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

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

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ABSTRACT

The European Commission (EC) is currently revising the EU Ambient Air Quality (AAQ) Directives [1,2] with the aim to set more strict ambient air quality standards (AAQS) in order to align them more closely with the World Health Organization (WHO) Air Quality Guidelines (AQG) which have been updated and published in September 2021 [4]. These are now serving as the reference to the proposal of the revision of the AAQD that has been published by the EC in October 2022 [5].

In this study, Concawe used forecast modelling to carry out sets of forward predictions of air quality across the European monitoring network for the period 2015 to 2050. These were based on the economic activity scenario developed for the Second Clean Air Outlook[1] [6]. These model predictions have been compared with the air quality interim target and guideline values proposed by WHO in its recent recommendations [4]. Specifically, the annual exceedance frequency of thresholds set for O_3, NO_2, PM_{10} and $PM_{2.5}$ daily mean concentrations were examined as were the annual mean concentration thresholds for NO_2, PM_{10} and $PM_{2.5}$.

The study uses the same methodology as the supporting studies carried out for the Second Clean Air Outlook of the European Commission [6,7]. Three activity scenarios have been explored: a base case comprising a projection of emissions subject to existing legislation, both effected and yet to come into force; an emission reduction scenario based on maximum technically feasible reductions (MTFR), which minimises emissions currently under regulatory control; an alternative energy scenario consistent with climate change measures with MTFR applied to controls, which reflects a reduction in consumption, particularly resources, a reduction in energy consumption through use of efficiencies and renewable sources, a revision in personal transport and transformation of the agricultural sector with reduced livestock farming. The scenario is called “MTFR + 1.5 LIFE” to reflect the target of 1.5 °C temperature rise by 2050 and implied life-style changes.

In addition, some illustrative emission reduction scenarios were also considered. These were simple cases where emissions from key sectors were set to zero in turn. The purpose was to determine if emissions from any of the sectors had, individually, a dominating effect on future air quality.

The geographic scope of the study is the EU-27 member countries and the report presents detailed results of the comparison for each pollutant and metric. In addition, and in order to illustrate the representativeness of these findings, results for four European countries (France, Poland, Italy and Spain) are also presented as indicative examples.

[1] This study uses the same methodology and scenarios as the supporting studies carried out for the Second Clean Air Outlook of the European Commission [6,7] being also part of the impact assessment of the AAQD revision. At the time of writing of this report, the European Commission has published the Third Clean Air Outlook (available here). However, the data underpinning the activity scenarios that were developed have not been made publicly available yet.

KEYWORDS & ABBREVIATIONS

Ambient Air Quality Directive (AAQD), Second Clean Air Outlook (CAO2), World Health Organization (WHO), Interim Target (IT), Air Quality Guidelines (AQG), Ambient Air Quality Standards (AAQS), Current Legislation (CLE), Maximum Technically Feasible Reduction (MTFR), O_3, NO_2, PM_{10}, $PM_{2.5}$, UNECE Convention on Long Range Transport of Pollution (CLRTAP), European Monitoring and Evaluation Program (EMEP)

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CONTENTS

LIST OF FIGURES

LIST OF TABLES

EXECUTIVE SUMMARY

The European Commission (EC) is currently in the process of revising the EU Ambient Air Quality (AAQ) Directives [1,2] with the aim to set more strict ambient air quality standards (AAQS) in order to align them more closely with the World Health Organization (WHO) Air Quality Guidelines (AQG).

The WHO AQG provide key advice on the impacts of air pollution and the 2005 version of the guidelines [3] has served as a reference for the present day AAQS set in 2008, which are in force since 2010. In 2021 however, WHO revised downwards its AQG [4] which now serve as the reference to the revised proposal of the AAQD that was published by the EC in October 2022 [5].

This study commissioned by Concawe uses a forecasting method to assess future concentrations of the key pollutants O_3, NO_2, PM_{10} and $PM_{2.5}$ which are most associated with health impacts. The metrics that are considered are the frequency of exceedance of a daily threshold value (days/year) and exceedance of an annual average concentration (µg/m^3).

The study uses the same methodology as the supporting studies carried out for the Second Clean Air Outlook (CAO2)[2] of the European Commission [6,7]. Three common scenarios for future emissions are considered under the CAO2 [6]:

- The baseline scenario which describes the future emissions expected to take place if no new emission control legislation is enacted. This study uses the term Current Legislation (CLE) and adopts the assumptions of the Second Clean Air Outlook. This takes into account the forecast economic activity and the consequential emissions together with the impact of legislated emission reductions, including national measures.
- Maximum Technically Feasible Reductions (MTFR). This applies the most stringent available emissions reduction to controlled sources without requiring closure of installations.
- Maximum Technically Feasible Reductions plus 1.5 LIFE (MTFR + 1.5 LIFE). This scenario includes economic activity changes consistent with a Climate Plan to limit global temperature rise to 1.5 ºC by 2050, primarily through change in energy use and efficiencies associated with a circular economy. It adopts revised transport demand, food/supply demand reforms, agricultural changes consistent with lower meat production, enhanced crop production, carbon sequestration etc. resulting in fewer NH_3 and CH_4 emissions. To this scenario, MTFR is applied to governed emission sources.

These represent the upper (CLE) and lower (MTFR) bounds to expected emissions in the years to 2050 without structural changes to the European economy, and a second lower bound (MTFR + 1.5 LIFE) with structural changes.

The Concawe study also includes some additional sector-specific emission reduction scenarios. The purpose of these is to identify which emission reduction components

[2] This study uses the same methodology and scenarios as the supporting studies carried out for the Second Clean Air Outlook of the European Commission [6,7] being also part of the impact assessment of the AAQD revision. At the time of writing of this report, the European Commission has published the Third Clean Air Outlook (available here). However, the data underpinning the activity scenarios that have been developed have not been made publicly available yet.

of the common scenarios are most influencing ambient air quality. Each scenario reduces emissions from a key emitting sector to zero.

All of the emission reduction scenarios start with reductions in 2025. The base year for the start of the modelling is 2015.

The Concawe study results are evaluated by comparing the predicted results at each monitoring station in Europe with the 2021 issued WHO Global AQG Interim Target and Guideline metrics [4]. The number of stations where the monitoring station concentration record meets the metric is counted. This also gives the number of stations that do not meet the metric. The number of stations where the metric is exceeded is expressed as a proportion (%) of the total number of stations to allow comparisons between countries, and of individual countries with the EU-27.

The geographic scope of the study is the EU-27 countries. Results for four countries (France, Poland, Italy and Spain) are also presented as indicative examples. However, the emission reductions associated with all scenarios are assumed to also take place in the UK.

The main findings of the study, by pollutant, and for the EU-27 as a whole are:

Ozone (O_3)[3]

- The WHO AQG recommend an exceedance frequency of less than four days a year (99^{th} percentile) for the maximum daily 8-hour mean O_3 concentration, with thresholds of 160 (IT 1), 120 (IT 2) and 100 $\mu g/m^3$ (guideline). The current AAQS is 120 $\mu g/m^3$ not to be exceeded on more than 25 days per year, averaged over 3 years.
- Under the CLE scenario of the Second Clean Air Outlook (CAO2), the proportion of stations not meeting the WHO exceedance thresholds in 2050 is 3% for IT 1, 58% for IT 2 and 95% for the guideline value.
- Under the maximum emission reduction scenarios MTFR and MTFR + 1.5 LIFE of the Second Clean Air Outlook, the proportion of stations not meeting the exceedance guideline value in 2050 slightly reduces to 93% and 92% respectively.
- The Concawe sensitivity scenarios suggest that the effective measures within those control scenarios are likely to be those on the reduction of industrial process emissions with emphasis on VOC. However, the improvement is predicted to be marginal.

Nitrogen Dioxide (NO_2)

- The WHO AQG recommend an exceedance frequency of less than four days a year (99^{th} percentile) for the NO_2 daily mean concentration, with thresholds of 120 (IT 1), 50 (IT 2) and 25 $\mu g/m^3$ (guideline). Under the current AAQD, there is no AAQS.

[3] It should be noted that modelling O_3 concentrations is subject to uncertainty which mainly arises from the complex O_3 chemistry, the meteorological conditions, and the impact of biogenic sources of VOC emission, an important precursor for O3. However, the projected future trends in O_3 compliance, even though they are subject to some uncertainty, are still dominated by the changes in emissions [HETC/ACM Technical Paper 2016/7]. The compliance picture is not, therefore, expected to change significantly.

- Under the CLE scenario, the proportion of stations in Europe not meeting the WHO exceedance thresholds in 2050 is 0% for IT 1, 1% for IT 2 and 17% for the guideline value.
- Under the maximum emission reduction scenarios MTFR and MTFR + 1.5 LIFE, the proportion of stations not meeting the exceedance guideline value in 2050 reduces to 15% and 13% respectively.
- The WHO guidelines recommend a limit on the annual mean concentration of NO_2 with limit values of 40 (IT 1), 30 (IT 2), 20 (IT 3) and 10 µg/m^3 (guideline). The current AAQS is 40 µg/m^3.
- Under the CLE scenario, the proportion of stations not meeting the WHO guidelines in 2050 is less than 1% for the interim target values and 11% for the guideline value.
- Under the maximum emission reduction scenarios MTFR and MTFR + 1.5 LIFE, the proportion of stations not meeting the guideline value in 2050 reduces to 7% and 3% respectively.
- The Concawe sensitivity scenarios suggest that the effective measures within these scenarios are likely to be those on the reduction of NO_x emissions from transport, without however achieving full compliance.

Particulate Matter - PM_{10}

- The WHO AQG recommend an exceedance frequency of less than four days a year (99th percentile) for the PM_{10} daily mean concentration, with thresholds of 150 (IT 1), 100 (IT 2), 75 (IT 3), 50 (IT 4) and 45 µg/m^3 (guideline). The current AAQS is 50 µg/m^3 not to be exceeded on more than 35 days per year.
- Under the CLE scenario, all stations in Europe are able to meet the WHO exceedance threshold IT 1, and very closely to meet IT 2 and IT 3 (1% and 3% of stations not meeting the targets respectively). The proportion of stations not meeting the WHO exceedance thresholds in 2050 is 17% for IT 4 and 22% for the guideline value.
- Under the maximum emission reduction scenarios MTFR and MTFR + 1.5 LIFE, the proportion of stations not meeting the WHO exceedance threshold IT 1 in 2050 is 13% and 10% respectively, while considering the exceedance guideline value in 2050, the proportion increases to 17% and 15% respectively.
- The WHO guidelines recommend a limit on the annual mean concentration of PM_{10} with limit values of 70 (IT 1), 50 (IT 2), 30 (IT 3), 20 (IT 4) and 15 µg/m^3 (guideline). The current AAQS is 40 µg/m^3.
- Under the CLE scenario, the proportion of stations not meeting the WHO annual mean thresholds in 2050 is less than 1% for IT 3, 10% for IT 4 and 35% for the guideline value.
- Under the maximum emission reduction scenarios MTFR and MTFR + 1.5 LIFE, the proportion of stations not meeting the annual mean threshold IT 4 is 7% and 6% respectively, while considering the annual mean guideline in 2050, the proportion of stations not meeting the guideline value remains significant at 26% and 21% respectively.
- The Concawe sensitivity scenarios suggest that the effective measures within these scenarios are likely to be those on the reduction of emissions from agriculture (NH_3) and domestic/commercial heating.

Particulate Matter - $PM_{2.5}$

- The WHO AQG recommend an exceedance frequency of less than four days a year (99th percentile) for the $PM_{2.5}$ daily mean concentration, with thresholds of 75 (IT 1), 50 (IT 2), 37.5 (IT 3), 20 (IT 4) and 15 µg/m^3 (guideline). Under the current AAQD, there is no AAQS for the exceedance frequency of a daily threshold.

- Under the CLE scenario, the proportion of stations not meeting the WHO exceedance thresholds in 2050 is less than 6% for IT 3, 19% for IT 4 and 62% for the guideline value.
- Under the maximum emission reduction scenarios MTFR and MTFR + 1.5 LIFE, the proportion of stations not meeting the IT 4 is 12% and 9% respectively, while considering the exceedance guideline value in 2050, the proportion increases to 43% and 35% respectively.
- The WHO guidelines recommend a limit on the annual mean concentration of $PM_{2.5}$ with limit values of 35 (IT 1), 25 (IT 2), 15 (IT 3), 10 (IT 4) and 5 µg/m^3 (guideline). The current AAQS is 25 µg/m^3 with the long-term objective that average concentrations should fall below 20 µg/m^3.
- Under the CLE scenario, the proportion of stations not meeting the WHO guidelines in 2050 is less than 1% for IT 3, 10% for IT 4 and 75% for the guideline value.
- Under the maximum emission reduction scenario MTFR, the proportion of stations not meeting the annual mean threshold IT 4 is less than 3% while under MTFR + 1.5 LIFE almost all stations are able to meet the IT 4 threshold. The proportion of stations not meeting the annual mean guideline value in 2050 is significant in both scenarios being, 52% for MTFR and 37% for MTFR + 1.5 LIFE respectively.
- The Concawe sensitivity scenarios suggest that the effective measures within these scenarios are likely to be those on the reduction of emissions from agriculture (NH_3) and domestic/commercial heating.

To test the representativeness of these findings, the results for four countries were examined in detail. These countries were France, Poland, Italy and Spain.

For ozone exceedance of a daily threshold, which represents the maximum daily 8-hr mean ozone concentrations, the results are similar to those of the EU-27 taken as a whole.

For the other pollutant metrics there were differences. Poland and Italy experience generally higher particulate matter concentrations, both peak and average and the proportion of monitoring stations in those countries have more frequent exceedances of daily thresholds and higher annual average concentrations, compared with the WHO interim and guideline criteria, than the EU-27 as a whole. The same pattern is observed for both PM_{10} and $PM_{2.5}$ (which makes up part of PM_{10}) although the variation between countries is larger for $PM_{2.5}$.

For NO_2, there is also variation between countries with Italy generally having a larger proportion of stations not meeting the guideline criteria compared with the EU-27 as a whole.

In conclusion, the study finds that air quality in Europe improves over time towards the horizon of 2050. This is due to the reduction in emissions already legislated within the economic outlook of the Second Clean Air Outlook.

The study shows that air quality in Europe will not meet the guideline criteria set out in the 2021 guidelines under the Second Clean Air Outlook forecast energy/activity pathway. Although air quality will not meet the guideline criteria, the forecasted air quality under the current pathway is largely consistent with the more ambitious of the interim target criteria. However, there is variability within countries and the distribution of air quality is not uniform over Europe.

The effect of emission controls was explored using two maximal emission reduction scenarios. Under the Second Clean Air Outlook (CAO2) MTFR scenario, controls that are technically (but not necessarily economically) feasible are applied to the baseline economic/activity pathway. Broadly, these extend controls on already regulated sources. MTFR leads to some improvement in air quality, but the WHO air quality guideline values are not achieved.

The scenario MTFR + 1.5 LIFE results overall in improved air quality compared to MTFR alone with mainly benefits to particulate matter concentrations.

Concawe sensitivity calculations, show that there is no single sector emission that has a dominant effect on how ambient air quality at monitoring stations will compare with the interim target and guideline criteria. While reduction of NO_x emissions from transport are influencing the NO_2, prediction calculations show that agricultural emissions (primarily NH_3) have a strong effect on particulate matter concentrations. Road transport emissions lose importance after 2030 because of the drop in older vehicles within the fleet. Off-road emissions for transport and construction play a growing role as their contribution becomes larger relative to on-road. Reductions in domestic emissions associated with the use of fuel for heating of homes and commercial premises also have an impact on particulate matter concentrations. 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.

These sensitivity calculations support the findings of the control scenarios, namely that the MTFR + 1.5 LIFE is more effective than MTFR alone in improving air quality, because it takes a broader approach to reducing emissions from a whole range of sectors.

The outlook for 2030 and for 2050 is therefore 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 as set out in the recently updated WHO Global Air Quality Guidelines (2021). However, air quality is unlikely to meet the WHO guideline values at many locations in Europe covered by the current monitoring networks.

1. 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 (primary pollutants) or formed in the atmosphere by chemical reactions (secondary pollutants). Air quality is judged as good or poor according to how these concentrations compare with Ambient Air Quality Standards (AAQS). Due to successful policies to reduce man-made (anthropogenic) emissions, the trend is for air quality to improve. The AAQS are periodically reviewed to ensure they continue to be relevant and appropriate.

The EU Ambient Air Quality Directives (AAQD) [1,2] came into force in 2008. They formalised AAQS from earlier regulation and in particular recognised advice from the World Health Organization (WHO) on the importance of air-borne particulate matter (PM) on human health. Because of a paucity of information on actual air concentrations of PM as well as concentrations of NO_2, the Directive required the measurement and monitoring of air quality in proportion to population. As a result, a comprehensive network of measurement stations has been established across Europe. The administration of the network is a national responsibility. In a very effective cooperation this work expands a long-standing network organised under the United Nations Economic Commission for Europe (UNECE) Convention on Long Range Transport of Air Pollution (CLRTAP).

Although not usually framed in risk quantitative terms, air pollutant concentrations that meet AAQS are viewed as tolerable but not necessarily harmless. The choice of an AAQS is influenced by advice on the harmful effects of the pollutant. This advice is provided by the WHO through its air quality guidelines. It is also influenced by practical and economic considerations. AAQS must be able to be achieved even if lower concentrations would be preferred.

The WHO in September 2021 revised its Global Guidelines for Air Quality (AQG) [4]. Particularly, they recommended downward changes to guideline values for particulate matter (PM_{10} and $PM_{2.5}$), ozone (O_3), nitrogen dioxide (NO_2), sulphur dioxide (SO_2) and carbon monoxide (CO) made in their 2005 Air Quality Guidelines [3] which informed the 2008 AAQDs.

European populations are now exposed to generally lower concentrations of pollutants than in 2005 as a result of continuing regulation of European air quality and emissions. The relationship between population health and exposure to pollutants at these lower concentrations is better known. The WHO review issued in 2021 identified guideline values that are, for practical purposes, fully protective of health. However, air quality in many, if not most, regions across the world does not meet these guideline values. Therefore, in keeping with past methodology, WHO suggests Interim Targets (IT) 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 step wise improvements in air quality can then be judged to provide positive health benefits. A long-term objective would be to attain the guidelines.

The EU Environment strategy has, as its long-time goal, zero harm to human health or the environment from air pollution. Accordingly, close attention has been paid to the new WHO guidelines. The current AAQS overlap with the WHO AQG interim targets as shown in **Table 1**.

The AAQS and the WHO AQ Guideline metrics take one of two 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, 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 are counted over a year.

Alignment of AAQS with the WHO AQ Guidelines, a key objective of the AAQD revision [5], would involve changes to concentration upper limit values and to exceedance frequency limits. For new AAQS to be met, there has to be a meaningful reduction in anthropogenic emissions across Europe. This reduction must be able to be achieved if there is not to be a future compliance problem.

The pollutants of prime interest, O_3 and $PM_{2.5}$, are transboundary pollutants whose concentrations are not able to be controlled only locally, i.e., within the administrative scope of the national contribution to the air quality network. Their concentrations are also influenced by natural emissions, by climate and meteorology. Their concentrations in turn influence the concentrations of NO_2 and PM_{10}.

The setting of new AAQS has to take careful account of future trends in emissions to ensure that the AAQS can be achieved on a legislated timescale.

Concawe has commissioned a study, conducted by the consultant Salix Analytics[4], to examine how future ambient air quality might compare with the new WHO AQG and IT metrics. The study simulates future air concentrations at selected measuring stations of the European Air Quality Network. The selection is of reliable stations shown to provide year on year data on the pollutant metrics concerned. The geographic scope is chosen to be EU-27. Examples for specific countries (France, Poland, Italy and Spain) are also given to illustrate variability between countries.

The study uses a similar methodology to that supporting the Second Clean Air Outlook Second Clean Air Outlook [6] published by the European Commission in 2021. In particular, it considers the Current Legislation (CLE) trend and two scenario assumptions made in the Clean Air Outlook about maximum emissions reduction potential [7]. The study also investigates which sector emissions might be most important in determining air quality.

Results are expressed graphically as the proportion (%) of measurement stations that would NOT meet each of the WHO metrics (interim target and guideline values) in the years to 2050.

[4] Salix Analytics consist of modelling experts being previously at Aeris Europe Ltd (https://aeriseurope.com/). For this study, Salix has made use of Aeris' modelling tools that have been applied to previous Concawe studies.

Table 1 Comparison between current EU Air Quality Standards (2008) and latest WHO Air Quality Guidelines (2021) (Source: EEA, 2021)

		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 μg/m3							
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 [a]	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

2. METHODOLOGY

2.1. BACKGROUND

The concentration of air pollutants depends on pollutant emissions, meteorology and climatic conditions. Most pollutants undergo some form of chemical transformation in the atmosphere. This is significant for three of the pollutants considered in this study, fine particulate matter ($PM_{2.5}$), ozone (O_3) and nitrogen dioxide (NO_2). $PM_{2.5}$ makes up part of PM_{10} so PM_{10} is affected indirectly.

A significant contribution to the air pollution measured at a monitoring station originates from distant emission sources. Some pollutants and pollutant precursors occur naturally, and these sources cannot be controlled. Volatile organic compounds (VOC) of biogenic origin for example, are important for O_3 and secondary $PM_{2.5}$ formation. Wind-blown dust contributes significantly to particulate matter, which is also deposited and resuspended. PM_{10} and $PM_{2.5}$ concentrations can therefore have aged as well as primarily emitted components from both anthropogenic and natural sources.

Where long range transport of pollutants is a dominant factor in determining air concentrations and air quality is close to or exceeding AAQS, the local authorities responsible for monitoring and reporting pollutant concentrations have limited ability to control air quality through their own actions. The most direct constraints are on urban planning, permitting of new construction, industry and transport. Measures such as clean air zones in which transport and domestic/commercial emissions are limited, generally require national consent or cooperation. In the case of road transport, where there are concerns over AAQS violations for NO_2 in particular, deep policy measures to promote substitution of fossil fuelled vehicles by electrical vehicles have been introduced.

Because pollution crosses borders, it has been long recognised that co-ordinated international action is needed to address air quality. The resources established under the UN-ECE Convention on Long Range Transboundary Air Pollution (CLRTAP), and in particular the European Monitoring and Evaluation Program (EMEP) [8] provide the infrastructure and expertise to design and assess emission reduction strategies to the benefit of air quality. The Gothenburg Protocol and the National Emissions reduction Commitments (NEC) Directive [9], for the EU-27, share the same scope and objectives.

Sophisticated methods have evolved to address the quantitative relationship between emissions, meteorology, atmospheric chemical production and the rates of pollutant deposition on air concentrations. The impact of pollution on human health, forests, crops, nature and the built environment are also assessed within this collaboration.

This study of Concawe makes use of these methods.

2.2. INPUTS

The main elements needed for air quality assessment are:

- Emissions: Detailed spatial information on emissions is gathered across Europe including height information for large point sources. Emissions data is generally built “bottom up” from knowledge of particular source categories. For broad policy purposes and in this report, these are aggregated into ten SNAP [10] sectors. SNAP, standing for “Standard Nomenclature for Air Pollution” is the simplest sectoral representation. The underlying work uses a more detailed system. Biogenic emissions (part of an additional SNAP sector (SNAP 11)) are calculated during modelling because they depend dynamically on the season and weather according to land-use.

- Future emissions are calculated considering three main factors. The type of emission source, the activity of the source (number of sources and their rate of production) and an abatement profile which quantifies how much emission can be reduced, usually as a result of the applicability of available technical measures.
- Meteorology and Climate: Detailed information on meteorology (wind, rain) including climatic conditions (temperature, pressure, insolation) from historic record are used inside a meteorological model to calculate detailed wind-field information to be used within a chemical transport model.
- Chemical Transport Model (CTM): A type of computer numerical model that takes emission, meteorological and climate data to predict the concentration and deposition of pollutants. The EMEP model is the consensus model for use in air policy. It provides estimates of ground level concentration typically averaged over 28x28 km square areas although higher resolution can be embedded to give estimates of ground-level concentration over smaller areas, ~7x7 km square.
- Economic model: In order to project future emissions, certain assumptions have to be made about economic development and what it entails for industrial and agricultural production, energy generation/consumption and so forth. The European Commission produces activity scenarios for use in modelling using the PRIMES model [11].
- Integrated Assessment Model: The activity from the economic model, the forecast from the emissions model modified by emission controls corresponding to current regulations and the results from the chemical transport model are brought together to forecast future air quality. An effects module calculates environmental and health endpoints. The model used to perform these assessments for European policy makers is the IIASA GAINS EUROPE model [12].
- In GAINS scenario mode, the controls on emissions (abatement technology) can be altered and the associated costs evaluated. In optimisation mode, the most cost-effective emission controls needed to meet a given environmental endpoint can be evaluated, provided this is achievable.

This study uses three GAINS scenarios developed for the European Commission’s Second Clean Air Outlook [6]. These comprise a baseline case and two maximal emission reduction scenarios:

- The baseline scenario (CLE): This is the expected trend in emissions in Europe between 2015 and 2050. This includes 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). 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 until 2030, and implementation of the current policies on non-CO_2 greenhouse gas emissions.
- The Maximum Technically Feasible Reduction (MTFR) scenario: This is the air-quality outcome if emissions constructed within GAINS are reduced as far as possible using technology, 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 stabilisation objective of the global temperature increase at 1.5 °C. It assumes, inter alia, movement toward 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, dietary shift that reduces demand for red meat and consequentially animal numbers and their need for feed provision. MTFR controls are applied to this new baseline.

2.3. EMISSION SCENARIOS

To better understand the results of the GAINS maximal reduction scenarios, this study uses some simple sectoral emission reduction scenarios. These sensitivity scenarios reduce the emissions from a specific SNAP sector to zero. If the scenario produces a change in air quality that affects the comparison with the WHO AQG, then 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 year 2025 and for subsequent years. The different scenarios are summarized in **Table 2**.

Table 2 List of emissions reduction scenarios assessed in the study. 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).

Case (0)	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 VOC 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, VOC, and NH_3 from process industry, including the use of solvents (VOC) 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 VOC 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 VOC 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 CH_4, NH_3 and CO_2 emissions reduction.

2.4. AIR QUALITY MONITORING STATION SIMULATIONS

The monitoring network established under the Air Quality Directive (2008) is organised on a national basis. Station details and the monitoring data gathered are collated under the direction of the European Environment Agency (EEA) [13]. Data is validated and processed into a form consistent with the metrics used in the AAQS. From this data, compliance with AAQS can be assessed.

Monitoring stations serve different purposes. Not all stations measure all pollutants. The method used to select stations is detailed below. However, for assessing future air quality, there are some implicit assumptions:

- The network in place in 2015 is representative of the network in 2030 and 2050. This equivalently assumes no large changes to the physical extent of populated areas.
- The quality of data from a station remains the same and the reliability of data provision is unchanged.
- The criteria for determining air quality compliance with AAQS does not change. Specifically, that certain locations or types of stations would not become exempt from reporting under future rules.
- Individual stations are not physically moved so that the station location in 2050 is the same as it was in 2015.

The methodology applied by the consultant Salix Analytics has been described in previous reports [14, 15].

Monitoring station data from across the EU is held centrally by the EEA [13]. Data from this source was downloaded and subjected to validation checks. Data was processed into daily average concentrations (daily averages of highest 8 hours of concentration for ozone), and annual average concentrations. Stations with incomplete data were discarded. Of the remaining stations, those with a history of providing reliable daily and annual statistics were selected. The reasoning is that these stations are located in necessary positions to monitor air quality, have been maintained, and are likely so to continue.

Following this procedure, the number of stations selected for the EU-27 were:

- Ozone (O_3): 1308 stations that provide consistent data to evaluate the maximum daily 8-hr mean concentration that can be compared with a threshold and exceedances over a year evaluated.
- Nitrogen Dioxide (NO_2): 1524 stations that provide consistent data to evaluate an annual mean value.
- Nitrogen Dioxide (NO_2): 1509 stations that provide consistent data to evaluate a daily (24-hour) mean value that can be compared with a threshold and exceedances over a year evaluated.
- Particulate Matter - PM_{10}: 837 stations that provide consistent data to evaluate an annual mean value.
- Particulate Matter - PM_{10}: 801 stations that provide consistent data to evaluate a daily (24 hour) mean value that can be compared with a threshold and exceedances over a year evaluated.
- Particulate Matter - $PM_{2.5}$: 1090 stations that provide consistent data to evaluate an annual mean value.

- Particulate Matter - $PM_{2.5}$: 1069 stations that provide consistent data to evaluate a daily (24-hour) mean value that can be compared with a threshold and exceedances over a year evaluated.

More detailed information regarding the distribution of the selected traffic stations as a function of type (traffic vs. background) and area (rural, suburban, urban) is provided in **Table 3** and **Table 4** respectively.

Table 3 Number of stations used for the assessment and their type of distribution.

	Traffic	Background
O_3: exceedance days	84	1224
NO_2: annual mean	445	1079
NO_2: exceedance days	442	1067
PM_{10}: annual mean	236	601
PM_{10}: exceedance days	223	578
$PM_{2.5}$: annual mean	285	805
$PM_{2.5}$: exceedance days	280	789

Table 4 Distribution of selected stations according to the area they represent.

	Rural	Suburban	Urban
O_3: exceedance days	374	336	598
NO_2: annual mean	293	273	958
NO_2: exceedance days	289	269	951
PM_{10}: annual mean	139	128	570
PM_{10}: exceedance days	132	124	545
$PM_{2.5}$: annual mean	194	192	704
$PM_{2.5}$: exceedance days	188	188	693

For each selected monitoring station, air quality simulations were carried out using an emulation of the GAINS model developed and maintained by Salix Analytics. This uses results from the EMEP model to predict hourly air concentrations over Europe. The model works on a 7 x 7 km grid resolution. 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, shown robust over historic years, 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 [14] of air quality response to emission changes, a confidence interval has been calculated for the predicted air quality metric at each monitoring station location.

This study is not designed to evaluate the performance of specific emission interventions on air quality or to design potential AAQS and so the central value of the prediction has been used for each air quality parameter.

For each monitoring station, the requisite annual air quality metrics of each pollutant were calculated based on the hourly concentrations from the model.

For exceedance frequency, this involved calculating each daily average, or in case of ozone the maximum daily 8-hr mean concentration. This value was then compared with each of the WHO AQG interim target and guideline values in turn. If the prediction exceeded the WHO AQG target value, then a counter was incremented. The annual result is the count of exceedances.

For annual average concentration, the average of hourly values was evaluated and reported.

In post-processing for exceedance frequency, 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 AQG 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.

In post-processing for annual mean, the calculated annual average for each station was compared to see if it was less than or equal to the WHO AQG 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.

It should be noted that this procedure uses the same methodology as the supporting studies carried out for the Second Clean Air Outlook [6,7], but it differs in two ways. The forward concentrations calculated in that study were taken as the highest of the grid concentrations overlapping a populated area. Here an uplift is applied to the concentration in the grid containing the specific measuring stations. That study expressed the proportion of population exposed to annual concentrations below certain thresholds. This study calculates the proportion of monitoring stations exposed to annual concentrations below certain thresholds. It is not possible to draw a direct analogy between population and the number of monitoring stations because:

- not all conurbations have an equal density of monitoring stations;
- monitoring stations should be situated in locations where there is concern that pollution may exceed AAQS;
- not all monitoring stations are included in this study because of the acceptance criteria on performance that have been applied.

3. EU-27

3.1. 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.

From the methodology description, the study results are calculated in terms of the number of stations where the pollutant metrics are below the WHO AQG interim target and guideline values. These results are tabulated in the following sections. However, it is the complement of this information which is of more direct interest. Therefore, the graphics below show the proportion (in %) of stations where pollutant metrics exceed the WHO AQG interim target and guideline values.

To recap on the metrics considered, these are:

Ozone: The number of days in a year that the average of the maximum daily 8-hr mean concentration exceeds a threshold value.

NO_2:
a) The number of days a year the daily average concentration exceeds a threshold value.
b) The annual mean concentration is less than a threshold value.

PM_{10}:
a) The number of days a year the daily average concentration exceeds a threshold value.
b) The annual mean concentration is less than a threshold value.

$PM_{2.5}$:
a) The number of days a year the daily average concentration exceeds a threshold value.
b) The annual mean concentration is less than a threshold value.

For brevity, these will be referred to as Exceedance and Annual Mean tests in the following text.

3.2. THE CURRENT LEGISLATION (CLE) SCENARIO

The results for exceedance and annual mean tests for all the WHO AQG values, when future emissions follow the trajectory assumed by the Second Clean Air Outlook are given below. Current AAQS are given for reference and the results are ordered by pollutant.

3.2.1. Ozone - Exceedance

The current AAQD set a (non-binding) target that the O_3 daily maximum 8-hr mean concentration should not exceed 120 µg/m^3 on more than 25 days per year. This is evaluated as an average number of exceedances across three years in order to accommodate inter-annual variability in meteorology. The Directive sets a long-term objective that foresees the number of exceedances falling to zero.

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. They suggest, two interim targets, concentration values of 160 and 120 µg/m^3 and a guideline value of 100 µg/m³. Although the second interim target of 120 µg/m³ is numerically the same concentration as given in the Air Quality directive the limit of fewer than four exceedances per year is much more restrictive than the 25 per year, averaged over 3 years.

Figure 1 shows that that the interim target 1 (160 µg/m³ not to be exceeded on more than four days) is not met by a small proportion of stations and this proportion decreases in time under current legislation (less than 5% in all European stations by 2050). The interim target 2 is not met by a substantial proportion of stations (80% of the stations in 2020) and this proportion decreases with time until 2040. The WHO air quality guideline value 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 the interim target 2 as well as the WHO air quality guideline will still remain significant.

It should be noted that O_3 modelling is subject to uncertainty which mainly arises from the complex O_3 chemistry, the meteorological conditions, and the impact of biogenic sources of VOC emission, an important precursor for O_3. However, the projected future trends in O_3 compliance, even though they are subject to some uncertainty, are still dominated by the changes in emissions [16]. The compliance picture is not, therefore, expected to change significantly.

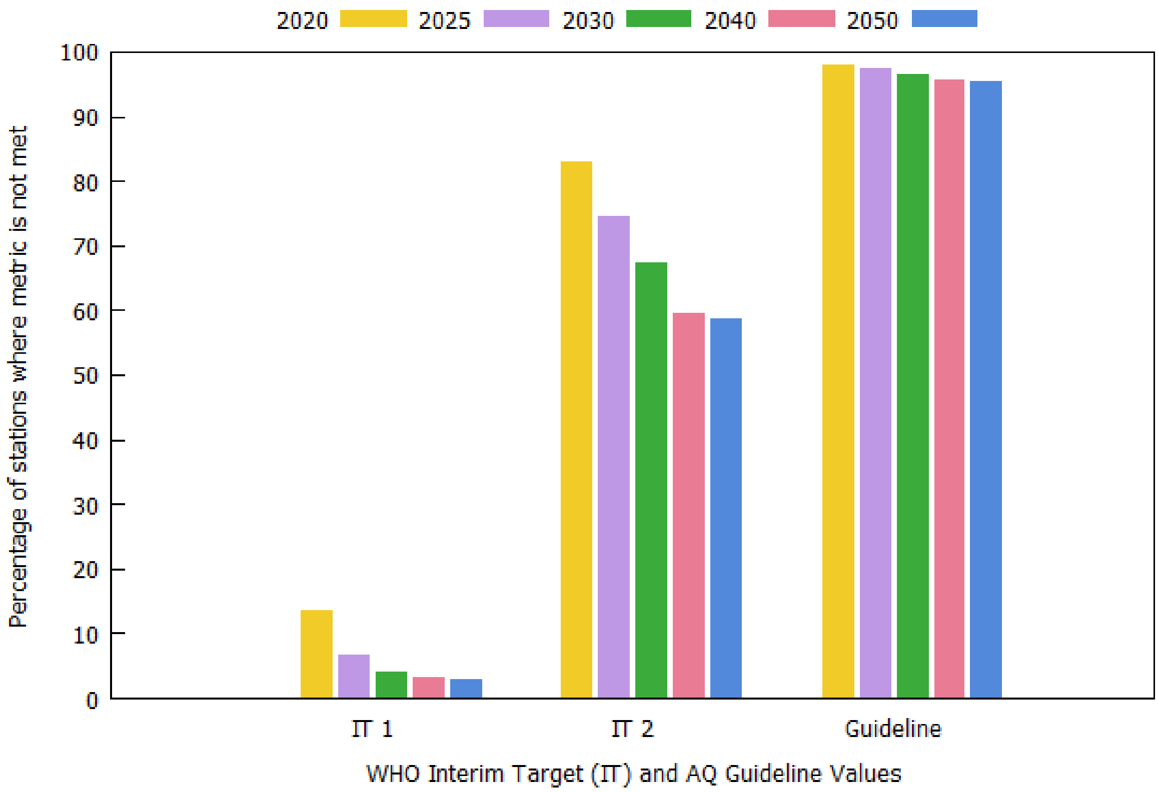

Figure 1 O_3 exceedance – EU27: Proportion of stations predicted NOT to meet the WHO interim target and guideline values.

