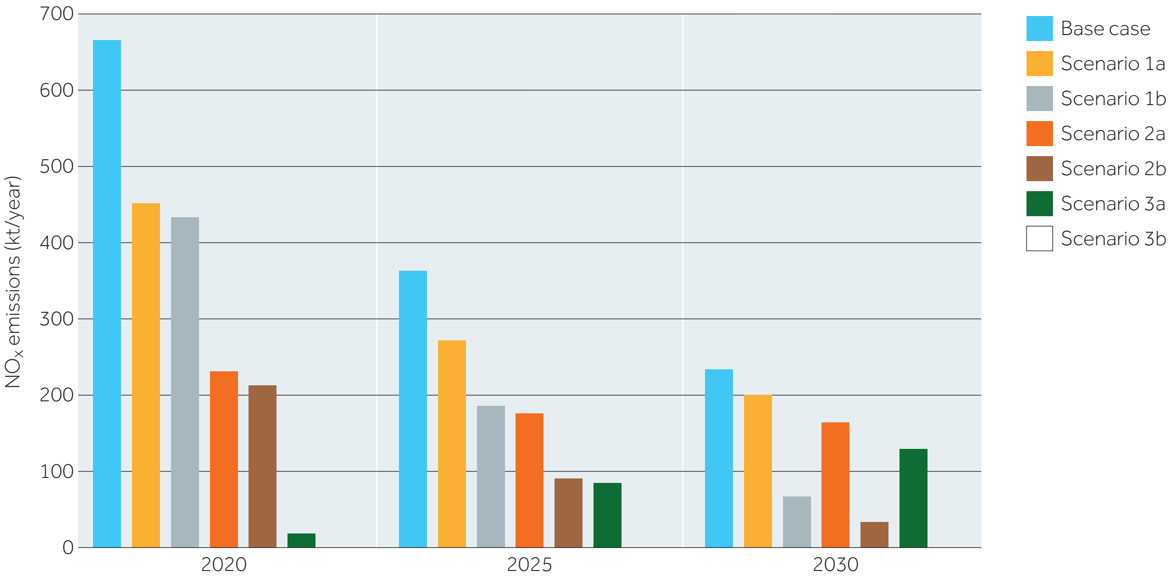
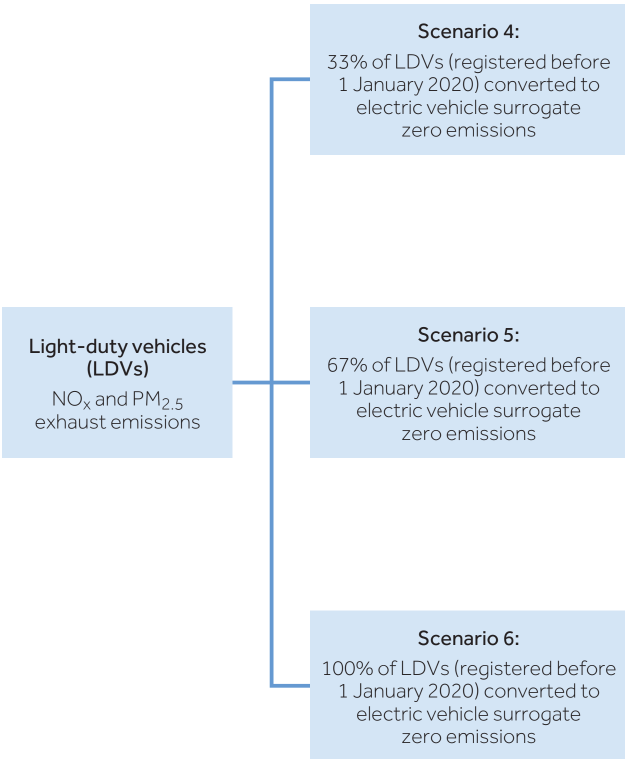


Figure 4: Light-duty vehicles (LDVs) scenarios examined in the study, and the associated NO_x emissions

