Revising EU ambient air quality standards—the implications for compliance in Europe towards 2050

This article summarises the results of a Concawe study to predict future concentrations of key air pollutants (O_3, NO_2, PM) at selected measuring stations of the European Air Quality Network, and to assess how these might compare with the air quality guidelines and interim target metrics set out in the recently updated WHO global air quality guidelines (2021). The study uses a similar methodology to that supporting *The Second Clean Air Outlook* published by the European Commission in 2021 by considering a number of emission scenarios. Overall, it is predicted that air quality in Europe will improve, and that both short- and long-term average concentrations will fall within the range of the WHO interim target values. However, even under the most ambitious scenario, air quality in Europe is unlikely to meet the WHO guideline values by 2050 at many locations in Europe covered by the current monitoring network.

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Introduction

Ambient air quality is quantified using the concentrations of pollutants associated with emissions from anthropogenic and biogenic origin. The pollutants may be emitted directly from sources (primary pollutants) or formed in the atmosphere by chemical reactions (secondary pollutants). Air quality is then judged as being good or poor according to how these concentrations compare with ambient air quality (AAQ) standards which will eventually determine the compliance status (i.e. compliance = concentrations at or below AAQ standards). Due to successful policies to reduce man-made (anthropogenic) emissions, the trend is for air quality to improve. At the same time, the AAQ standards are periodically reviewed to ensure that they continue to be relevant and appropriate and in close alignment with the latest scientific findings.

The EU Ambient Air Quality Directives[1,2] came into force in 2008. They formalised AAQ standards from earlier regulations and, in particular, recognised advice from the World Health Organization (WHO) on the importance of airborne particulate matter (PM) in terms of its impact on human health. The 2005 version of the WHO *Air Quality Guidelines*[3] served as reference for the present day AAQ standards set in 2008.

Since 2005, important developments on air quality monitoring and epidemiological health studies have taken place. The existing AAQ Directives[1,2] required systematic monitoring of air quality across Europe, as it had been recognised that too little was known about key pollutant concentrations, particularly $PM_{2.5}$ and NO_2. As a result, a comprehensive network of measurement stations has been established across Europe.[4] In addition, many epidemiological studies have been carried out to better investigate the relationship between exposure to air pollution and population health. Using this data, the WHO concluded that the effect of air pollution on health was underestimated in certain respects and therefore, in 2021, the WHO air quality guidelines were revised downwards.[5]

The WHO guidelines provide two levels of advice. The guideline metrics themselves are as protective of population health as possible. However, recognising that ambient air pollution in many, if not most, areas exceeds these guideline metrics, interim target values are provided for policy makers to consider. The progressive step between each interim target value provides a quantifiable gain in public health. Policy measures that lead to stepwise improvements in air quality can then be judged to provide positive health benefits. A long-term objective would be to attain the guideline metrics. For most of the regulated pollutants, the European standards set in the existing AAQ Directives fall within the range of interim targets suggested by the 2021 *WHO global air quality guidelines*[5] (Table 1).

The European Commission is currently in the process of revising the AAQ Directives, and its current proposal for a revised Directive[6] is considering these developments, as it sets lower AAQ standards for 2030, while it points to a post-2030 perspective for a full alignment with the 2021 WHO air quality guidelines, whilst also getting on track towards alignment with future WHO guidelines to achieve the zero pollution vision by 2050.

Table 1: Comparison between current EU air quality standards (2008) and the latest WHO air quality guidelines (2021)

The proposed new EU AAQ standards for O_3,* NO_2, $PM_{2.5}$ and PM_{10} (to be met by 2030) are highlighted with the red boxes

		EU Air Quality Directives			WHO Air Quality Guidelines					
Pollutant	Averaging period	Objective	Concentration	Comments	Concentration					Comments
					Interim targets				AQG level	
					1.	2.	3.	4.		
$PM_{2.5}$	24-hour	Target value			75	50	37.5	25	$15\ \mu g/m^3$	99th percentile (i.e. 3–4 exc. days/year)
$PM_{2.5}$	Annual	Limit value	$25\ \mu g/m^3$		35	25	15	10	$5\ \mu g/m^3$	
$PM_{2.5}$	Annual	Indicative limit value	$20\ \mu g/m^3$							
PM_{10}	24-hour	Limit value	$50\ \mu g/m^3$	Not to be exceeded on more than 35 days/year	150	100	75	50	$45\ \mu g/m^3$	99th percentile (i.e. 3–4 exc. days/year)
PM_{10}	Annual	Limit value	$40\ \mu g/m^3$		70	50	30	20	$15\ \mu g/m^3$	
O_3	Max. daily 8-hour mean	Target value	$120\ \mu g/m^3$	Not to be exceeded on more than 25 days/year (averaged over 3 years)						
O_3	Max. daily 8-hour mean	Long-term objective	$120\ \mu g/m^3$							
O_3	8-hour	Target value			160	120	–	–	$100\ \mu g/m^3$	99th percentile (i.e. 3–4 exc. days/year)
O_3	Peak season	Target value			100	70	–	–	$60\ \mu g/m^3$	
NO_2	Hourly	Limit value	$200\ \mu g/m^3$	Not to be exceeded on more than 18 hours/year					$200\ \mu g/m^3$	
NO_2	Annual	Limit value	$40\ \mu g/m^3$		40	30	20	–	$10\ \mu g/m^3$	
NO_2	24-hour	Target value			120	50	–	–	$25\ \mu g/m^3$	99th percentile (i.e. 3–4 exc. days/year)
SO_2	Hourly	Limit value	$350\ \mu g/m^3$	Not to be exceeded on more than 24 hours/year						
SO_2	24-hour	Limit value	$125\ \mu g/m^3$	Not to be exceeded on more than 3 days/year	125	50	–	–	$40\ \mu g/m^3$	99th percentile (i.e. 3–4 exc. days/year)
CO	Max. daily 8-hour mean	Limit value	$10\ mg/m^3$						$10\ mg/m^3$	
CO	24-hour	Target value			7	–	–	–	$4\ mg/m^3$	99th percentile (i.e. 3–4 exc. days/year)
C_6H_6	Annual	Limit value	$5\ \mu g/m^3$						$1.7\ \mu g/m^3$	Reference level
BaP	Annual	Target value	$1\ ng/m^3$	Measured as content in PM_{10}						
Pb	Annual	Limit value	$0.5\ \mu g/m^3$	Measured as content in PM_{10}					$0.5\ \mu g/m^3$	
As	Annual	Target value	$6\ ng/m^3$	Measured as content in PM_{10}					$6.6\ ng/m^3$	Reference level
Cd	Annual	Target value	$5\ ng/m^3$	Measured as content in PM_{10}					$5\ ng/m^3$	
Ni	Annual	Target value	$20\ ng/m^3$	Measured as content in PM_{10}					$25\ ng/m^3$	Reference level

* The proposed target value for the maximum daily 8-hour mean O_3 concentrations in the EU's proposal for a revised AAQ Directive is set at $120\ \mu g/m^3$ not to be exceeded on more than 18 days per calendar year (versus 3–4 exceedance days/year in the 2021 WHO air quality guidelines). (Source: EEA, 2021)

The alignment of AAQ standards with the WHO guidelines, and the need for new AAQ standards to be met to ensure compliance, would most likely involve the need for a meaningful reduction in anthropogenic emissions across Europe. This reduction will need to be achieved to avoid compliance problems in the future.