The number of stations, out of a total of 1308, where the number of O_3 exceedances is predicted to be below the WHO interim target and air quality guideline values is tabulated below.

Table 5 Monitoring stations in Europe predicted to meet the WHO AQG IT and guideline values for ozone exceedance.

Year	Number of stations (of 1308) meeting WHO AQG criteria for ozone exceedance		
	Interim Target 1	Interim Target 2	AQ Guideline
	160 µg/m^3 (< 4 days/year)	120 µg/m^3 (< 4 days/year)	100 µg/m^3 (< 4 days/year)
2015	999	173	23
2020	1131	224	27
2025	1220	332	35
2030	1256	428	46
2040	1267	529	57
2050	1269	540	60

As time progresses, the number of stations where interim target 1 is met is predicted to increase from 999 in 2015 to 1269 in 2050. This is still less than the total number of stations. The complementary figure (proportion of stations where the interim target 1 is NOT met) shown in **Figure 1** decreases from 24% in 2015 to 3% in 2050.

In 2030, only 428 stations are predicted to achieve the WHO interim target 2 of 120 µg/m^3 as a 99th percentile, the complementary value is 67%. For the WHO air quality guideline value of 100 µg/m^3, the 99th percentile is achieved by only 46 stations in 2030, slightly increasing to 60 in 2050. The complementary values (i.e., proportion of stations where the WHO air quality guideline is NOT met) are 96% and 95% respectively.

3.2.2. NO_2 Exceedance

The current AAQD does not set a criterion for the daily concentration of NO_2.

The WHO guidelines propose that a target value be met as a 99th percentile, i.e., less than four exceedances per year with two interim targets of 120 µg/m^3 and 50 µg/m^3 and an air quality guideline value of 25 µg/m^3.

Results are shown in **Figure 2**. Under current legislation, interim target 1 is predicted to be met at all stations as from 2025. Interim target 2 is substantially met as from 2030. A significantly larger number of stations is predicted to see more exceedances of the WHO air quality guideline threshold, although this number does decrease with time. The proportion of stations with exceedances of the WHO air quality guideline threshold is 29% in 2030 and reducing to 17% in 2050.

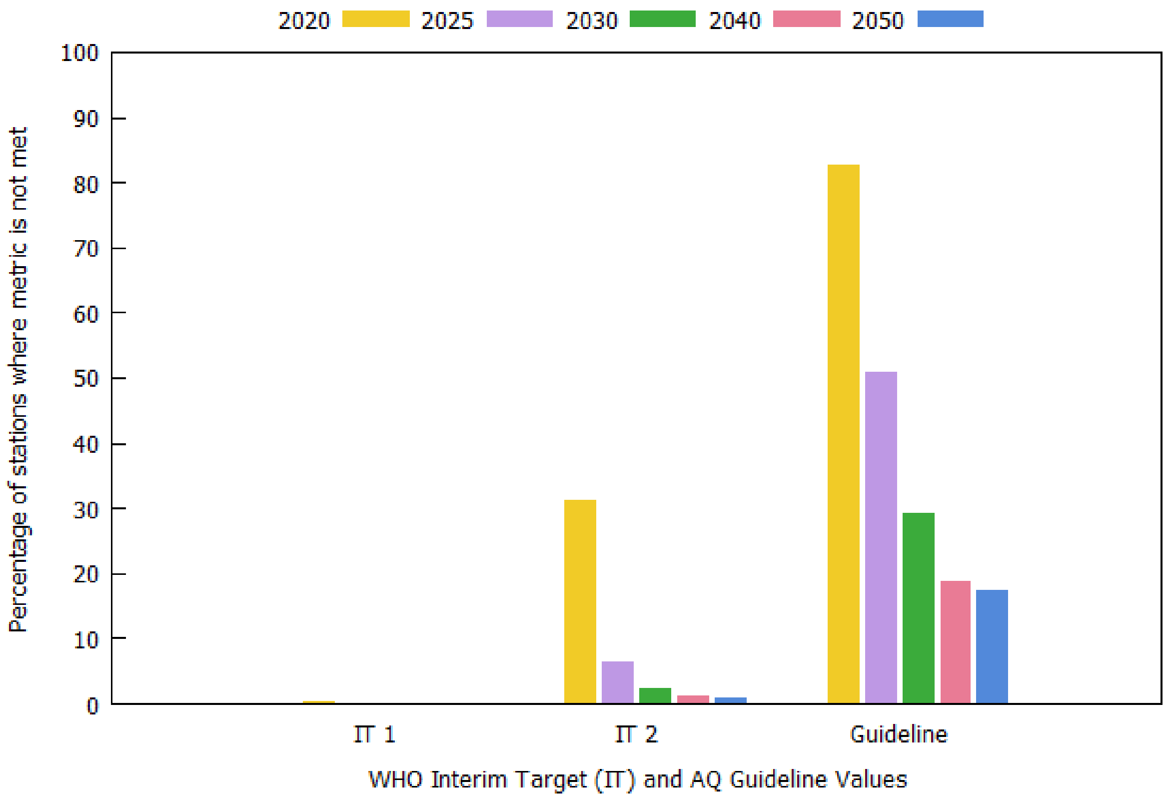

Figure 2 NO_2 exceedance – EU27: Proportion of stations predicted NOT to meet the WHO interim target and guideline values.

The number of stations, out of a total of 1509, where the number of NO_2 exceedances is predicted to be below the WHO interim target and air quality guideline values is tabulated below.

Table 6 Monitoring stations in Europe predicted to meet the WHO AQG IT and guideline values for NO_2 exceedance.

Year	Number of stations (of 1509) meeting WHO AQG criteria for NO_2 exceedance		
	Interim Target 1	Interim Target 2	AQ Guideline
	120 μg/m^3 (< 4 days/year)	50 μg/m^3 (< 4 days/year)	25 μg/m^3 (< 4 days/year)
2015	1498	750	154
2020	1506	1040	262
2025	1509	1412	742
2030	1509	1474	1070
2040	1509	1490	1227
2050	1509	1494	1249

3.2.3. NO_2 Annual Mean

A limit value of 40 µg/m^3 for the annual mean value of NO_2 is set in the current AAQD. This limit value has been difficult to attain in many areas. The WHO air quality guidelines propose interim target values of 40, 30 and 20 µg/m^3 and a guideline value of 10 µg/m^3.

The model results show that there are a very small number of stations measuring higher annual concentrations than the interim target 1 (which is equal to the current AAQS) in 2020 (**Figure 3**). This number increases for interim target 2 and interim target 3, while for the WHO air quality guideline nearly 77% of stations is predicted to measure higher annual mean concentrations in 2020.

Beyond 2030, under the baseline scenario, almost all stations are predicted to measure concentrations below the interim target 2 (30 µg/m^3). In 2030, concentrations are above the interim target 3 (20 µg/m^3) at only 8% of stations and above the WHO air quality guideline value at 37% of stations. In 2050, it is predicted that concentrations would still be above the guideline at 11% of stations.

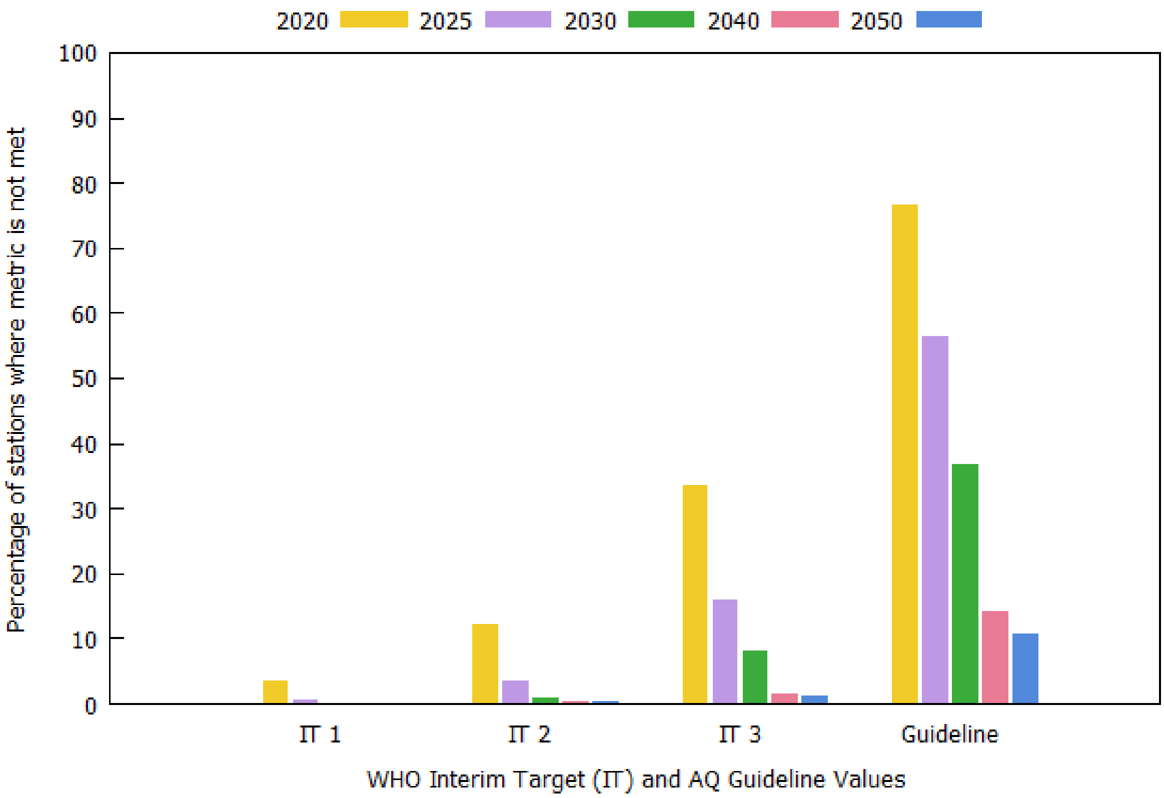

Figure 3 NO_2 annual mean – EU27: Proportion of stations predicted NOT to meet the WHO interim target and guideline values for.

The number of stations, out of a total of 1524, where NO_2 annual mean concentrations are predicted to be below the WHO interim target and air quality guideline values is tabulated below.

Table 7 Monitoring stations in Europe predicted to meet the WHO AQG IT and guideline values for NO_2 annual mean concentration.

Year	Number of stations (of 1524) meeting WHO AQG thresholds for NO_2 annual mean			
	Interim Target 1	Interim Target 2	Interim Target 3	AQ Guideline
	40 µg/m^3	30 µg/m^3	20 µg/m^3	10 µg/m^3
2015	1384	1174	760	227
2020	1471	1340	1015	355
2025	1515	1472	1283	664
2030	1523	1509	1399	965
2040	1523	1521	1500	1309
2050	1523	1521	1508	1361

3.2.4. PM_{10} Exceedance

The current AAQD set a PM_{10} limit value of 50 µg/m^3 not to be exceeded on more than 35 days per year. The WHO guidelines again propose a 99th percentile limit, to be exceeded less than four times per year, on four interim targets of 150, 100, 75 and 50 µg/m^3, and an air quality guideline value of 45 µg/m^3. As it is unlikely for the limit value to be revised upwards in the revised AAQD, the IT 1, IT 2, and IT 3 are of less relevance.

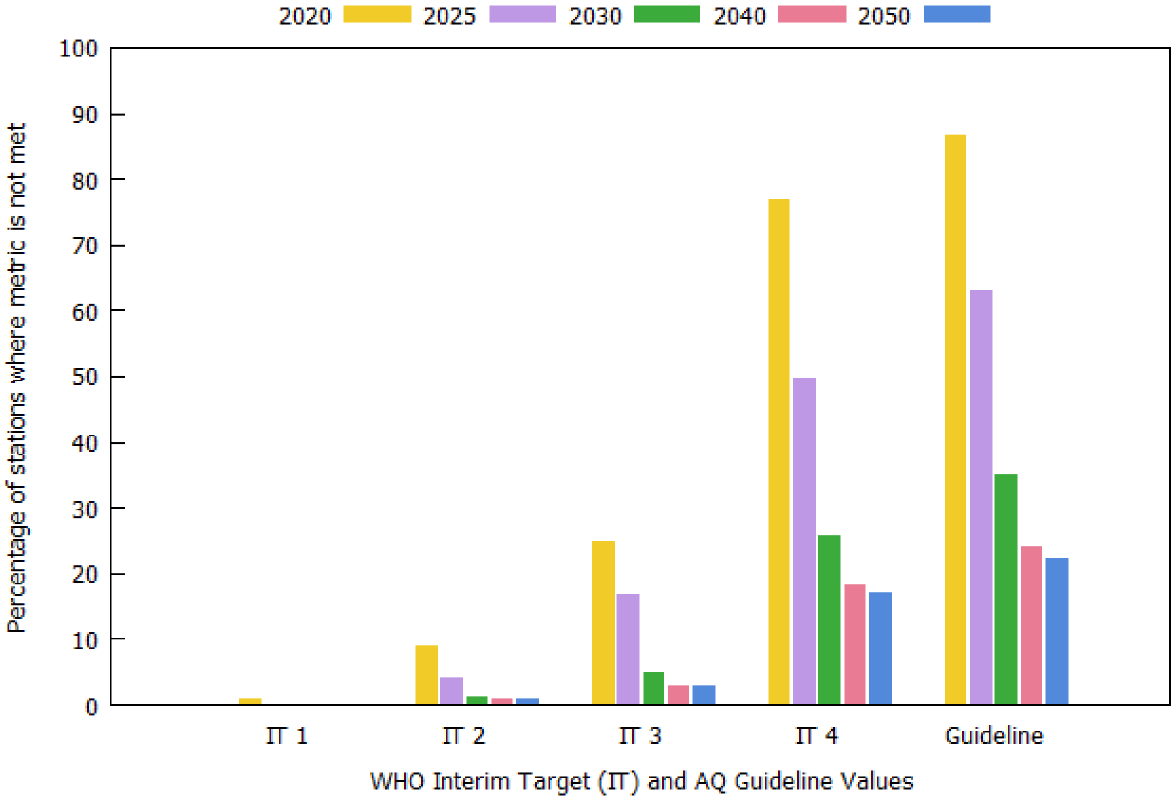

Figure 4 PM_{10} exceedance – EU27: Proportion of stations predicted NOT to meet the WHO interim target and guideline values.

The modelling results (**Figure 4**) show that the frequency criterion of less than four exceedance days per year is quite demanding. For interim target 4, the proportion of stations not meeting the target is 77% in 2020 reducing to 17% in 2050. At the WHO air quality guideline, the proportion of stations not meeting the threshold is 87% in 2020, reducing to 22% in 2050.

The number of stations, out of a total of 801, where the number of PM_{10} exceedances is predicted to be below the WHO interim target and air quality guideline values, is tabulated below.

Table 8 Monitoring stations in Europe predicted to meet the WHO AQG IT and guideline values for PM_{10} exceedance.

Year	Number of stations (of 801) meeting WHO AQG criteria for PM_{10} exceedance				
	Interim Target 1	Interim Target 2	Interim Target 3	Interim Target 4	AQ Guideline
	150 µg/m^3 (< 4 days/year)	100 µg/m^3 (< 4 days/year)	75 µg/m^3 (< 4 days/year)	50 µg/m^3 (< 4 days/year)	45 µg/m^3 (< 4 days/year)
2015	780	673	537	119	60
2020	795	729	603	186	107
2025	800	769	667	402	297
2030	801	791	762	595	522
2040	801	794	778	656	608
2050	801	794	779	665	622

3.2.5. PM_{10} Annual Mean

The current AAQD set a PM_{10} limit value of 40 µg/m^3 while WHO sets interim target values of 70, 50, 30, 20 µg/m^3 and an air quality guideline value of 15 µg/m^3.

In Europe, interim targets 1 and 2 should be, and are, met. **Figure 5** shows that annual mean concentrations at nearly all measuring stations are predicted to be below the interim target 3 by 2030.

Under current legislation, the proportion of stations where annual concentrations are above the interim target 4 value is predicted to be significant in 2020 (almost 47% of stations do not meet IT 4) but decreases to 10% in 2050. For the WHO air quality guideline, the proportion of stations not meeting the threshold of 15 µg/m^3 is predicted to be 86% in 2020, decreasing to 35% in 2050.

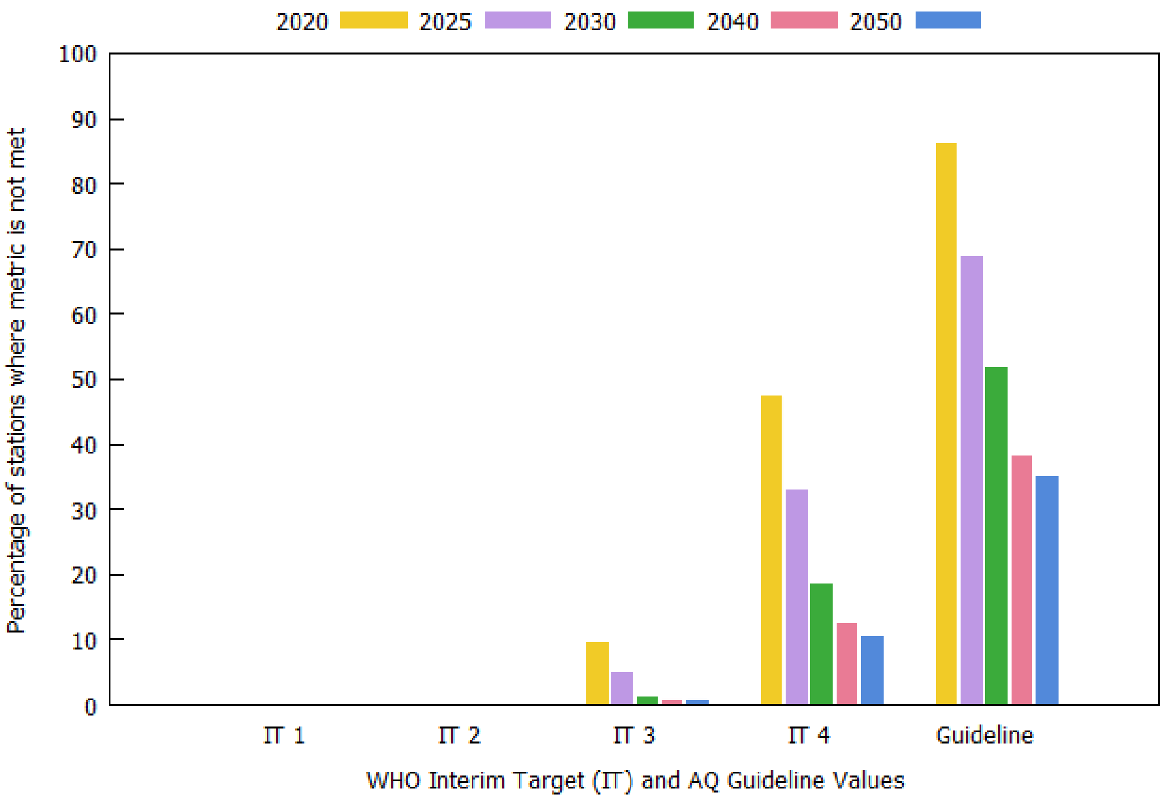

Figure 5 PM_{10} annual mean – EU27: Proportion of stations predicted NOT to meet the WHO interim target and guideline values.

The number of stations, out of a total of 837, where PM_{10} annual mean concentrations on an annual mean basis are lower than the WHO interim target and air quality guideline values is tabulated below.

Table 9 Monitoring stations in Europe predicted to meet the WHO AQG IT and guideline values for PM_{10} annual mean concentration.

Year	Number of stations (of 837) meeting WHO AQG thresholds for PM_{10} annual mean				
	Interim Target 1	Interim Target 2	Interim Target 3	Interim Target 4	AQ Guideline
	70 µg/m³	50 µg/m³	30 µg/m³	20 µg/m³	15 µg/m³
2015	837	836	679	308	86
2020	837	837	757	441	117
2025	837	837	797	562	261
2030	837	837	827	683	404
2040	837	837	831	734	517
2050	837	837	831	750	545

3.2.6. $PM_{2.5}$ Exceedance

For fine particulate matter ($PM_{2.5}$) the current AAQD does not stipulate a value for the daily average concentration and consequently no exceedance frequency.

WHO proposes four interim target values of daily average concentration to be 75, 50, 37.5 and 25 µg/m^3 and an air quality guideline value of 15 µg/m^3. These values to be exceeded on fewer than four days per year.

Modelling results are shown in **Figure 6**. The model predicts that exceedances will be lower than the interim target 1 at almost all stations from 2030 onwards. The proportion of stations observing concentrations higher than the target values increases markedly as the threshold decreases from interim 3 to interim 4 to the guideline value. In 2030, in 79% of the stations higher concentrations than the guideline value are predicted. This proportion decreases in 2050 but still remains significant (62% of the stations are predicted to exceed the WHO air quality guideline).

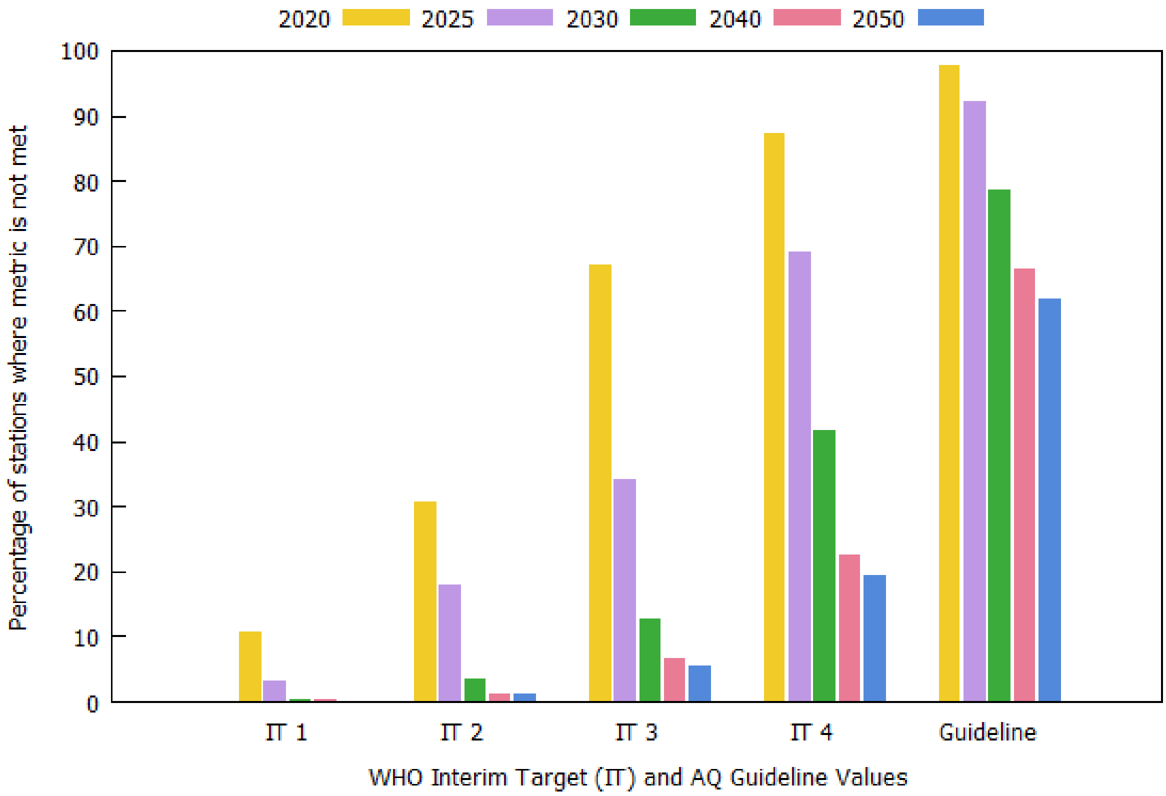

Figure 6 $PM_{2.5}$ exceedance – EU27: Proportion of stations predicted NOT to meet the WHO interim target and guideline values.

The number of stations, out of a total of 1069, where the number of $PM_{2.5}$ exceedances is predicted to be below the WHO interim target and air quality guideline values is tabulated below.

Table 10 Monitoring stations in Europe predicted to meet the WHO AQG IT and guideline values for $PM_{2.5}$ exceedance.

Year	Number of stations (of 1069) meeting WHO AQG criteria for $PM_{2.5}$ exceedance				
	Interim Target 1	Interim Target 2	Interim Target 3	Interim Target 4	AQ Guideline
	75 µg/m³ (< 4 days/year)	50 µg/m³ (< 4 days/year)	37.5 µg/m³ (< 4 days/year)	25 µg/m³ (< 4 days/year)	15 µg/m³ (< 4 days/year)
2015	885	545	259	96	19
2020	954	742	352	137	26
2025	1036	878	705	330	85
2030	1065	1032	932	623	229
2040	1067	1057	999	828	359
2050	1068	1058	1009	863	407

3.2.7. $PM_{2.5}$ Annual Mean

The current AAQD sets an annual mean concentration of 25 µg/m³ as limit value for $PM_{2.5}$. There is also a long-term objective that average concentrations should fall below 20 µg/m³. In its revised guidelines, WHO proposes gradually interim targets of 35, 25, 15, 10 µg/m³ and a guideline value of 5 µg/m³.

Figure 7 shows that, under current legislation, the annual mean concentration of $PM_{2.5}$ will be above the interim target 3 value in 2030 for only a small proportion of stations (less than 5%), while almost all stations are predicted to meet IT 3 in 2050. However, a substantial fraction of stations will observe concentrations above the interim target 4 and the air quality guideline values. For the guideline value, this is 87% of stations in 2030, decreasing to 75% in 2050.

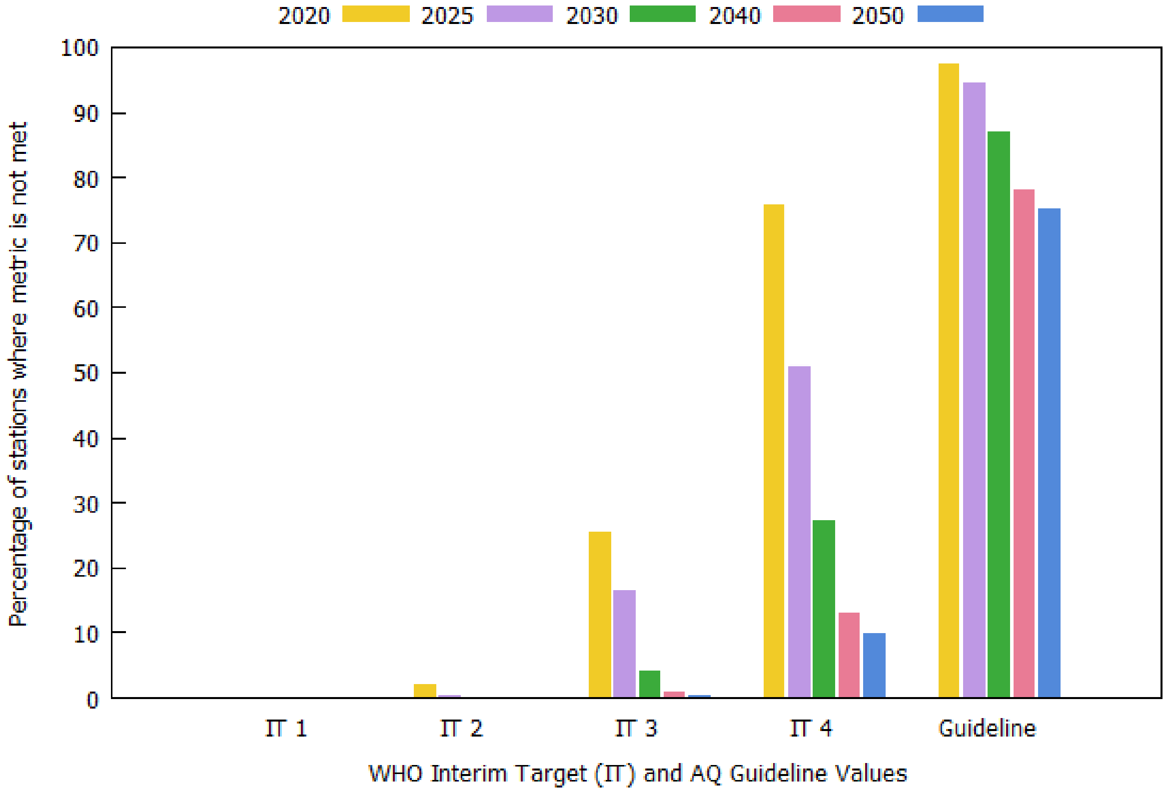

Figure 7 $PM_{2.5}$ annual mean - EU27: Proportion of stations predicted NOT to meet the WHO interim target and guideline values.

The number of stations, out of a total of 1090, where $PM_{2.5}$ annual mean concentrations are predicted to be below the WHO interim target and air quality guideline values is tabulated below.

Table 11 Monitoring stations in Europe predicted to meet the WHO AQG IT and guideline values for $PM_{2.5}$ annual mean concentration.

Year	Number of stations (of 1090) meeting WHO AQG thresholds for $PM_{2.5}$ annual mean				
	Interim Target 1	Interim Target 2	Interim Target 3	Interim Target 4	AQ Guideline
	35 µg/m^3	25 µg/m^3	15 µg/m^3	10 µg/m^3	5 µg/m^3
2015	1085	995	642	180	21
2020	1090	1068	814	264	30
2025	1090	1086	910	534	61
2030	1090	1090	1046	794	141
2040	1090	1090	1081	947	239
2050	1090	1090	1086	982	270

3.2.8. Summary

The following table summarises the outlook for the concentration metrics assuming emission progression according to current legislation and economic outlook:

Table 12 Summary outlook of the comparison between pollutants predicted concentrations in the monitoring stations and WHO IT and AQG values under the current legislation.

O_3	
O_3 Exceedance	• Exceedances for four or more days per year of the maximum daily 8-hr mean concentration above the WHO interim target 1 value of 160 µg/m^3 will remain at a few stations until 2050. • Exceedances for four or more days per year of the maximum daily 8-hr mean concentration above the WHO interim target 2 of 120 µg/m^3 will remain at a significant number of stations (more than 58%) up to and including 2050. • Exceedances for four or more days per year of the maximum daily 8-hr mean concentration above the WHO AQG value of 100 µg/m^3 will remain at the vast majority (more than 95%) of stations up to and including 2050.
NO_2	
NO_2 Exceedance	• Exceedances for four or more days per year of the daily mean value above the WHO interim target 1 value of 120 µg/m^3 are not predicted to occur at any of the stations. • Exceedances for four or more days per year of the daily mean value above the WHO interim target 2 value of 50 µg/m^3 will remain at a few stations in 2030 and beyond. • Exceedances for four or more days per year of the daily mean value above the WHO AQG value of 25 µg/m^3 will remain at many stations up to and including 2050. These amount to 29% in 2030 and 17% in 2050.
NO_2 Annual Mean	• Annual mean concentration will remain above the WHO interim target 2 value of 30 µg/m^3 at a very small number of stations in 2030 and beyond. • Annual mean concentration will remain above the WHO interim target 3 value of 20 µg/m^3 at a small number of stations beyond 2030, 8% in 2030 and 1% in 2050. • Annual mean concentration will remain above the WHO AQG of 10 µg/m^3 at a considerable number of stations up to and including 2050, 37% in 2030 and 11% in 2050.

PM_{10}	
PM_{10} Exceedance	• Exceedances for four or more days per year of the daily mean value above the WHO interim target 2 value of 100 µg/m^3 will remain at a small number of stations up to and including 2050. • Exceedances for four or more days per year of the daily mean value above the WHO interim target 3 value of 75 µg/m^3 will remain at a small number of stations up to and including 2050. • Exceedances for four or more days per year of the daily mean value above the WHO interim target 4 value of 50 µg/m^3 will remain at a significant number of stations, 26% in 2030 and 17% in 2050. • Exceedances for four or more days per year of the daily mean value above the WHO AQG value of 45 µg/m^3 will remain at a considerable number of stations, 35% in 2030 and 22% in 2050.
PM_{10} Annual Mean	• Annual mean concentration will remain above the WHO interim target 3 value of 30 µg/m^3 at a very small number of stations in 2030 and beyond. • Annual mean concentration will remain above the WHO interim target 4 value of 20 µg/m^3 at a considerable number of stations up to and including 2050, 18% in 2030 and 10% in 2050. • Annual mean concentration will remain above the WHO AQG of 15 µg/m^3 at a considerable number of stations up to and including 2050, 52% in 2030 and 35% in 2050.
$PM_{2.5}$	
$PM_{2.5}$ Exceedance	• Exceedances for four or more days per year of the daily mean value above the WHO interim target 2 value of 50 µg/m^3 will remain at a small number of stations up to and including 2050. • Exceedances for four or more days per year of the daily mean value above the WHO interim target 3 value of 37.5 µg/m^3 will remain at several stations up to and including 2050, 13% in 2030 and 6% in 2050. • Exceedances for four or more days per year of the daily mean value above the WHO interim target 4 value of 25 µg/m^3 will remain at a significant number of stations up to and including 2050, 42% in 2030 and 19% in 2050 • Exceedances for four or more days per year of the daily mean value above the WHO AQG value of 15 µg/m^3 will remain at most stations up to and including 2050, 79% in 2030 and 62% in 2050.
$PM_{2.5}$ Annual Mean	• Annual mean concentration will remain above the WHO interim target 3 value of 15 µg/m^3 at a very small number of stations beyond 2030.

	• Annual mean concentration will remain above the WHO interim target 4 value of 10 µg/m^3 at a number of stations in 2030 and beyond, 27% in 2030 and 10% in 2050. • Annual mean concentrations will remain above the WHO AQG of 5 µg/m^3 at most stations up to and including 2050, 87% in 2030 and 75% in 2050.

3.3. EMISSION REDUCTION SCENARIOS

Emission reductions beyond those planned in current legislation, and represented in the base case, would be expected to reduce pollutant concentrations generally. This should lead to lower annual mean concentrations and fewer exceedances of a daily concentration threshold. The extent to which an emission reduction is effective depends on the relationship between the emitted substance and the pollutant. This relationship is modified by weather/climatic conditions and the separation in distance between the sources of emission and the measurement location.

In the supporting studies for the Second Clean Air Outlook, two extreme emission reduction scenarios, MTFR and MTFR + 1.5 LIFE were investigated. Concawe has added 6 further scenarios to investigate which sector emissions influence air quality. These sensitivity scenarios simply reduce emissions of a given sector to zero each time.

This section compares the effect of sector emission reductions scenarios on the proportion (%) of stations where air quality does not meet the WHO air quality interim target or guideline values. The results are given for the years 2030 and 2050. Year 2030 results show the effect of sector emission reductions more clearly because air concentrations of pollutants are somewhat higher than in 2050. For convenience in the comparison, the results for the baseline scenario, as shown in the previous sections, are also presented in the graphs.

Also, for convenience the different emission reduction cases are - identical to **Table 2** repeated in the following table:

Table 2 List of emissions scenarios assessed in the study. Case (0) is the current legislation 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.

Case (0)	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 VOC 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, VOC, and NH_3 from process industry, including the use of solvents (VOC) 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 VOC 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 VOC 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 CH_4, NH_3 and CO_2 emissions reduction.

The charts should be read left to right in the usual way. The left most grouping, Case (0), represents the base case results, with no additional emission reductions beyond those legislated. The far-right columns show the maximal emission reduction scenarios MTFR (Case (7)) and MTFR + 1.5 LIFE (Case (8)). The Concawe scenarios lie in between. If the height of a bar for Cases (1)-(6) is similar to the height of the leftmost bar, then the sector reduction has no additional effect on the air quality parameter. If the height of a bar for Cases (1)-(6) reduces toward that of the Commission scenarios (Cases (7) – (8)) then the sector emissions do have an impact on air quality and the sector is likely to be subject to either MTFR controls or the structural changes assumed by 1.5 LIFE.