a) Light-duty vehicle scenarios



b) Light-duty vehicle NO_x emissions

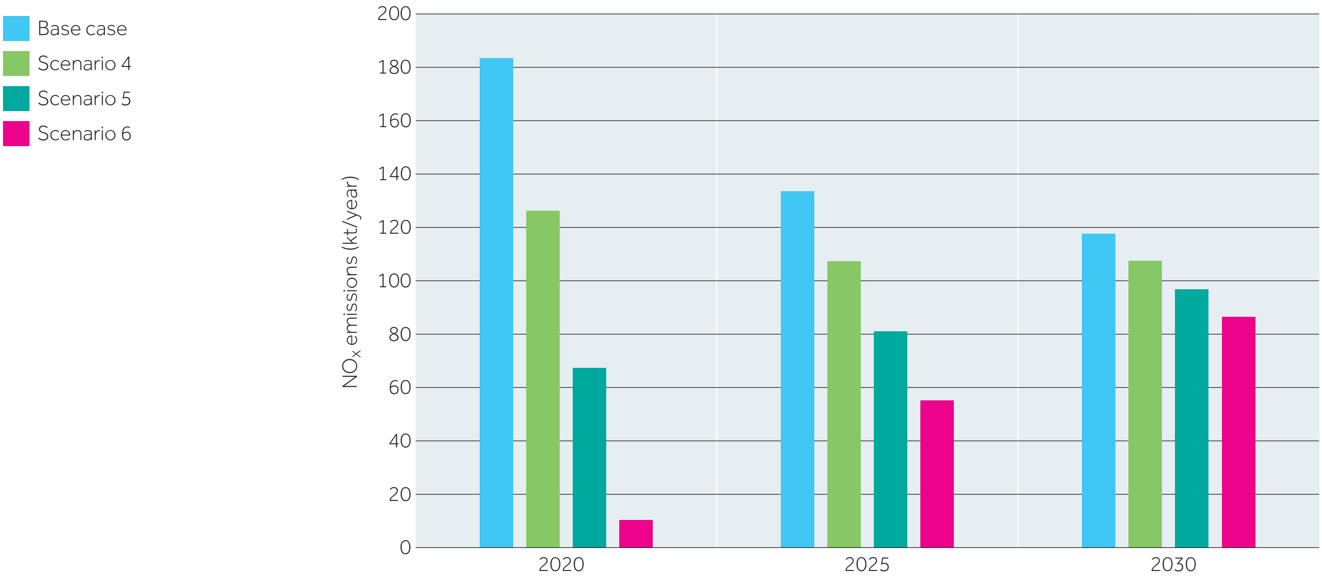
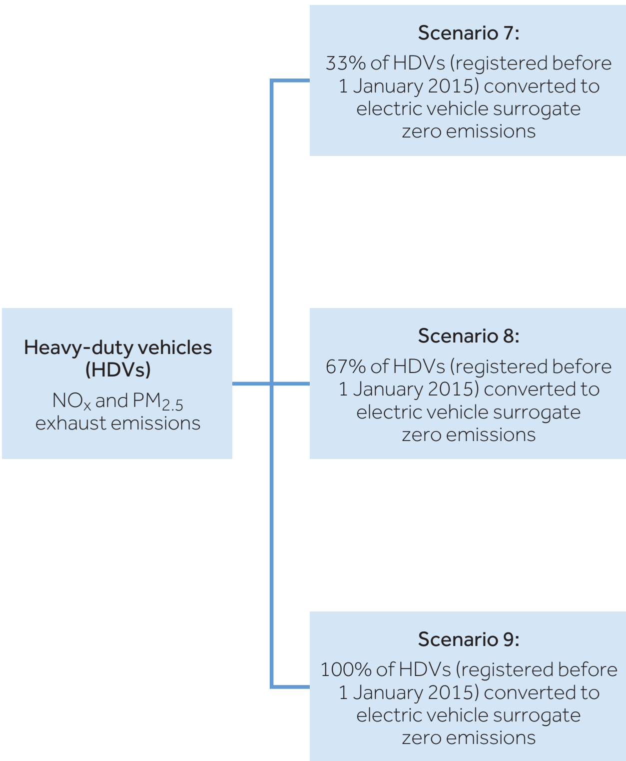
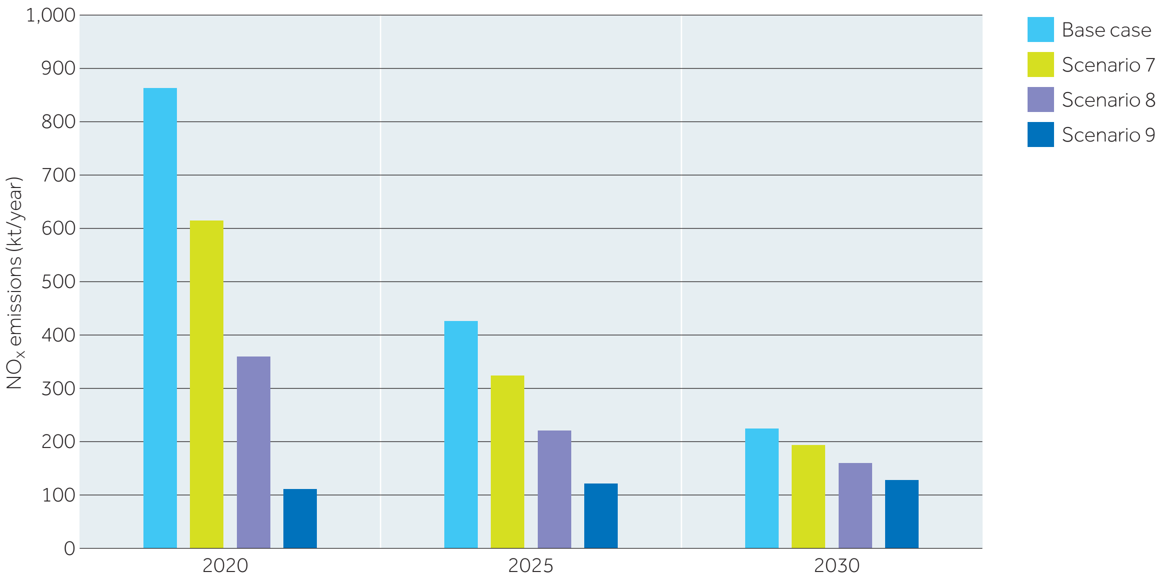


Figure 5: Heavy-duty vehicles (HDVs) and buses scenarios examined in the study, and the associated NO_x emissions

a) Heavy-duty vehicle and bus scenarios



b) Heavy-duty vehicle and bus NO_x emissions



Additional emissions scenarios evaluated

Additional emission reduction scenarios were examined in the study, to assess their further reduction potential as well as to put the contribution of road transport to compliance improvement in context. These scenarios involved measures/assumptions on emissions sources that are significant in urban areas (i.e. Scenarios 10, 11). Additionally, the study extended its focus in terms of the pollutants assessed, and included an assessment of O_3 compliance in urban areas. For this purpose, three additional scenarios were considered targeting VOCs emissions, an important precursor of O_3 formation. Table 2 provides a summary of the additional scenarios examined in this study.