In this context, Concawe commissioned a study, to examine how future ambient air quality in Europe might compare with the new WHO guidelines and interim target metrics. The study simulates future air concentrations of key pollutants (O_3, NO_2, $PM_{2.5}$ and PM_{10}) at selected measuring stations of the European Air Quality Network and assesses the implications with respect to compliance. The study uses a similar methodology to that supporting *The Second Clean Air Outlook* (CAO2)[1][7] published by the European Commission in 2021. In particular, it considers the Current Legislation (CLE) trend and two scenario assumptions made in *The Second Clean Air Outlook* about maximum emissions reduction potential.[8] The study also investigates which sector emissions might be most important in determining air quality. The geographic scope chosen is the EU-27. For brevity, the article discusses the results at European level. Further details of the analyses at a country level can be found in the full Concawe report.[9]

Methodology

Air quality monitoring station simulations

The AQUIReS+ model[10] has been used to forecast atmospheric concentrations of O_3, NO_2, $PM_{2.5}$ and PM_{10} at each selected monitoring station that is included in the European Environment Agency's (EEA's) Air Quality e-Reporting dataset.[4] This ensures that the modelling is directly related to the individual measuring stations used to monitor compliance with AAQ standards. The model uses a gridded emission inventory and source-receptor relationships.[11] These derive from regional chemical transport models (EMEP[12]) 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. A correlation between the EMEP model predictions and the hourly measurements made at each station is developed. The robustness of the correlation has been tested using hindcasting for several years of data.

It is assumed that this correlation can be used to predict the future measurements at the station from air quality predictions made using different assumptions about emissions. In more sophisticated evaluations[10] of air quality response to emission changes, a confidence interval has been calculated for the predicted air quality metric at each monitoring station location. A detailed overview of the model evaluation and a description of the data sources and dataflows in the model are presented in earlier studies.[10,13]

[1] At the time of writing this report, the European Commission has published *The Third Clean Air Outlook* (available at https://environment.ec.europa.eu/publications/third-clean-air-outlook_en). However, the data underpinning the activity scenarios that have been developed have not yet been made publicly available.

For each monitoring station, the requisite annual air quality metrics of each pollutant were calculated based on the hourly concentrations from the model. These metrics can take one of the two following forms:

- An upper limit value for a pollutant concentration, i.e. a value that should not be exceeded. In this study, these are annual average concentrations.
- An exceedance frequency limit: typically, this is the number of times a value can be exceeded in a prescribed time. This is appropriate to concentrations averaged over the short term, which can be variable. In this study, these are daily average concentrations and exceedances of a limit, and are counted over a year.

For annual average concentrations, the average of hourly values was evaluated and reported. In post-processing, the calculated annual average for each station was compared to see if it was less than or equal to the WHO interim target or guideline value. If this comparison was true, then the station was counted as meeting the criterion at that threshold for that year.

For the exceedance frequency, this involved calculating each daily average, or in the case of ozone the maximum daily 8-hour mean concentration. In post-processing, this value was then compared with each of the WHO interim target and guideline values in turn. If the prediction exceeded the WHO air quality guideline target value, then a counter was incremented. The annual result is the count of exceedances. The number of exceedances in one year for each station, for each target threshold, was evaluated to see if it was less than four, following that the WHO air quality guidelines use a 99% criterion for exceedance. If the condition was met, then the station was counted as meeting the criterion at that threshold for that year.

Detailed analyses of the results for all the above-mentioned metrics are provided in the Concawe report. In this article, the results for the ozone exceedance metric and the annual mean concentration metric for NO_2 and $PM_{2.5}$ are presented for brevity.

Emissions scenarios

The Second Clean Air Outlook scenarios

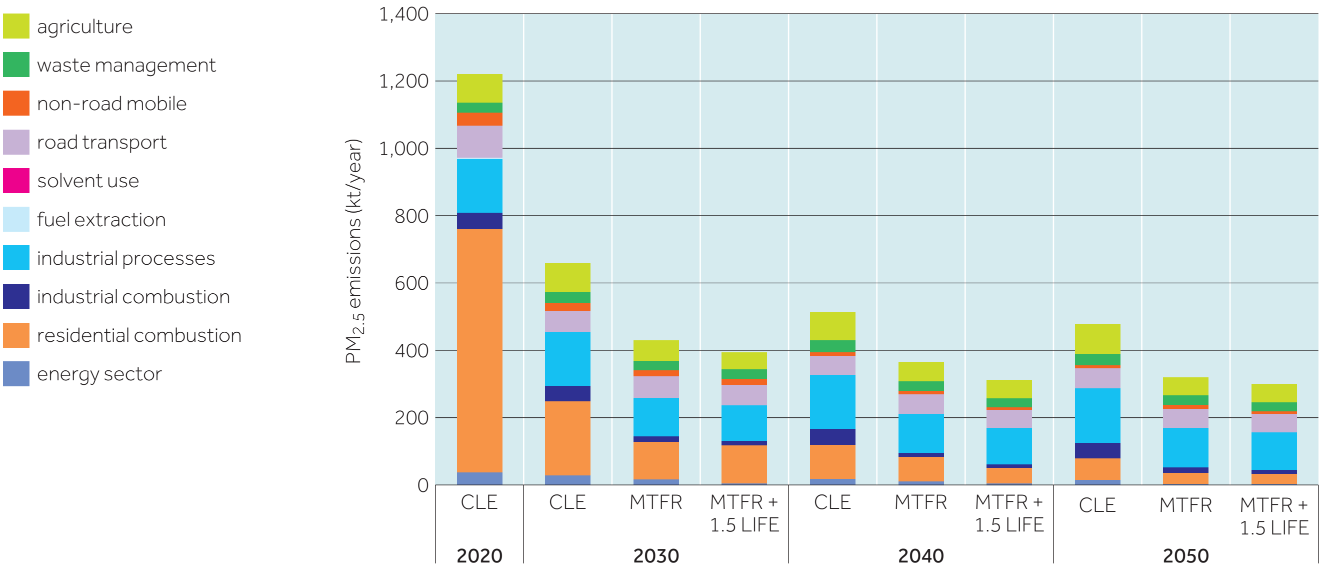
Three GAINS[2] scenarios developed for the European Commission's *The Second Clean Air Outlook*[7] are used in this study. These represent the upper bound (CLE) and lower bound (MTFR) for expected emissions in the years up to 2050 without structural changes to the European economy, and a second lower bound (MTFR + 1.5 LIFE) that includes structural changes. The three scenarios are summarised on the following page.