3.3.1. Ozone Exceedance

The results of the emission reduction scenarios for O_3 exceedance are shown in **Figure 8** for the year 2030 and in **Figure 9** for the year 2050. 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 IT and guideline values, being even higher than the effects caused by the MTFR and MTFR + 1.5 LIFE scenarios (Case (7) and Case (8) respectively). Removal of emissions from the transport sector (Case (4)) has the second highest impact among the sectors, but still the expected additional improvement is small, while reductions on the other sectors are ineffective.

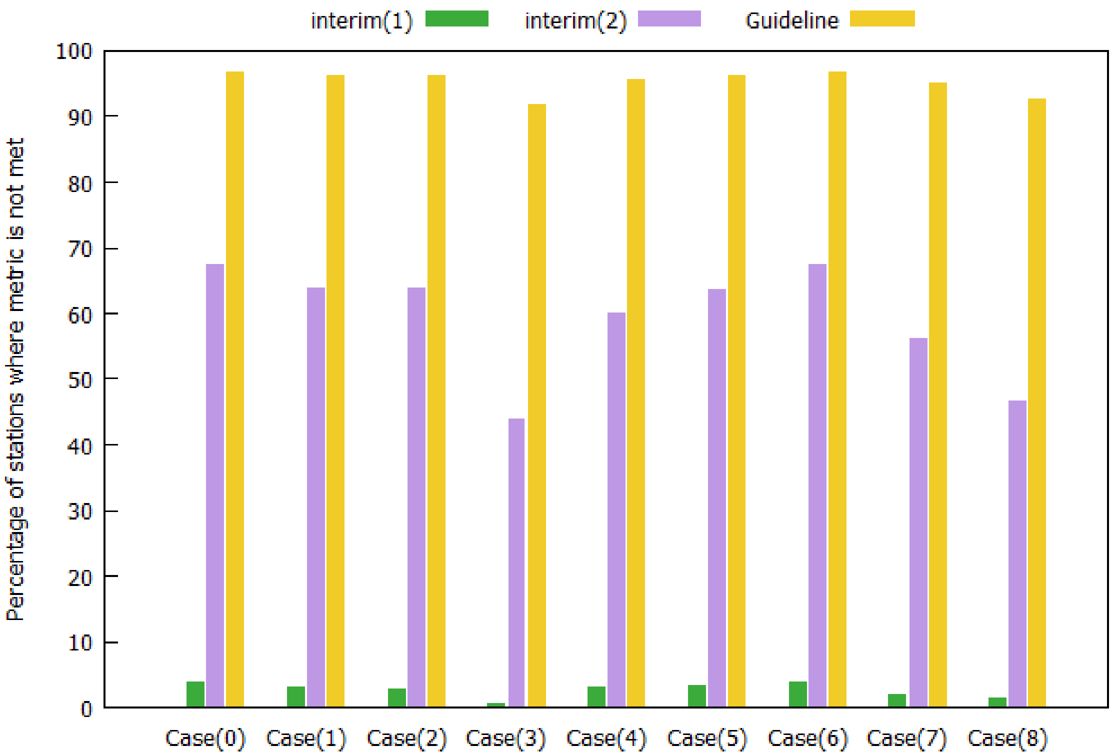

Figure 8 O_3 exceedance – EU27: Scenario comparison for the number of monitoring stations NOT meeting the WHO interim target and guideline values in 2030.

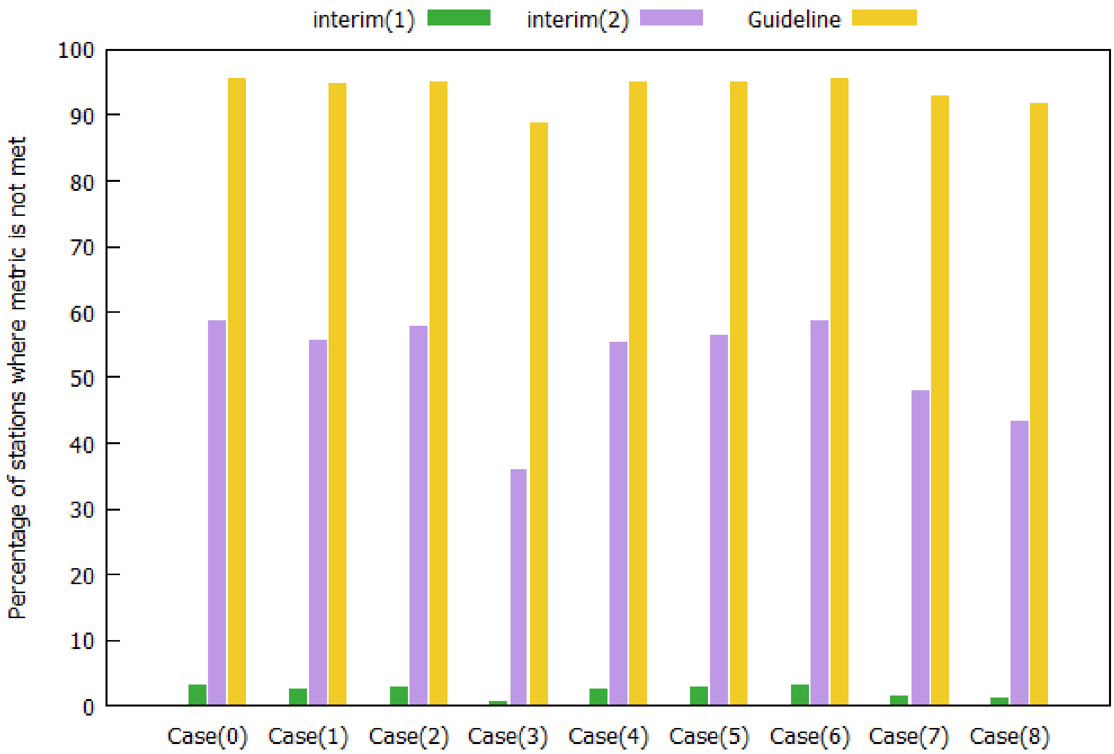

Figure 9 O_3 exceedance – EU27: Scenario comparison for the number of monitoring stations NOT meeting the WHO interim target and guideline values in 2050.

The results of the calculations showing the number of stations, out of a total of 1308, where the exceedance of the maximum daily 8-hr mean concentration of O_3 is below the WHO interim target and air quality guideline values are tabulated below.

Table 13 Monitoring stations in Europe predicted to meet the WHO AQG IT and guideline values for O_3 exceedance, under the different emission reduction scenarios in 2030.

Year: 2030	Number of stations (of 1308) meeting WHO AQG criteria for O_3 exceedance		
	Interim Target 1	Interim Target 2	AQ Guideline
Scenario	160 µg/m³ (< 4 days/year)	120 µg/m³ (< 4 days/year)	100 µg/m³ (< 4 days/year)
Baseline	1256	428	46
Case (1)	1269	474	53
Case (2)	1271	472	53
Case (3)	1300	736	110
Case (4)	1270	525	58
Case (5)	1264	476	53
Case (6)	1256	428	46
Case (7)	1283	572	66
Case (8)	1290	700	99

Table 14 Monitoring stations in Europe predicted to meet the WHO AQG IT and guideline values for O_3 exceedance, under the different emission reduction scenarios in 2050.

Year: 2050	Number of stations (of 1308) meeting WHO AQG criteria for O_3 exceedance		
	Interim Target 1	Interim Target 2	AQ Guideline
Scenario	160 µg/m³ (< 4 days/year)	120 µg/m³ (< 4 days/year)	100 µg/m³ (< 4 days/year)
Baseline	1269	540	60
Case (1)	1276	580	68
Case (2)	1272	554	65
Case (3)	1302	838	149
Case (4)	1276	584	67
Case (5)	1273	570	67
Case (6)	1269	540	60
Case (7)	1288	683	94
Case (8)	1294	741	110

3.3.2. NO_2 Exceedance

The results of the emission reduction scenarios for NO_2 exceedance are shown in **Figure 10** for the year 2030 and in **Figure 11** for the year 2050. In all scenarios, the WHO interim target 1 is entirely met by 2030, while the interim target 2 is met at almost all stations.

Looking across the chart from the baseline calculation, Case (0), a lower bar height indicates that an emission reduction has led to an increase in the number of stations meeting an WHO interim target or guideline.

Among the sectoral emissions reduction scenarios, the results predict that the removal of on-road transport emissions (Case (4)) has the largest effect, being close to the highest effects caused when considering the emission reductions under the MTFR + 1.5 LIFE scenario (Case (8)). In addition, removal of emissions from off-road transport is also predicted to lead to a considerable increase in the number of stations meeting an WHO interim target or guideline.

On the contrary, removal of emissions from the energy sector (Case (1)) and from the domestic and commercial sector (Case (2)) is predicted to have the lowest impact. The emission reduction scenarios lead to small changes to the number of stations where the exceedance frequency is above the WHO guideline value in either 2030 or 2050. It should also be noted that even in the case of the maximum technically feasible reduction (Case (7)) the additional increase of the stations meeting a WHO interim target or guideline compared to the current legislation (Case (0)) is small (e.g., 3% of additional stations meet WHO AQ guideline in 2050 compared to the current legislation).

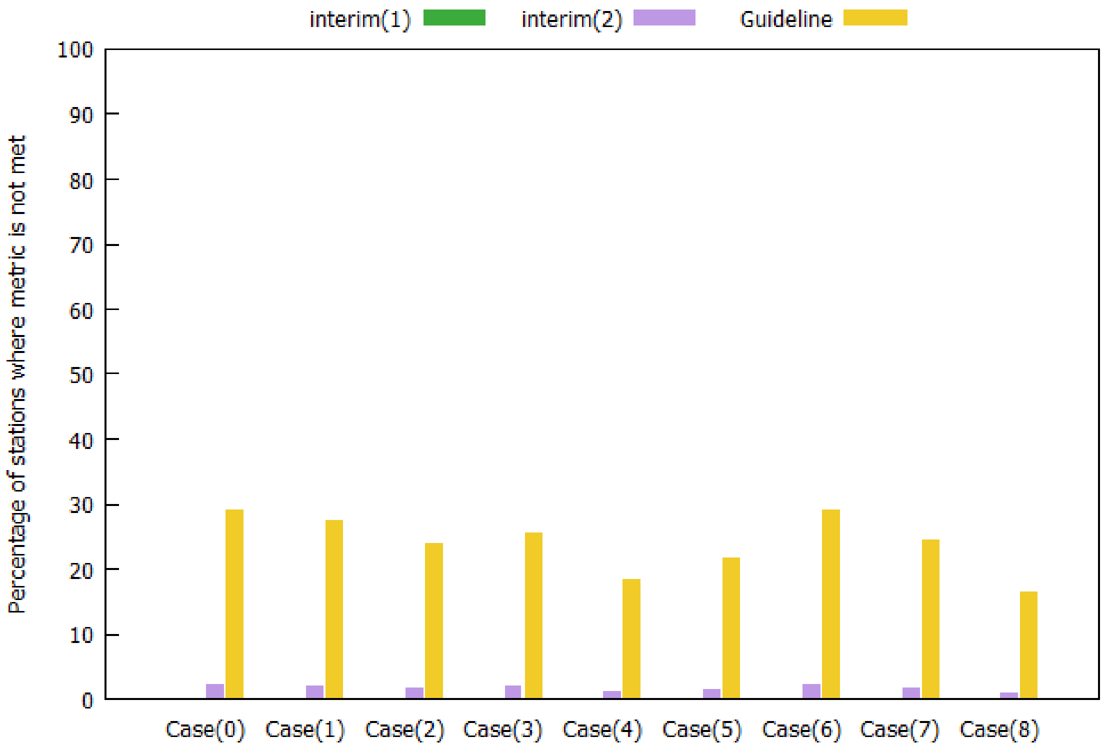

Figure 10 NO$_2$ exceedance - EU27: Scenario comparison for the number of monitoring stations NOT meeting the WHO interim target and guideline values in 2030.

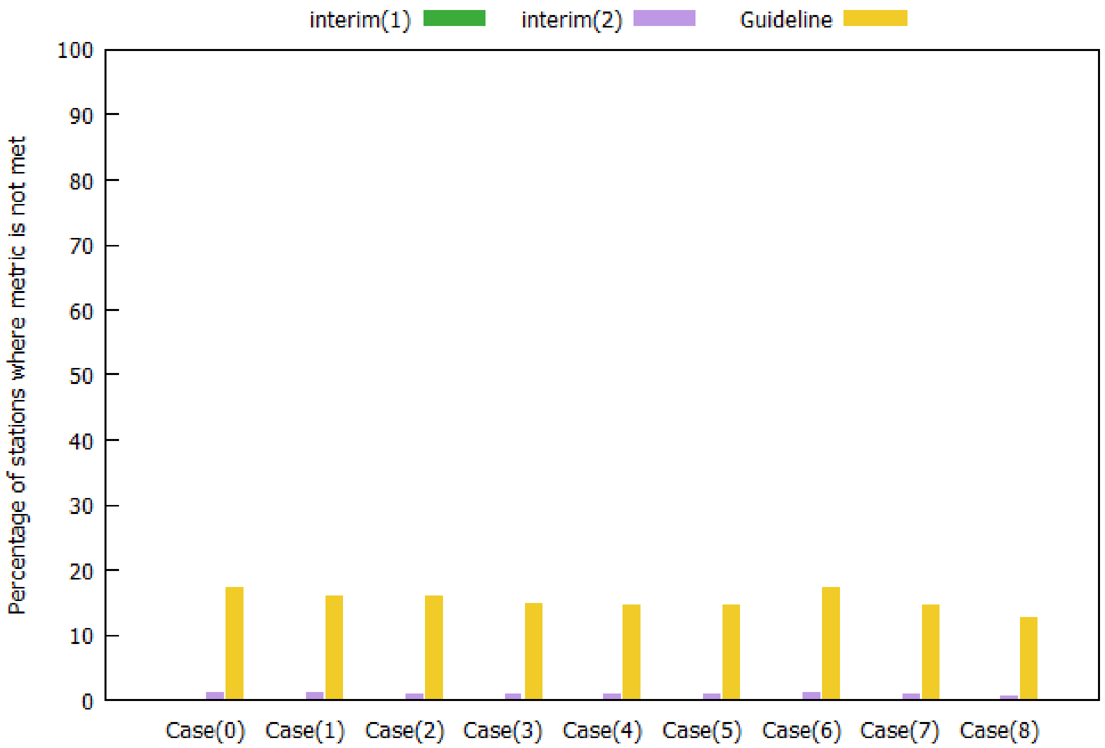

Figure 11 NO$_2$ exceedance - EU27: Scenario comparison for the number of monitoring stations NOT meeting the WHO interim target and guideline values in 2050.

The results of the calculations showing the number of stations, out of a total of 1509, where the exceedance frequency of daily average NO_2 concentration is below the WHO interim target and air quality guideline values are tabulated below.

Table 15 Monitoring stations in Europe predicted to meet the WHO AQG IT and guideline values for NO_2 exceedance, under the different emission reduction scenarios in 2030.

Year: 2030	Number of stations (of 1509) meeting WHO AQG criteria for NO_2 exceedance		
	Interim Target 1	Interim Target 2	AQ Guideline
Scenario	120 µg/m^3 (< 4 days/year)	50 µg/m^3 (< 4 days/year)	25 µg/m^3 (< 4 days/year)
Baseline	1509	1474	1070
Case (1)	1509	1478	1097
Case (2)	1509	1483	1148
Case (3)	1509	1481	1123
Case (4)	1509	1492	1232
Case (5)	1509	1486	1181
Case (6)	1509	1474	1070
Case (7)	1509	1483	1140
Case (8)	1509	1496	1262

Table 16 Monitoring stations in Europe predicted to meet the WHO AQG IT and guideline values for NO_2 exceedance, under the different emission reduction scenarios in 2050.

Year: 2050	Number of stations (of 1509) meeting WHO AQG criteria for NO_2 exceedance		
	Interim Target 1	Interim Target 2	AQ Guideline
Scenario	120 µg/m^3 (< 4 days/year)	50 µg/m^3 (< 4 days/year)	25 µg/m^3 (< 4 days/year)
Baseline	1509	1494	1249
Case (1)	1509	1494	1269
Case (2)	1509	1496	1270
Case (3)	1509	1496	1286
Case (4)	1509	1498	1290
Case (5)	1509	1497	1289
Case (6)	1509	1494	1249
Case (7)	1509	1496	1288
Case (8)	1509	1501	1319

3.3.3. NO_2 Annual Mean

The results of the emission reduction scenarios for NO_2 annual mean concentration are shown in **Figure 12** for the year 2030 and in **Figure 13** for the year 2050. Interim target 2 annual mean concentration is met by nearly all stations in 2030 and in all reduction scenarios in 2050.

Similar to the results for NO_2 exceedance, the removal of on-road (Case (4)) and off-road transport (Case (5)) emissions are predicted to have the largest effect among the sectoral emissions reduction scenarios and particularly for 2030. The predicted effect of the on-road transport emissions removal in 2030 is actually comparable to the effects associated with the MTFR + 1.5 LIFE scenario (Case (8)) which is predicted to result in the highest number of monitoring stations meeting the WHO AQ guideline. However, even in the case of removing all on-road transport emissions around 14% of the monitoring stations in Europe in 2030 are still predicted to measure concentrations above the WHO AQ guideline (approximately 7% in 2050). On the contrary, removal of emissions from the energy sector (Case (1)) is predicted to have the lowest impact.

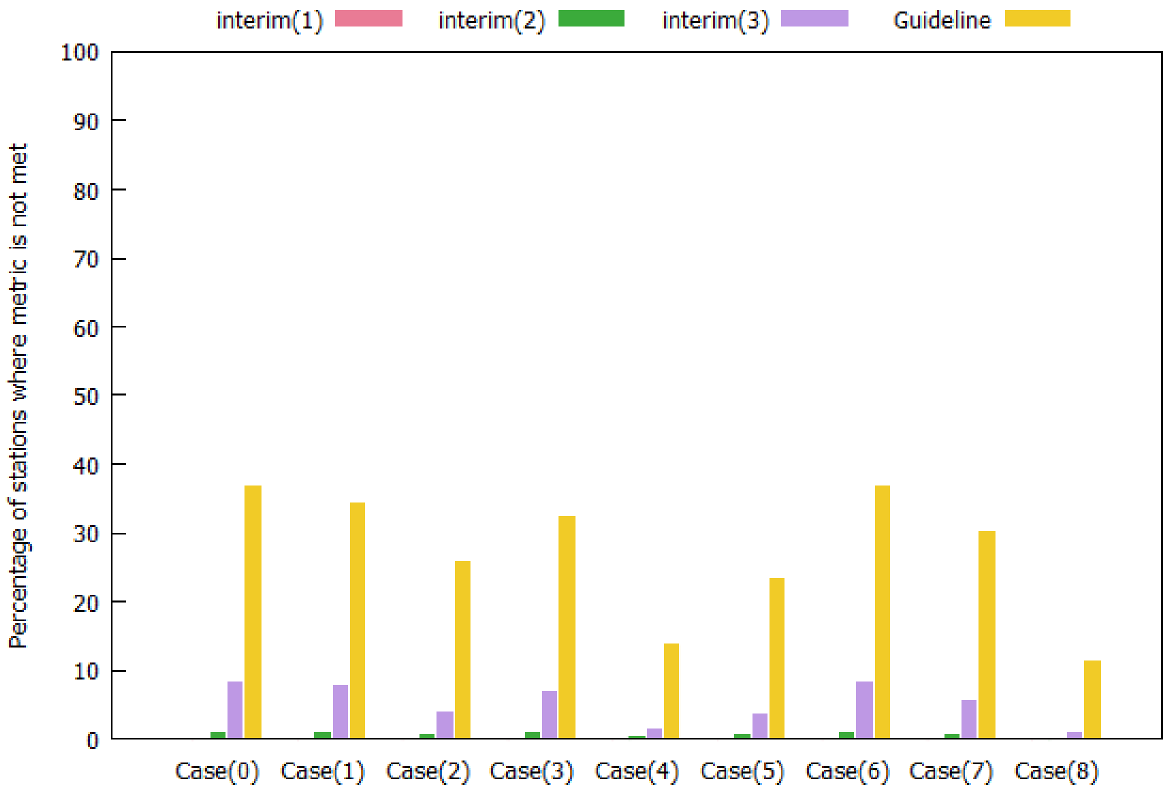

Figure 12 NO_2 annual mean – EU27: Scenario comparison for the number of monitoring stations NOT meeting the WHO interim target and guideline values in 2030.

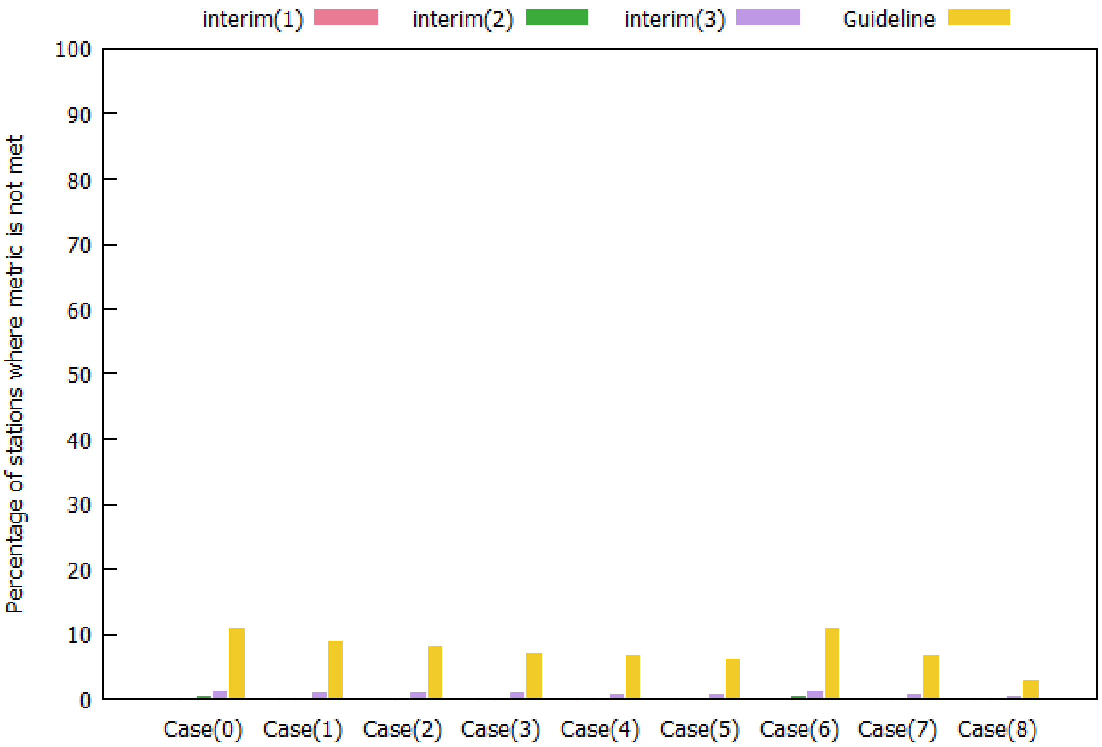

Figure 13 NO$_2$ annual mean – EU27: Scenario comparison for the number of monitoring stations NOT meeting the WHO interim target and guideline values in 2050.

The results of the calculations showing the number of stations, out of a total of 1524, where the NO$_2$ annual average concentration is below the WHO interim target and air quality guideline values are tabulated below.

Table 17 Monitoring stations in Europe predicted to meet the WHO AQG IT and guideline values for NO$_2$ annual mean concentration, under the different emission reduction scenarios in 2030.

Year: 2030	Number of stations (of 1524) meeting WHO AQG thresholds for NO$_2$ annual mean			
	Interim Target 1	Interim Target 2	Interim Target 3	AQ Guideline
Scenario	40 µg/m^3	30 µg/m^3	20 µg/m^3	10 µg/m^3
Baseline	1523	1509	1399	965
Case (1)	1523	1512	1407	1002
Case (2)	1523	1517	1466	1130
Case (3)	1523	1512	1420	1030
Case (4)	1523	1521	1503	1316
Case (5)	1523	1517	1471	1171
Case (6)	1523	1509	1399	965
Case (7)	1523	1514	1440	1064
Case (8)	1523	1523	1509	1352

Table 18 Monitoring stations in Europe predicted to meet the WHO AQG IT and guideline values for NO_2 annual mean concentration, under the different emission reduction scenarios in 2050.

Year: 2050	Number of stations (of 1524) meeting WHO AQG thresholds for NO_2 annual mean			
	Interim Target 1	Interim Target 2	Interim Target 3	AQ Guideline
Scenario	40 µg/m^3	30 µg/m^3	20 µg/m^3	10 µg/m^3
Baseline	1523	1521	1508	1361
Case (1)	1523	1522	1510	1390
Case (2)	1523	1523	1513	1403
Case (3)	1523	1523	1513	1420
Case (4)	1523	1523	1515	1424
Case (5)	1523	1522	1514	1430
Case (6)	1523	1521	1508	1361
Case (7)	1523	1523	1516	1425
Case (8)	1523	1523	1521	1481

3.3.4. PM_{10} Exceedance

The results of the emission reduction scenarios for PM_{10} exceedance are shown in **Figure 14** for the year 2030 and in **Figure 15** for the year 2050. In all scenarios, the WHO interim target 1 is entirely met by 2030, while the interim target 2 is met at almost all stations.

The removal of NH_3 emissions from agriculture (Case (6)) is predicted to have the largest effect among the sectoral emissions reduction scenarios assessed. In particular, it is predicted that by 2050, the increase of stations meeting the WHO guideline value as result of the NH_3 agriculture emissions removal is comparable to the effects associated with the MTFR + 1.5 LIFE scenario (Case (8)) which corresponds to maximum technically feasible reduction of all pollutants accompanied by a structural change to agriculture and energy use. Removal of domestic and commercial emissions (Case (2)) is also predicted to have considerable effects for the year 2030.

However, it should be noted that none of the scenarios is effective enough to lead to all monitoring stations meeting the WHO interim target 4 and guideline value. By 2050 for example, between 14% (Case (6)) and 22% (Case (1)) of the monitoring stations in Europe, depending on the scenario considered, is predicted to still measure higher exceedances than the WHO guideline value.

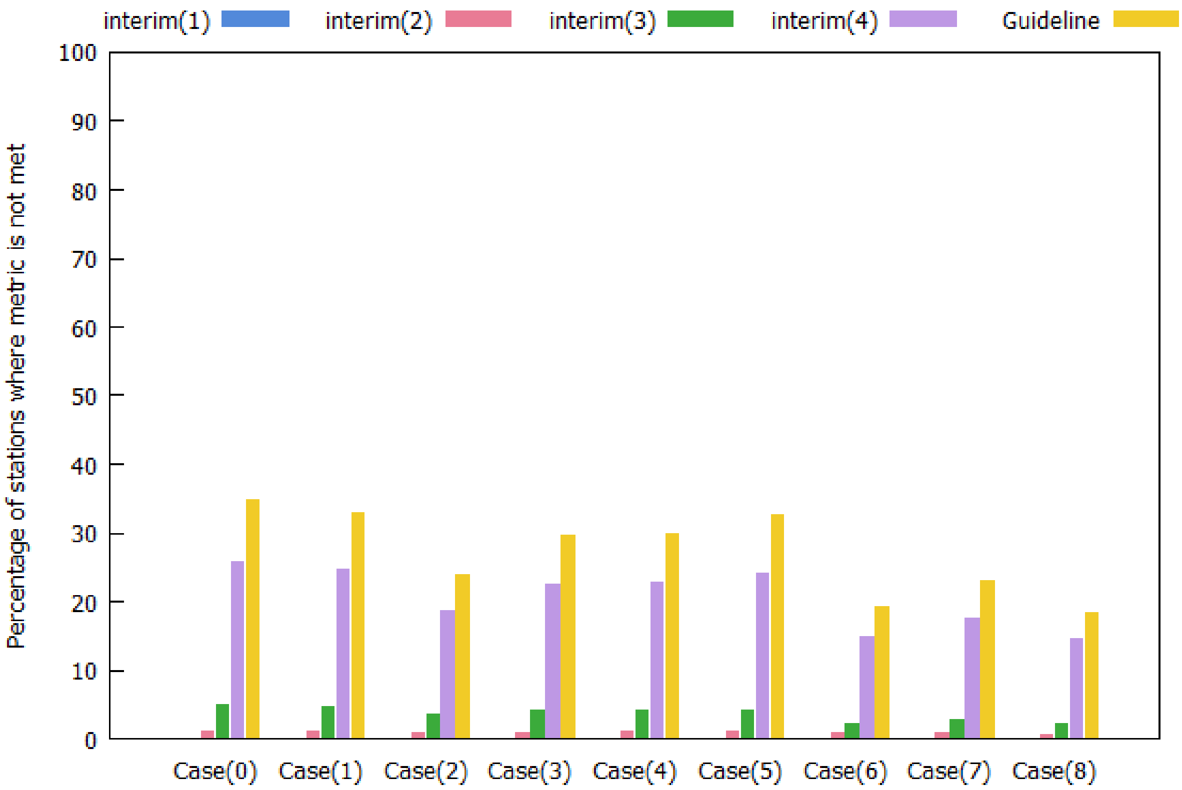

Figure 14 PM$_{10}$ exceedance – EU27: Scenario comparison for the number of monitoring stations NOT meeting the WHO interim target and guideline values in 2030.

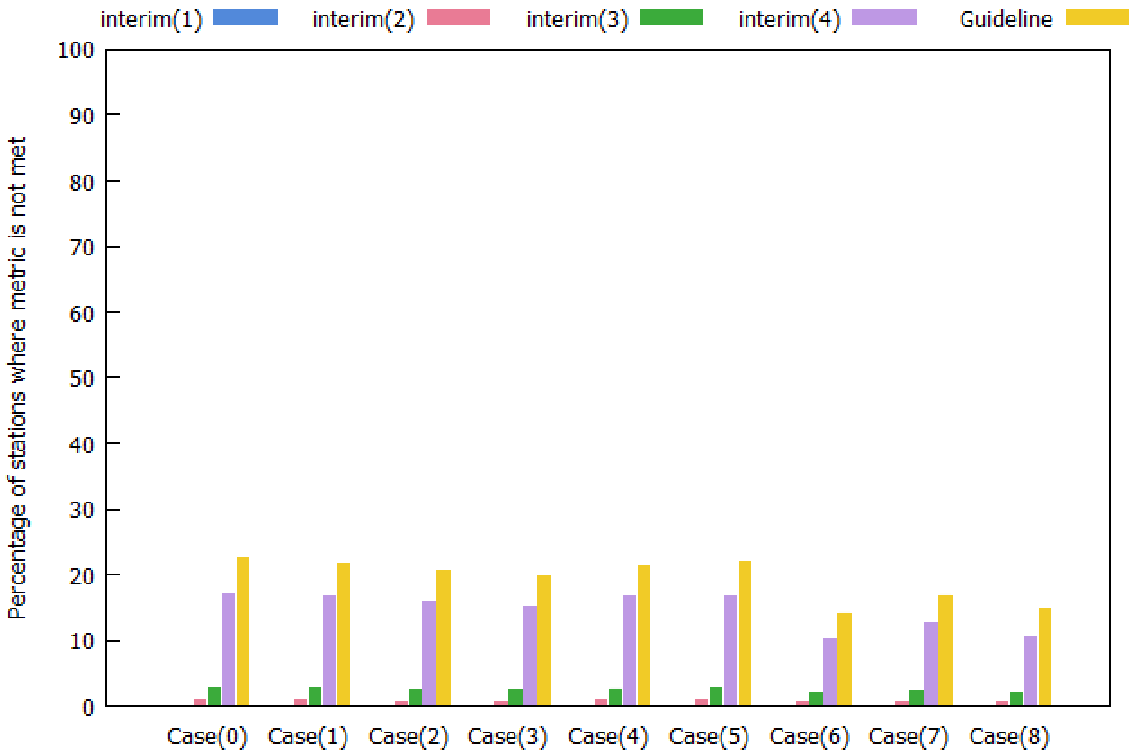

Figure 15 PM_{10} exceedance – EU27: Scenario comparison for the number of monitoring stations NOT meeting the WHO interim target and guideline values in 2050.

The results of the calculations showing the number of stations, out of a total of 801, where the exceedance frequency of daily average PM_{10} concentration is below the WHO interim target and air quality guideline values are tabulated below.

Table 19 Monitoring stations in Europe predicted to meet the WHO AQG IT and guideline values for PM_{10} exceedance, under the different emission reduction scenarios in 2030.

Year: 2030	Number of stations (of 801) meeting WHO AQG criteria for PM_{10} exceedance				
	Interim Target 1	Interim Target 2	Interim Target 3	Interim Target 4	AQ Guideline
Scenario	150 µg/m^3 (< 4 days/year)	100 µg/m^3 (< 4 days/year)	75 µg/m^3 (< 4 days/year)	50 µg/m^3 (< 4 days/year)	45 µg/m^3 (< 4 days/year)
Baseline	801	791	762	595	522
Case (1)	801	792	764	603	537
Case (2)	801	794	773	652	611
Case (3)	801	794	769	622	565
Case (4)	801	793	769	619	563
Case (5)	801	792	767	607	541
Case (6)	801	795	783	682	647
Case (7)	801	794	779	661	617
Case (8)	801	796	783	684	654

Table 20 Monitoring stations in Europe predicted to meet the WHO AQG IT and guideline values for PM_{10} exceedance, under the different emission reduction scenarios in 2050.

Year: 2050	Number of stations (of 801) meeting WHO AQG criteria for PM_{10} exceedance				
	Interim Target 1	Interim Target 2	Interim Target 3	Interim Target 4	AQ Guideline
Scenario	150 μg/m^3 (< 4 days/year)	100 μg/m^3 (< 4 days/year)	75 μg/m^3 (< 4 days/year)	50 μg/m^3 (< 4 days/year)	45 μg/m^3 (< 4 days/year)
Baseline	801	794	779	665	622
Case (1)	801	794	779	667	627
Case (2)	801	796	782	674	637
Case (3)	801	796	782	680	642
Case (4)	801	794	780	668	629
Case (5)	801	794	779	667	626
Case (6)	801	797	786	719	688
Case (7)	801	797	784	700	666
Case (8)	801	797	786	718	683

3.3.5. PM_{10} Annual Mean

The results of the emission reduction scenarios for PM_{10} annual mean concentration are shown in **Figure 16** for the year 2030 and in **Figure 17** for the year 2050. In all scenarios, the WHO interim target 1 and interim target 2 are entirely met by 2030, while the interim target 3 is met at almost all stations.

Similar to the results of the PM_{10} exceedance, it is predicted that the removal of NH_3 emissions from agriculture (Case (6)) is predicted to have the largest effect among the sectoral emissions reduction scenarios assessed, being comparable to the effects associated with the MTFR (Case (7)) and MTFR + 1.5 LIFE scenarios (Case (8)). The removal of domestic and commercial emissions (Case (2)) is predicted to have the second highest effect among the sectoral emissions reduction scenarios for the year 2030.

However, when comparing with the WHO interim target 4 and with the guideline value, the results indicate that none of the scenarios is effective enough for all monitoring stations to meet the values. In particular, by 2050 and depending on the scenario considered, 20% to 34% of the stations in Europe are predicted to record PM_{10} annual mean concentrations above the WHO guideline value.