Table 2: List of the additional scenarios examined in this study

Scenario	Description	Examined pollutant(s)
Scenario 10	Emissions as described in the base case but with maximum available NO_x and PM abatement technologies assumed for the domestic heating sector from 2025.	$NO_x/PM_{2.5}$
Scenario 11	Emissions as described in the base case but, from 2020, with substitution of base case solid fuel burning in the domestic sector with gas oil/natural gas.	$PM_{2.5}$
Scenario 12	Emissions as described in the base case but, from 2020, with road transport VOC emissions reduced to zero.	O_3
Scenario 13	Emissions as described in the base case but, from 2020, with road transport VOC emissions doubled.	O_3
Scenario 14	Emissions as described in the base case but, from 2020, with VOC emissions from the storage and distribution of gasoline reduced to zero.	O_3

Results

NO_2 compliance

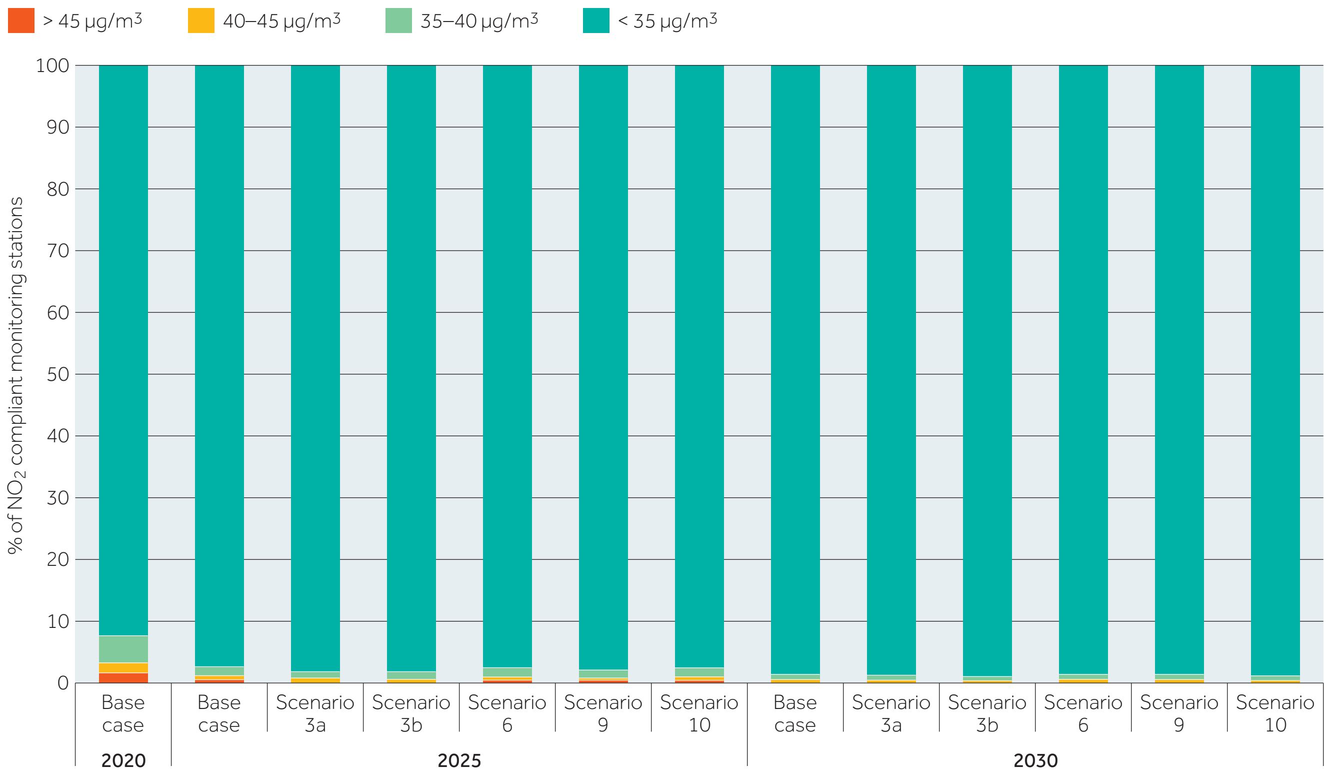
Figure 6 on page 39 shows how the modelled compliance of NO_2 monitoring stations[7] with the current EU AQLVs at a European level is projected from 2020 onwards until 2030 under the base case as well as under some of the emissions scenarios examined in this study.

A high degree of NO_2 compliance with the current AQLVs is already being achieved from 2020 across the EU under the base case scenario, with around 96% of the stations being compliant or probably compliant.[8]

[7] As the focus of the study is on air quality in urban areas, only stations located at urban and suburban areas were used in the analyses.

[8] To account for uncertainty in the model with respect to compliance with the given AQLV, a specific band of uncertainty has been assigned to each monitoring station (i.e. 5 µg/m^3).

Figure 6: NO_2 station compliance (2020–2030) in Europe under the base case and different scenarios examined (EU AQLV = 40 μg/m^3)