[2] GAINS: **G**reenhouse gas and **A**ir pollution **In**teractions and **S**ynergies (http://gains.iiasa.ac.at)

- **The baseline scenario (CLE):** This is the expected trend in emissions in Europe between 2015 and 2050. This includes the impact of changes in European economic activity on emissions and the effect of current and pending legislation on abatement. The scenario differs in detail from that used to develop the revised NEC Directive (2016).[3] Specifically, the CLE scenario assumes achievement of the EU energy efficiency target of 32.5% and a renewable energy target of 32% as agreed in the 'Clean energy for all Europeans' package[4] until 2030, and implementation of the current policies on non-CO_2 greenhouse gas emissions.
- **The Maximum Technically Feasible Reduction (MTFR) scenario:** This is a scenario whereby emissions from all sectors, as described in GAINS, are reduced as far as technically possible, regardless of cost.
- **The MTFR + 1.5 LIFE Scenario:** The 1.5 LIFE scenario is an additional decarbonisation scenario of the EU energy and agricultural systems aligned with the objective of stabilising the global temperature increase at 1.5°C above pre-industrial levels. It assumes, inter alia, movement towards a more circular economy with reduced consumption of goods and energy, a move away from personal transport towards shared transport systems, reduced demand for energy in heating/cooling, and a dietary shift that reduces the demand for red meat and, consequentially, animal numbers and their need for forage provision. MTFR controls are applied to this 1.5 LIFE scenario.

Figures 1 and 2 provide an overview of the projected EU-27 emissions load[5] of $PM_{2.5}$ and NO_x, under the three CAO2 scenarios for the years 2030, 2040 and 2050. Each source sector is shown separately so that the contribution of each sector to the overall emissions can be clearly seen.

Figure 1: Sectoral $PM_{2.5}$ emissions for the EU-27 under the three scenarios (CLE, MTFR and MTFR + 1.5 LIFE) developed for the European Commission's *Second Clean Air Outlook*



3 https://www.eea.europa.eu/policy-documents/directive-2016-2284-eu-national

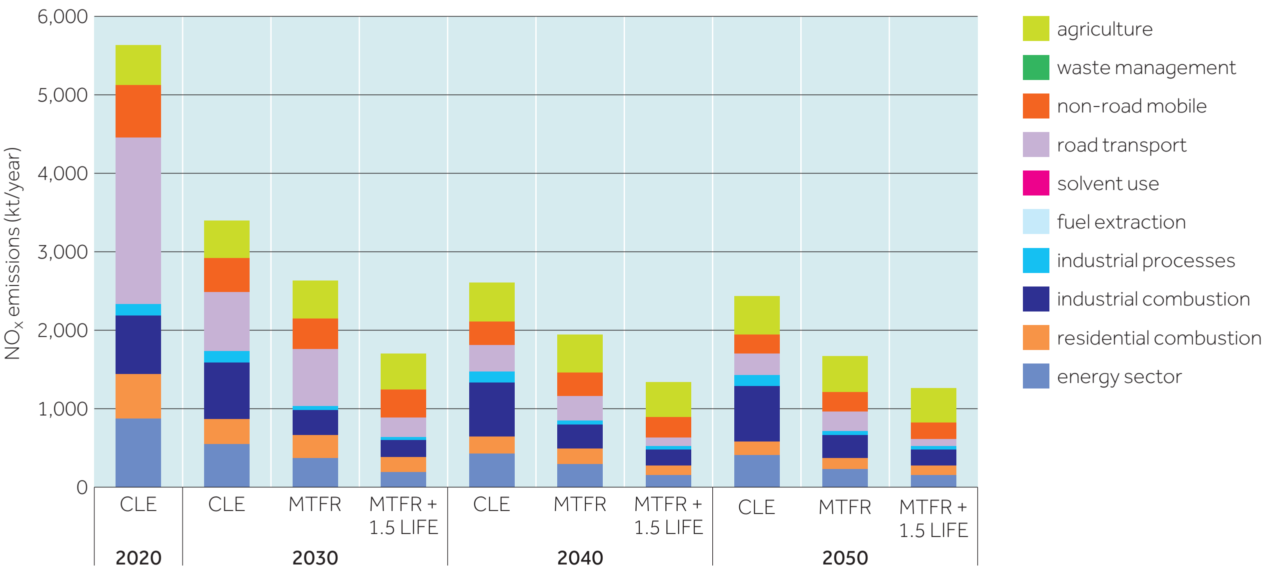
4 https://energy.ec.europa.eu/topics/energy-strategy/clean-energy-all-europeans-package_en

5 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-27 countries. The absolute values, however, are country-specific.

Under the baseline scenario, $PM_{2.5}$ emissions are projected to decline significantly over the 10-year period from 2020 to 2030 (approximately 46%) (Figure 1). Residential combustion is expected to have the largest reduction of all sectors, amounting to approximately 70% by 2030, and 91% by 2050. It is also important to highlight that by 2050, industrial processes and agriculture are predicted to become the most significant sources of $PM_{2.5}$ emissions. $PM_{2.5}$ emissions are projected to continue their downward trend in 2040 and 2050, however the reduction rate is lower (60% reduction under CLE by 2050 compared to 2020). Under the maximum reduction scenarios, a larger decline is predicted for $PM_{2.5}$ emissions. By 2050, the additional reduction of $PM_{2.5}$ emissions compared to the baseline scenario is 33% for MTFR and 37% for MTFR + 1.5 LIFE.

NO_x emissions also show a significant downward trend for the baseline scenario over the 10-year period from 2020 to 2030, with a 40% reduction by 2030 (Figure 2). Up to 2030, road transport remains the most important source of NO_x emissions; however, the sector is projected to have the largest reductions of all sectors, amounting to 65% by 2030. In addition, beyond 2030, it is forecast that road transport will no longer be the primary contributing sector, with the energy sector and industrial combustion becoming the dominant sources, accounting for 18% and 29% of NO_x emissions by 2050, respectively. NO_x emissions are projected to continue their downward trend in 2040 and 2050, although the reduction rate is lower (57% reduction under CLE by 2050 compared to 2020).