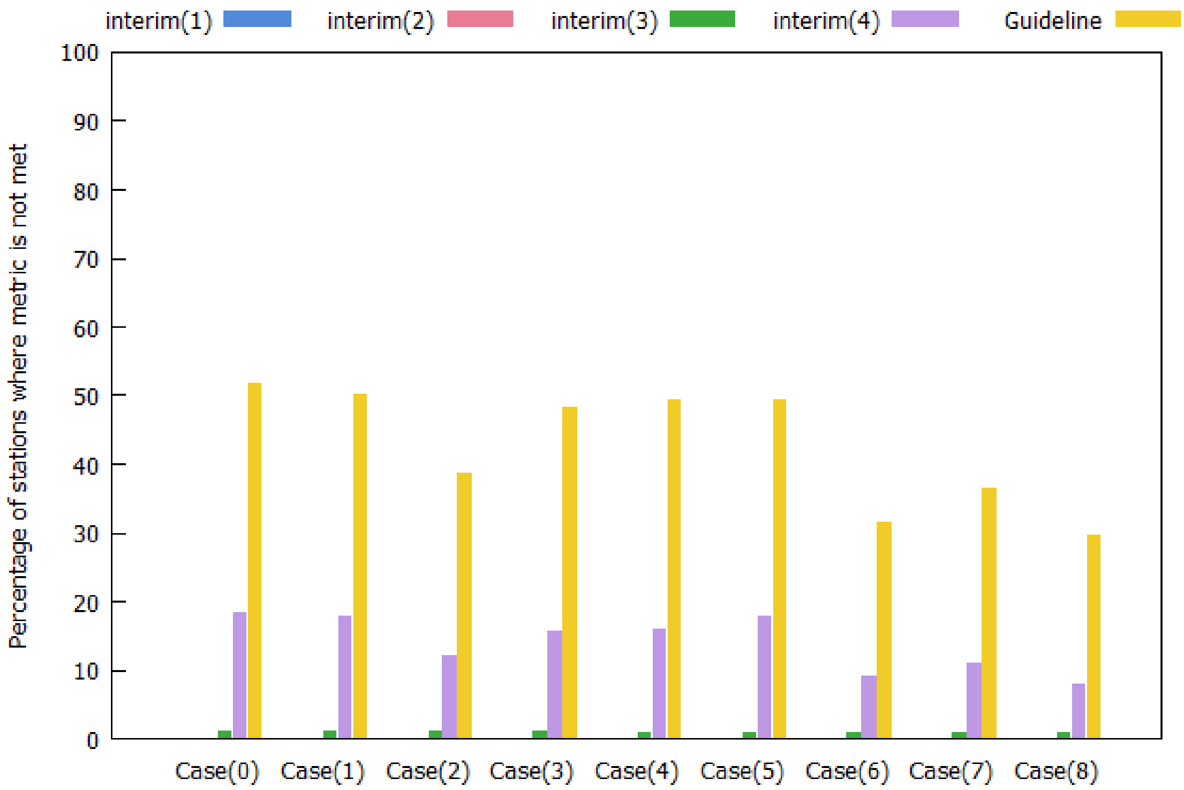

Figure 16 PM$_{10}$ annual mean – EU27: Scenario comparison for the number of monitoring stations NOT meeting the WHO interim target and guideline values in 2030.

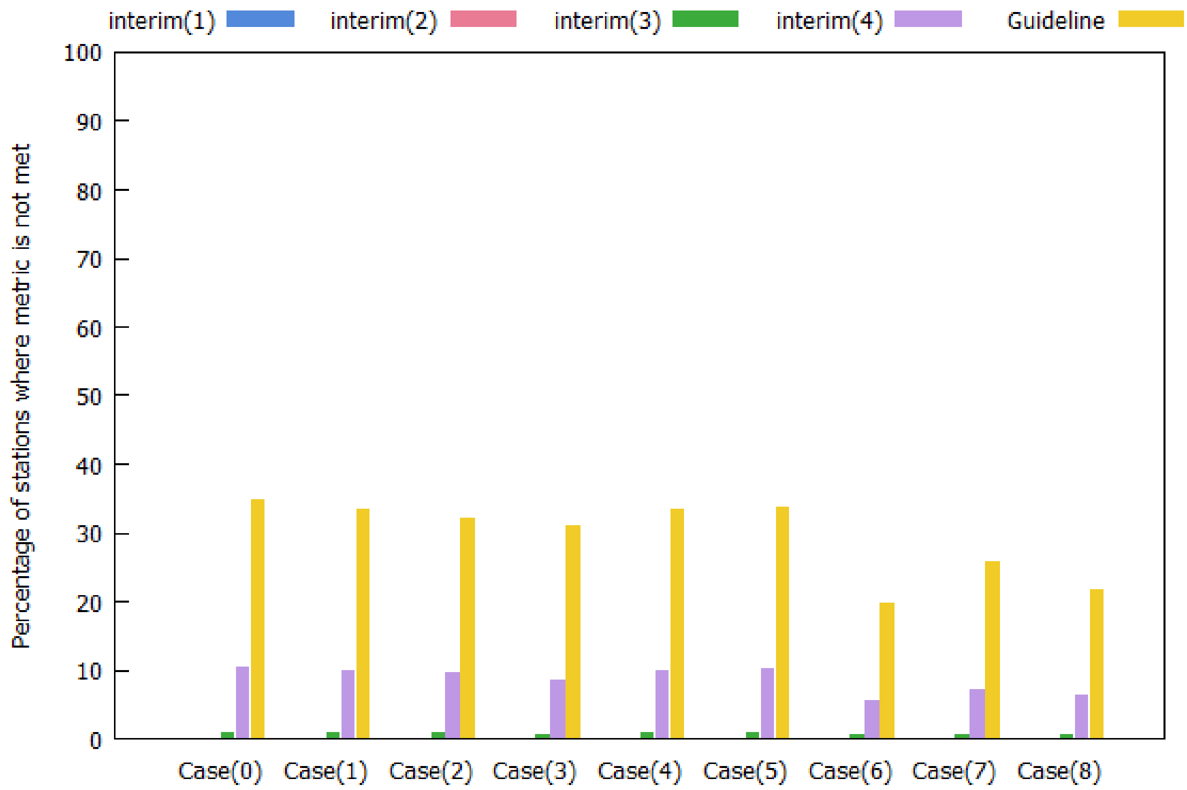

Figure 17 PM_{10} annual mean - EU27: Scenario comparison for the number of monitoring stations NOT meeting the WHO interim target and guideline values in 2050.

The results of the calculations showing the number of stations, out of a total of 837, where the PM_{10} annual mean concentration is below the WHO interim target and air quality guideline values are tabulated below.

Table 21 Monitoring stations in Europe predicted to meet the WHO AQG IT and guideline values for PM_{10} annual mean concentration, under the different emission reduction scenarios in 2030.

Year: 2030	Number of stations (of 837) meeting WHO AQG thresholds for PM_{10} annual mean				
	Interim Target 1	Interim Target 2	Interim Target 3	Interim Target 4	AQ Guideline
Scenario	70 µg/m^3	50 µg/m^3	30 µg/m^3	20 µg/m^3	15 µg/m^3
Baseline	837	837	827	683	404
Case (1)	837	837	827	689	419
Case (2)	837	837	828	735	513
Case (3)	837	837	828	706	434
Case (4)	837	837	830	705	424
Case (5)	837	837	829	688	424
Case (6)	837	837	830	762	573
Case (7)	837	837	829	745	532
Case (8)	837	837	831	771	589

Table 22 Monitoring stations in Europe predicted to meet the WHO AQG IT and guideline values for PM_{10} annual mean concentration, under the different emission reduction scenarios in 2050.

Year: 2050	Number of stations (of 837) meeting WHO AQG thresholds for PM_{10} annual mean				
	Interim Target 1	Interim Target 2	Interim Target 3	Interim Target 4	AQ Guideline
Scenario	70 µg/m³	50 µg/m³	30 µg/m³	20 µg/m³	15 µg/m³
Baseline	837	837	831	750	545
Case (1)	837	837	831	754	557
Case (2)	837	837	831	757	570
Case (3)	837	837	832	766	578
Case (4)	837	837	831	755	558
Case (5)	837	837	831	751	554
Case (6)	837	837	832	791	671
Case (7)	837	837	832	777	621
Case (8)	837	837	832	785	657

3.3.6. $PM_{2.5}$ Exceedance

The results of the emission reduction scenarios for $PM_{2.5}$ exceedance are shown in **Figure 18** for the year 2030 and in **Figure 19** for the year 2050. As $PM_{2.5}$ is a subset of PM_{10}, the results are consistent with the findings for PM_{10}. In particular, in all scenarios, the WHO interim target 1 is predicted to be almost entirely met by 2030, while the interim target 2 is met at more than 96% of all monitoring stations.

The removal of NH_3 emissions from agriculture (Case (6)) is still predicted to have the largest effect among the sectoral emissions reduction scenarios assessed. In particular, it is predicted that by 2050, the predicted increase of the stations meeting the WHO AQ guideline value as a result of the NH_3 agriculture emissions removal is comparable to the effects associated with the MTFR + 1.5 LIFE scenario (Case (8)) which corresponds to maximum technically feasible reduction of all pollutants accompanied by a structural change to agriculture and energy use. Removal of domestic and commercial emissions (Case (2)) is also predicted to have considerable effects in 2030, while by 2050, it is the removal of industry combustion/process and solvent/product use emissions (Case (3)) that are predicted to have the second largest effect among the sector emission reduction scenarios, mainly due to significant reduction of VOC emissions. Interestingly, the removal of the energy sector emissions is predicted to have the lowest effect among the scenarios considered.

Similarly to PM_{10} results, and despite the significant decreases of emissions in all scenarios, a considerable portion of monitoring stations across Europe will still not be able to meet all WHO interim targets and air quality guideline values. For example, by 2050, around 29% to 60% of the stations in Europe, depending on the scenario considered, will not be able to meet the WHO air quality guideline value.

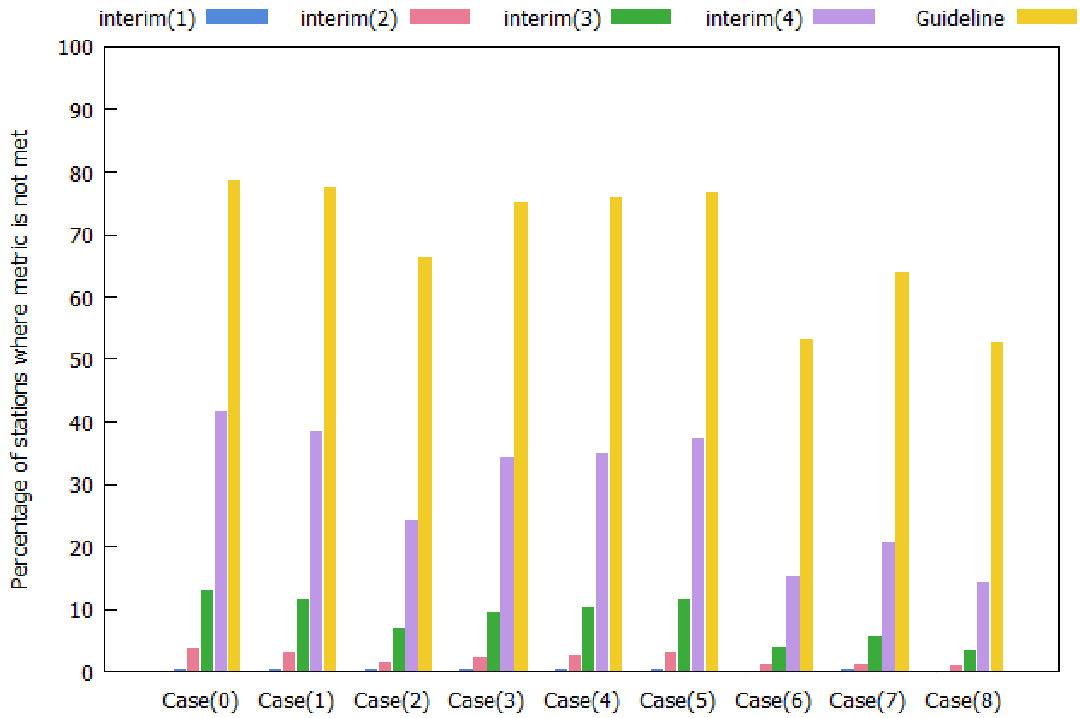

Figure 18 PM$_{2.5}$ exceedance - EU27: Scenario comparison for the number of monitoring stations NOT meeting the WHO interim target and guideline values in 2030.

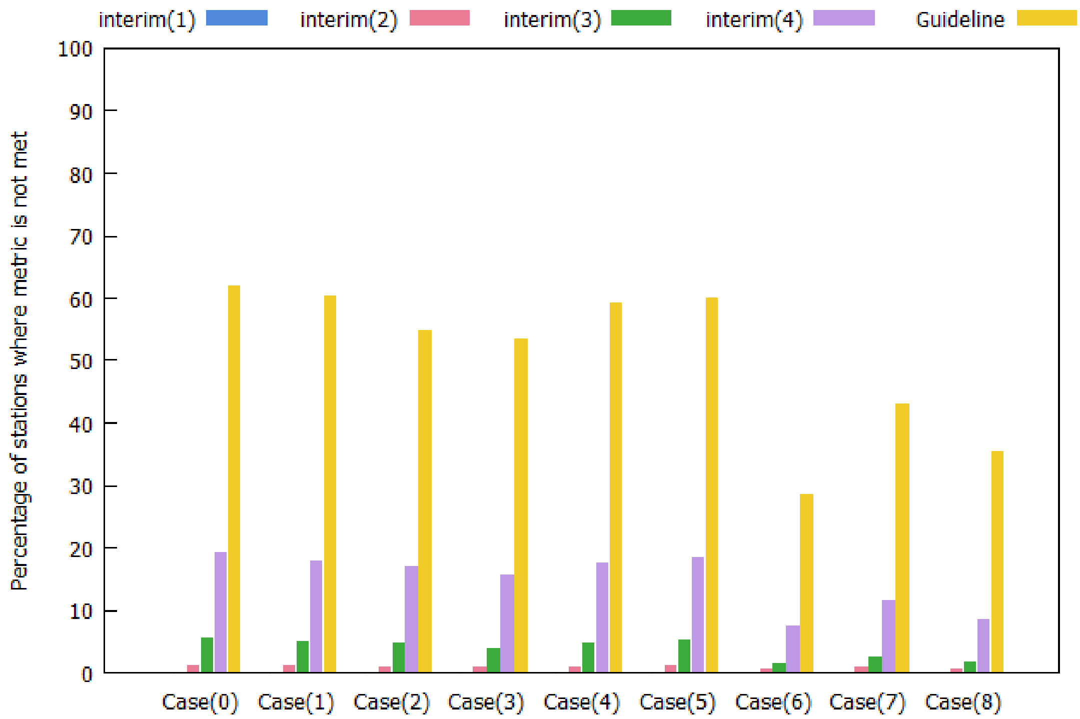

Figure 19 PM$_{2.5}$ exceedance - EU27: Scenario comparison for the number of monitoring stations NOT meeting the WHO interim target and guideline values in 2050.

The results of the calculations showing the number of stations, out of a total of 1069, where the exceedance frequency of daily average $PM_{2.5}$ concentrations below the WHO interim target and air quality guideline values is less than four times a year, are tabulated below.

Table 23 Monitoring stations in Europe predicted to meet the WHO AQG IT and guideline values for $PM_{2.5}$ exceedance, under the different emission reduction scenarios in 2030.

Year: 2030	Number of stations (of 1069) meeting WHO AQG criteria for $PM_{2.5}$ exceedance				
	Interim Target 1	Interim Target 2	Interim Target 3	Interim Target 4	AQ Guideline
Scenario	75 µg/m³ (< 4 days/year)	50 µg/m³ (< 4 days/year)	37.5 µg/m³ (< 4 days/year)	25 µg/m³ (< 4 days/year)	15 µg/m³ (< 4 days/year)
Baseline	1065	1032	932	623	229
Case (1)	1065	1035	945	658	240
Case (2)	1066	1054	996	812	360
Case (3)	1065	1045	969	704	268
Case (4)	1066	1043	961	697	260
Case (5)	1066	1038	945	670	251
Case (6)	1068	1058	1028	909	501
Case (7)	1067	1057	1010	848	388
Case (8)	1068	1060	1034	916	508

Table 24 Monitoring stations in Europe predicted to meet the WHO AQG IT and guideline values for $PM_{2.5}$ exceedance, under the different emission reduction scenarios in 2050.

Year: 2050	Number of stations (of 1069) meeting WHO AQG criteria for $PM_{2.5}$ exceedance				
	Interim Target 1	Interim Target 2	Interim Target 3	Interim Target 4	AQ Guideline
Scenario	75 µg/m³ (< 4 days/year)	50 µg/m³ (< 4 days/year)	37.5 µg/m³ (< 4 days/year)	25 µg/m³ (< 4 days/year)	15 µg/m³ (< 4 days/year)
Baseline	1068	1058	1009	863	407
Case (1)	1068	1058	1015	879	425
Case (2)	1068	1059	1020	888	483
Case (3)	1068	1059	1028	903	499
Case (4)	1068	1059	1019	882	437
Case (5)	1068	1058	1012	873	428
Case (6)	1069	1064	1054	991	764
Case (7)	1069	1061	1041	945	611
Case (8)	1069	1063	1052	977	692

3.3.7. $PM_{2.5}$ Annual Mean

The results of the emission reduction scenarios for $PM_{2.5}$ annual mean concentration are shown in **Figure 20** for the year 2030 and in **Figure 21** for the year 2050. In all scenarios considered, the WHO interim target 1 and interim target 2 are entirely met by 2030, while the interim target 3 is met at almost all stations by 2050.

However, meeting the WHO interim target 4, and the AQ guideline value in particular, is predicted to be challenging.

The removal of NH_3 emissions from agriculture (Case (6)) is still predicted to have the highest effect among the sectoral emissions reduction scenarios assessed. In particular, it is predicted that by 2050, the increase of the stations meeting the WHO AQ guideline value will reach its highest when NH_3 agriculture emissions are removed. However, even under this scenario a considerable portion of stations is predicted to still record concentrations of $PM_{2.5}$ above the WHO AQ guideline value (24%).

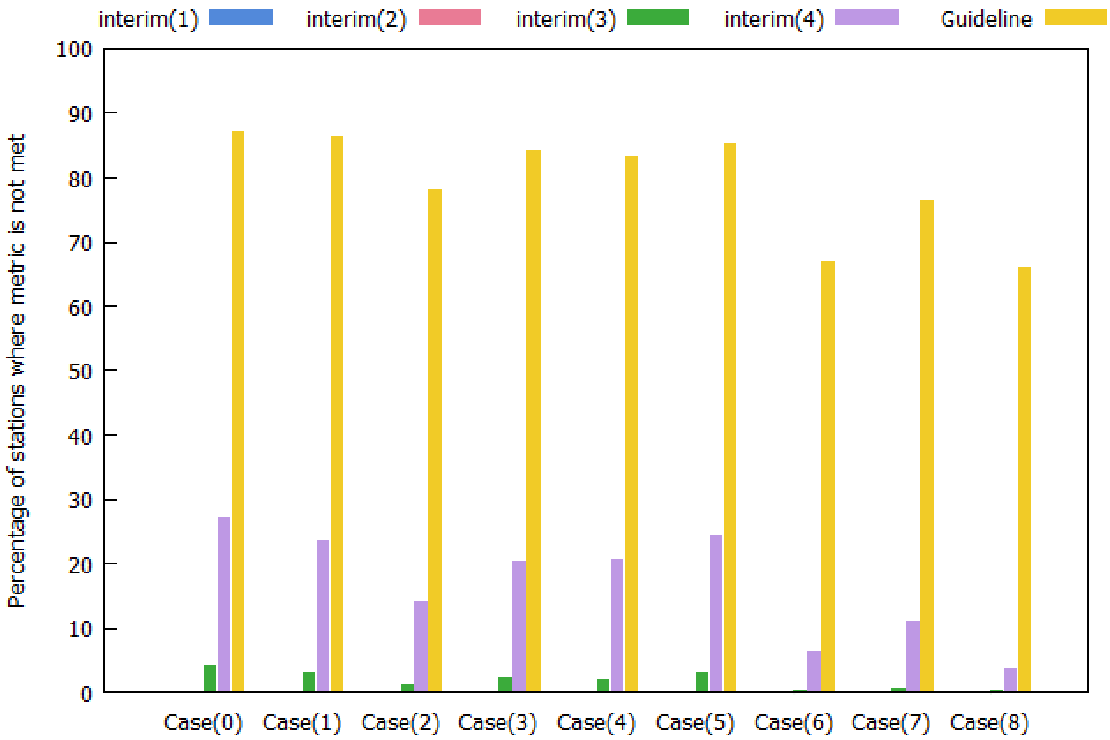

Figure 20 $PM_{2.5}$ annual mean - EU27: Scenario comparison for the number of monitoring stations NOT meeting the WHO interim target and guideline values in 2030.

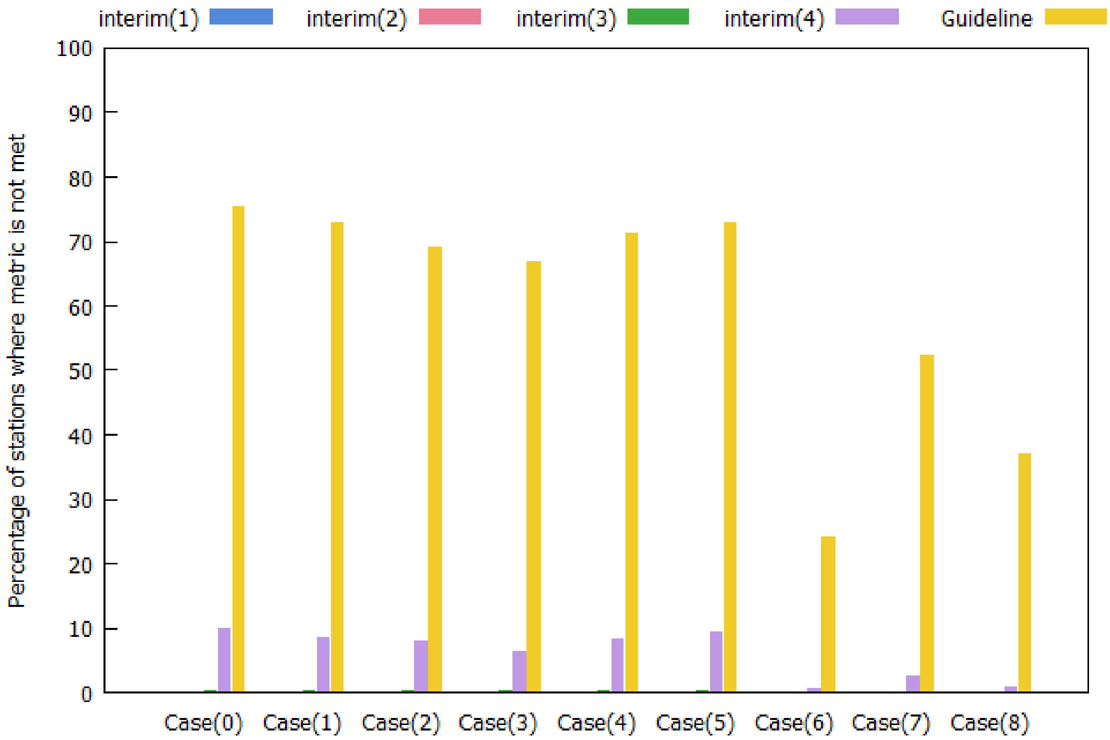

Figure 21 $PM_{2.5}$ annual mean - EU27: Scenario comparison for the number of monitoring stations NOT meeting the WHO interim target and guideline values in 2050.

The results of the calculations showing the number of stations, out of a total of 1090, where the $PM_{2.5}$ annual mean concentration is below the WHO interim target and air quality guideline values are tabulated below.

Table 25 Monitoring stations in Europe predicted to meet the WHO AQG IT and guideline values for $PM_{2.5}$ annual mean concentration, under the different emission reduction scenarios in 2030.

Year: 2030	Number of stations (of 1090) meeting WHO AQG thresholds for $PM_{2.5}$ annual mean				
	Interim Target 1	Interim Target 2	Interim Target 3	Interim Target 4	AQ Guideline
Scenario	35 µg/m^3	25 µg/m^3	15 µg/m^3	10 µg/m^3	5 µg/m^3
Baseline	1090	1090	1046	794	141
Case (1)	1090	1090	1056	832	149
Case (2)	1090	1090	1078	939	241
Case (3)	1090	1090	1067	870	175
Case (4)	1090	1090	1070	867	183
Case (5)	1090	1090	1057	825	162
Case (6)	1090	1090	1088	1022	362
Case (7)	1090	1090	1085	969	258
Case (8)	1090	1090	1088	1050	372

Table 26 Monitoring stations in Europe predicted to meet the WHO AQG IT and guideline values for $PM_{2.5}$ annual mean concentration, under the different emission reduction scenarios in 2050.

Year: 2050	Number of stations (of 1090) meeting WHO AQG thresholds for $PM_{2.5}$ annual mean				
	Interim Target 1	Interim Target 2	Interim Target 3	Interim Target 4	AQ Guideline
Scenario	35 µg/m^3	25 µg/m^3	15 µg/m^3	10 µg/m^3	5 µg/m^3
Baseline	1090	1090	1086	982	270
Case (1)	1090	1090	1086	998	295
Case (2)	1090	1090	1086	1004	338
Case (3)	1090	1090	1086	1020	361
Case (4)	1090	1090	1087	1001	314
Case (5)	1090	1090	1086	989	297
Case (6)	1090	1090	1089	1084	828
Case (7)	1090	1090	1089	1063	520
Case (8)	1090	1090	1090	1082	686

4. COUNTRY SPECIFIC CASES

Individual countries have different exposures to background pollutant concentrations according to their location and climate. Domestic energy use, particularly fuel type, influences primary particulate emissions. The intensity of agriculture influences emissions of ammonia which in term impacts on secondary particulate formation (mainly $PM_{2.5}$).

As examples of how countries differ from the overall European picture, specific results were analysed for France, Poland, Italy and Spain. Because the amount of information is large, the main results are summarised in tables below. This summary data comprises the proportion by number of air quality stations not meeting the WHO air quality guideline value in 2030 and in 2050. This is done for the current legislation scenario (Case (0)) and the two control scenarios, Maximum technically feasible reductions (Case (7)) and the MTFR + 1.5 LIFE scenario (Case (8)). The latter assumes modifications in energy demand and agriculture aimed at reducing greenhouse gas emissions.

The full results for each country are presented graphically in following sections. These show the time trend for the base case scenario for the proportion of stations where the WHO air quality interim target and guideline values are not met. The effect of the emission reduction sensitivity scenarios, (Cases (1) – (6)) of Concawe in 2030 and in 2050 are also shown alongside the base line scenario (Case (0)) and the two control scenarios (Cases (7) and (8)) of the Second Clean Air Outlook.

As previously, the abbreviations used are:

- Exceedance: This short-term exposure metric requires that the daily mean concentration, or daily mean of maximum ozone concentration hours, exceeds a threshold value on fewer than four days per year.
- Annual Mean: This long-term exposure metric requires that the annual mean concentration is less than a threshold concentration.

4.1. CURRENT LEGISLATION (CLE)

Table 27 summarises the proportion of monitoring stations NOT meeting the WHO AQ guideline value for each of the pollution metrics for the years 2030 and 2050 under the current legislation (Case (0) in this study).

In comparison to the combined results of the EU-27:

- France differs mainly in the PM_{10} metrics with proportionately more stations meeting the guideline value for daily exceedance and annual mean concentration in both 2030 and 2050.
- Poland shows proportionately more stations meeting the guideline value for NO_2 but significantly fewer for PM_{10} and $PM_{2.5}$. The $PM_{2.5}$ annual mean guideline is exceeded at all monitoring stations in 2030 and 2050.
- Italy shows that for NO_2 metrics there are proportionately more stations not meeting the guideline value. The gap is larger for daily exceedance in both 2030 and 2050 and for annual mean in 2050. Italy also has proportionately more stations not meeting both the PM_{10} metrics and $PM_{2.5}$ annual mean in 2030 and 2050.

- Spain differs mainly in the particulate matter metrics where, for both PM_{10} and $PM_{2.5}$ the proportion of stations not meeting the WHO guidelines for these metrics is less than for the EU-27 overall in both 2030 and 2050.

For ozone exceedance, the vast majority of monitoring stations in the four countries do not meet the guideline value in both 2030 and 2050.

Table 27 Country comparison with the EU-27 of the proportion (%) of monitoring stations NOT meeting the proposed WHO Air Quality Guideline values in 2030, respectively in 2050. Current Legislation Scenario (Case (0)) for the Second Clean Air Outlook.

		O_3 exceedance (%)	NO_2 exceedance (%)	NO_2 annual mean (%)	PM_{10} exceedance (%)	PM_{10} annual mean (%)	$PM_{2.5}$ exceedance (%)	$PM_{2.5}$ annual mean (%)
2030	FR	99.2	24.4	28.6	8.7	25.0	70.7	84.9
	PL	96.6	14.3	26.6	57.5	84.0	97.9	100
	IT	96.9	50.4	45.5	53.5	71.1	78.0	97.0
	ES	95.7	29.7	32.6	13.5	19.0	22.9	48.2
	EU-27	96.5	29.1	36.7	34.8	51.7	78.6	87.1
2050	FR	97.7	15.2	6.4	6.7	16.7	42.9	57.5
	PL	94.3	9.5	10.1	36.3	59.3	94.8	100
	IT	96.9	37.6	31.5	39.5	53.5	57.3	81.5
	ES	94.1	13.4	9.9	9.6	17.2	14.5	31.3
	EU-27	95.4	17.2	10.7	22.3	34.9	61.9	75.2

Note: In this table, the following abbreviations are used: FR = France, PL = Poland, IT = Italy, ES = Spain, EU-27 = 27 European Member States

4.2. MAXIMUM TECHNICALLY FEASIBLE REDUCTIONS (MTFR)

Table 28 shows the corresponding results for the MTFR scenario of the Second Clean Air Outlook (Case (7) in this study). The application of maximum emission controls reduces overall the proportion of monitoring stations not meeting the WHO guideline values.

The country-specific results indicate that for all pollutants and metrics, none of the countries will be able to ensure full compliance with the WHO air quality guidelines by 2050, considering the application of maximum emissions control measures. The level of compliance though, differs among the countries and the pollutants/metrics considered.

For ozone exceedance, the MTFR controls make little difference and in all four countries most stations (more than 90%) do not meet the guideline value in 2030 or 2050 and are comparable to the EU-27.

For NO_2 exceedance, Poland is predicted to have fewer (~7%-11%) and Italy more stations (~28%-43%) exceeding the WHO air quality guideline in 2030 and 2050.

For NO_2 annual mean concentration, the countries are better matched with the overall EU-27 picture, but Italy is still experiencing a high portion of stations (~18% in 2050) with annual mean concentrations above the WHO air quality guideline value. In 2050, Spain is predicted to have only 3% of its monitoring stations above that value.

Regarding PM_{10} exceedance, the largest non-compliances are predicted in Poland and Italy with almost double the proportion of stations not meeting the WHO air quality guideline in 2030 compared to EU-27. This is true for Italy in 2050 as well, while Poland aligns closer to EU-27. France and Spain are predicted to have fewer stations not meeting the guideline criteria when compared to EU-27.

For PM_{10} annual mean concentration, the same pattern holds with more stations in Poland and Italy having higher average concentrations and in France and Spain fewer stations having annual concentrations higher than the WHO air quality guideline.

$PM_{2.5}$ contributes to PM_{10} so the effect of $PM_{2.5}$ controls are to some extent consistent with the PM_{10} results. Spain has a low proportion of stations where $PM_{2.5}$ exceedance does not meet the guideline criteria compared to EU-27 and the other countries. Poland has a majority of stations not meeting the criteria in 2030 and the gap with the EU-27 is larger in 2050.

For $PM_{2.5}$ annual mean concentration, the majority of stations in Italy and Poland have higher than the guideline values and for Poland this amounts to all stations in 2030 and only decreasing slightly in 2050. Spain in contrast is forecasted to have a far smaller proportion of stations not meeting the guideline in both 2030 and 2050.

Table 28 Country comparison with the EU-27 of the proportion (%) of monitoring stations NOT meeting the proposed WHO Air Quality Guideline values in 2030, respectively in 2050. MTFR Scenario (Case (7)) for the Second Clean Air Outlook.

		O_3 exceedance (%)	NO_2 exceedance (%)	NO_2 annual mean (%)	PM_{10} exceedance (%)	PM_{10} annual mean (%)	$PM_{2.5}$ exceedance (%)	$PM_{2.5}$ annual mean (%)
2030	FR	97.4	22.0	22.8	6.7	19.4	44.3	59.6
	PL	94.3	11.4	24.8	37.5	60.5	93.8	100
	IT	96.9	43.3	38.5	42.2	59.4	64.3	89.7
	ES	93.6	23.3	27.9	9.6	15.5	3.6	19.3
	EU-27	95.0	24.5	30.2	23.0	36.4	63.7	76.3
2050	FR	95.1	14.3	5.5	4.8	15.7	23.6	22.6

	PL	92.0	6.7	6.4	22.5	39.5	89.6	90.6
	IT	95.1	28.4	18.2	33.5	44.4	49.3	58.8
	ES	89.9	9.1	3.0	9.6	15.5	3.6	10.8
	EU-27	92.8	14.6	6.5	16.9	25.8	42.8	52.3

Note: In this table, the following abbreviations are used: FR = France, PL = Poland, IT = Italy, ES = Spain, EU-27 = 27 European Member States

4.3. MAXIMUM TECHNICALLY FEASIBLE REDUCTION WITH 1.5 LIFE ENERGY PATHWAY (MTFR + 1.5 LIFE)

The second control scenario is based on an alternative energy and activity pathway that has fundamentally lower emissions in some sectors. MTFR is then imposed on the conventional sources but may in itself be less effective if the underlying emissions are reduced through changes in demand for emission generating activities. Agriculture is probably the sector where controls change the most.

Table 29 shows the corresponding results for the MTFR + 1.5 LIFE scenario of the Second Clean Air Outlook (Case (8) in this study). Despite the additional emissions reductions associated to the MTFR + 1.5 LIFE scenario, the country-specific results indicate non-compliance issues with the WHO air quality guidelines for all pollutants and metrics by 2050 ($PM_{2.5}$ exceedance in Spain appears to be the only exception). As already seen from the previous scenarios, the level of compliance though, differs among the countries and the pollutants/metrics considered.

For ozone exceedance, the control scenario makes little difference and the majority of monitoring stations in all four countries not meeting the guideline criteria remains very high and similar to the EU-27 as a whole.

For NO_2 exceedance, Italy has a larger and both Poland and Spain a smaller proportion of stations not meeting the WHO air quality guideline compared to the EU-27 as a whole.

For NO_2 annual mean concentration, the spread among countries is less but Italy has a larger proportion of stations with higher annual mean concentrations than the EU-27 as a whole.

For PM_{10} exceedance, Italy and Poland have a larger proportion of stations than the EU-27 as a whole not meeting the guideline criteria. France and Spain have fewer. PM_{10} annual mean concentration follows the same pattern.

$PM_{2.5}$ exceedance follows the same pattern as PM_{10} exceedance, but the spread of values is much larger with almost all stations in Spain meeting the guideline under this scenario whereas almost none of the stations in Poland do. France has fewer stations meeting the guideline criteria than the EU-27 as a whole. $PM_{2.5}$ annual mean concentration shows a similar pattern, whereas 81% of the stations in Poland is predicted to record annual mean concentrations above the WHO air quality guideline. A significant proportion of non-compliant stations is also predicted in Italy.

Table 29 Country comparison with the EU-27 of the proportion (%) of monitoring stations NOT meeting the proposed WHO Air Quality Guideline values in 2030, respectively in 2050. MTFR + 1.5 LIFE Scenario (Case (8)) for the Second Clean Air Outlook.

		O_3 exceedance (%)	NO_2 exceedance (%)	NO_2 annual mean (%)	PM_{10} exceedance (%)	PM_{10} annual mean (%)	$PM_{2.5}$ exceedance (%)	$PM_{2.5}$ annual mean (%)
2030	FR	94.7	14.3	5.2	5.8	15.7	30.7	40.4
	PL	92.0	8.6	8.3	26.3	45.7	90.6	99.0
	IT	94.4	28.4	20.3	35.7	50.3	55.1	72.5
	ES	89.4	11.6	8.6	9.6	15.5	3.6	12.0
	EU-27	92.4	16.4	11.3	18.4	29.6	52.5	65.9
2050	FR	94.7	12.8	2.1	4.8	13.9	12.9	10.3
	PL	89.8	5.7	2.8	20.0	30.9	83.3	81.3
	IT	92.6	22.0	9.1	28.1	36.4	44.5	42.9
	ES	88.3	7.8	1.3	9.6	15.5	0.0	7.2
	EU-27	91.6	12.6	2.8	14.7	21.5	35.3	37.1

Note: In this table, the following abbreviations are used: FR = France, PL = Poland, IT = Italy, ES = Spain, EU-27 = 27 European Member States

4.4. FRANCE

4.4.1. Ozone Exceedance

France has 266 stations with an established record of monitoring hourly concentrations of ozone from which the maximum daily 8-hr mean concentration and the number of threshold exceedances can be calculated.