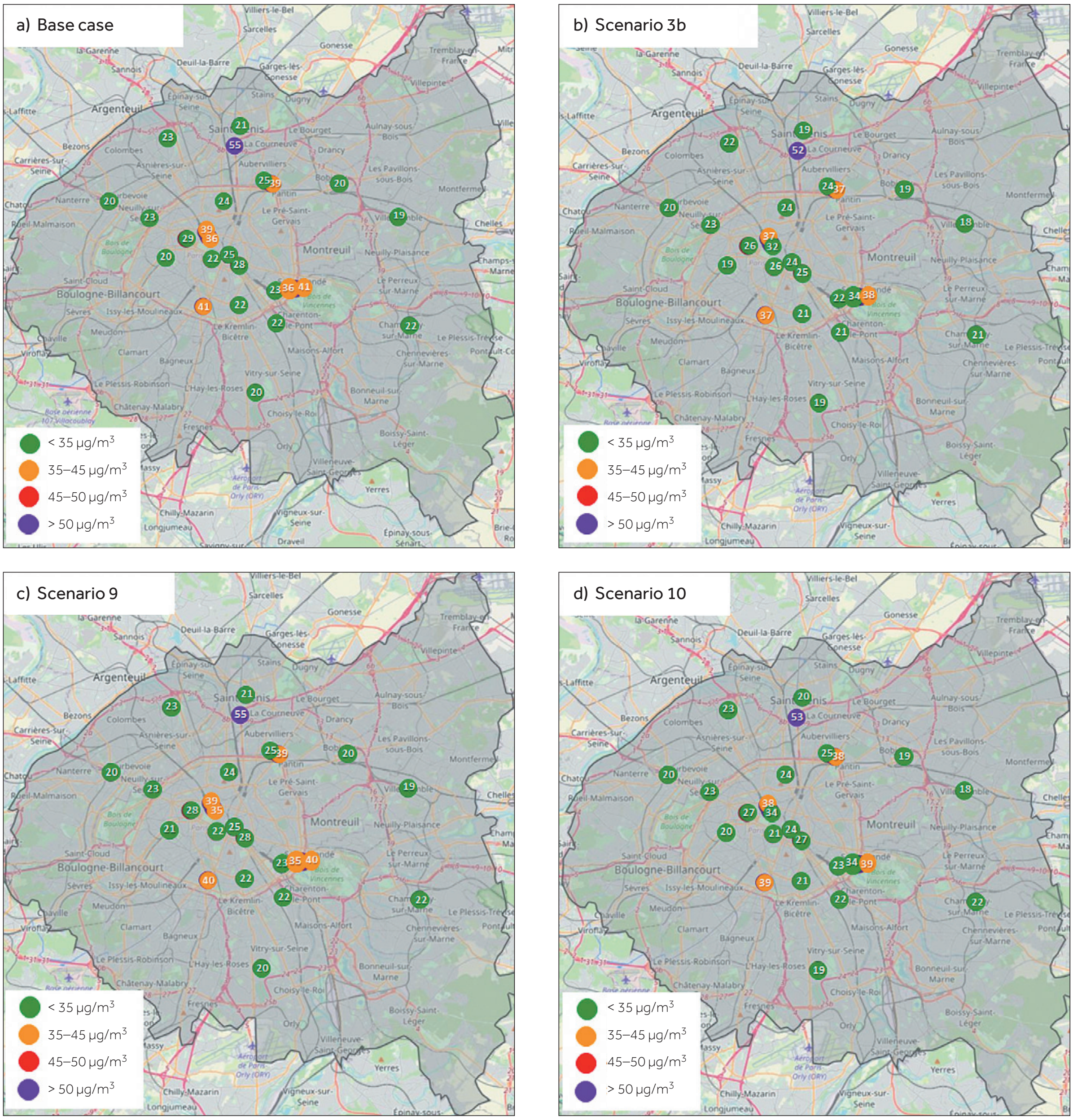


NO_2 compliance is projected to increase over the years, with almost 99% of the monitoring stations (urban/suburban) being compliant in the EU by 2030. The additional 'beyond the base case' scenarios are predicted to improve NO_2 compliance slightly, with measures targeting diesel passenger cars and heavy-duty vehicles being more effective (Scenarios 3a/b and 9 respectively). However, this slight improvement is rather limited and only achieved in the shorter term (i.e. 2020–2025), while post 2025 all additional road transport scenarios are predicted to have a limited further impact on the NO_2 compliance picture. In addition, the implementation of all available NO_x abatement technologies in the domestic heating sector (Scenario 10) is also predicted to have a negligible improvement in NO_2 compliance.

The analyses of the results at a national level indicate that, from 2025 onwards, NO_2 compliance with the current EU AQLV will no longer be an EU-wide issue, as the majority of the countries are predicted to achieve full compliance with the current NO_2 AQLV. Only a handful of stations (~15) remain non-compliant by 2030, with half of them located in France and the remainder in Germany, Italy and the UK.