Figure 2: Sectoral NO_x emissions for the EU-27 under the three scenarios (CLE, MTFR and MTFR + 1.5LIFE) developed for the European Commission's *Second Clean Air Outlook*



Similarly to the overall trend of NO_x sectoral emissions, the additional reduction of NO_x emissions from road transport in 2040 and 2050 is lower, while as of 2040, no additional reduction is projected for NO_x emissions from road transport under MTFR, an indication that all available existing technical measures have been already applied to the maximum extent under the baseline scenario. Under the maximum reduction scenarios, a larger decline is predicted for NO_x emissions. By 2050, the additional reduction of NO_x emissions compared to the baseline scenario is 31% for MTFR and 48% for MTFR + 1.5 LIFE, respectively, with the largest additional reductions to be expected in the industrial combustion sector.

Sectoral emissions scenarios

In addition to *The Second Clean Air Outlook* scenarios described on pages 43–44, the study includes some additional sector-specific emission reduction scenarios (see Table 2). The purpose of these is to identify which emission reduction components of the common scenarios are having the greatest influence on ambient air quality.

Table 2: List of emissions reduction scenarios assessed in the study

Scenario	Description
Case (0)	*The Second Clean Air Outlook* (CAO2) — Current Legislation (CLE) Baseline: Expected trend in emissions with time, taking account of forecast economic activity and phasing in of legislation that affects emissions.
Case (1)	Removal of Energy Sector Emissions: Emissions of NO_x, SO_2 and particulate matter from large combustion plants used for power and energy products generation are set to zero.
Case (2)	Removal of Domestic-Commercial Emissions: Emissions of NO_x, SO_2, PM, and volatile organic compounds (VOCs) from domestic, shop and office heating systems are set to zero.
Case (3)	Removal of Industry Combustion/Process and Solvent/Product Use Emissions: Emissions of NO_x, SO_2, PM, VOCs and NH_3 from process industry, including the use of solvents (VOCs) in degreasing, ink and paint production, etc. are set to zero.
Case (4)	Removal of Road Transport Emissions: Emissions of NO_x, SO_2, PM and VOCs from both private and commercial vehicles used for road transport are set to zero.
Case (5)	Removal of Non-Road Transport Emissions: Emissions of NO_x, SO_2, PM and VOCs used in off-road applications (e.g. construction, agriculture) and on inland waterways are set to zero.
Case (6)	Removal of Agricultural NH_3 Emissions: Emissions of NH_3 from agriculture are set to zero.
Case (7)	CAO2-MTFR: Emissions from all sectors are reduced to the minimum technically possible according to the methods encoded in the GAINS EUROPE model.
Case (8)	'Beyond MTFR' — CAO2 MTFR + 1.5 LIFE: Emissions are reduced beyond the MTFR assuming major structural changes in the agricultural sector and in energy use aimed predominantly at reducing CH_4, NH_3 and CO_2 emissions.

Notes:
Case (0) is the Current Legislation (CLE) base case within which emission reductions are already mandated.
Cases (1)–(6) are illustrative only.
Cases (7) and (8) are reduction scenarios associated with *The Second Clean Air Outlook* (CAO2).

Each scenario reduces emissions from a key emitting sector to zero. If the scenario produces a change in air quality that affects the comparison with the WHO air quality guidelines, this indicates which components of the GAINS scenarios are likely to be important.

The scenarios, including the baseline and maximal reduction scenarios, are presented in the order in which they were executed. The emission reductions are assumed to be applied in 2025 and for subsequent years.

EU-27 results

Presentation of results

The objective of this study is to evaluate how many of the monitoring stations would be likely to record a concentration, or an exceedance frequency, that is lower than each of the WHO interim target and air quality guideline values under the different scenarios examined. Therefore, the study results are calculated in terms of the number of stations where the pollutant metrics are at or below the interim target and guideline values set out in the WHO air quality guidelines. However, it is the converse that is of more direct interest. Therefore, the graphics presented on the following pages show the proportion (%) of stations where pollutant metrics exceed the WHO's interim target and guideline values.

The metrics considered in the study are:

- **Ozone:** The number of days in a year on which the average of the maximum daily 8-hour mean concentration exceeds a threshold value.
- **NO_2:** a) The number of days in a year on which the daily average concentration exceeds a threshold value.
  b) The annual mean concentration versus a threshold value.
- **$PM_{2.5}$:** a) The number of days in a year on which the daily average concentration exceeds a threshold value.
  b) The annual mean concentration versus a threshold value.
- **PM_{10}:** a) The number of days in a year on which the daily average concentration exceeds a threshold value.
  b) The annual mean concentration versus a threshold value.

Detailed analyses of the results for all the above-mentioned metrics are available in the Concawe report.[9] For brevity, the results for the ozone exceedance metric and the annual mean concentration metric for NO_2 and $PM_{2.5}$ are presented in this article.