Under the baseline scenario (Case (0)) (**Figure 22**), the WHO AQ interim target 2 for ozone exceedance is not met for a majority of stations in 2030 or in 2050, while only a few stations are predicted to meet the WHO air quality guideline value in either year.

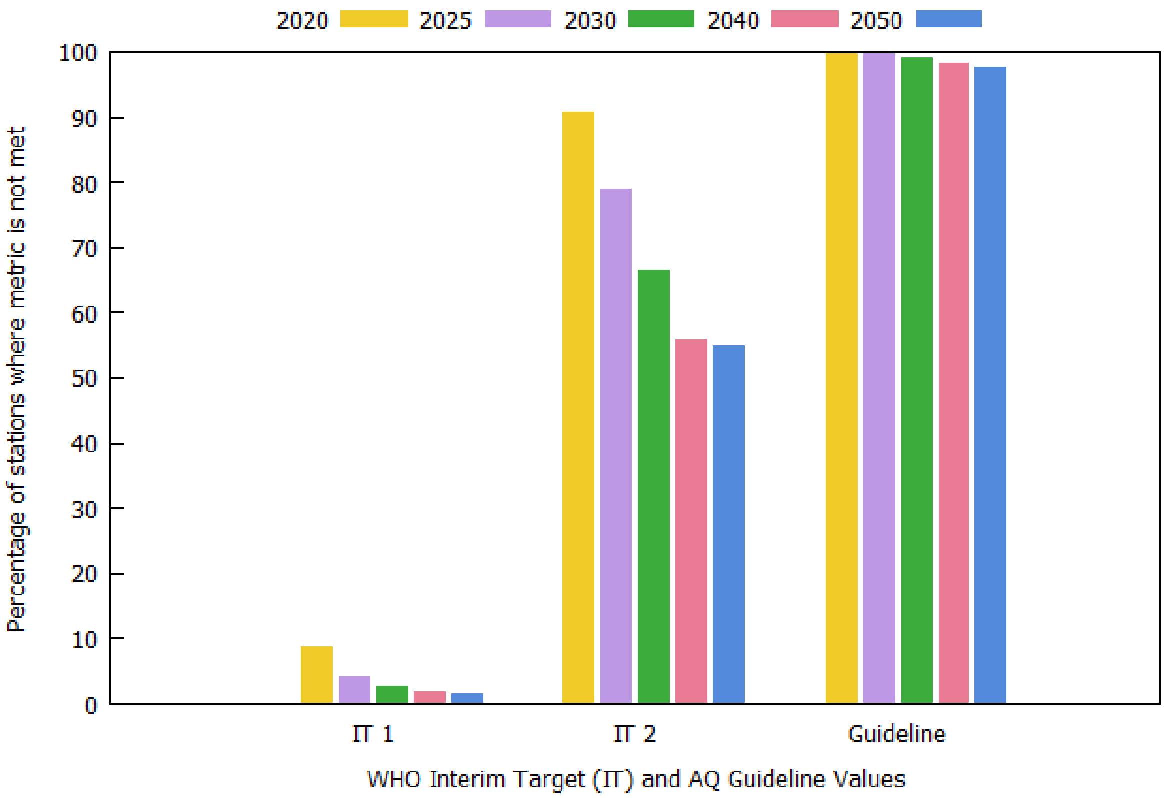

Figure 22 O_3 exceedance - France: Proportion of stations predicted NOT to meet the WHO interim target and guideline values under the baseline scenario (Case (0)).

The effect of emission reductions on predicted station results is shown in **Figure 23** and **Figure 24** for the years 2030 and 2050 respectively. As previously, the scenarios are as given in **Table 30** and summarised here for convenience. Cases (1) – (6) are sensitivity cases to test if the sector emissions are significant for the indicator.

Note that the emission reductions are applied to the EU-27+UK and not just to France.

Table 30 List of emissions scenarios assessed in the study.

Case (0)	Baseline, only mandated reductions.
Case (1)	Zero energy sector emissions.
Case (2)	Zero domestic and commercial emissions.
Case (3)	Zero industry and solvent product/use emissions.
Case (4)	Zero road transport emissions.
Case (5)	Zero non-road transport/machinery emissions.
Case (6)	Zero agricultural emissions, notably NH_3.
Case (7)	Maximum Technically Feasible Reduction (MTFR).
Case (8)	MTFR + 1.5 LIFE Emissions.

For ozone exceedance, the largest sensitivity is predicted when considering the removal of industry combustion/process and solvent/product use emissions (Case (3)), and most notably the VOC associated emissions. The predicted effect is more significant than the effects caused by the MTFR and MTFR + 1.5 LIFE scenarios (Case (7) and Case (8) respectively). Removal of emissions from the transport sector (Case (4)) has the second largest impact among the sectors, but still the expected improvement from the baseline scenario is small, while reductions on the other sectors are ineffective. This is a similar pattern to the EU-27 as a whole results as can be expected for a secondary pollutant that develops high concentrations during episodes over a wide geographic area.

The WHO guideline value is generally not met irrespective of actions taken, with more than 90% of stations recording exceedances above the guideline criteria in all scenarios.

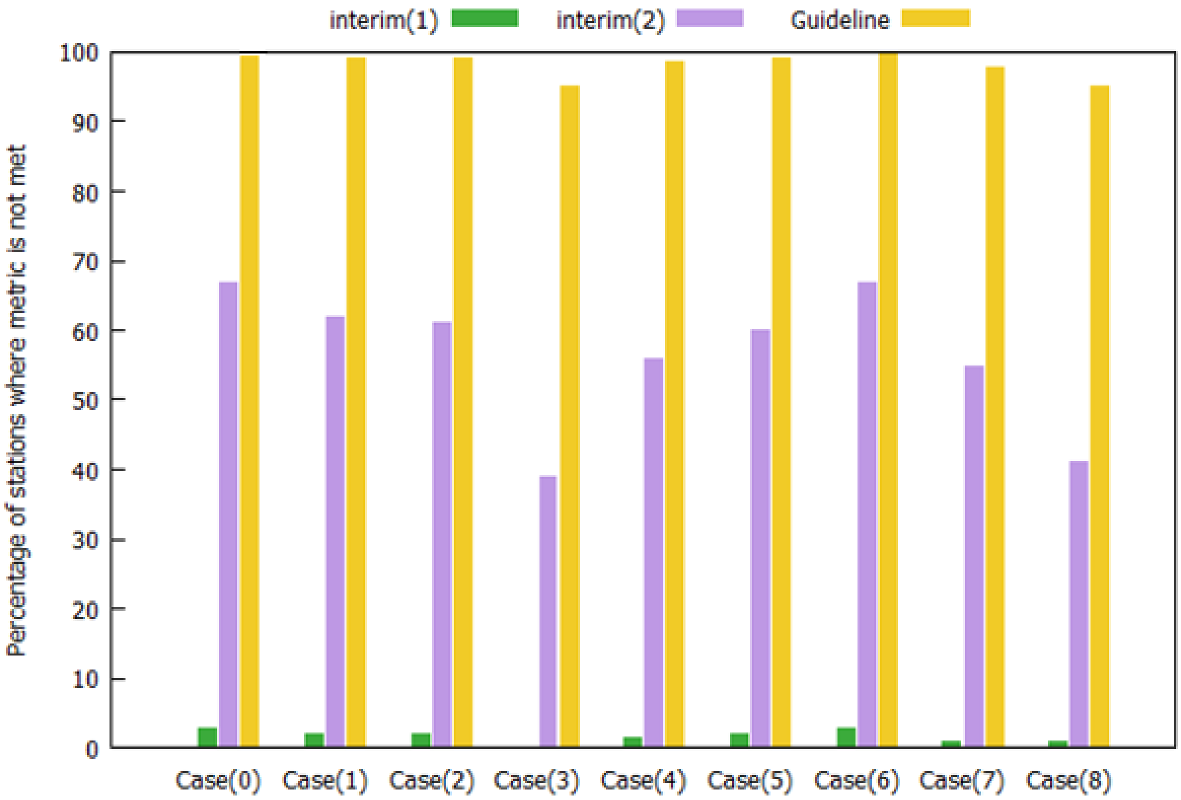

Figure 23 O_3 exceedance - France: Scenario comparison for the number of monitoring stations NOT meeting the WHO interim target and guideline values in 2030.

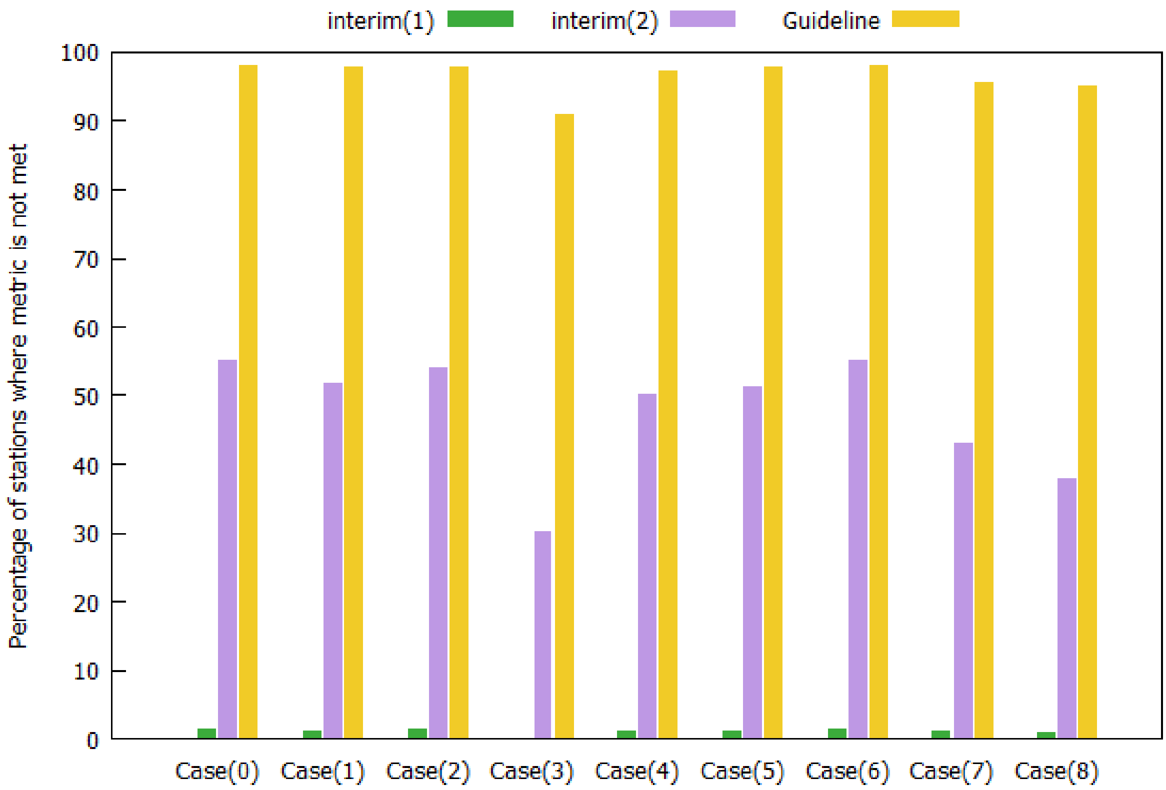

Figure 24 O_3 exceedance - France: Scenario comparison for the number of monitoring stations NOT meeting each WHO interim target and guideline values in 2050.

4.4.2. NO_2 Exceedance

France has 328 stations with an established record of monitoring hourly concentrations of NO_2 from which the daily mean value and the number of threshold exceedances can be calculated.

Under the baseline scenario (Case (0)) (**Figure 25**), the number of stations NOT meeting the WHO guideline decreases significantly over time and by 2030, nearly all stations meet the interim target 2 of less than four days per year where the daily mean concentration exceeds 50 µg/m^3.

The emission reduction scenarios for 2030 and 2050 (**Figure 26** and **Figure 27** respectively) show that there is no outstanding sectoral contribution. Transport emissions (road and non-road) for Cases (4) and (5) respectively have a slightly higher effect in reducing the proportion of stations not meeting the guideline value in 2030, while differences are less obvious in 2050. In addition, even in the cases of the MTFR (Case (7)) and MTFR + 1.5 LIFE (Case (8)) scenarios, the additional increase of the stations meeting an WHO interim target or guideline compared to the current legislation and other sectoral emission reduction scenarios is small.

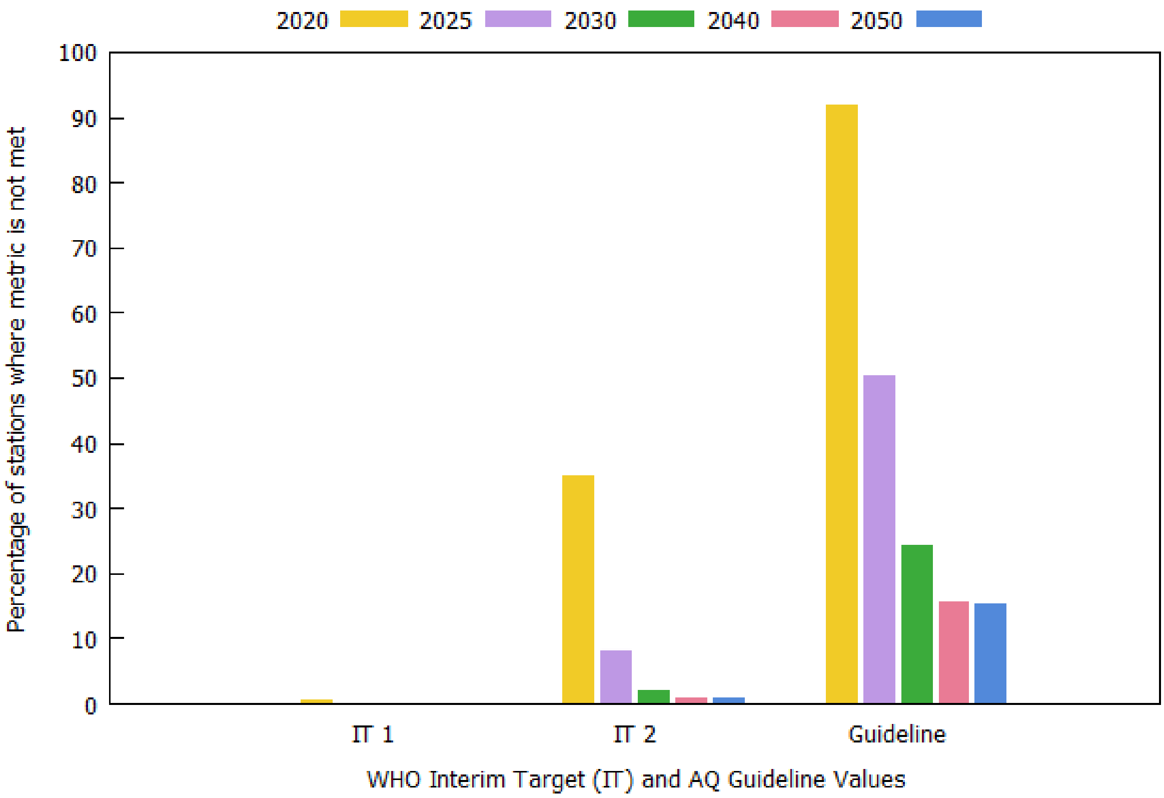

Figure 25 NO_2 exceedance - France: Proportion of stations predicted NOT to meet the WHO interim target and guideline values under the baseline scenario (Case (0)).

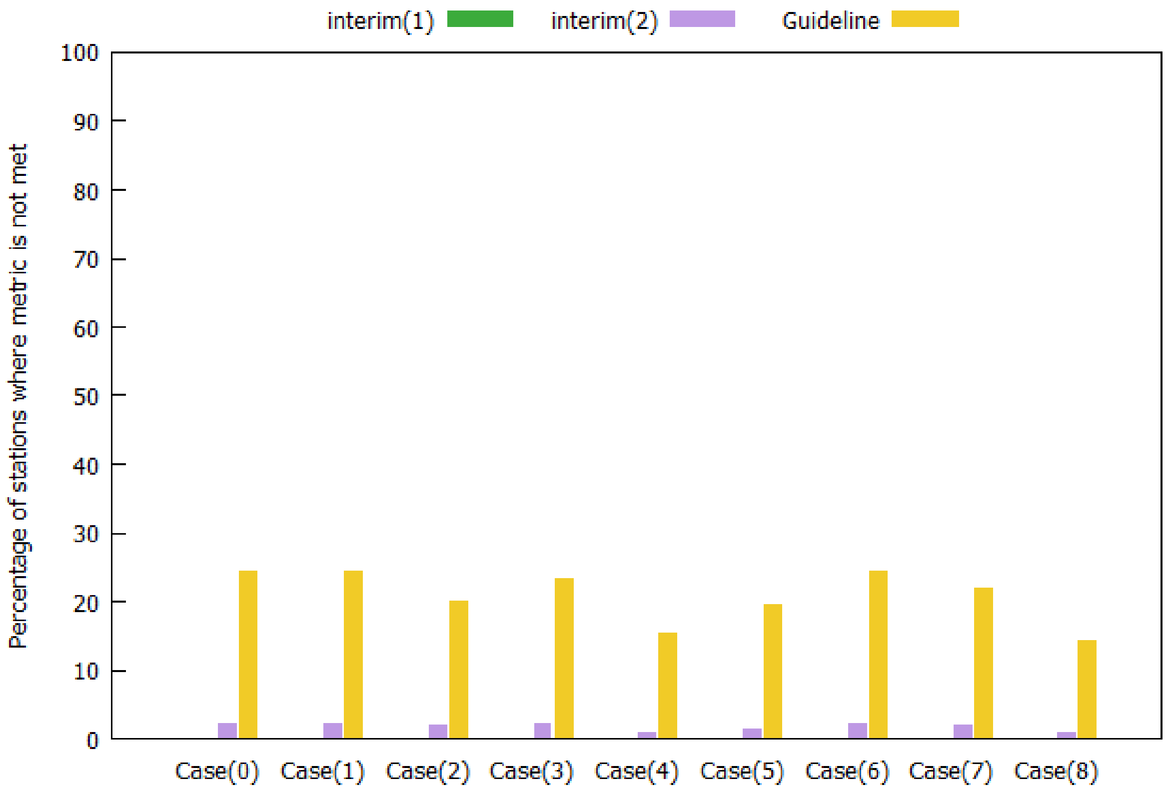

Figure 26 NO_2 exceedance - France: Scenario comparison for the number of monitoring stations NOT meeting the WHO interim target and guideline values in 2030.

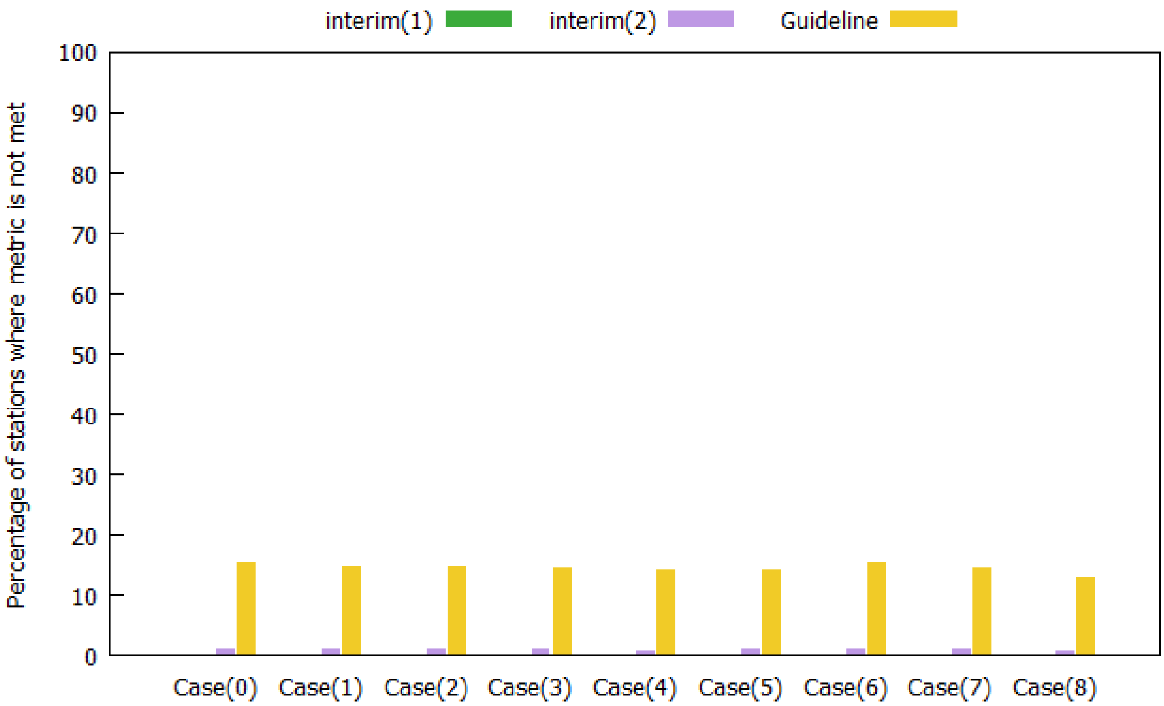

Figure 27 NO_2 exceedance - France: Scenario comparison for the number of monitoring stations NOT meeting the WHO interim target and guideline values in 2050.

4.4.3. NO_2 Annual Mean

France has 329 stations with an established record of monitoring hourly concentrations of NO_2 from which the annual mean value can be calculated and compared with a limit value.

Under the baseline scenario (**Figure 28**), the number of stations where annual mean concentrations are exceeding the interim target values decreases over time and nearly all stations are below the interim target 3 value of 20 µg/m^3 by 2040.

Of the emission reduction sensitivity cases for 2030 and 2050 (**Figure 29** and **Figure 30** respectively) the reduction in on-road (Case (4)) emissions has the largest effect on the proportion of stations not meeting the standard. The non-road transport emissions (Case (5)) and domestic/commercial emissions (Case (2)) are also predicted to be influential.

The MTFR + 1.5 LIFE scenario (Case (8)) is predicted to be the most effective scenario in reducing NO_2 annual mean concentrations and this shows more clearly in 2030. From the description of the scenario, it is clear that the energy and social changes would reduce NO_x emissions from domestic heating/cooking and from transport. However, it should be noted that even under this scenario, a few stations are still predicted to record concentrations above the WHO air quality guideline value.

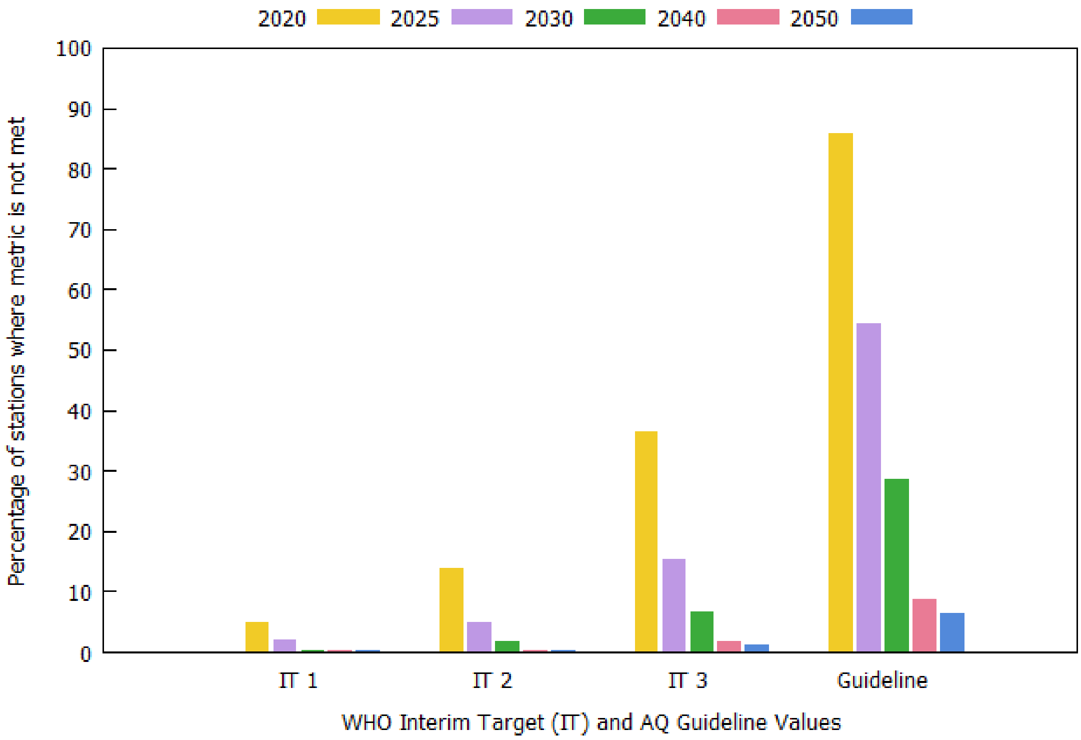

Figure 28 NO$_2$ annual mean - France: Proportion of stations predicted NOT to meet the WHO interim target and guideline values under the baseline scenario (Case (0)).

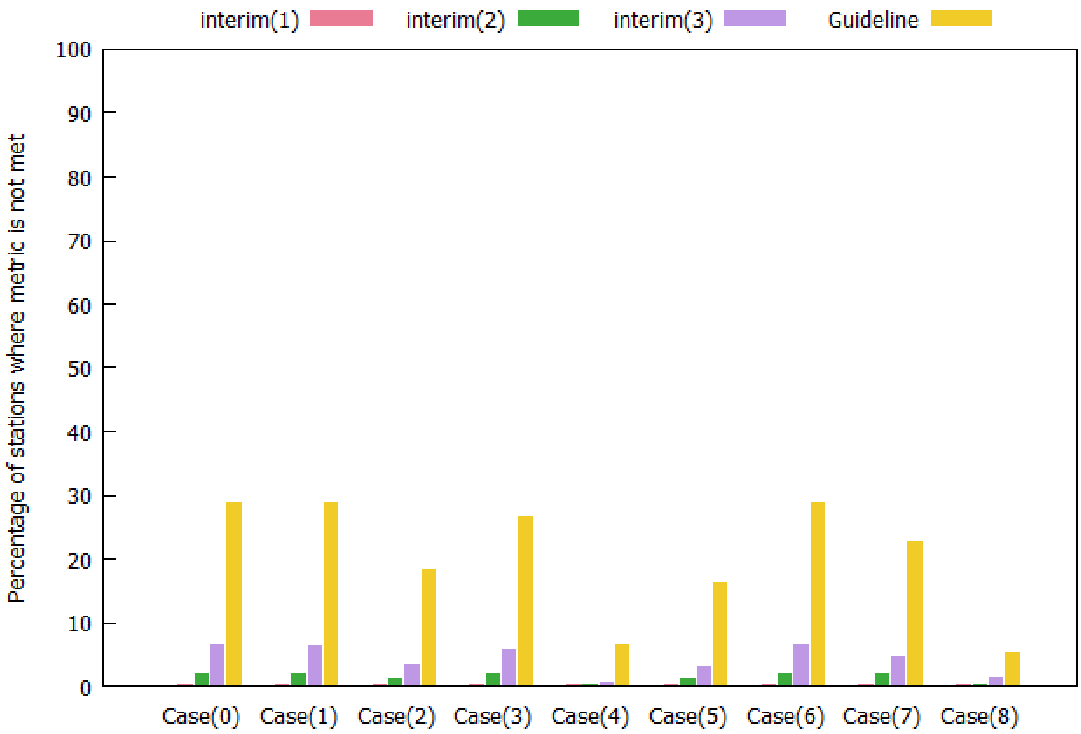

Figure 29 NO$_2$ annual mean - France: Scenario comparison for the number of monitoring stations NOT meeting the WHO interim target and guideline values in 2030.

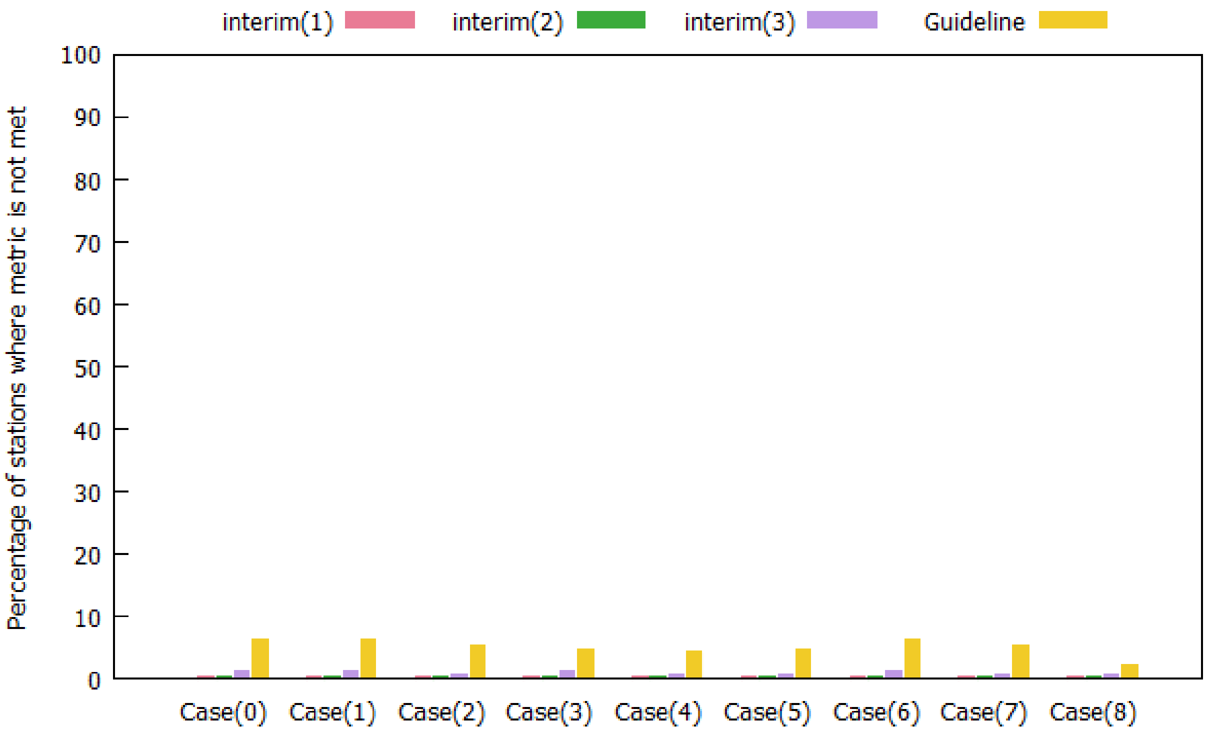

Figure 30 NO_2 annual mean - France: Scenario comparison for the number of monitoring stations NOT meeting the WHO interim target and guideline values in 2050.

4.4.4. PM_{10} Exceedance

France has 104 stations with an established record of monitoring hourly concentrations of PM_{10} from which the daily mean value and the number of threshold exceedances can be calculated.

Under the baseline scenario (**Figure 31**), the number of stations where the WHO interim target and guideline values are not met decreases markedly with time. By 2030 and 2050, most stations are predicted to meet the interim target 4 threshold of 50 µg/m^3 and the guideline value of 45 µg/m^3 daily average concentration on less than four times a year (less than 10%).

The emission reduction sensitivity scenarios for 2030 and 2050 (**Figure 32** and **Figure 33** respectively) do not show a single outstanding sectoral contribution. The removal of NH_3 emissions from agriculture (Case (6)) is predicted to have the largest influence, with the results being more apparent in 2030 than in 2050. MTFR (Case (7)) and MTFR + 1.5 LIFE (Case (8)) are quite similar in effect, while in all cases, a small number of stations (i.e., less than 10%) is predicted not meeting the interim target 4 and the air quality guideline values.

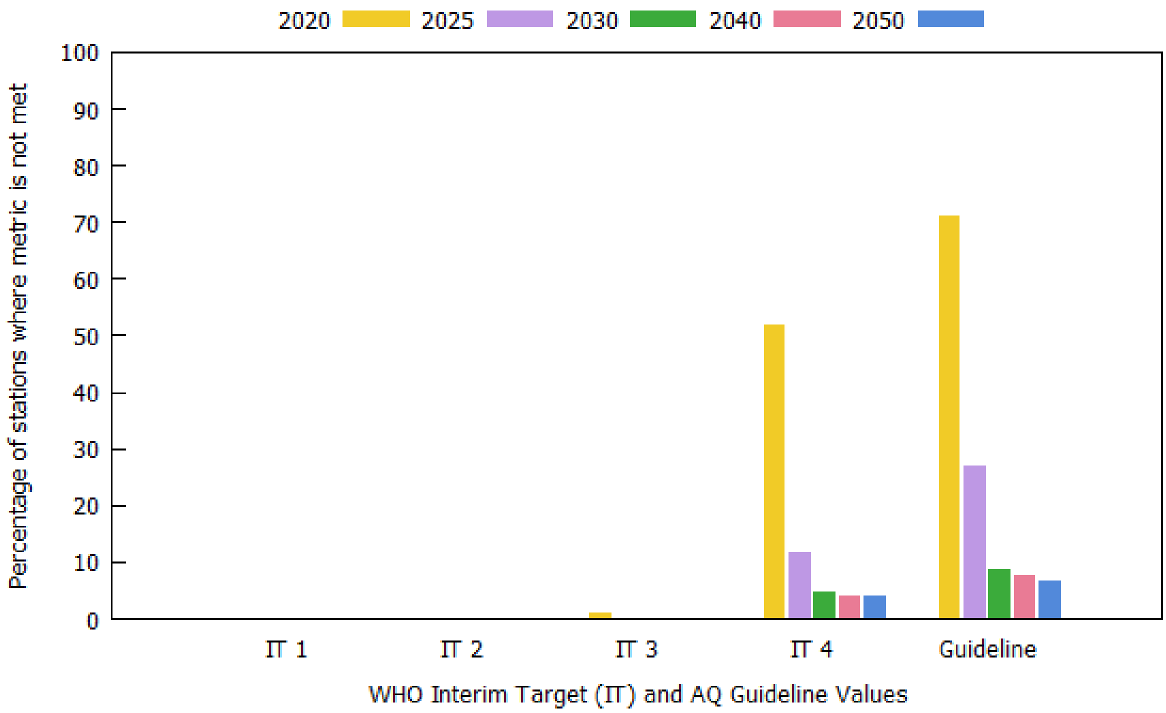

Figure 31 PM$_{10}$ exceedance - France: Proportion of stations predicted NOT to meet the WHO interim target and guideline values under the baseline scenario (Case (0)).

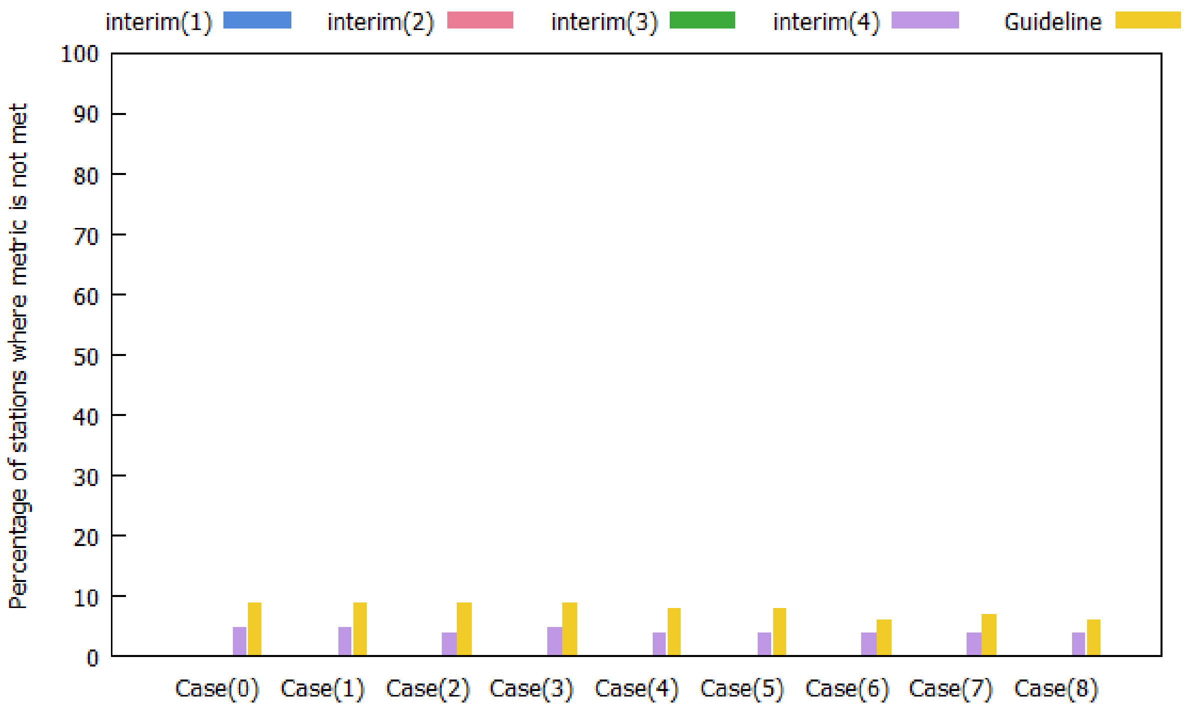

Figure 32 PM$_{10}$ exceedance - France: Scenario comparison for the number of monitoring stations NOT meeting the WHO interim target and guideline values in 2030.