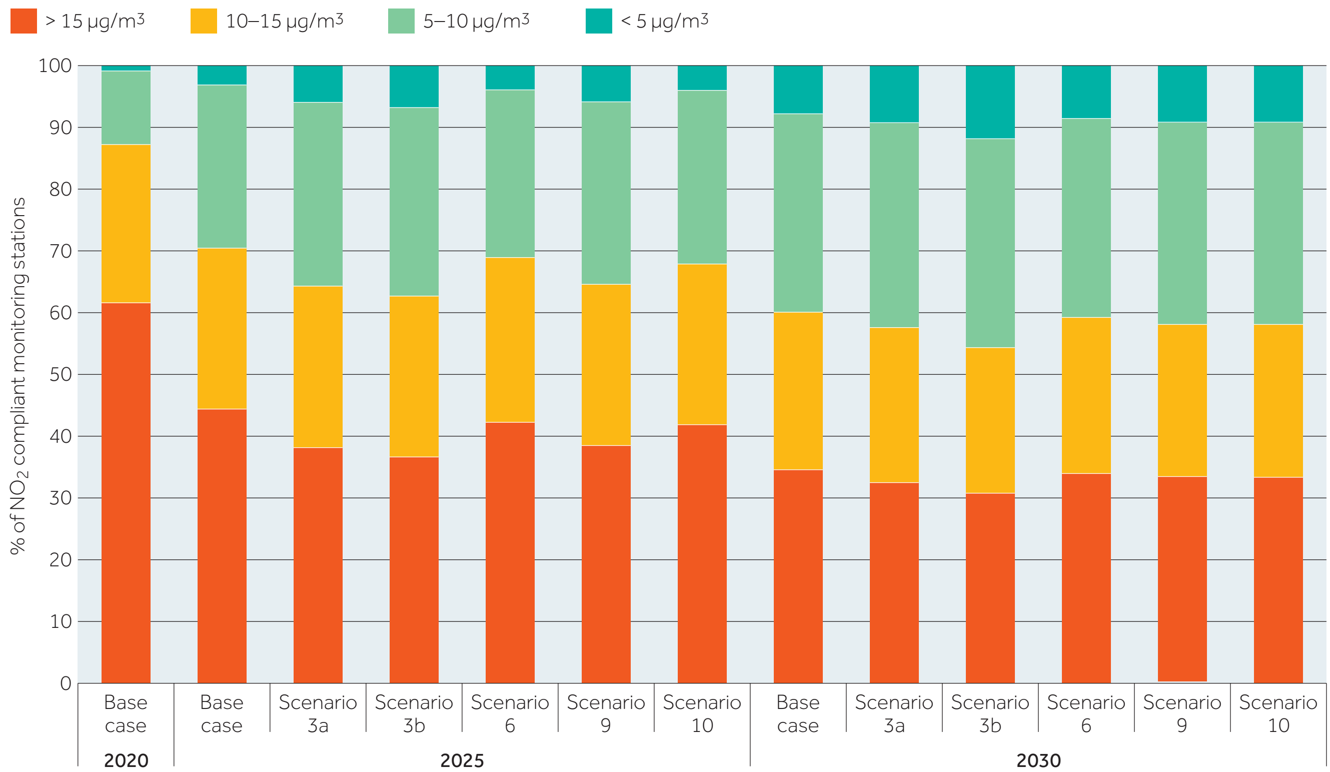
A further city-focused analysis in these non-compliant countries shows that NO_2 non-compliance will be an issue in specific parts of major cities (e.g. Paris) (Figure 7a), regardless of the measures taken nationally. These findings highlight the importance of targeted city-specific measures, identified by a thorough source attribution analysis, rather than further national or European-wide measures. This is also evident from the limited impact of NO_2 compliance improvement that the 'beyond the base case' scenarios will offer in the long term.

Figure 7: NO_2 monitoring station compliance in Paris in 2030, under four different scenarios examined in the study



However, if the current EU NO_2 AQLV is lowered to align with the revised WHO air quality guideline value (i.e. 10 µg/m^3), it is predicted that non-compliance will not only affect specific cities but will become an EU-wide problem (Figure 8). By 2030, more than half of the stations located in urban areas will exceed (or probably exceed) the WHO air quality guideline value under the base case scenario, while significant non-compliance issues will still exist in all additional 'beyond the base case' transport scenarios examined here. This indicates both (a) the need for considering additional measures beyond the transport sector to further improve compliance, and (b) the fact that the alignment of the EU AQLV with the WHO air quality guideline value by 2030 will present considerable challenges.

Figure 8: NO_2 station compliance (2020–2030) in Europe under the base case and different scenarios examined in the study
(WHO air quality guideline value = 10 µg/m^3)