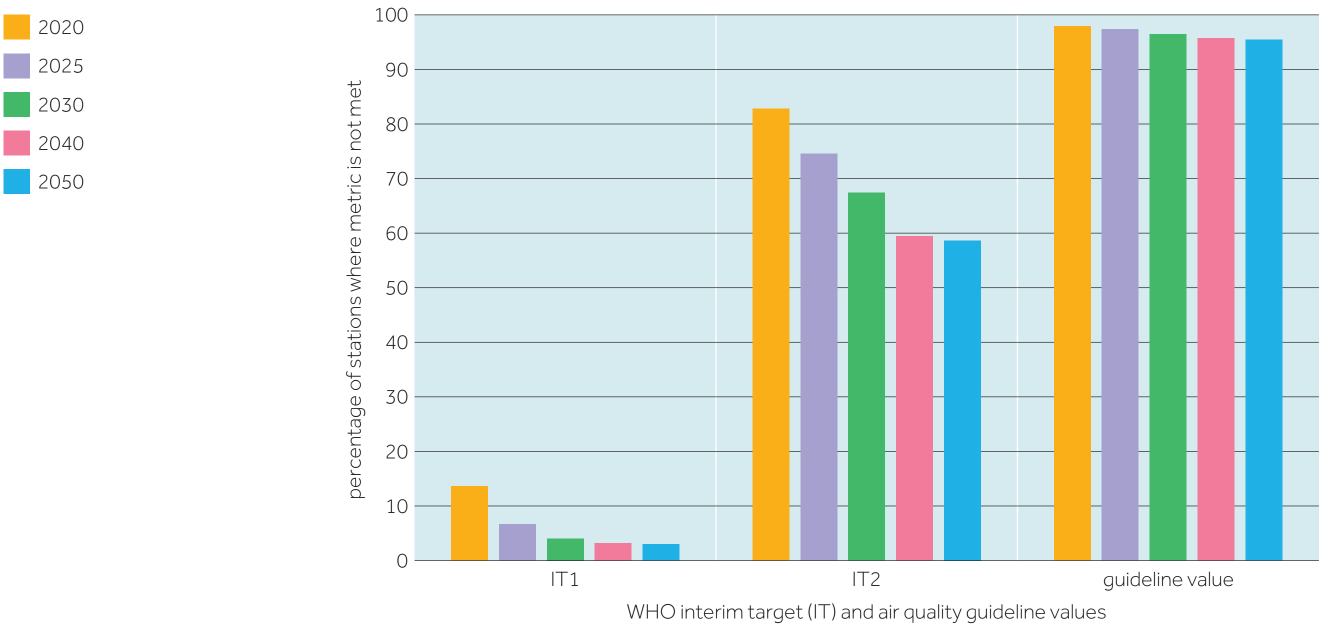
Ozone exceedance

The current EU AAQ Directive sets a (non-binding) target of 120 µg/m^3 for maximum daily 8-hour O_3 mean concentrations, not to be exceeded on more than 25 days per year. This is evaluated as an average number of exceedances across three years in order to accommodate interannual variability in meteorology. The Directive also sets a long-term objective that foresees the number of exceedances falling to zero. In the proposed revision of the AAQ Directive, the maximum number of exceedance days is reduced from 25 down to 18 days, and the long-term objective is reduced down to 100 µg/m^3.

The WHO guidelines propose that all target thresholds be met as a 99th percentile of daily values, which is fewer than four exceedances per year. For ozone, the WHO suggests two interim targets (IT) with concentration values of 160 (IT1) and 120 µg/m^3 (IT2), respectively, and a guideline value of 100 µg/m^3. Although the second interim target of 120 µg/m^3 is numerically the same concentration as given in the EU Directive, the limit of fewer than four exceedances per year is much more restrictive than the 25 per year, averaged over 3 years.

The number of stations at which the predicted O_3 daily maximum 8-hour mean concentration exceeds the WHO interim target and air quality guideline values under current legislation is shown in Figure 3. Under current legislation, the results show that interim target 1 (160 µg/m^3 not to be exceeded on more than four days) is not met by a small proportion of stations, and this proportion decreases in time (less than 5% in all European stations by 2050).

Figure 3: O_3 exceedance for the EU-27—proportion of stations predicted NOT to meet the WHO interim target and guideline values under current legislation

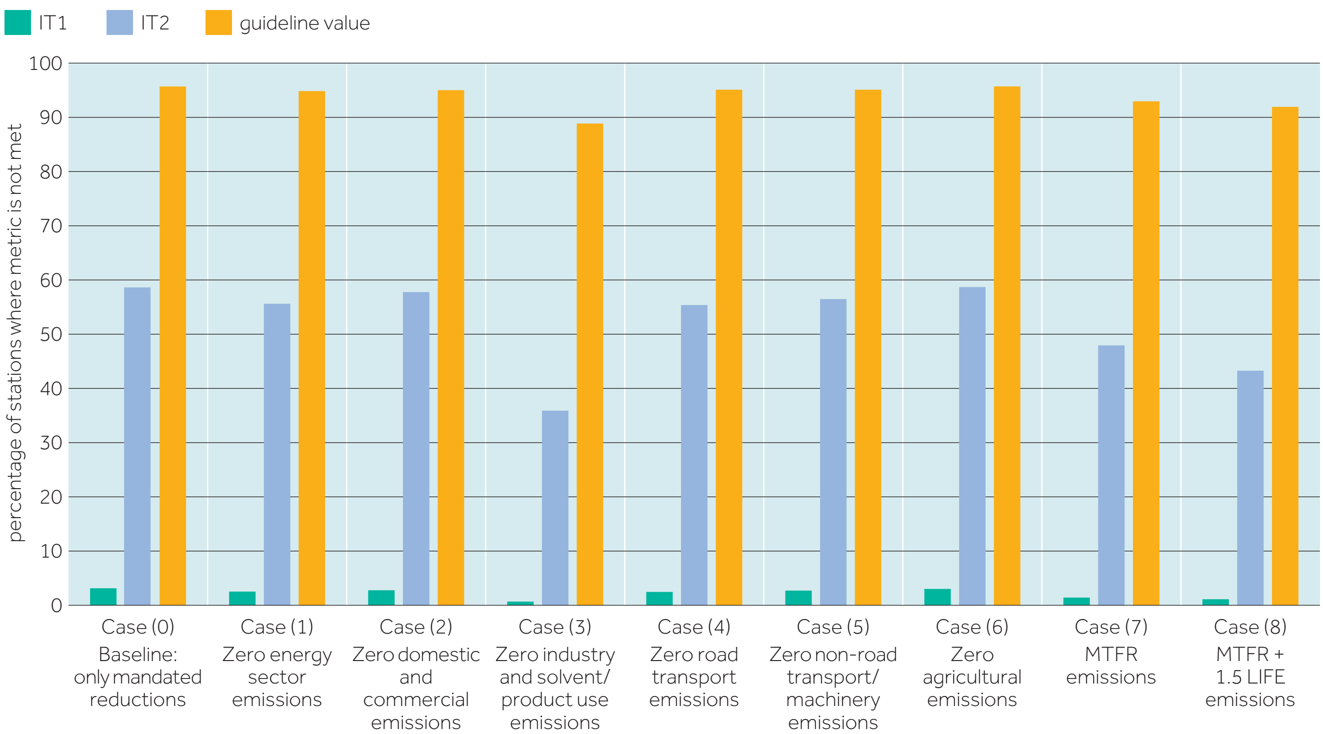


Interim target 2 (120 µg/m^3) is predicted to be exceeded by a substantial proportion of stations (80% of the stations in 2020) and this proportion decreases with time until 2040. However, even by 2050, more than half of the stations are not able to meet interim target 2 for the ozone exceedance.

The results predict that the WHO air quality guideline value (100 µg/m^3) is not met at more than 90% of stations in any forecast year. This proportion may change year by year depending on how climatic conditions affect ozone production. However, the number of stations not meeting both interim target 2 and the WHO air quality guideline will still remain significant. In particular, by 2050, around 95% of monitoring stations are predicted not to meet the WHO air quality guideline values, indicating that the full alignment of EU air quality standards with the 2021 WHO air quality guidelines by 2050 will be extremely challenging.

The results of the various emission reduction scenarios for O_3 exceedance for the year 2050, each also compared with current legislation, are shown in Figure 4. The results predict that the removal of VOC emissions from industrial production and solvent/product use (Case (3)) has the largest effect on increasing the number of stations meeting the WHO interim target and guideline values, being even higher than the effects under the MTFR and MTFR + 1.5 LIFE scenarios (Case (7) and Case (8), respectively). Removal of emissions from all other sectors are predicted to be ineffective.