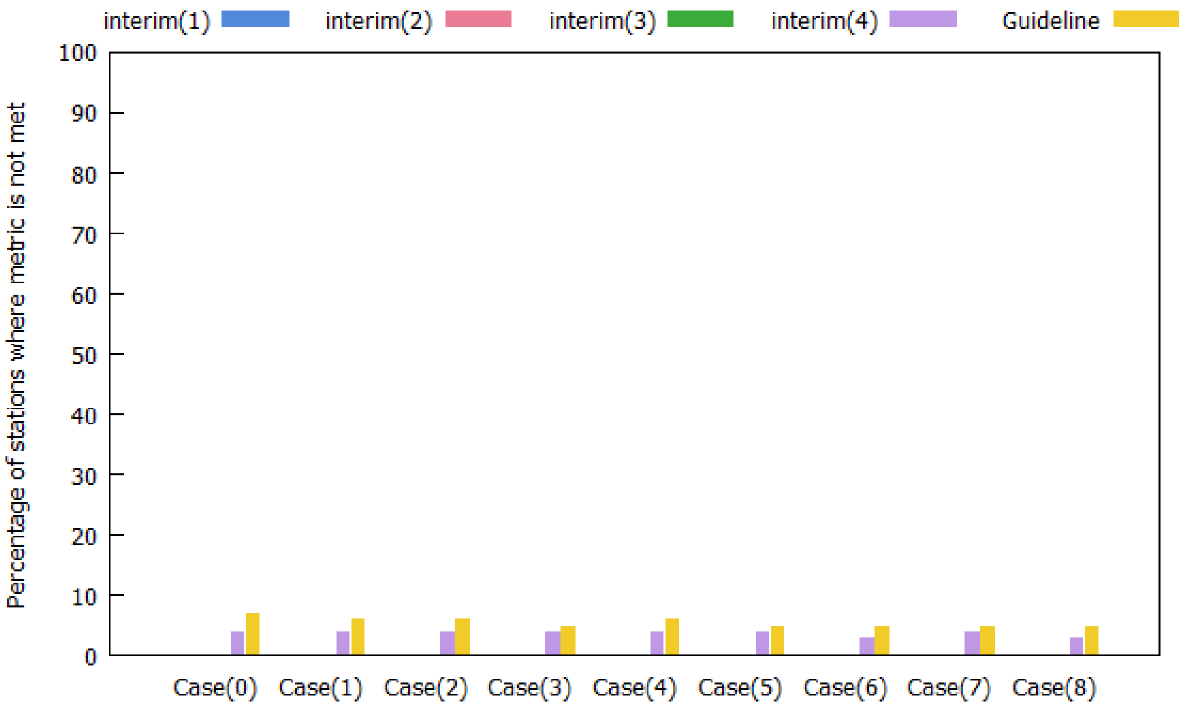

Figure 33 PM_{10} exceedance - France: Scenario comparison for the number of monitoring stations NOT meeting the WHO interim target and guideline values in 2050.

4.4.5. PM_{10} Annual Mean

France has 108 stations with an established record of monitoring hourly concentrations of PM_{10} from which the annual mean value can be calculated and compared with a limit value.

Under the baseline scenario (**Figure 34**), only a few stations do not meet the WHO interim target 4 value of 20 µg/m^3 by 2030 (i.e., less than 10%), however the portion increases significantly when considering the guideline value of 15 µg/m^3 with 25% of the stations not meeting the value in 2030 and around 17% in 2050.

Of the emission reduction sensitivity cases for 2030 and 2050 (**Figure 35** and **Figure 36** respectively), there is no outstanding sector whose omission makes a large change in the proportion of stations meeting the interim target 4 or guideline value. The removal of agricultural emissions, Case (6), is predicted to have some effect in both 2030 and 2050. The same does the removal of domestic and commercial emissions (Case (2)) in 2030 but not in 2050 by which it is assumed that domestic use of solid fuel for heating is much reduced. Consistent with the results regarding PM_{10} exceedance, there still remain a few stations not meeting the interim target 4 even under the control scenarios MTFR and MTFR + 1.5 LIFE, Cases (7) and (8) respectively.

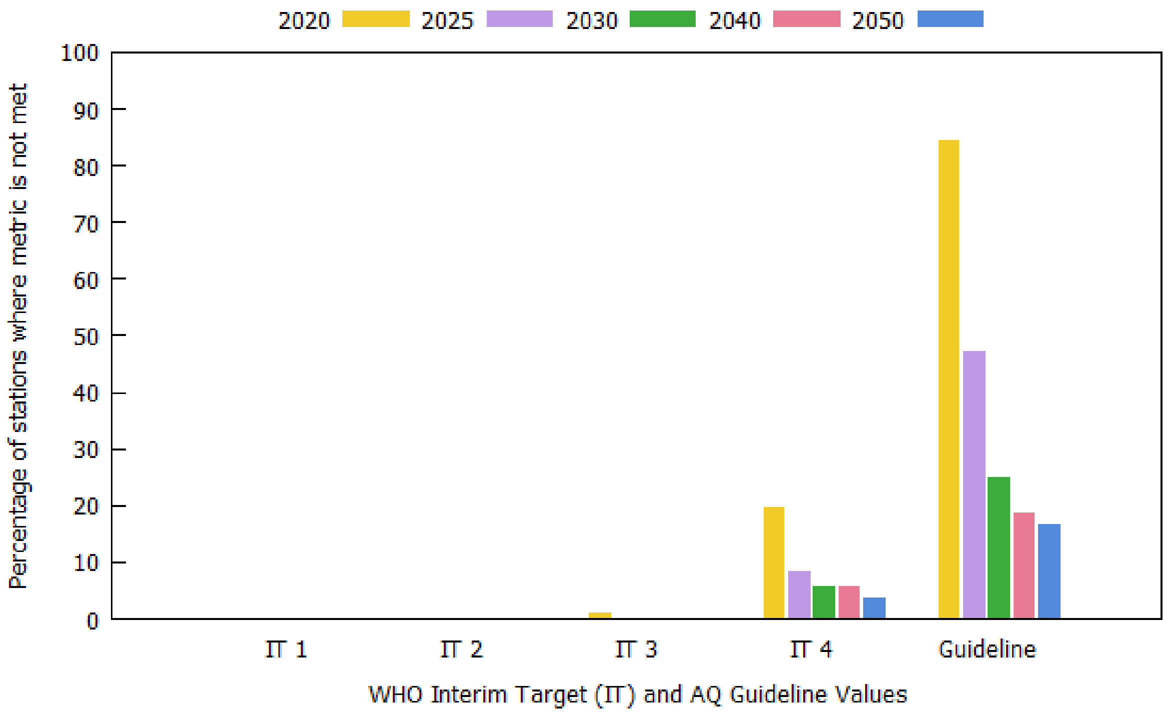

Figure 34 PM_{10} annual mean - France: Proportion of stations predicted NOT to meet the WHO interim target and guideline values under the baseline scenario (Case (0)).

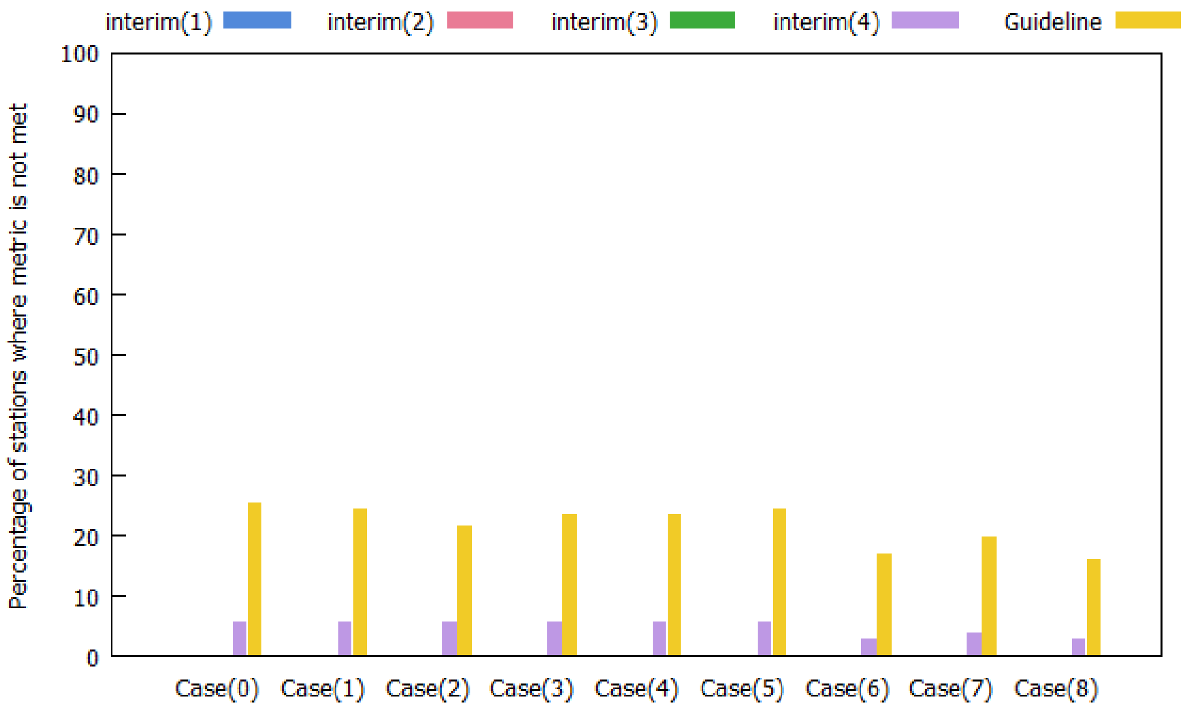

Figure 35 PM_{10} annual mean - France: Scenario comparison for the number of monitoring stations NOT meeting the WHO interim target and guideline values in 2030.

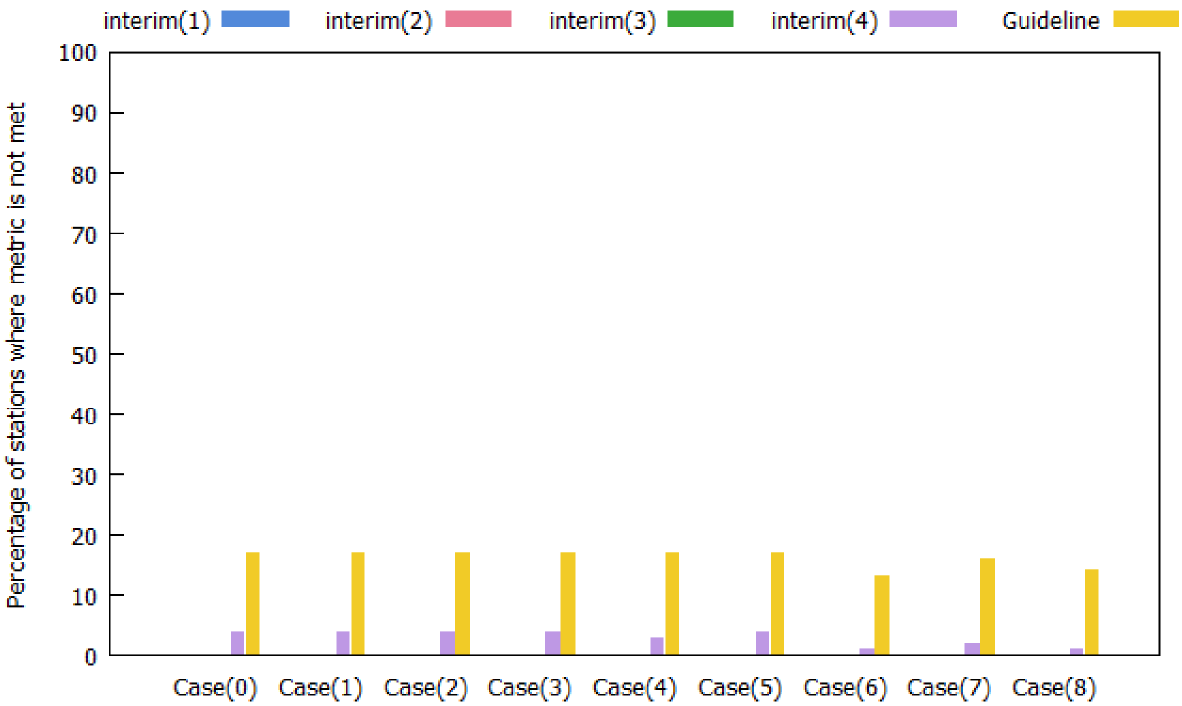

Figure 36 PM_{10} annual mean - France: Scenario comparison for the number of monitoring stations NOT meeting the WHO interim target and guideline values in 2050.

4.4.6. $PM_{2.5}$ Exceedance

France has 140 stations with an established record of monitoring hourly concentrations of $PM_{2.5}$ from which the daily mean value and the number of threshold exceedances can be calculated.

Under the baseline scenario (**Figure 37**), only a small number of stations is predicted to have four or more exceedances per year of the WHO interim target 2 and 3 thresholds by 2030. These thresholds are 50 and 37.5 µg/m^3 respectively. At the interim target 4 threshold of 25 µg/m^3, there is a clear progressive decrease over time in the number of stations having four or more exceedances until 2030 (more than 90% in 2020, compared to around 10% in 2030), but from 2030 onwards, the additional improvement is relatively small. Considering the WHO guideline value of 15 µg/m^3, the number of stations having four or more exceedance days per year remains high in 2030 and also in 2050 (more than 40% of the stations in 2050).

The emission reduction sensitivity scenarios for 2030 and 2050 (**Figure 38** and **Figure 39** respectively) show a strong response to the removal of agricultural emissions of NH_3 (Case (6)), and lesser response to emission reductions from other sectors which include both NO_x but also primary $PM_{2.5}$. In 2050, there is a stronger response to reduction in process emissions, (Case (3)) than in 2030. These emissions include VOC. These sensitivities are consistent with the reduction in $PM_{2.5}$ being attributable to a reduction in secondary $PM_{2.5}$ of which ammonium nitrate and organic particulates make a large part.

Of the two control scenarios, MTFR + 1.5 LIFE (Case (8)) results in fewer exceedance days in 2030 and in 2050 than MTFR (Case (7)). This would be consistent with the larger change in agricultural emissions implied by the MTFR + 1.5 LIFE scenario. Nevertheless, more than 10% of the stations are still predicted not to meet the WHO air quality guideline value in 2050.

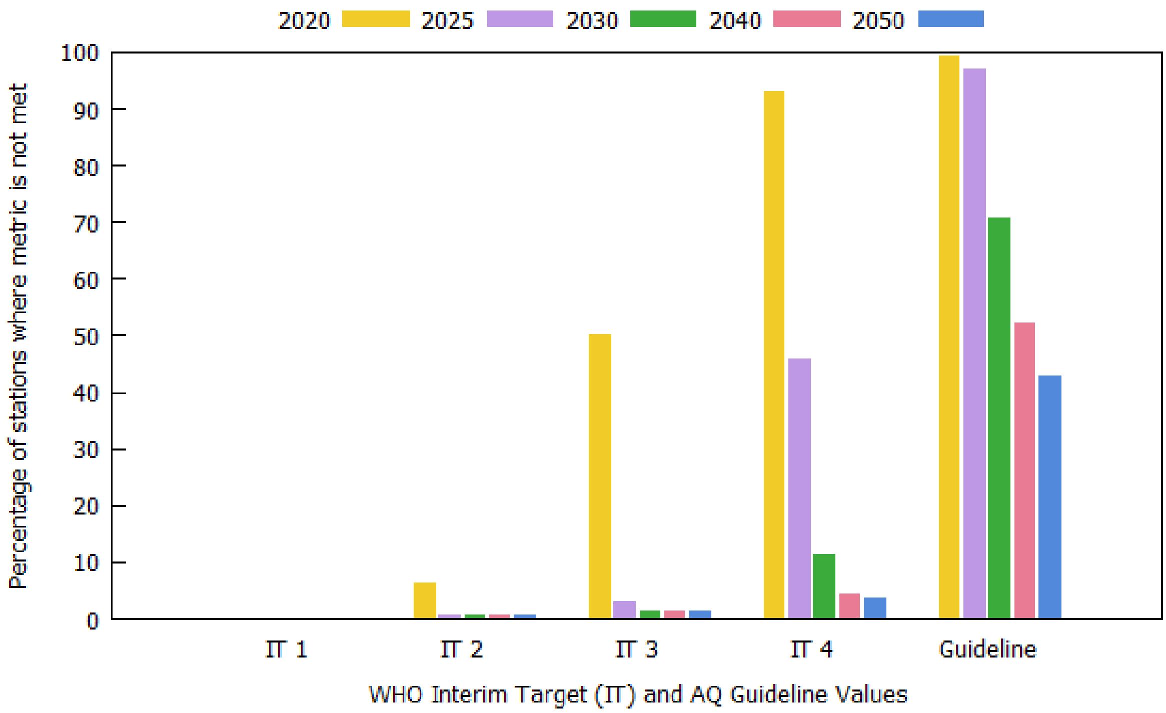

Figure 37 PM$_{2.5}$ exceedance - France: Proportion of stations predicted NOT to meet the WHO interim target and guideline values under the baseline scenario (Case (0)).

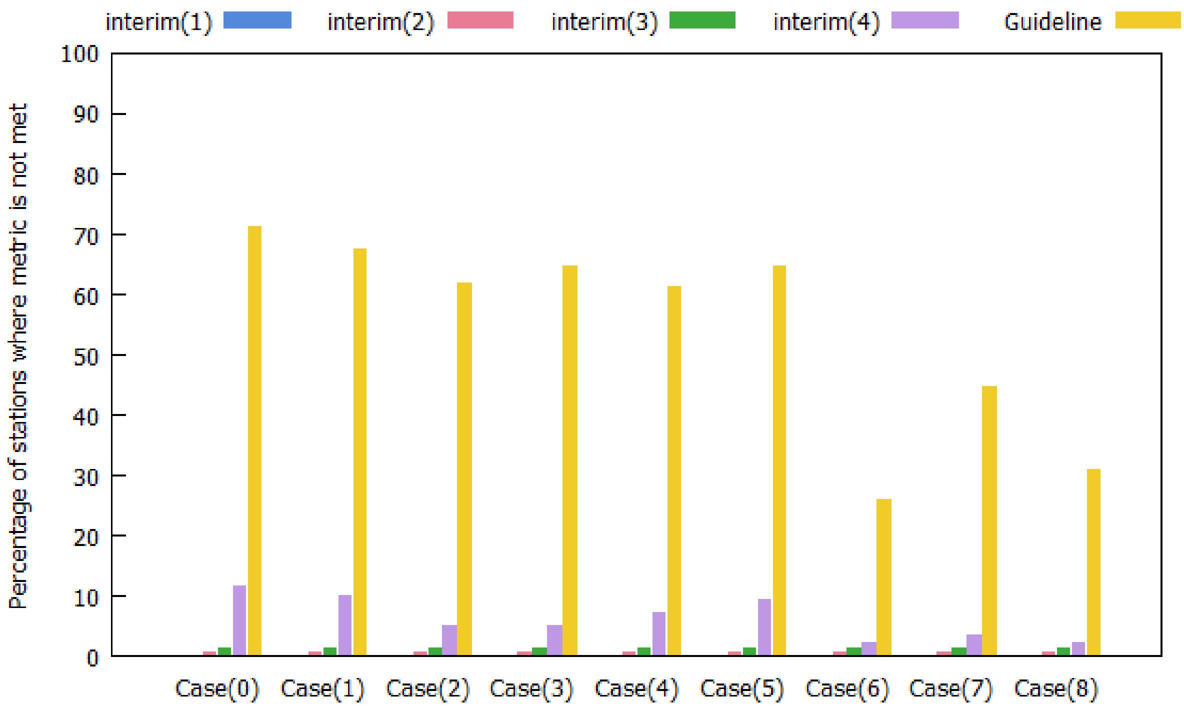

Figure 38 PM$_{2.5}$ exceedance - France: Scenario comparison for the number of monitoring stations NOT meeting the WHO interim target and guideline values in 2030.

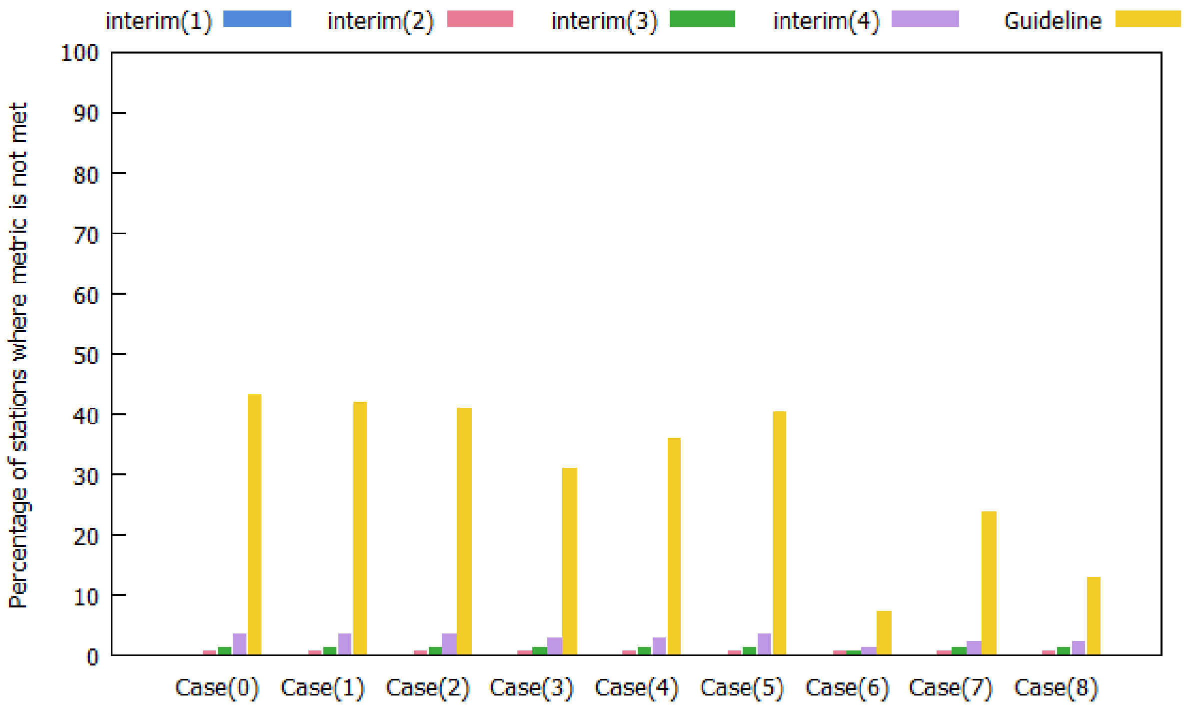

Figure 39 $PM_{2.5}$ exceedance - France: Scenario comparison for the number of monitoring stations NOT meeting the WHO interim target and guideline values in 2050.

4.4.7. $PM_{2.5}$ Annual Mean

France has 146 stations with an established record of monitoring hourly concentrations of $PM_{2.5}$ from which the annual mean value can be calculated and compared with a limit value.

Under the baseline scenario (**Figure 40**), the WHO interim target values are all met by 2050 with only a very few stations not meeting interim target 4 in 2030. This is an annual concentration of 10 $\mu g/m^3$. When considering the WHO air quality guideline value of 5 $\mu g/m^3$, there is a progressive decrease over time in the number of monitoring stations having an annual concentration exceeding the guideline value, but the majority of stations is expected to still experience higher average concentrations in 2050 (i.e., more than 57%).

Among the sectoral emission control sensitivity scenarios for 2030 and 2050 (**Figure 41** and **Figure 42** respectively), a similar pattern to the daily exceedances is shown. Annual mean concentrations are most sensitive to removal of agricultural emissions (Case (6)) and are also influenced by reduction in NO_x, primary $PM_{2.5}$ and VOC sources (Case (3)); the latter more significantly in 2050.

Of the two control scenarios, MTFR + 1.5 LIFE (Case (8)) reduces annual concentrations more than does MTFR (Case (7)) which again could be expected from the larger reduction in agricultural emissions.

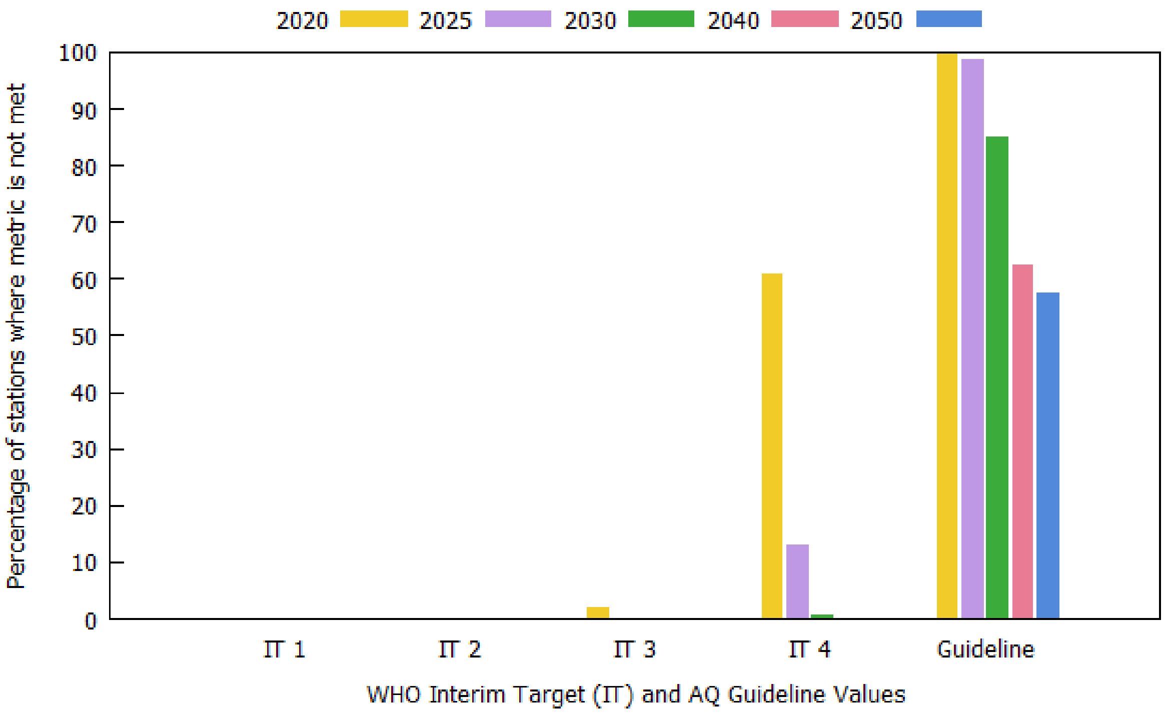

Figure 40 PM$_{2.5}$ annual mean - France: Proportion of stations predicted NOT to meet the WHO interim target and guideline values under the baseline scenario (Case (0)).

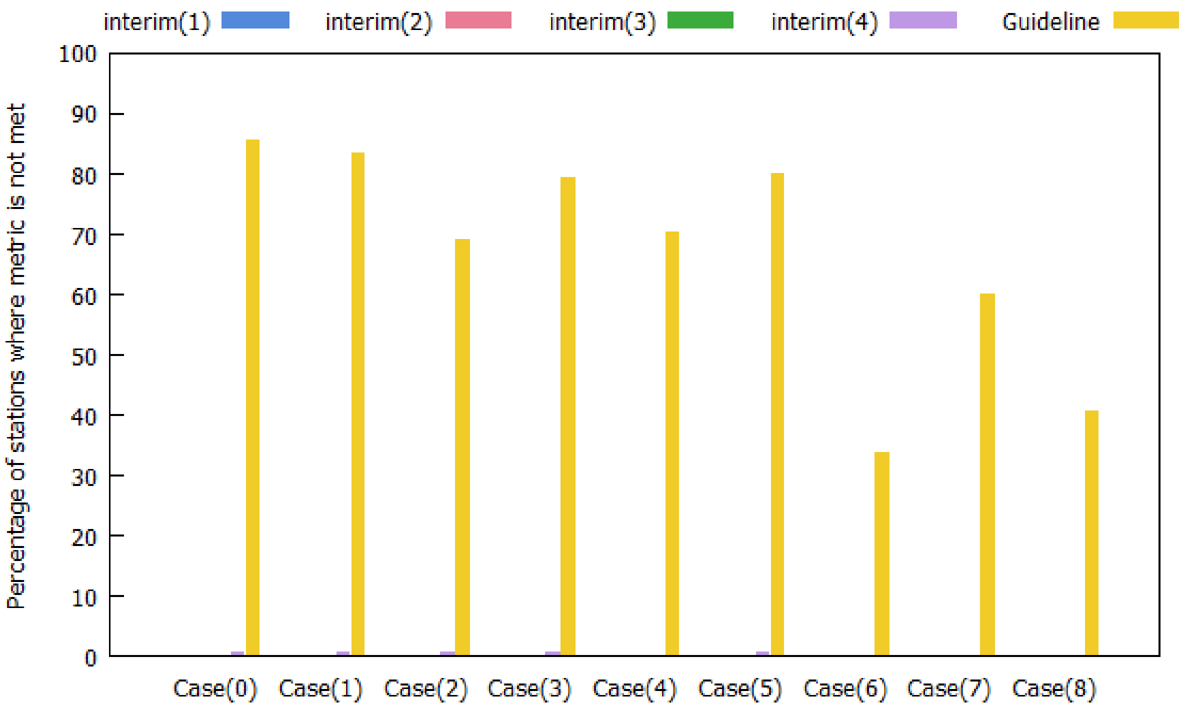

Figure 41 PM$_{2.5}$ annual mean - France: Scenario comparison for the number of monitoring stations NOT meeting the WHO interim target and guideline values in 2030.

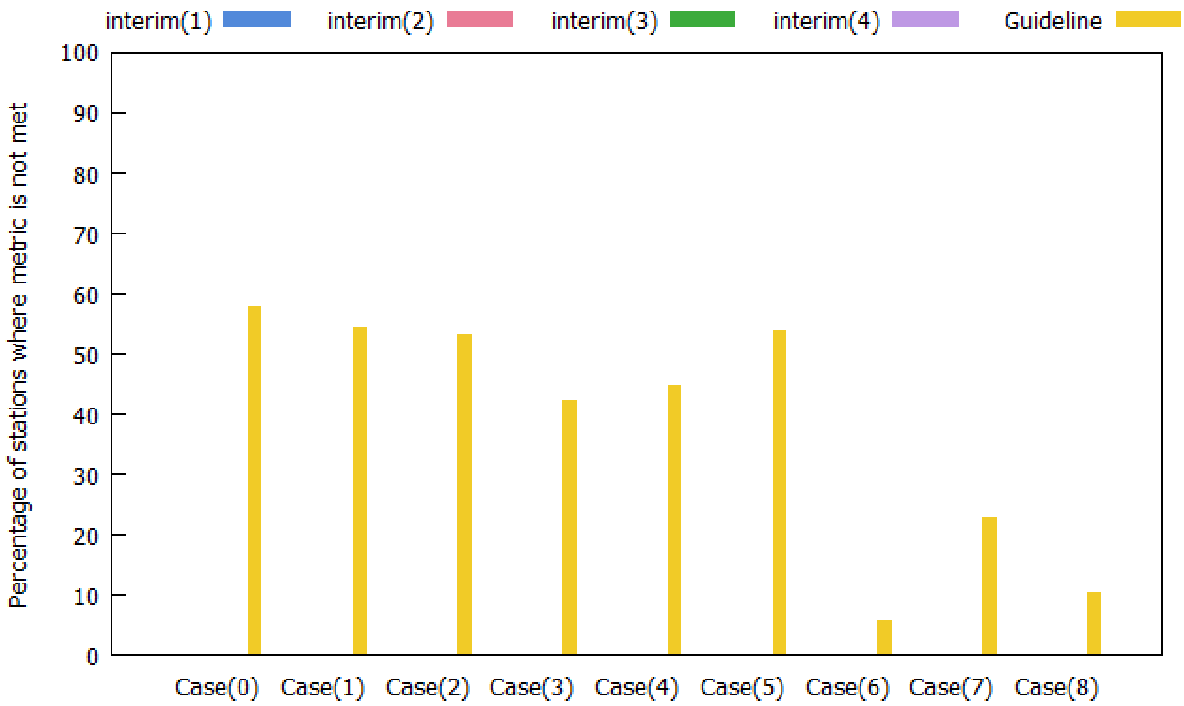

Figure 42 $PM_{2.5}$ annual mean - France: Scenario comparison for the number of monitoring stations NOT meeting the WHO interim target and guideline values in 2050.

4.5. POLAND

4.5.1. Ozone Exceedance

Poland has 88 stations with an established record of monitoring hourly concentrations of ozone from which the maximum daily 8-hr mean concentration and the number of threshold exceedances can be calculated.

The time evolution under the baseline scenario (**Figure 43**) is similar to France. There is a decrease in exceedances over the station network at the WHO interim target 2 threshold of 120 µg/m^3 but changes at the WHO guideline threshold of 100 µg/m^3 are few and more than 90% of the stations are predicted to not meet the WHO air quality guideline. On the contrary, in comparison to France, the interim target 1 of 160 µg/m^3 is already met in all stations as of 2025.

The response in Poland to the emission reduction sensitivity cases for 2030 and 2050 (**Figure 44** and **Figure 45** respectively) shows that the largest effect is due to the elimination of industry combustion/process and solvent/produce use emissions (Case (3)) and most notably the VOC associated emissions. In all remaining sectoral emission reduction scenarios, the additional improvement in the number of stations meeting the WHO interim target and guideline values is rather small. The predicted effect is larger than the effects caused by the MTFR and MTFR + 1.5 LIFE scenarios (Case (7) and Case (8) respectively).

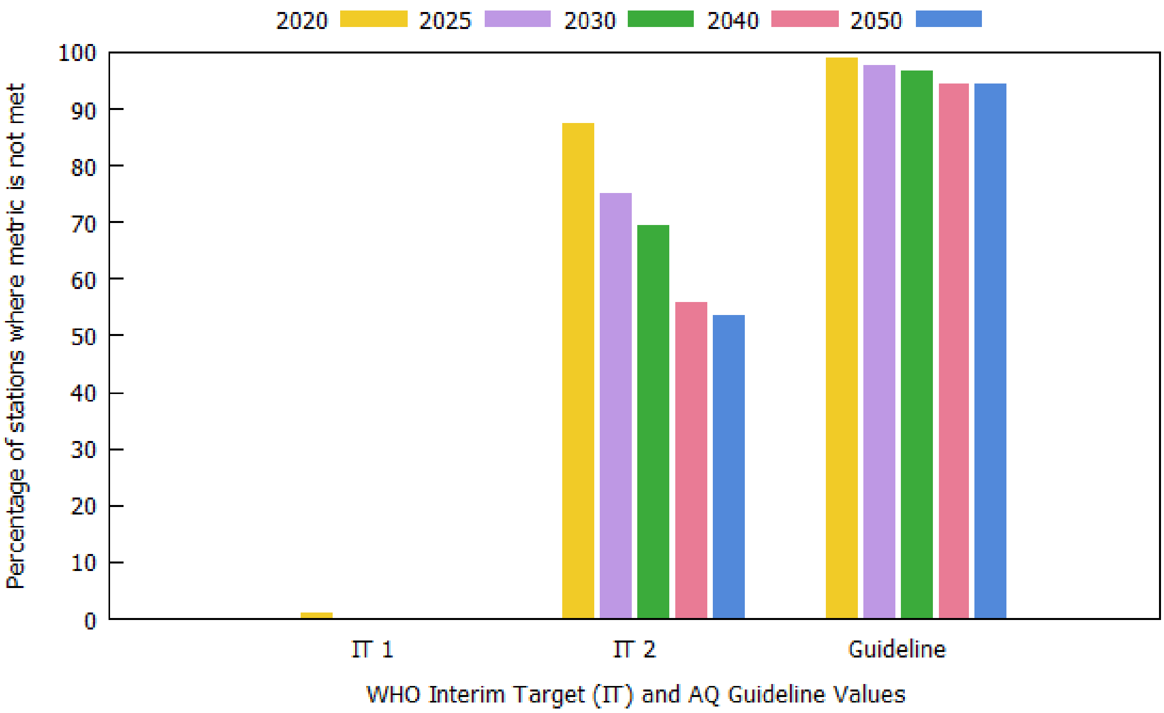

Figure 43 O_3 exceedance - Poland: Proportion of stations predicted NOT to meet the WHO interim target and guideline values under the baseline scenario (Case (0)).