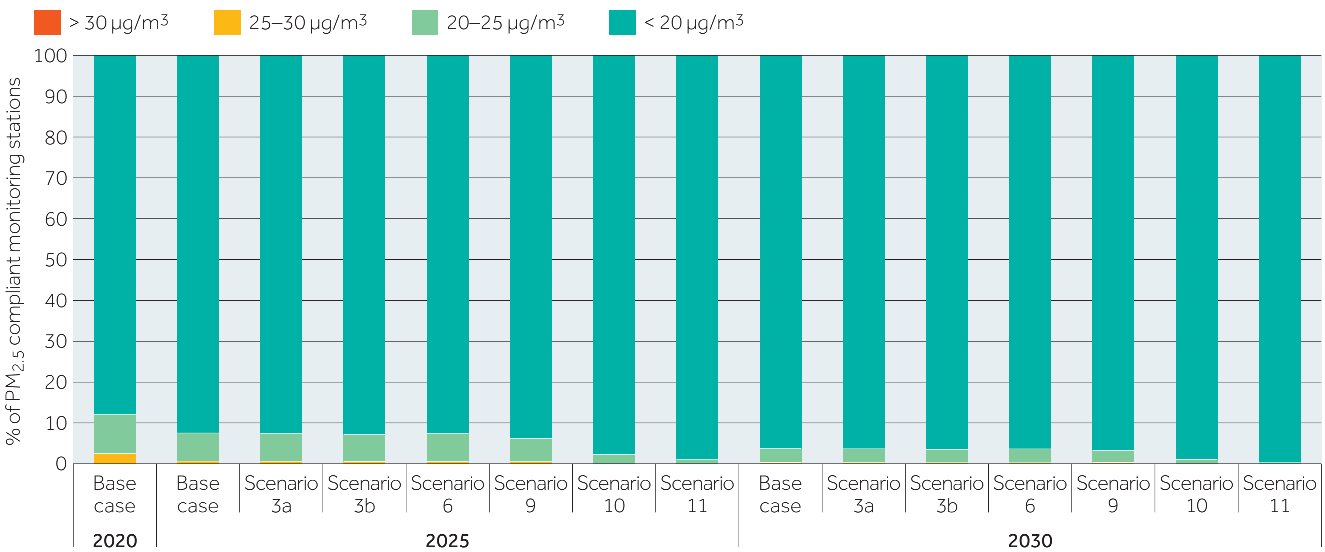


$PM_{2.5}$ compliance

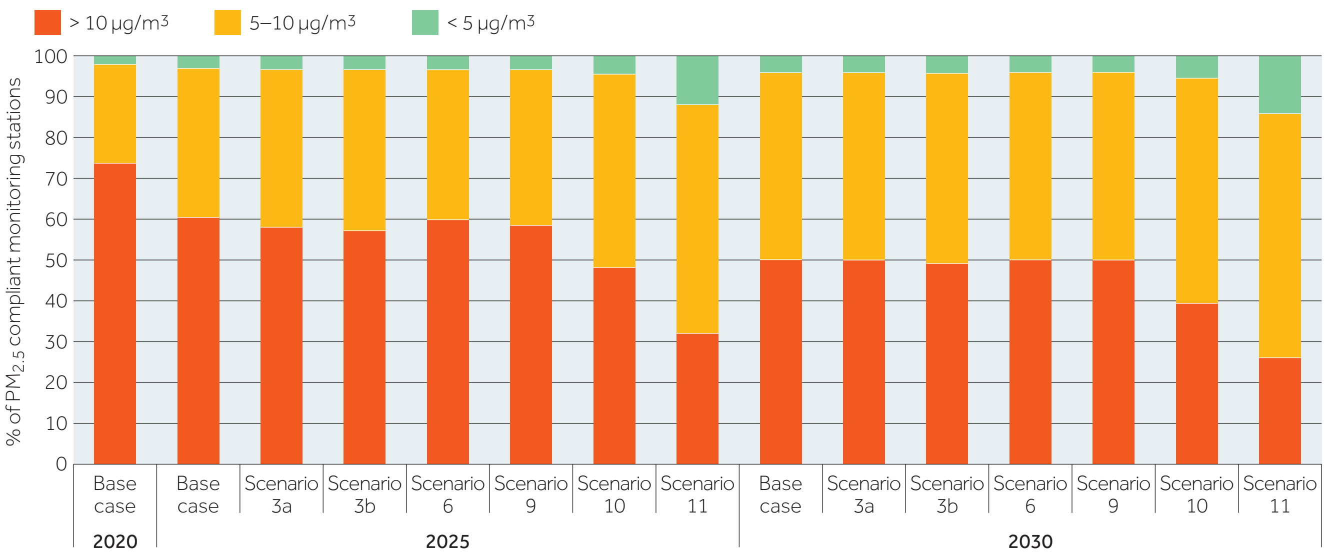
The already-legislated emission reduction measures are predicted to result in a high degree of $PM_{2.5}$ compliance with the current EU AQLV at monitoring stations in all EU Member States. By 2025, almost complete compliance is predicted for $PM_{2.5}$ across the EU, with approximately 92% of all $PM_{2.5}$ monitoring stations (urban/suburban) in Europe measuring $PM_{2.5}$ below 20 µg/m^3 and 7% of them registering $PM_{2.5}$ concentrations between 20–25 µg/m^3 (Figure 9).

Figure 9: $PM_{2.5}$ station compliance (2020–2030) in Europe under the base case and different scenarios examined

a) $PM_{2.5}$ compliance with the current EU AQLV (25 µg/m^3)



b) $PM_{2.5}$ compliance if the current EU AQLV is lowered to align with the WHO guideline value of 5 µg/m^3



Of the scenarios considered, the results show that none of the 'beyond the base case scenarios' targeting road transport will offer any improvement in terms of $PM_{2.5}$ compliance beyond 2025, while their impact in the shorter term (between 2020 and 2025) will be limited, with most improvements resulting from the targeting of HDVs (Figure 9a). On the other hand, further emission controls or fuel substitution of solid fuel burning in the domestic sector are predicted to have a more significant impact on the residual $PM_{2.5}$ non-compliance.

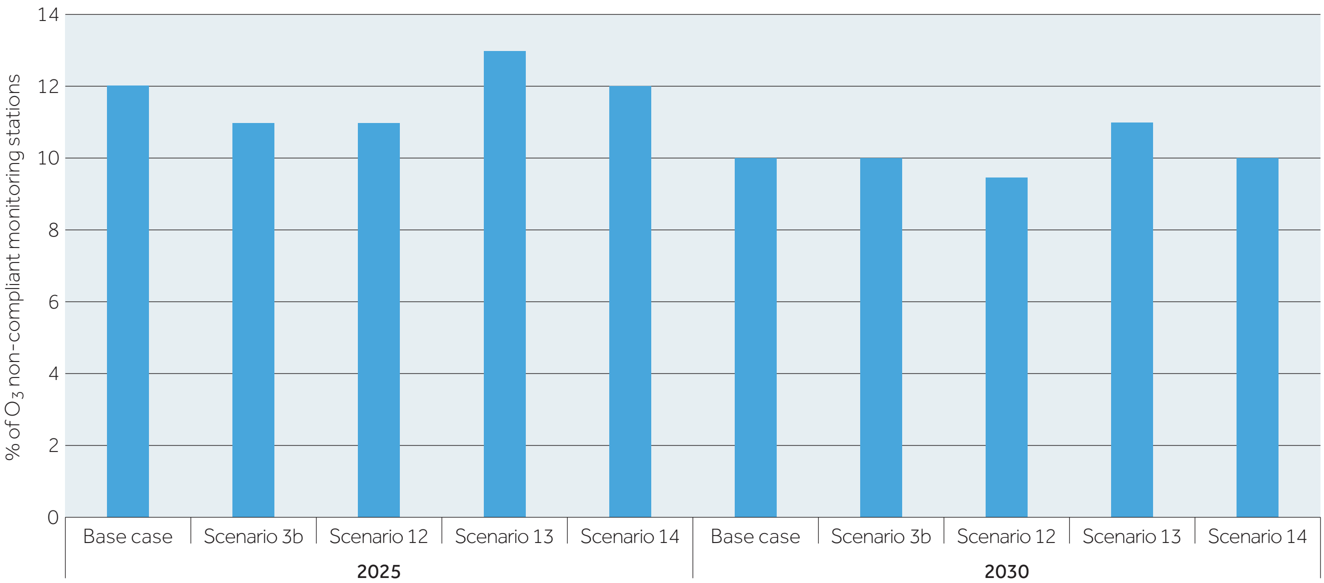
The $PM_{2.5}$ compliance picture in the EU changes significantly if the current EU AQLV for $PM_{2.5}$ is lowered to align with the WHO air quality guideline value (i.e. 5 µg/m^3), as this will impose significant and widespread non-compliance issues in the EU (Figure 9b). As expected, further road-transport measures only offer a negligible improvement in compliance with the WHO air quality guideline value, while in comparison, implementing measures to mitigate emissions from the domestic sector (Scenarios 10, 11) will greatly improve the number of monitoring stations compliant with the WHO air quality guideline value. However, even under these scenarios more than 80% of EU stations will still measure $PM_{2.5}$ above the limit value in 2030, and full compliance will not be achieved in the majority of EU Member States. This is clearly seen in the examples of Poland and Italy, where an alignment of the current EU AQLV with the WHO air quality guideline value will result in both countries — which are otherwise predicted to be fully compliant (Italy) or close to achieving full compliance (Poland) in 2030 — facing significant non-compliance issues (see Figure 10 on page 44). In particular, in Poland none of the scenarios examined in this study will result in $PM_{2.5}$ concentrations below the WHO air quality guideline value; this highlights the significant non-compliance challenge that Member States will face when a close alignment between the EU AQLVs and the WHO air quality guideline values is considered. These findings are consistent with an earlier Concawe study[15] which examined in detail the practicability of achieving compliance with the current EU AQLVs for $PM_{2.5}$ and NO_2, as well as lower limit values, under some potential emission reduction scenarios.