Figure 4: O_3 exceedance for the EU-27 — scenario comparison for the number of monitoring stations NOT meeting the WHO interim target and guideline values in 2050

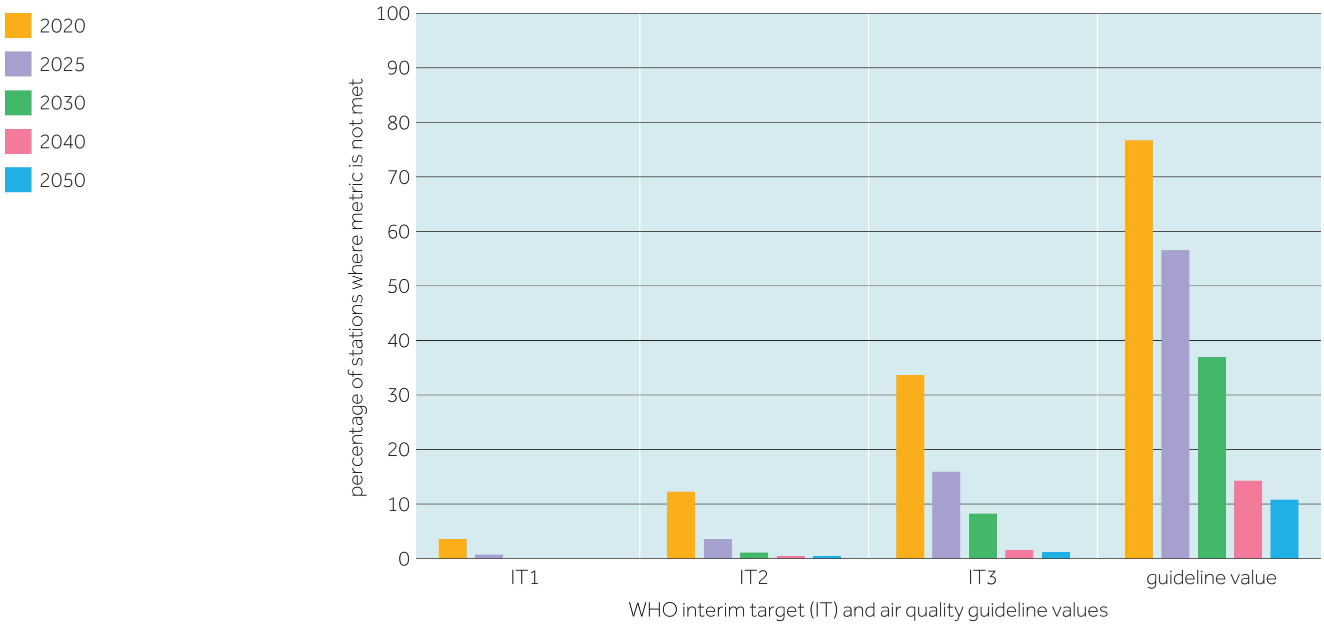


NO_2 annual mean

The current EU AAQ Directive sets a limit value of 40 µg/m^3 for the annual mean value of NO_2, while the WHO air quality guidelines propose interim target values of 40 (IT1), 30 (IT2) and 20 µg/m^3 (IT3), and a guideline value of 10 µg/m^3.

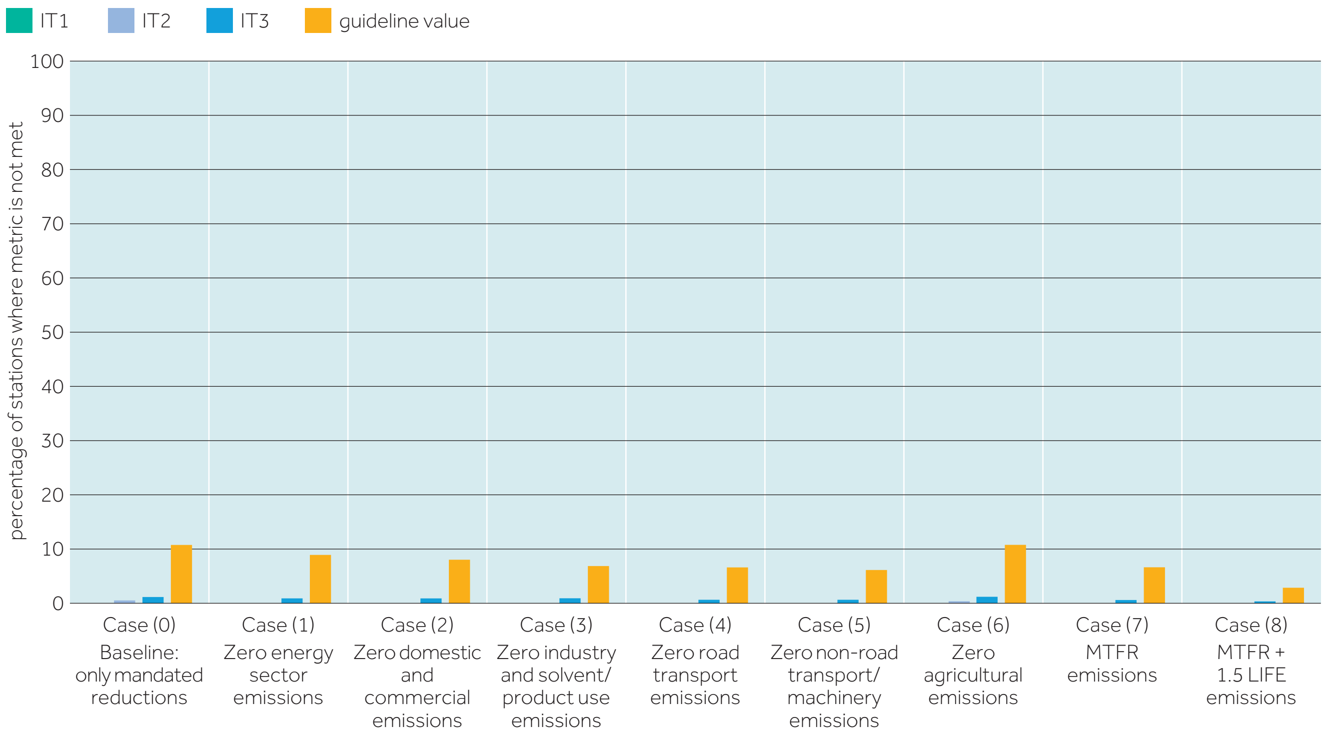
The model results show that, under current legislation, there is a very small number of stations measuring NO_2 annual mean concentrations above interim target 1 (which is equal to the current AAQ standards) in 2025 (Figure 5) while as of 2030, all stations are predicted to meet this target. The number of non-compliant stations increases for interim target 2 and interim target 3. In particular for interim target 3, which is equal to the proposed new AAQ standards (to be met by 2030), around 8% of the stations are predicted not to meet the target in 2030, which reduces to ~2% by 2050. With respect to the WHO air quality guideline level, the model results show that nearly 37% of the stations are predicted to measure higher NO_2 annual mean concentrations in 2030. In 2050, it is predicted that annual concentrations would still be above the guideline at 11% of stations.