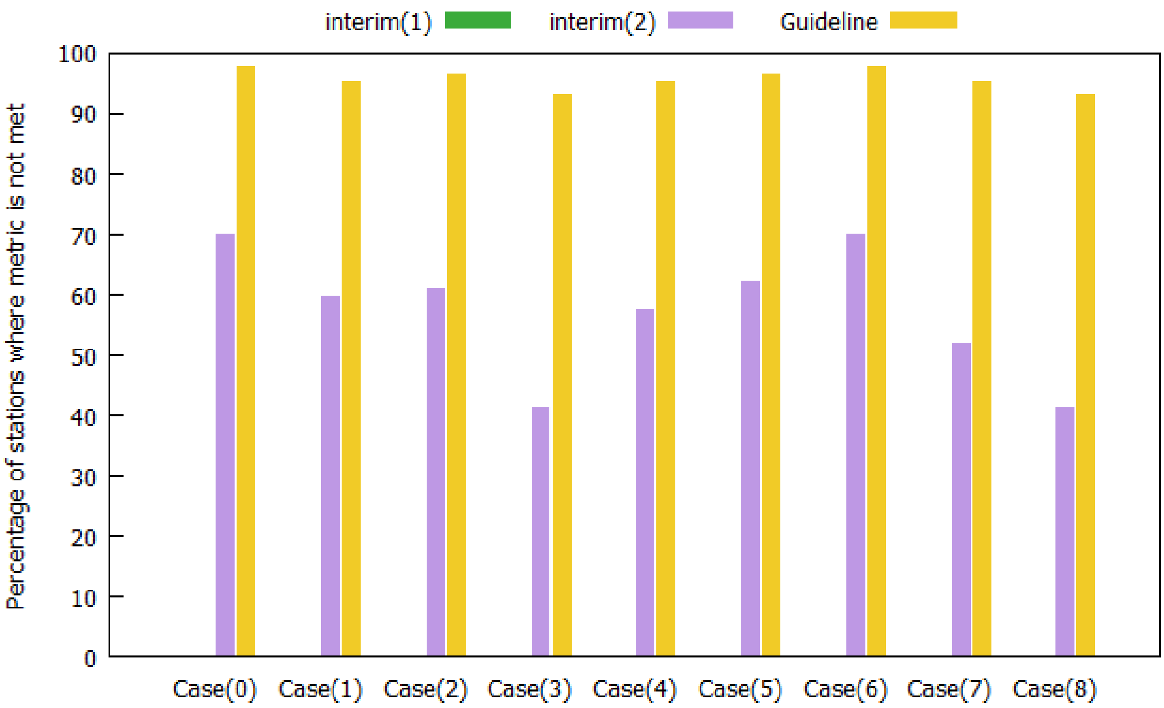

Figure 44 O_3 exceedance - Poland: Scenario comparison for the number of monitoring stations NOT meeting the WHO interim target and guideline values in 2030.

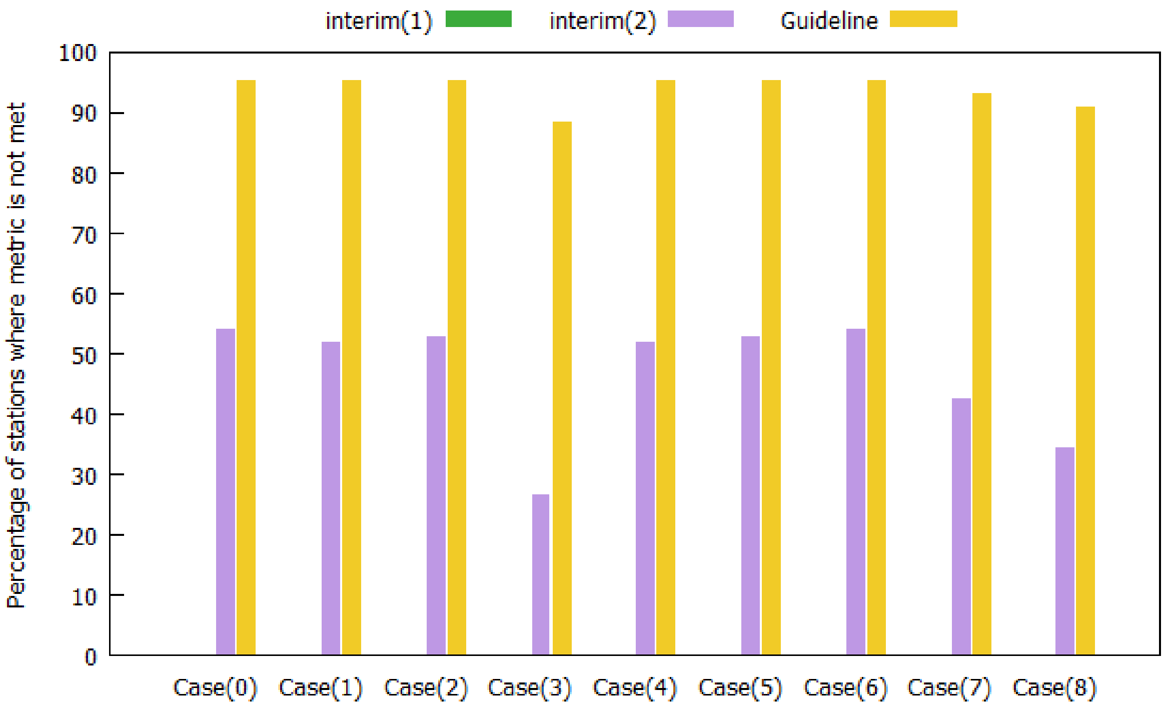

Figure 45 O_3 exceedance - Poland: Scenario comparison for the number of monitoring stations NOT meeting the WHO interim target and guideline values in 2050.

4.5.2. NO_2 Exceedance

Poland has 105 stations with an established record of monitoring hourly concentrations of NO_2 from which the daily mean value and the number of threshold exceedances can be calculated.

Under the baseline scenario (**Figure 46**), all stations in Poland are predicted to meet the WHO interim target 1 of 120 µg/m^3. In addition, the number of stations where the interim target 2 of 50 µg/m^3 or the air quality guideline value of 25 µg/m^3 are exceeded on four or more times a year decreases with time. However, a small proportion of stations remain above these values (i.e., around 10% of the stations for the guideline value in 2050).

The emission reduction scenarios for 2030 and 2050 (**Figure 47** and **Figure 48** respectively) show that there is no outstanding sectoral contribution. The removal of on-road transport emissions (Case (4)) has a slightly higher effect in reducing the proportion of stations not meeting the guideline value in 2030, while differences are less obvious in 2050. In addition, even in the cases of the MTFR (Case (7)) and MTFR + 1.5 LIFE (Case (8)) scenarios, the additional increase of the number of stations meeting a WHO interim target or guideline compared to the current legislation and other sectoral emission reduction scenarios is small.

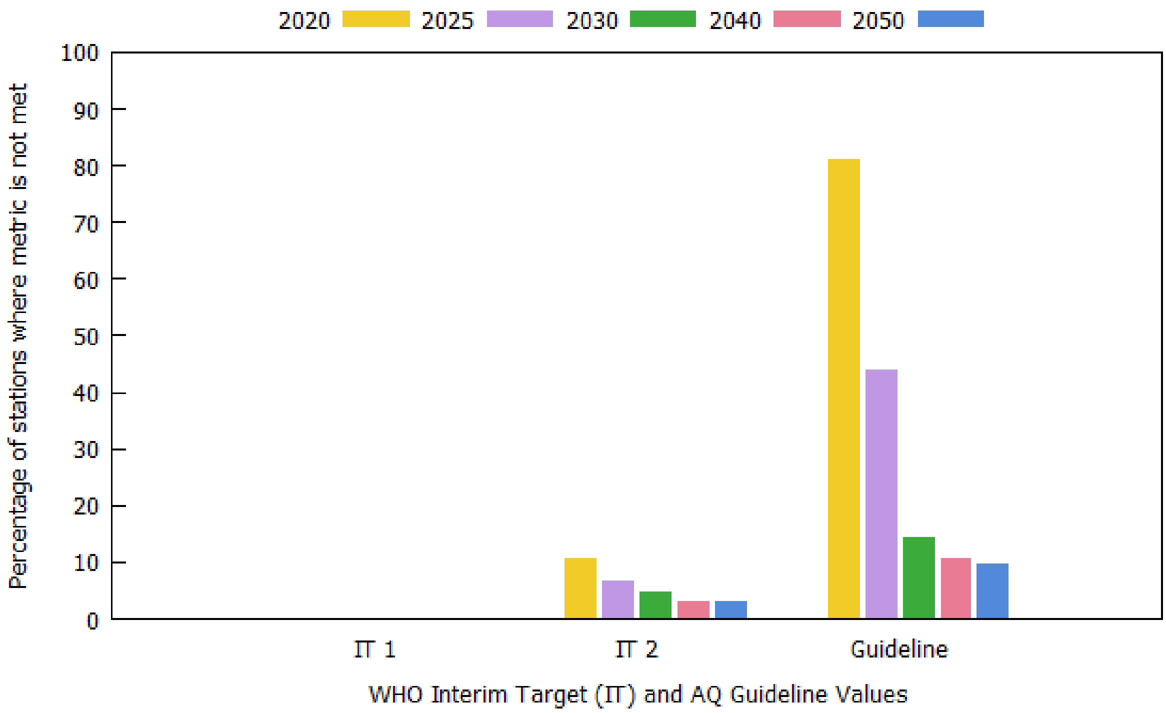

Figure 46 NO$_2$ exceedance - Poland: Proportion of stations predicted NOT to meet the WHO interim target and guideline values for under the baseline scenario (Case (0)).

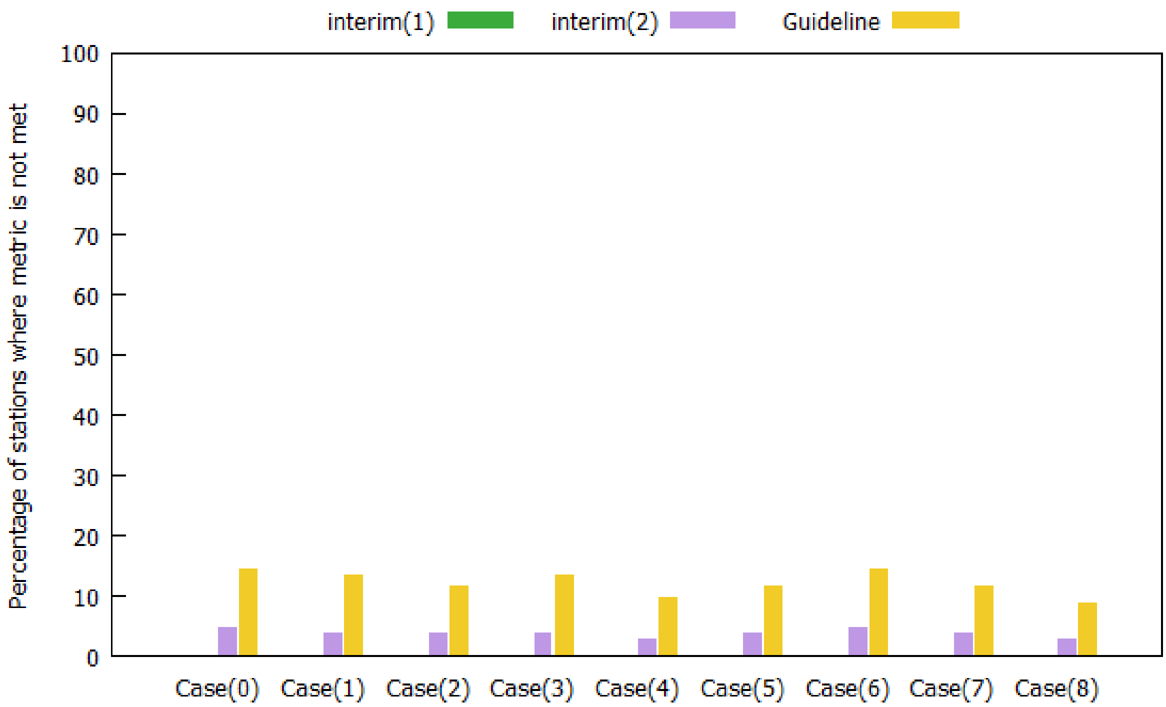

Figure 47 NO$_2$ exceedance - Poland: Scenario comparison for the number of monitoring stations NOT meeting the WHO interim target and guideline values in 2030.

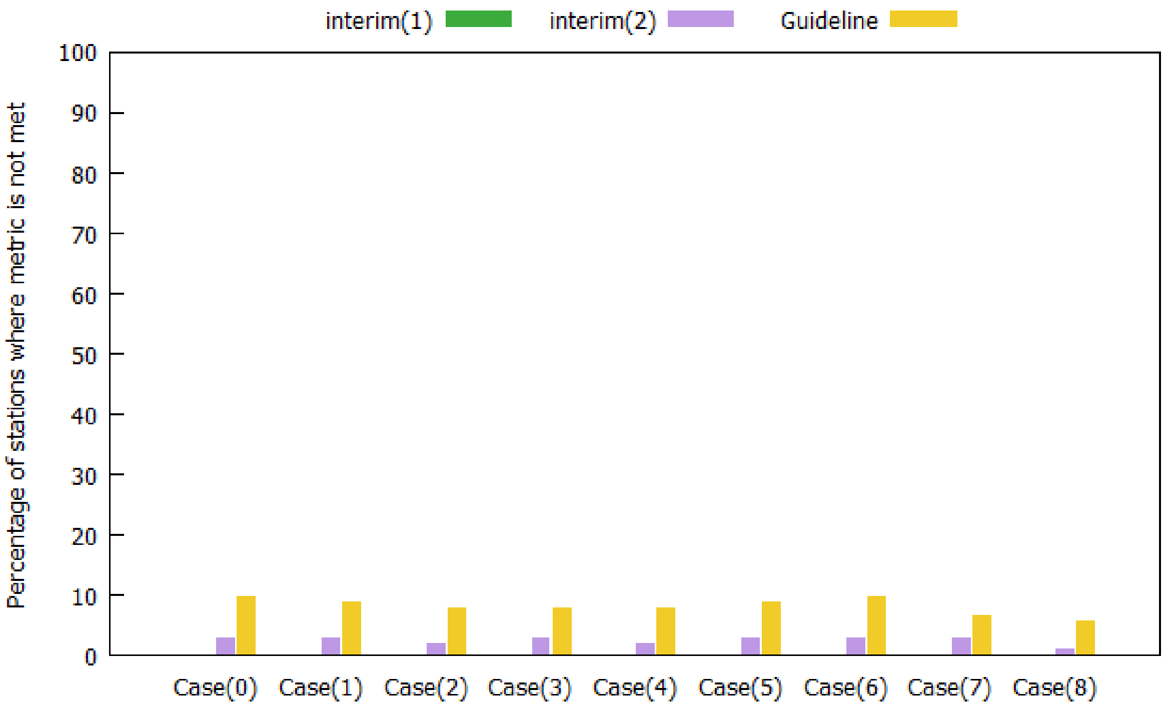

Figure 48 NO_2 exceedance - Poland: Scenario comparison for the number of monitoring stations NOT meeting the WHO interim target and guideline values in 2050.

4.5.3. NO_2 Annual Mean

Poland has 109 stations with an established record of monitoring hourly concentrations of NO_2 from which the annual mean value can be calculated and compared with a limit value.

Under the baseline scenario (**Figure 49**), there are predicted to be very few stations where WHO interim target 2 threshold of 30 µg/m^3 is not met in 2040. Slightly more for the interim target 3 value of 20 µg/m^3 and about 10% of stations at the WHO guideline value of 10 µg/m^3.

The emission reduction sensitivity cases for 2030 (**Figure 50**) show a general response to the elimination of low-level sources of NO_x with on-road transport emissions (Case (4)) having the largest effect. Domestic emissions (Case (2)) and emissions from non-road transport (Case (5)) are also having an effect. For 2050 (**Figure 51**), there is no outstanding sectoral contribution.

In addition, of the two control scenarios, MTFR + 1.5 LIFE (Case (8)) scenario produces the larger reduction in the number of stations not meeting the air quality guideline in both 2030 and 2050 compared to the MTFR scenario applied to the baseline activity scenario (Case (7)). However, neither the sectoral emission reduction scenarios nor the two control scenarios are effective enough to result in all stations meeting the WHO air quality guideline value for NO_2 annual mean.

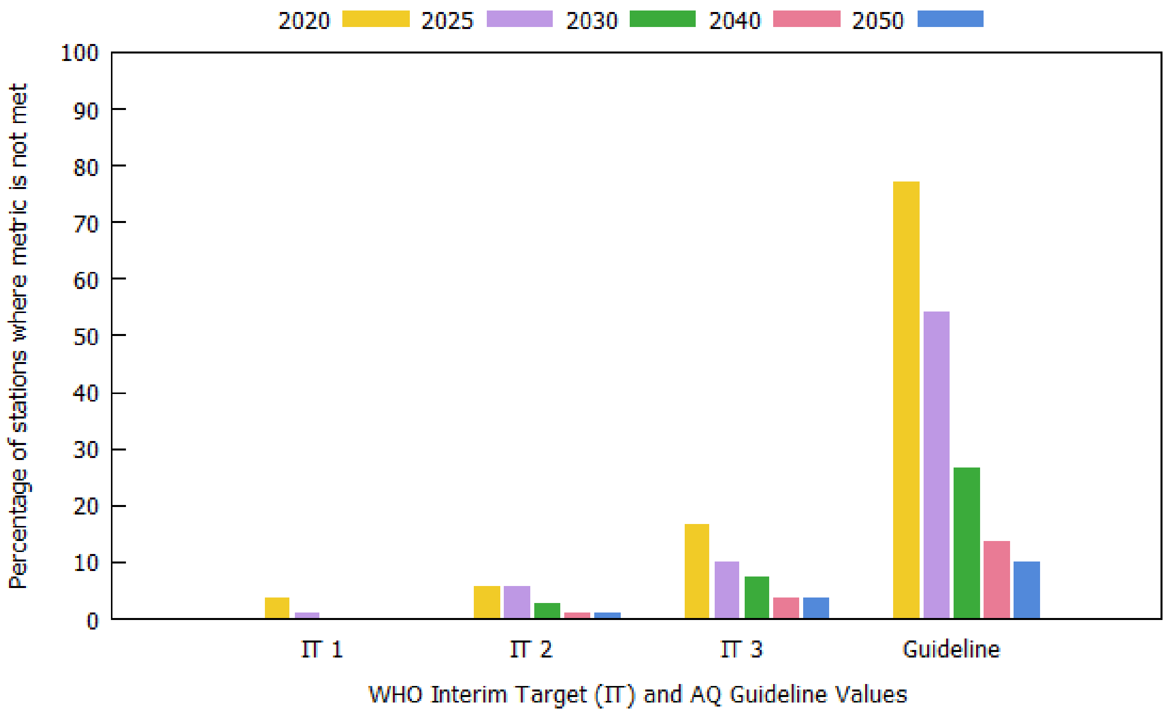

Figure 49 NO_2 annual mean - Poland: Proportion of stations predicted NOT to meet the WHO interim target and guideline values under the baseline scenario (Case (0)).

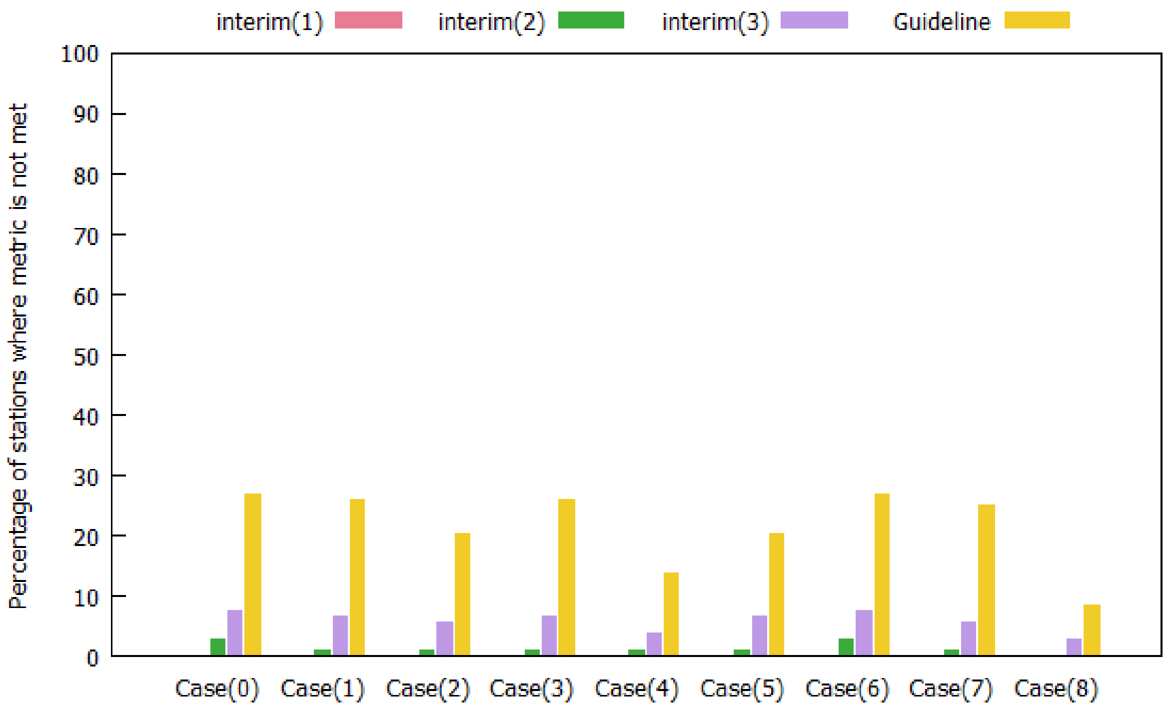

Figure 50 NO_2 annual mean - Poland: Scenario comparison for the number of monitoring stations NOT meeting the WHO interim target and guideline values in 2030.

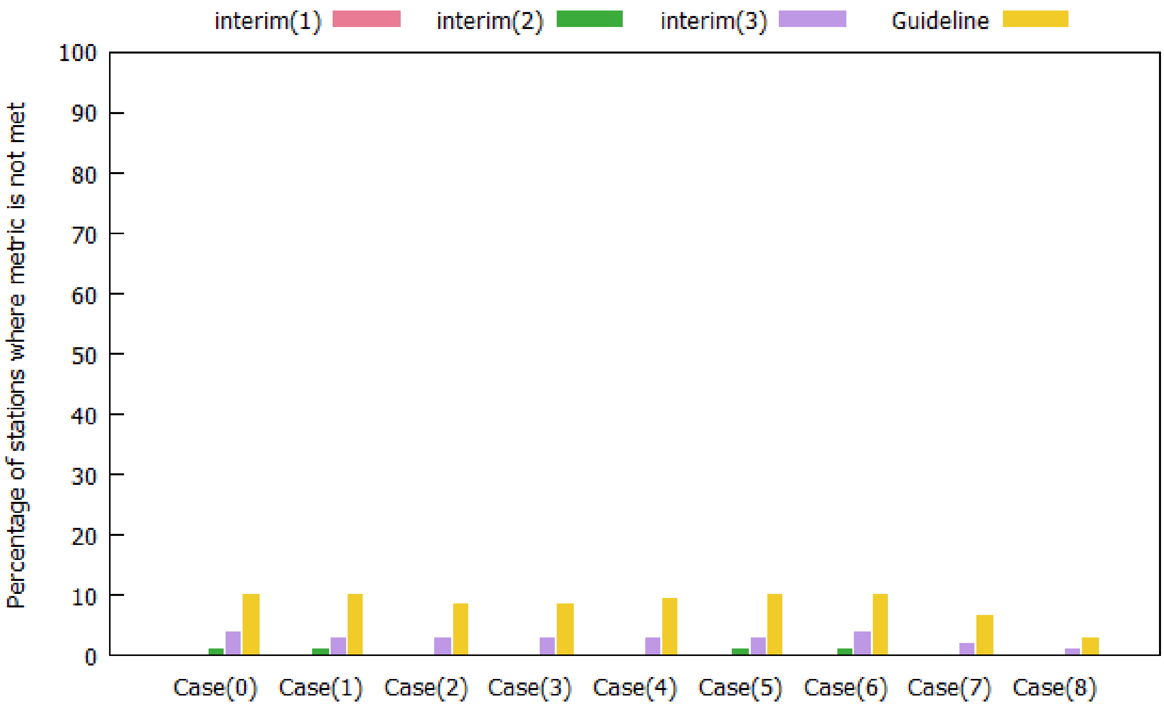

Figure 51 NO_2 annual mean - Poland: Scenario comparison for the number of monitoring stations NOT meeting the WHO interim target and guideline values in 2050.

4.5.4. PM_{10} Exceedance

Poland has 80 stations with an established record of monitoring hourly concentrations of PM_{10} from which the daily mean value and the number of threshold exceedances can be calculated.

Under the baseline scenario (**Figure 52**), there remain some stations exceeding the WHO interim target 2 threshold of 100 µg/m³ on four or more occasions a year. The number of stations not meeting the interim targets 3 and 4, and the guideline value decreases over time but there are still 36% of stations predicted to be above the air guideline value (45 µg/m_3) in 2050.

The emission reduction sensitivity cases for 2030 and 2050 (**Figure 53** and **Figure 54** respectively) show the strongest effect when considering the elimination of agricultural emissions (Case (6)). As previously mentioned, this reduces PM_{10} exceedance frequency through the contribution made by secondary $PM_{2.5}$ to the PM_{10} concentration. Elimination of domestic and commercial emissions (Case (2)) has the second largest effect, with more notable influence in 2030.

In addition, MTFR (Case (7)) and MTFR + 1.5 LIFE (Case (8)) are quite similar in effect in 2050, but even under these control scenarios, a significant proportion of stations (more than 20%) do not meet the WHO air quality guideline in 2050.

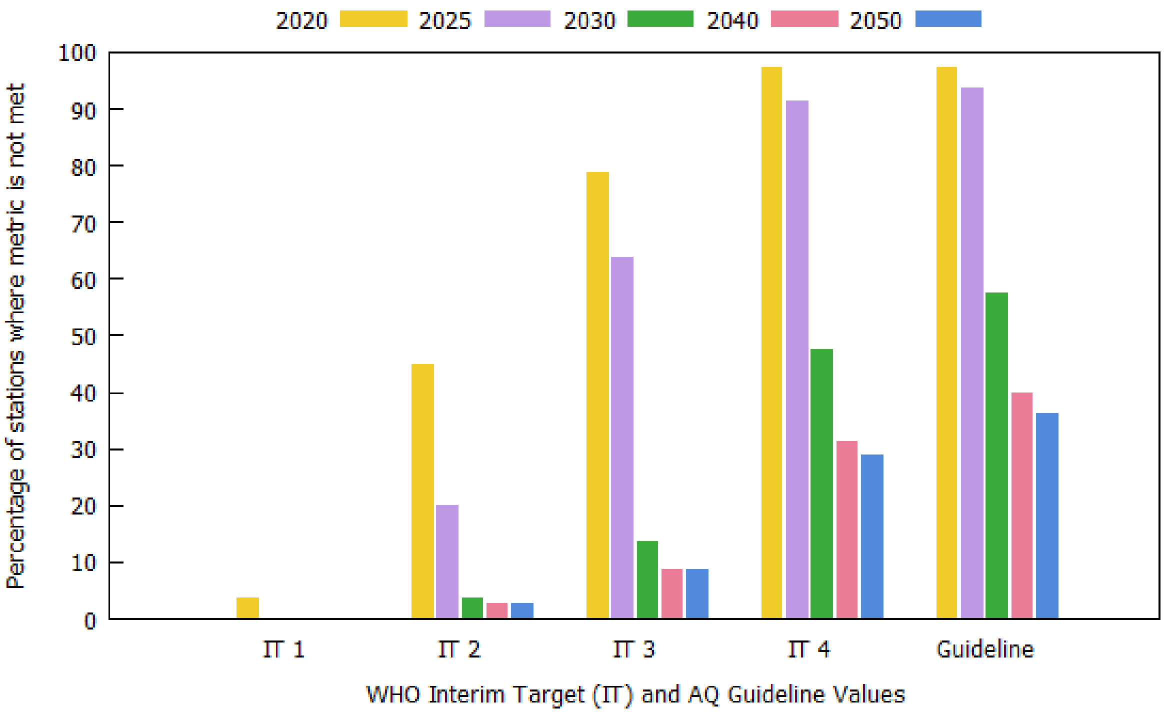

Figure 52 PM$_{10}$ exceedance - Poland: Proportion of stations predicted NOT to meet the WHO interim target and guideline values under the baseline scenario (Case (0)).

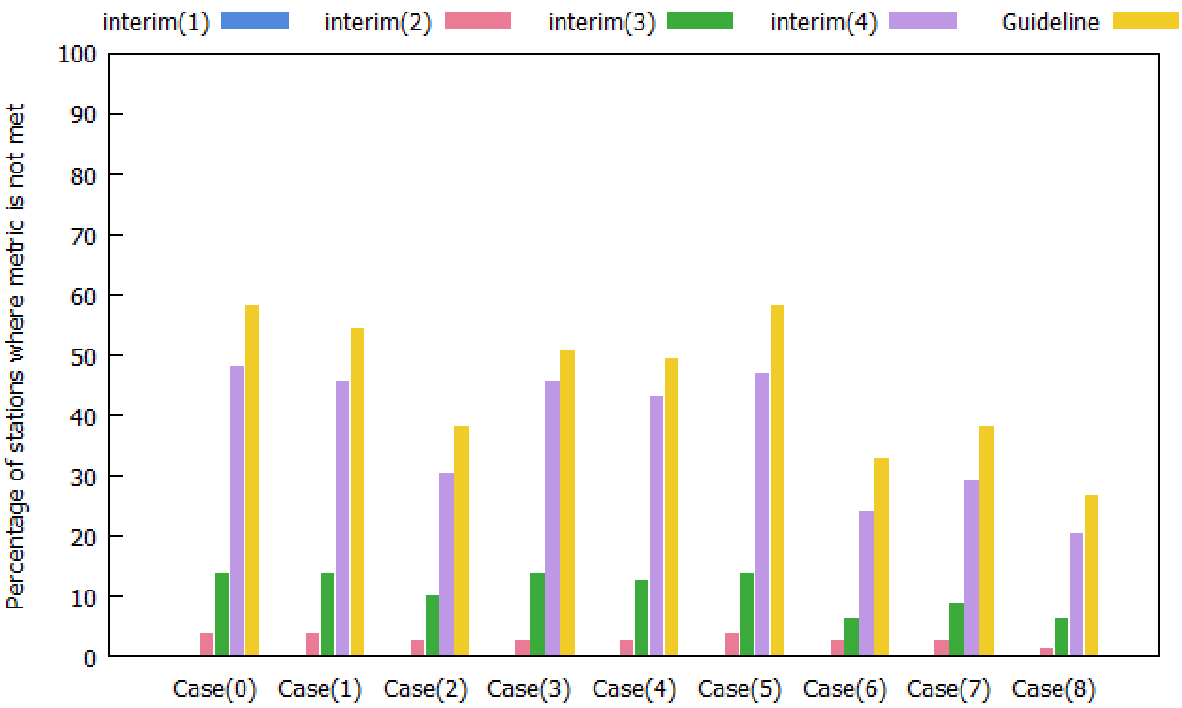

Figure 53 PM$_{10}$ exceedance - Poland: Scenario comparison for the number of monitoring stations NOT meeting the WHO interim target and guideline values in 2030.

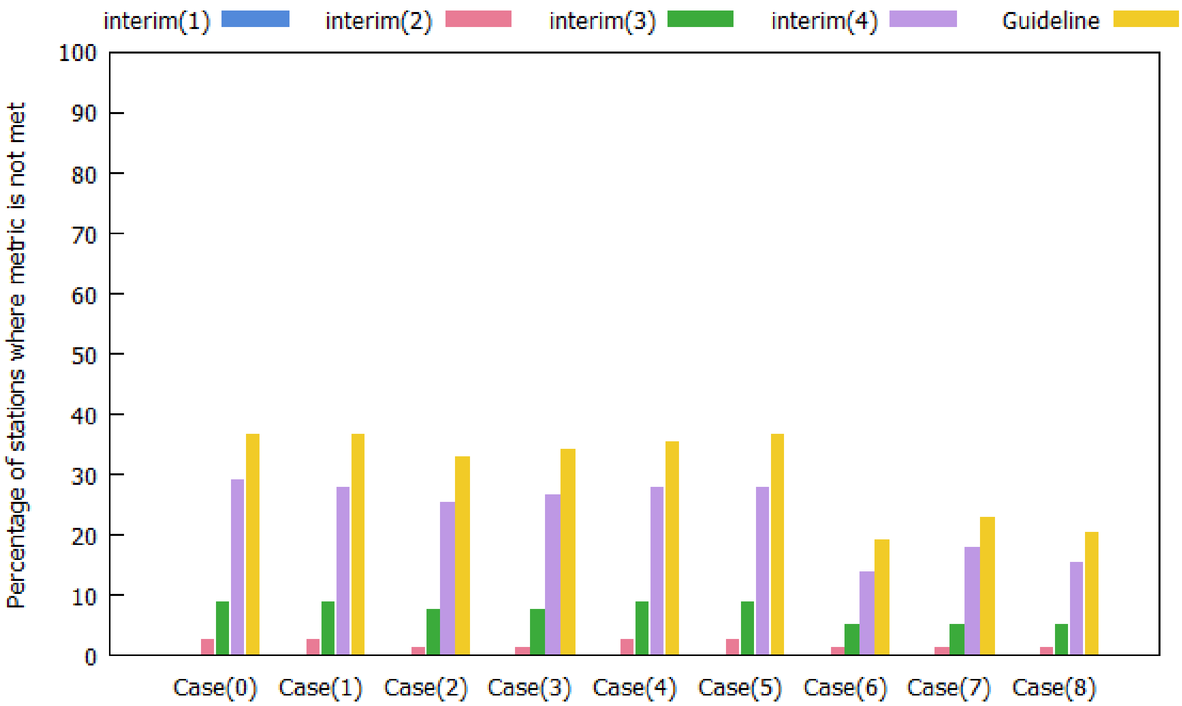

Figure 54 PM_{10} exceedance - Poland: Scenario comparison for the number of monitoring stations NOT meeting the WHO interim target and guideline values in 2050.

4.5.5. PM_{10} Annual Mean

Poland has 81 stations with an established record of monitoring hourly concentrations of PM_{10} from which the annual mean value can be calculated and compared with a limit value.

Under the baseline scenario (**Figure 55**), the annual mean concentrations measured at stations decrease over time. There remain very few stations where the WHO interim target 3 of 30 µg/m^3 is exceeded in 2030, but nearly 20% of the stations are predicted to still have annual concentrations above the interim target 4 value of 20 µg/m^3 in 2050. When considering the guideline value of 15 µg/m^3 almost 60% of the stations in Poland are predicted to exceed it in 2050.