Figure 10: Predicted percentage of $PM_{2.5}$ non-compliant stations in Poland and Italy in 2030, under the different scenarios examined

O_3 compliance

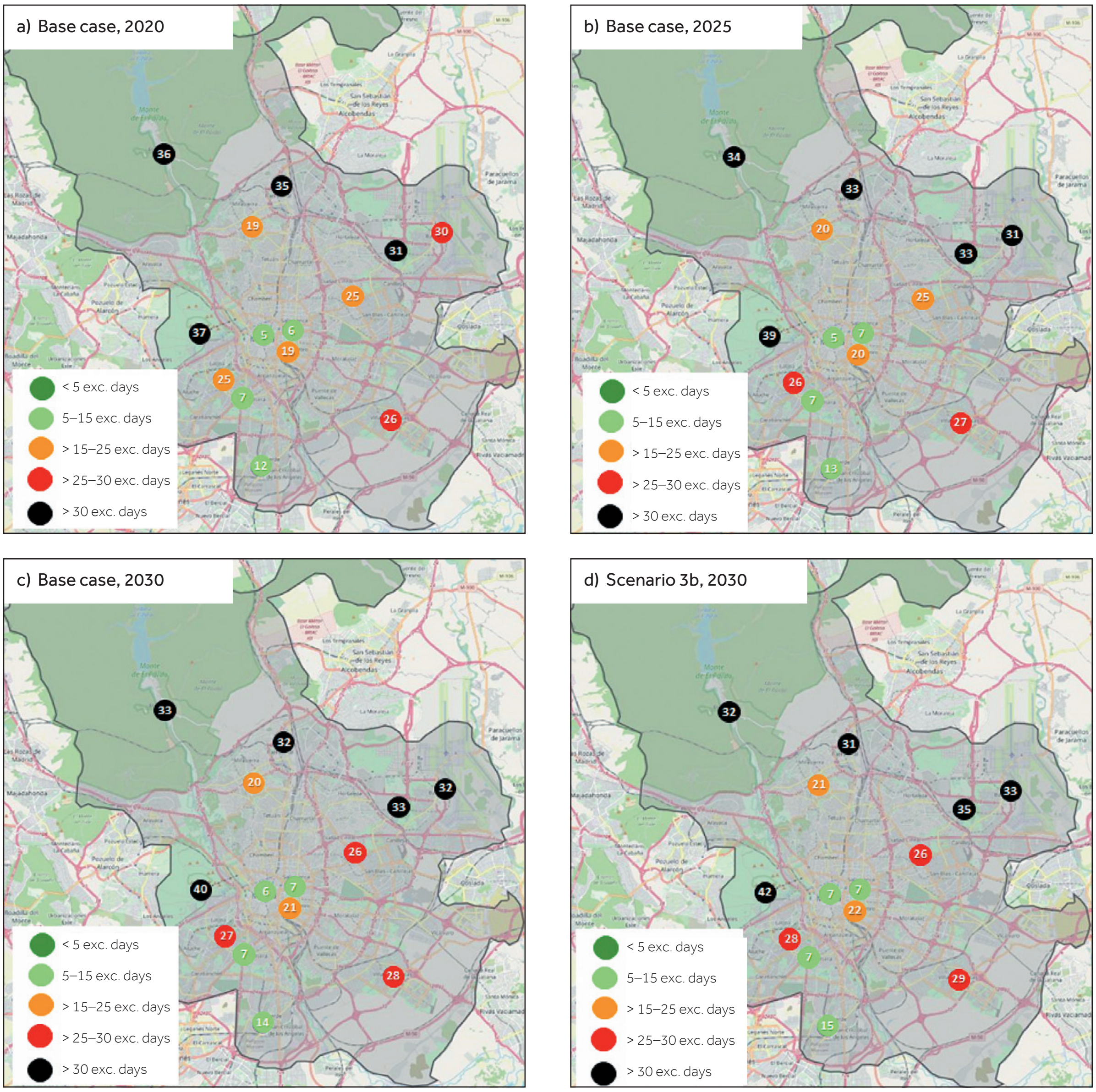
As O_3 is considered a significant pollutant of concern in urban areas, the study analysed the predicted compliance change for O_3 under the current AQLV of 120 µg/m^3 (with an exceedance allowance of 25 days) from 2020 onwards. For this purpose, O_3 compliance under the base case was studied, as well as compliance under some of the emissions scenarios that targeted NO_x and VOC emissions — two important precursors of O_3 formation. Figure 11 shows the modelled compliance of O_3 monitoring stations (urban/suburban) at the European level in 2025 and 2030 under the different scenarios examined in the study.