Figure 5: NO_2 annual mean for the EU-27 — proportion of stations predicted NOT to meet the WHO interim target and guideline values under current legislation



The results of the various emission reduction scenarios for NO_2 annual mean concentrations are shown in Figure 6 for the year 2050. In all scenarios, the interim target 2 annual mean concentration is met by all stations in 2050, while only a few stations (less than 1%) will not be able to meet interim target 3. In general, the removal of on-road (Case (4)) and non-road transport (Case (5)) emissions are predicted to have the largest effect among the sectoral emissions reduction scenarios. The predicted effect of the on-road transport emissions removal is actually similar to the effects associated with the MTFR scenario (Case (7)), and close to the effects of the MTFR + 1.5 LIFE scenario (Case (8)) which is predicted to result in the highest number of monitoring stations meeting the WHO air quality guideline. However, even in the case of removing all on-road transport emissions, around 7% of the monitoring stations in Europe in 2050 are still predicted to measure annual NO_2 concentrations above the WHO air quality guideline. In contrast, removal of emissions from the energy sector (Case (1)) is predicted to have the lowest impact.

Figure 6: NO_2 annual mean for the EU-27 — scenario comparison for the number of monitoring stations NOT meeting the WHO interim target and guideline values in 2050



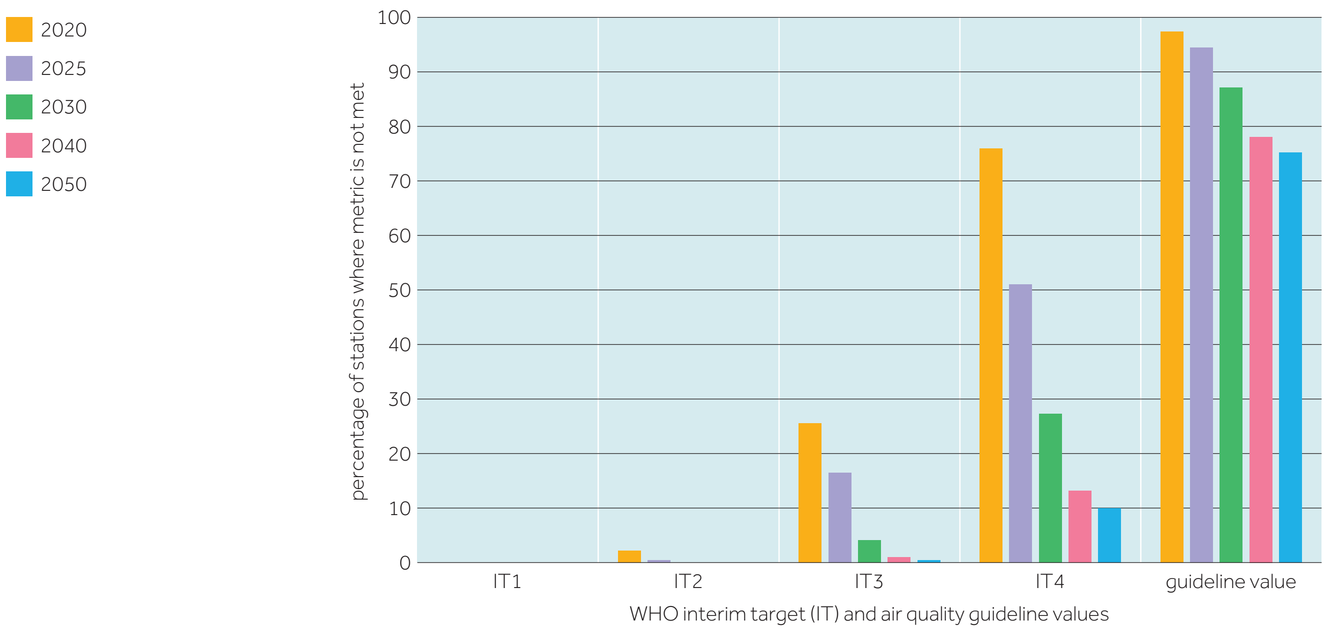
$PM_{2.5}$ annual mean

The current EU AAQ Directive sets an annual mean concentration of 25 µg/m^3 as the limit value for $PM_{2.5}$, while there is also a long-term objective that average concentrations should fall below 20 µg/m^3. In its revised guidelines, the WHO proposes interim targets of 35 (IT1), 25 (IT2), 15 (IT3) and 10 µg/m^3 (IT4), and a guideline value of 5 µg/m^3.

The number of stations at which the predicted $PM_{2.5}$ annual mean concentration exceeds the WHO interim target and guideline values under current legislation is shown in Figure 7. The results show that, as of 2025, interim target 2, which is equal to the existing EU AAQ standard, will be met at nearly all stations, while only a small proportion of stations (less than 5%) will be above the interim target 3 value in 2030. In 2050, almost all stations are predicted to meet interim target 3.

When assessing the compliance status with respect to interim target 4, the results predict that a substantial portion of stations will observe concentrations above the target value. In 2030, around 27% of stations will not be able to meet interim target 4, while in 2050, 10% of stations will still have concentrations above 10 µg/m^3. It should be noted that, in its proposal for a revised AAQ Directive, the European Commission sets a new AAQ standard for $PM_{2.5}$ annual mean concentration (to be met by 2030) that is equal to the WHO's interim target 4.

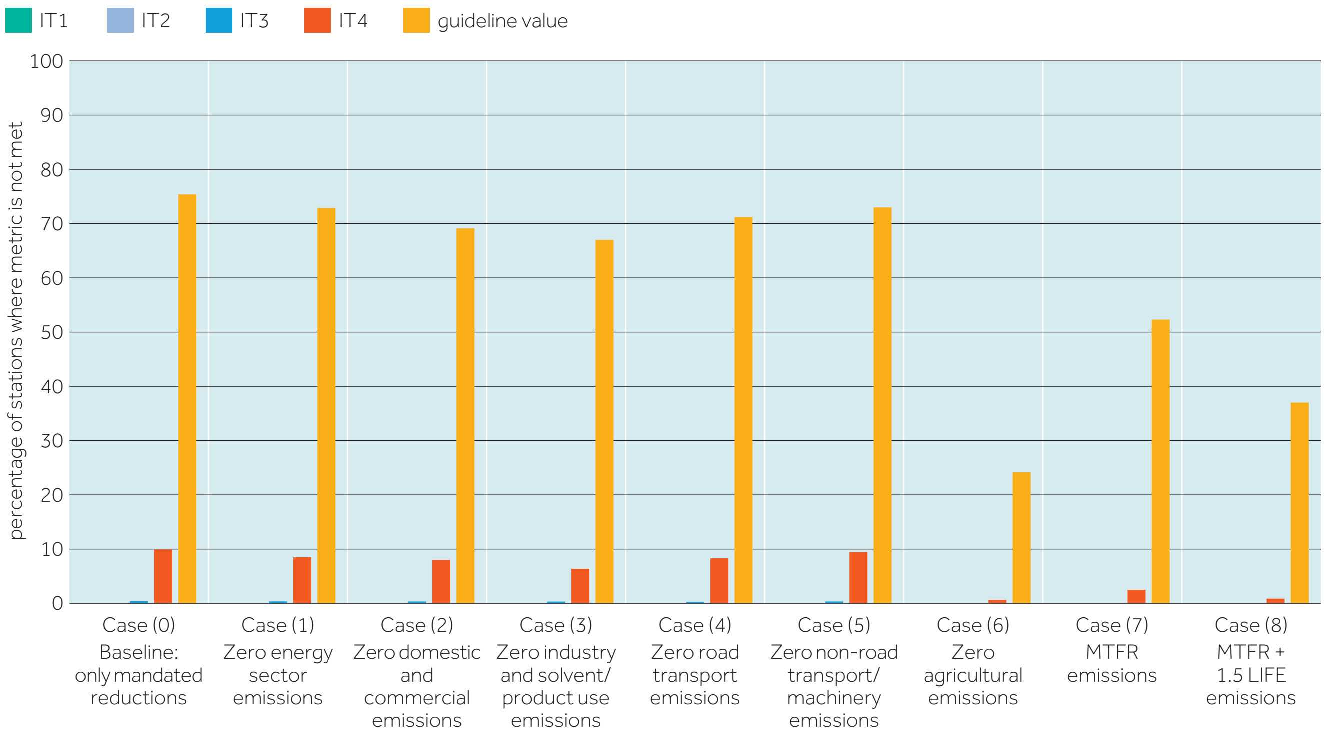
Figure 7: $PM_{2.5}$ annual mean for the EU-27 — proportion of stations predicted NOT to meet the WHO interim target and guideline values under current legislation



With regard to the WHO air quality guideline value, the results show a significant non-compliance issue as the vast majority of stations are predicted to observe annual $PM_{2.5}$ concentrations above the guideline value. In particular in 2030, almost 87% of the stations do not meet the guideline value of 5 µg/m^3, only slightly decreasing to 75% in 2050. The above results indicate that full alignment of the EU AAQ standards with the 2021 WHO air quality guideline by 2050 will be extremely challenging.

The results of the various emission reduction scenarios for $PM_{2.5}$ annual mean concentrations are shown in Figure 8 for the year 2050. Meeting the WHO's interim target 4, and the air quality guideline value in particular, is predicted to be challenging. In all sectoral emissions reduction scenarios assessed, the removal of NH_3 emissions from agriculture (Case (6)) is predicted to have the largest effect, being larger even than the effects associated with the maximum emission reduction of the MTFR (Case (7)) and MTFR + 1.5 LIFE scenarios (Case (8)). However, even under this theoretical scenario, a considerable proportion of stations is predicted to still record $PM_{2.5}$ concentrations above the WHO air quality guideline value (24%). The respective proportion of stations predicted not to meet the WHO air quality guideline value ranges from 37% to 73% in the remaining scenarios considered.

Figure 8: $PM_{2.5}$ annual mean for the EU-27 — scenario comparison for the number of monitoring stations NOT meeting the WHO interim target and guideline values in 2050



Conclusions

The ongoing review of the EU Ambient Air Quality Directive[1,2] aims to set lower ambient air quality standards in order to align them more closely with the WHO air quality guidelines that were recently revised[3] towards lower values.

In this context, Concawe commissioned a study to carry out sets of forward predictions for air concentrations of key pollutants (O_3, NO_2, $PM_{2.5}$, PM_{10}) across the European monitoring network for the period of 2015 to 2050, and to assess how these might compare with the new WHO air quality guidelines and interim target metrics. The study uses a similar methodology to that supporting *The Second Clean Air Outlook* (CAO2)[7] published by the European Commission in 2021, by considering three emission scenarios: a Current Legislation (CLE) trend scenario and two scenario assumptions about maximum emissions reduction potential (i.e. MTFR and MTFR + 1.5 LIFE). The study also considers some illustrative emission reduction scenarios that are simple cases where emissions from key sectors are each set to zero in turn. The purpose of this is to determine whether emissions from any of the sectors are predicted to have, individually, a dominating effect on future air quality.

The results from the modelled scenarios show the following:

- Air quality in Europe, represented by the pollutants and metrics tested and determined across the air quality monitoring network, improves over time towards the 2050 horizon. This is due to the reduction in emissions already legislated within the economic outlook of *The Second Clean Air Outlook* which will result in almost full compliance for $PM_{2.5}$ and NO_2 with the current EU AAQ standards across Europe from 2025 onwards.
- Under the current legislation pathway, the forecast air quality is largely consistent with the most ambitious of the WHO interim target criteria. However, the study shows that air quality in Europe in 2050 will not meet the guideline criteria set out in the 2021 WHO air quality guidelines. However, air quality is not uniform over Europe, and variability occurs within countries (see the Concawe report[9] for details).
- Additional improvements in air quality are predicted under the two maximal emission reduction scenarios, namely MTFR and MTFR + 1.5 LIFE. In particular, the MTFR + 1.5 LIFE scenario results in improved air quality overall, compared to MTFR alone which mainly benefits particulate matter concentrations. However, neither of these two scenarios is effective enough to ensure that the WHO guideline values will be met by 2050 for all pollutants assessed.
- The sensitivity calculations, in which emissions from individual sectors were each set to zero in turn, show that agricultural emissions have a strong effect on $PM_{2.5}$ concentrations. Road transport emissions lose importance with respect to their effect on NO_2 after 2030 because of the drop in older vehicles within the fleet, while non-road emissions for transport and construction play a growing role as their contribution becomes larger relative to on-road emissions. Further reductions in process industry emissions have a relatively small impact on ozone and particulate matter, which would be consistent with reductions in VOC emissions. Eliminating emissions from large industrial producers of energy—traditionally the source of air pollution—has very little effect on the air quality predictions. Finally, the results show that there is no single sector emission that has a dominant effect on how air quality at monitoring stations will compare with the WHO interim target and guideline criteria.

Overall, the outlook for 2030 and 2050 is that air quality in Europe will improve. Larger improvements will result if consumption is reduced as well as controls put in place and measures extended to agriculture. The majority of stations will register short-term and long-term average concentrations that fall within the range of interim target values set out in the recently updated *WHO global air quality guidelines* (2021). However, even under the most ambitious MTFR + 1.5 LIFE scenario, air quality in Europe is unlikely to meet the WHO guideline values by 2050 at many locations in Europe covered by the current monitoring networks.

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