Figure 11: Predicted percentage of O_3 non-compliant stations in Europe (2025–2030) under the base case and different scenarios examined



By 2025, the already-legislated emission reduction measures as described in the base case will result in about 88% of European monitoring stations (urban/suburban) achieving the current EU AQLV of 120 µg/m^3 (not to be exceeded on more than 25 days) with an additional slight improvement in 2030. However, even in 2030, the remaining 10% of monitoring stations are predicted to record exceedances in O_3 concentrations for more than 25 days. A very limited further improvement in the base case situation is also predicted in all 'beyond the base case' road transport scenarios examined. This limited further reduction in O_3 concentrations in urban areas can, to a large extent, be explained by the NO titration effect.[16,17,18] NO_2 is a precursor of O_3, but O_3 is consumed by reaction with NO. In the presence of high NO concentrations, O_3 concentration values can become very low. The removal of O_3 by reaction with NO to form NO_2 is called titration. When NO_x concentrations are in excess, as is usually the case in urban areas, the further reduction of NO_x could potentially favour the formation of O_3 due to the loss of the titrating effect of NO on ozone, and could eventually offset any reduction in O_3 that results from the emission reduction measures described in the base case. This is particularly evident when looking at the results at the individual city centre level, where O_3 exceedance days are predicted to increase in the base case with time, with further increases in O_3 concentrations when introducing additional measures targeting road transport (see Figure 12 on page 46, which shows the results for Madrid as an example).

Figure 12: O_3 monitoring station compliance in Madrid under the base case in 2020, 2025 and 2030, and under the diesel passenger car scenario 3b in 2030



Targeting VOC emissions from road transport, as well as from the distribution and storage of gasoline, appears to be ineffective in improving O_3 compliance in the future, as all scenarios examined in the study suggest a change of ±1.5% in the number of O_3 non-compliant stations compared to the base case. Findings from recent studies suggest that a more effective strategy to reduce O_3 concentrations and improve compliance, especially in urban areas, is to target NMVOC emissions from the solvent and product use sector.[10]

Conclusions

Concawe recently undertook two modelling studies focusing on the contribution of road transport emissions to overall air quality in urban areas of Europe with a particular focus on concerns over non-compliance with the annual AQLVs for NO_2 and PM. Among other important findings, the study concluded that the fleet turnover from older vehicles to new vehicles (i.e. specifically to Euro 6d compliant vehicles) will improve air quality compliance in a comparable way with the results of a widespread deployment of zero-emission vehicles.

In the context of compliance improvement, this study followed the same methodology used in the earlier UAQ studies and extended the focus to explore whether further actions on emissions sectors could potentially improve compliance in Europe, and in major urban cities in particular. Road transport was the core focus of the assessment through a number of scenarios exploring the effects of various rates of substitution of diesel-powered road transport vehicles (e.g. passenger cars, light-duty commercial and heavy-duty vehicles) with electric-powered vehicles undertaking the same level of activity. Additional emission reduction scenarios from other urban sectors were also explored to improve understanding of the contribution of road transport to improving compliance compared to other sources.

Results from the modelled scenarios have shown the following:

- Already-legislated measures, as described in the updated base case scenario, will result in a high degree of NO_2 compliance with the current EU AQLV across Europe from 2020 onwards (with almost 99% of EU monitoring stations being compliant by 2030). This is in accordance with the findings of previous UAQ studies.
- All additional 'beyond the base case' road transport scenarios, assuming increased (up to 100%) rates of substitution of the pre-2020 diesel-powered vehicle fleet with electric-powered vehicles, will improve NO_2 compliance in the shorter term (between 2020–2025), but post 2025 their impact will be limited. In addition, any scenario targeting NO_x emissions from the domestic sector will also offer a negligible improvement in NO_2 compliance.
- Any remaining exceedances of NO_2 are likely to be addressed through targeted and city-specific measures rather than through further EU-wide and/or national emissions reductions. This would require a thorough and robust source attribution analysis to better understand the contribution of the vehicle segment and other sources.
- Non-compliance will, however, become an EU-wide issue if the current EU NO_2 AQLV is lowered to align with the recently revised WHO air quality guideline value. In all scenarios examined in the study, 30% (or more, depending on the scenario) of EU monitoring stations will record exceedances.
- $PM_{2.5}$ is predicted to achieve nearly complete compliance across the EU in 2025, under the base case scenario. Any additional measures to mitigate exhaust PM emissions from road transport will only offer a limited further improvement in $PM_{2.5}$ compliance, and only in the shorter term, while post 2025 the impact will be negligible.

- Further emission controls or fuel substitution of solid fuel burning in the domestic sector is predicted to be the most effective strategy for reducing $PM_{2.5}$ concentrations and addressing any remaining exceedances. This will be an important point in any (likely) future alignment of the current EU $PM_{2.5}$ AQLV with the (lower) WHO air quality guideline value, which would impose significant and widespread $PM_{2.5}$ non-compliance issues in the EU.
- O_3 will be reduced from 2025 onwards with the measures implemented under the base case, and compliance will be achieved at around 90% of EU monitoring stations.
- None of the 'beyond the base case' road transport scenarios examined will offer a significant further improvement in O_3 compliance. Indeed, further reductions in NO_x emissions and the accompanying loss of NO titration could eventually lead to an increase in the number of O_3 exceedance days, making O_3 compliance even more challenging.

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