The emission reduction sensitivity calculations for 2030 and 2050 (**Figure 56** and **Figure 57** respectively) show that excluding domestic and commercial emissions (Case (2)) and excluding agricultural emissions (Case (6)) have the largest impact on the proportion of stations where concentrations are higher than the above WHO thresholds. The effect associated with the elimination of domestic and commercial emissions is rather short term and most noticeable in 2030 which is consistent with a phase-out of solid fuel use for heating in the base scenario toward 2050, while the removal of agricultural emissions will continue reducing the number of stations not meeting the WHO values in 2050.

The control scenario MTFR + 1.5 LIFE (Case (8)) is predicted to give fewer stations with annual concentrations above the thresholds than MTFR alone (Case (7)) suggesting that the associated activity changes are important. However, even under these control scenarios as well as the most significant sectoral emission reduction scenarios (Case (6) and Case (2)), there still remains a significant proportion of stations above the WHO air quality guideline value of 15 µg/m^3 in 2050 (ranging from 30% up to 55% depending on the scenario).

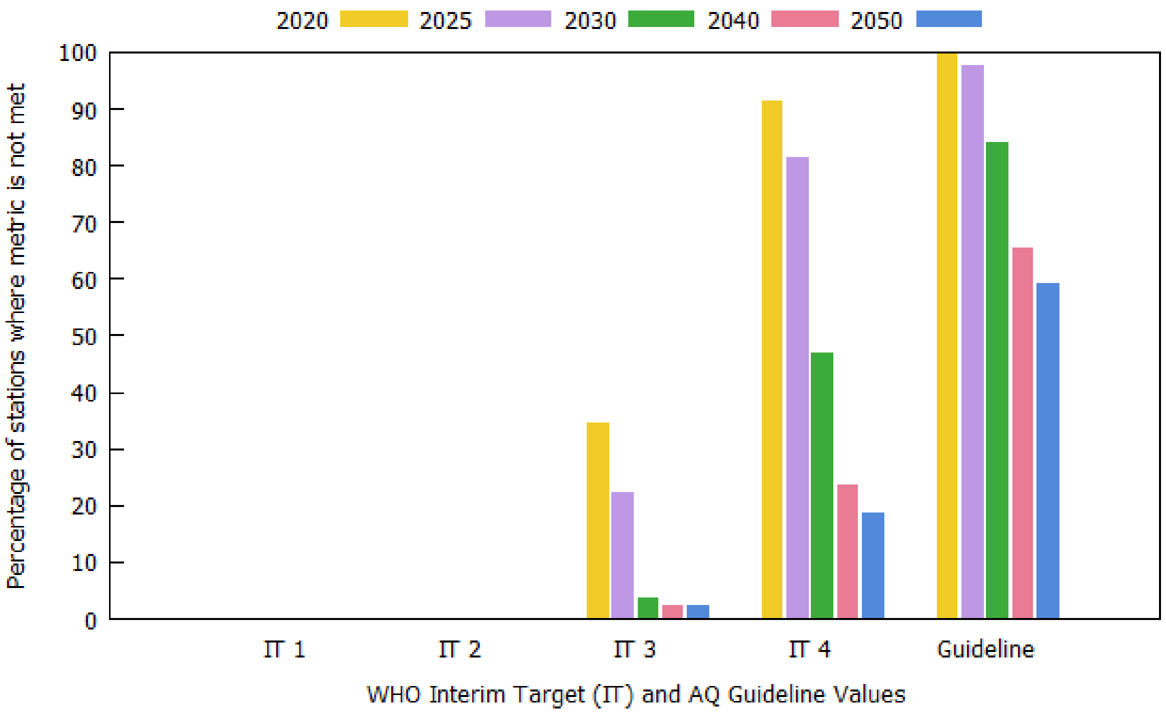

Figure 55 PM_{10} annual mean - Poland: Proportion of stations predicted NOT to meet the WHO interim target and guideline values under the baseline scenario (Case (0)).

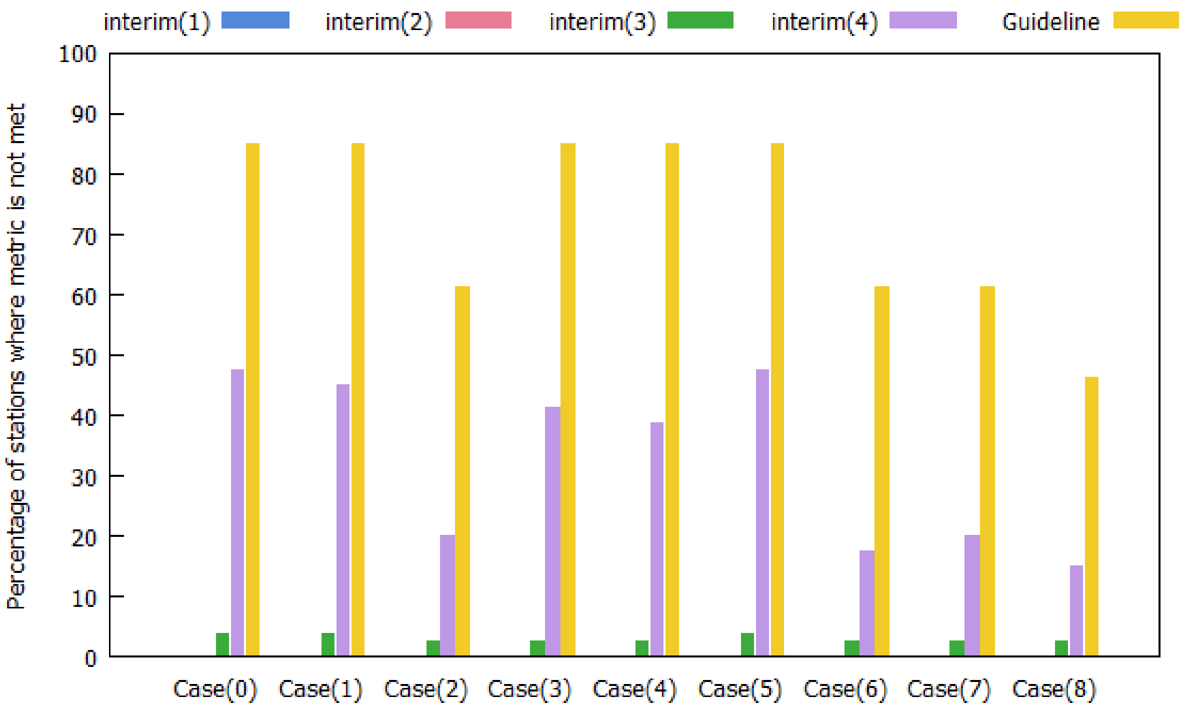

Figure 56 PM_{10} annual mean - Poland: Scenario comparison for the number of monitoring stations NOT meeting the WHO interim target and guideline values in 2030.

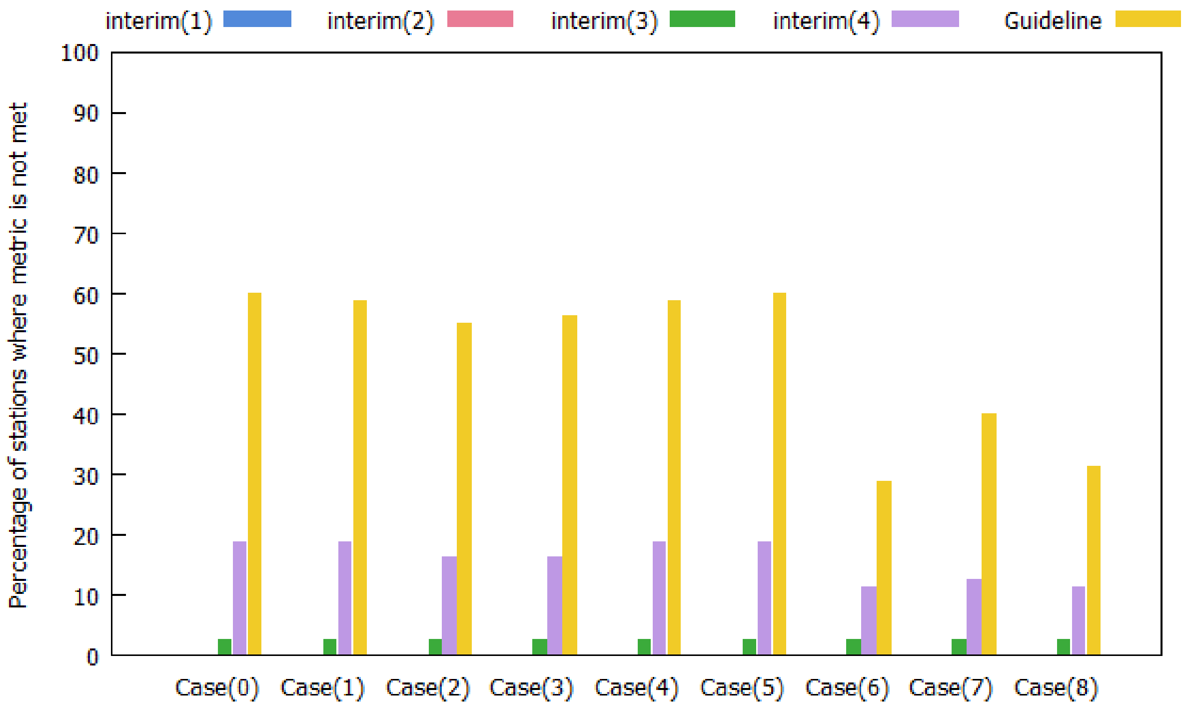

Figure 57 PM_{10} annual mean - Poland: Scenario comparison for the number of monitoring stations NOT meeting the WHO interim target and guideline values in 2050.

4.5.6. $PM_{2.5}$ Exceedance

Poland has 96 stations with an established record of monitoring hourly concentrations of $PM_{2.5}$ from which the daily mean value and the number of threshold exceedances can be calculated.

Under the baseline scenario (**Figure 58**), there are stations where the daily average $PM_{2.5}$ concentration at all WHO interim target and guideline values is exceeded on four or more occasions a year, even in 2050. For example, more than half of the stations have exceedances at the interim target 4 of 25 µg/m^3, while nearly all stations have exceedances at the guideline value of 15 µg/m^3.

Similarly to PM_{10} results, the emission reduction sensitivity scenarios for 2030 and 2050 (**Figure 59** and **Figure 60** respectively) show the strongest effect when removing agricultural emissions (Case (6)), while eliminating emissions from other sectors will have a negligible effect.

The two control scenarios make only a modest change at the WHO guideline value to the proportion of stations having exceedances. At the interim target values, the MTFR + 1.5 LIFE (Case (8)) reduces this proportion more than does MTFR (Case (7)) but in 2050, there still remain some stations not even meeting the exceedance target at the interim target 2 value. It is also important to note that in all scenarios examined, more than 80% of the stations are constantly predicted not to meet the WHO air quality guideline value in 2050 (can exceed even 95% depending on the scenario).

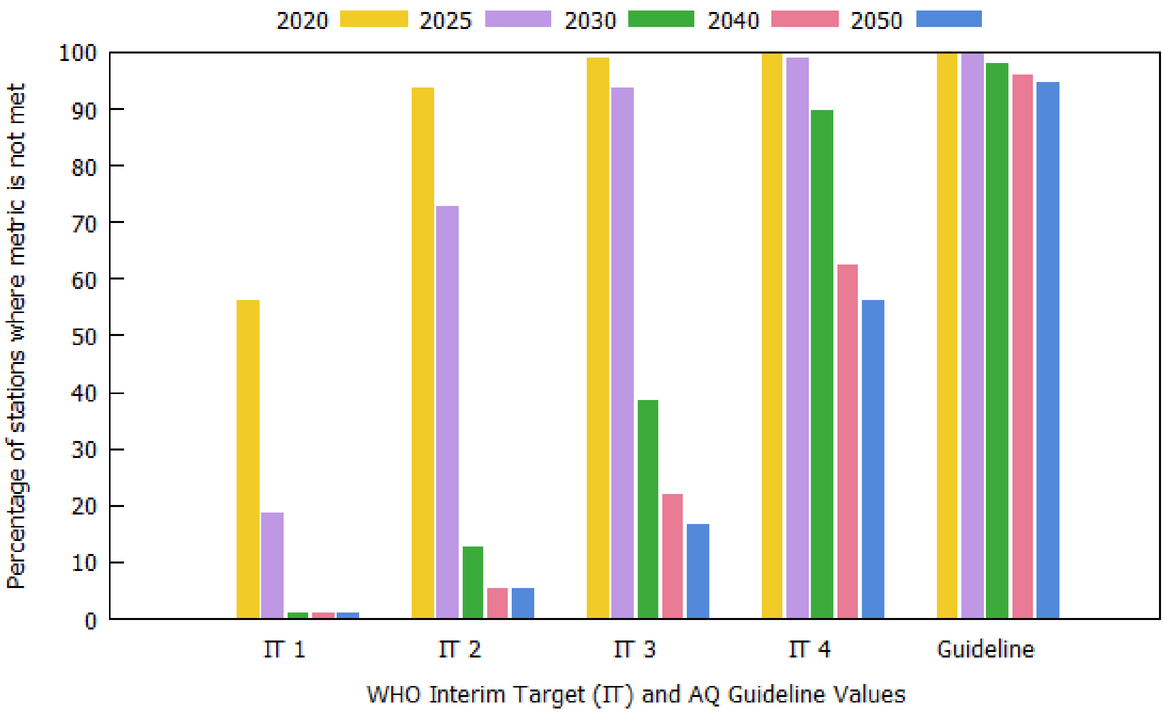

Figure 58 PM$_{2.5}$ exceedance - Poland: Proportion of stations predicted NOT to meet the WHO interim target and guideline values under the baseline scenario (Case (0)).

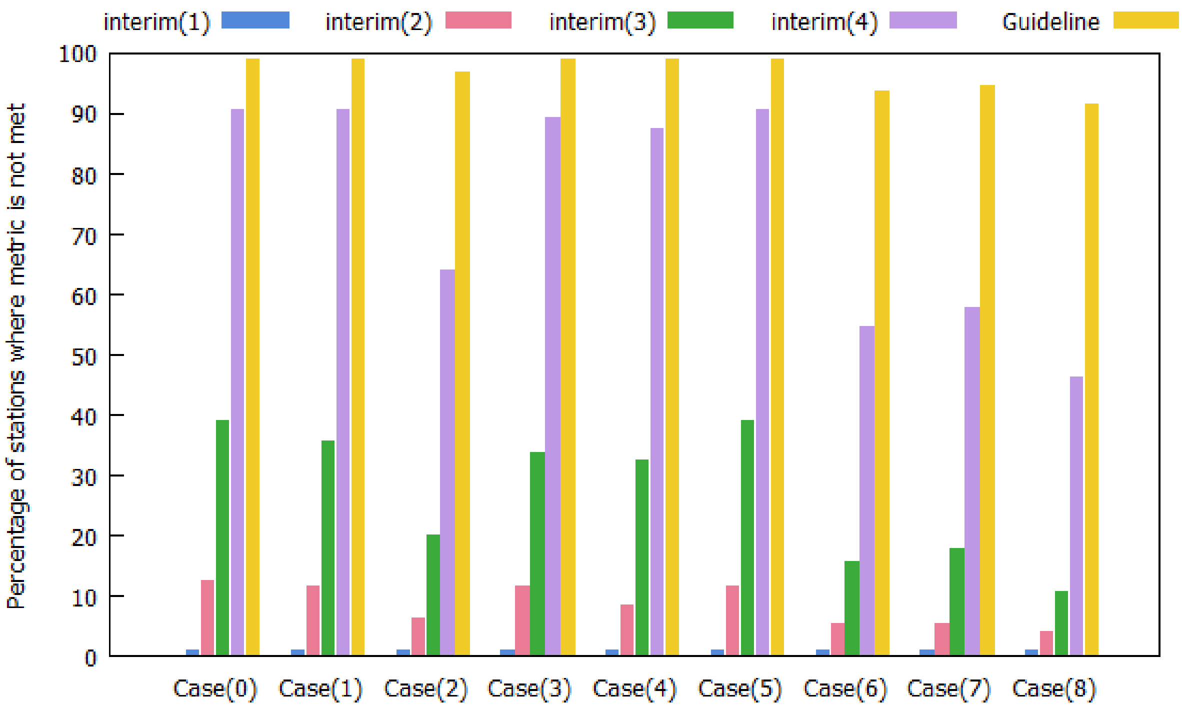

Figure 59 PM$_{2.5}$ exceedance - Poland: Scenario comparison for the number of monitoring stations NOT meeting the WHO interim target and guideline values in 2030.

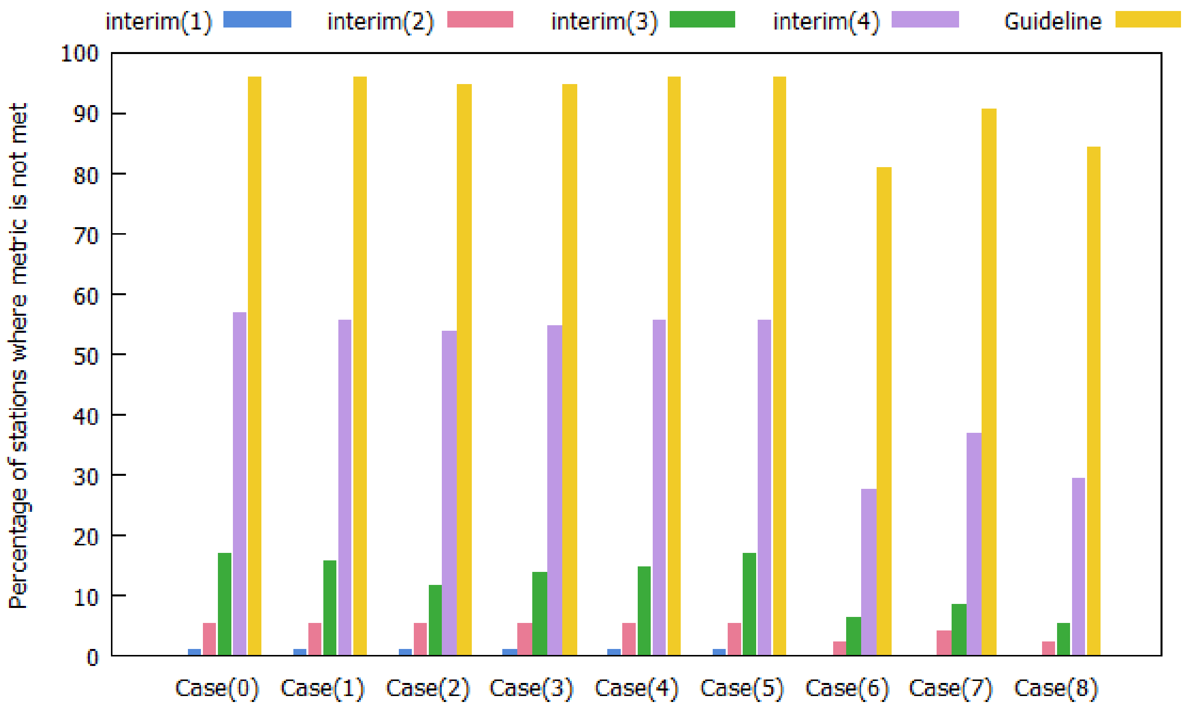

Figure 60 $PM_{2.5}$ exceedance - Poland: Scenario comparison for the number of monitoring stations NOT meeting the WHO interim target and guideline values in 2050.

4.5.7. $PM_{2.5}$ Annual Mean

Poland has 96 stations with an established record of monitoring hourly concentrations of $PM_{2.5}$ from which the annual mean value can be calculated and compared with a limit value.

Under the baseline scenario (**Figure 61**), annual concentrations reduce over time but remain high compared to the WHO interim target 4 and air quality guideline value. In particular, approximately 40% of the stations have an annual mean concentration above the interim target 4 value of 10 µg/m^3 and all stations have an annual mean concentration above the WHO air quality guideline of 5 µg/m^3.

The emission reduction sensitivity scenarios for 2030 and 2050 (**Figure 62** and **Figure 63** respectively) show that in 2030 no emission reduction, whether by eliminating a single sector emission or combining reductions across sectors, reduces the annual mean $PM_{2.5}$ concentration at any of the stations below the guideline threshold of 5 µg/m^3. Eliminating emissions from the domestic and commercial sector (Case (2)) and from agriculture (Case (6)) has the largest effect on the number of stations where the annual concentration is above the interim target 4 of 10 µg/m^3.

In 2050, the control scenario MTFR (Case (7)) reduces the proportion of stations where the annual concentration is above the interim target 3 value of 15 µg/m^3 to 1% and above the interim target 4 value of 10 µg/m^3 to 6%. The control scenario MTFR + 1.5 LIFE (Case (8)) reduces the latter to 3%. With respect to the air quality guideline value of 5 µg/m^3, most stations have annual concentrations that do not meet the limit value (90% of the stations under MTFR (Case (7)) and 81% under MTFR + 1.5 LIFE (Case (8)) scenarios).

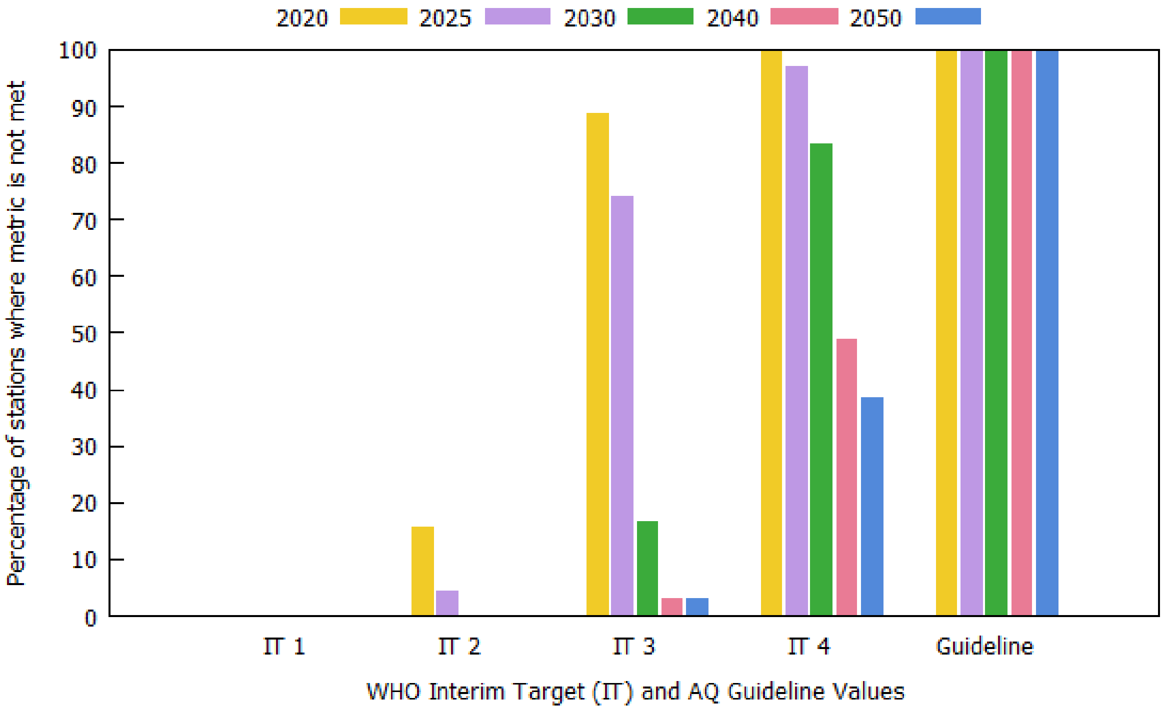

Figure 61 $PM_{2.5}$ annual mean - Poland: Proportion of stations predicted NOT to meet the WHO interim target and guideline values under the baseline scenario (Case (0)).

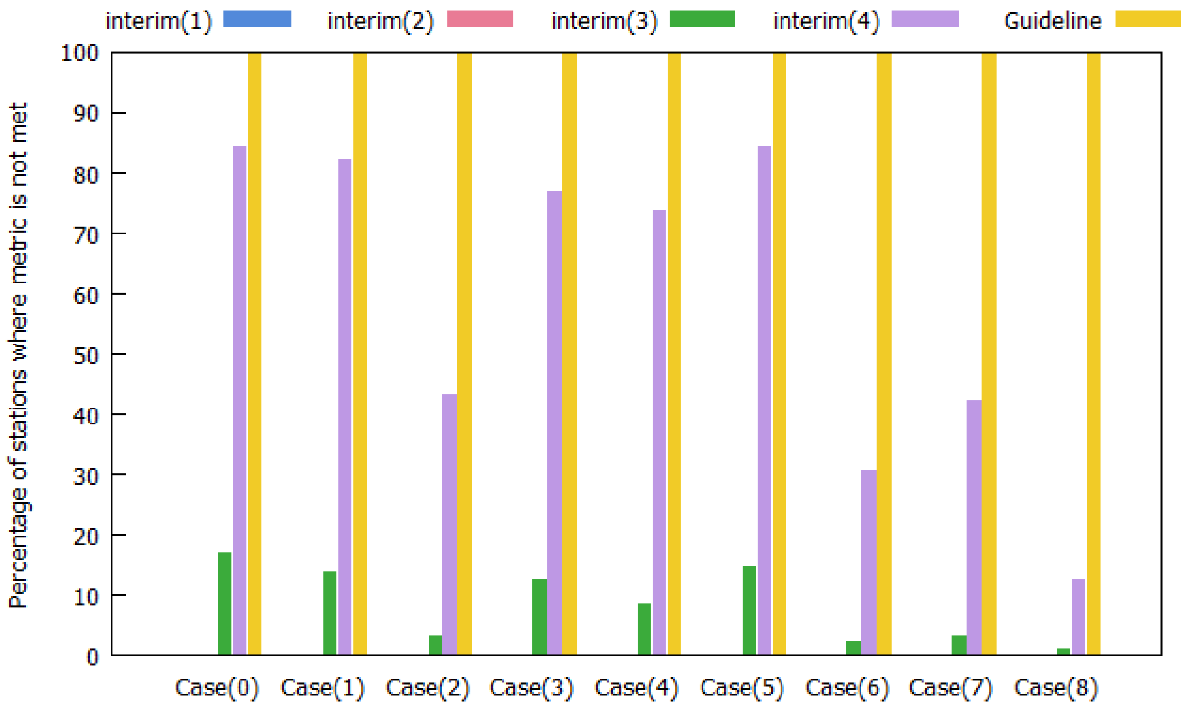

Figure 62 PM$_{2.5}$ annual mean - Poland: Scenario comparison for the number of monitoring stations NOT meeting the WHO interim target and guideline values in 2030.

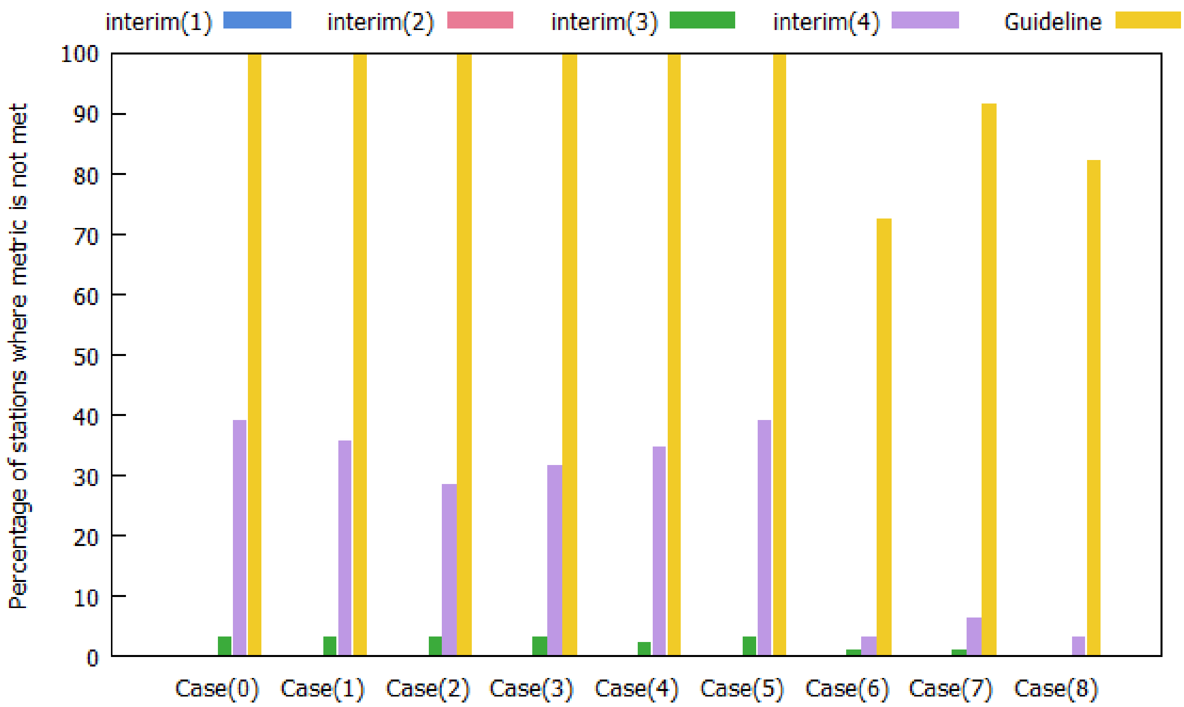

Figure 63 PM$_{2.5}$ annual mean - Poland: Scenario comparison for the number of monitoring stations NOT meeting the WHO interim target and guideline values in 2050.

4.6. ITALY

4.6.1. Ozone Exceedance

Italy has 162 stations with an established record of monitoring hourly concentrations of ozone from which the maximum daily 8-hr mean concentration and the number of threshold exceedances can be calculated.

Under the baseline scenario (

Figure *64*), the proportion of stations where the ozone exceedance targets are not met decrease with time. However, Italy is predicted to face significant challenges in fully meeting the WHO interim target and air quality guideline values. In 2050 for example, there are a number of stations (~7%) that have four or more exceedances per year of the interim target 1 (160 µg/m^3) and the majority (73%) of stations have four or more daily concentrations above the interim target 2 (120 µg/m^3) value. Regarding the air quality guideline value, only a few stations are predicted to meet the value, with around 97% having four or more days of ozone concentration above 100 µg/m^3.

The emission reduction sensitivity scenarios for 2030 and 2050 are shown in **Figure 65** and **Figure 66** respectively. Similar to the results for France and Poland, the elimination of industry combustion/process and solvent produce/use emissions (Case (3)) has the largest effect in increasing the number of stations that meet the WHO interim target and guideline values. In all remaining sectoral emission reduction scenarios, the additional improvement of stations meeting the WHO values is rather small.

Neither of the two control scenarios MTFR (Case (7)) and MTFR + 1.5 LIFE (Case (8)) results in all stations meeting the WHO values. A large proportion of stations will not meet the interim target 2 exceedance criteria in 2050 (~57% for Case (7) and 48% for Case (8)), while more than 92% of the stations will not meet the WHO air quality guideline in 2050.

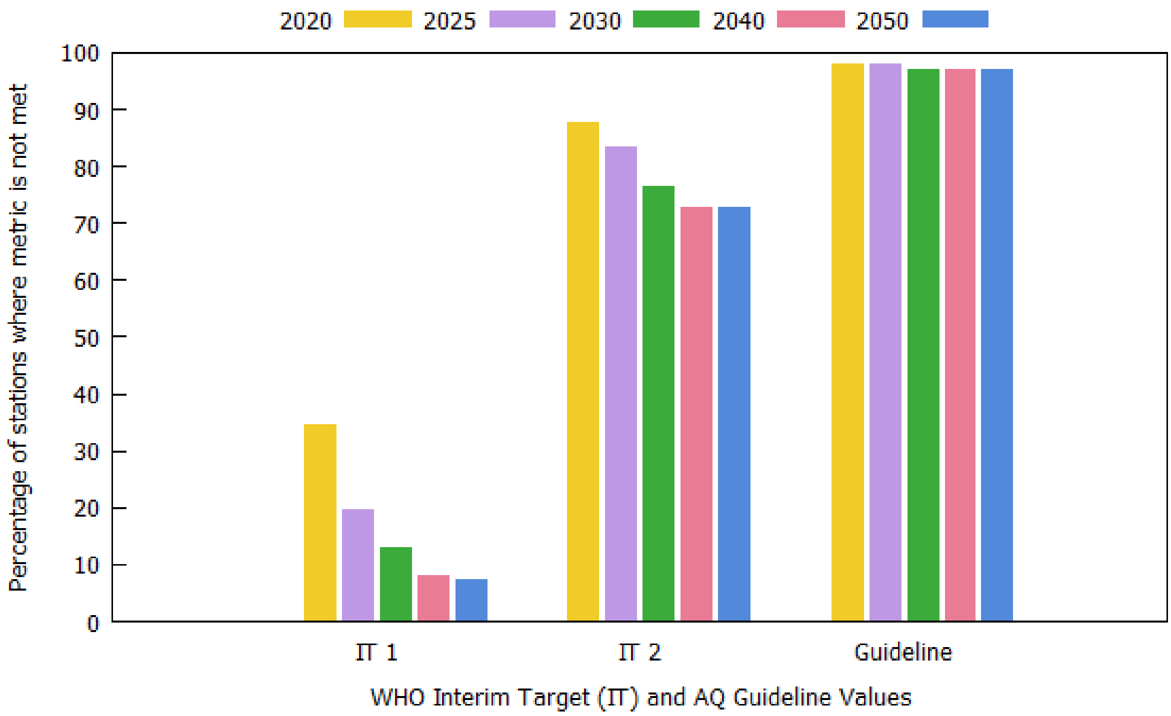

Figure 64 O_3 exceedance - Italy: Proportion of stations predicted NOT to meet the WHO interim target and guideline values under the baseline scenario (Case (0)).

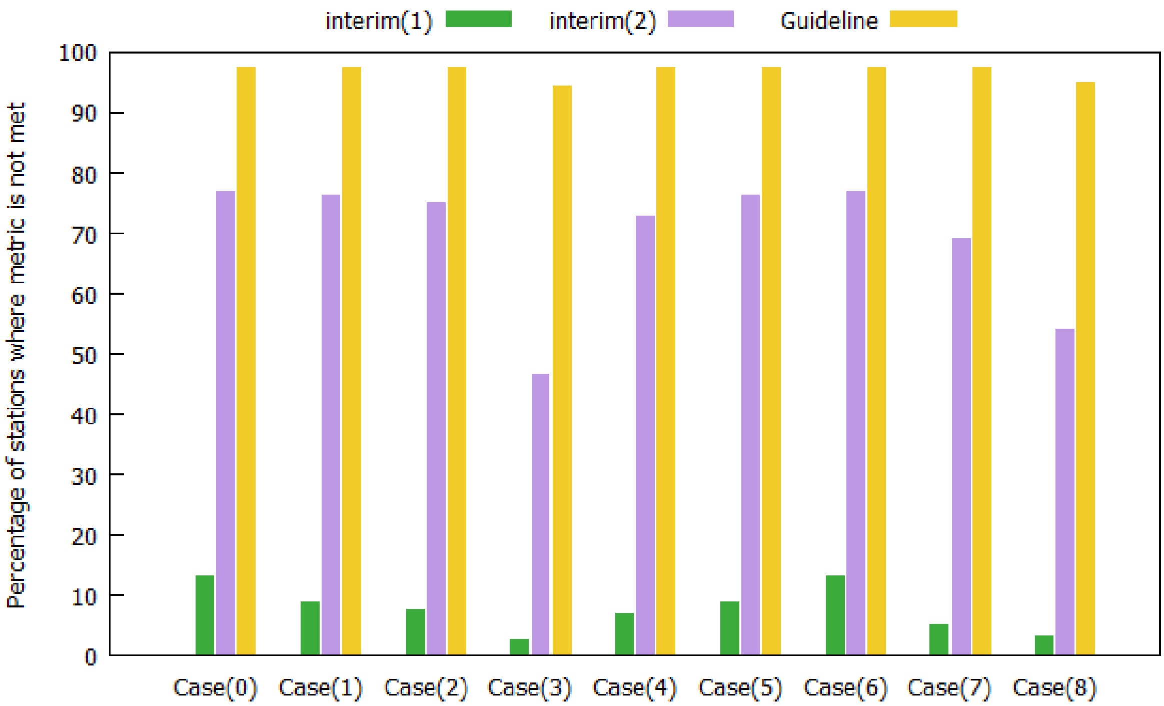

Figure 65 O_3 exceedance - Italy: Scenario comparison for the number of monitoring stations NOT meeting the WHO interim target and guideline values in 2030.

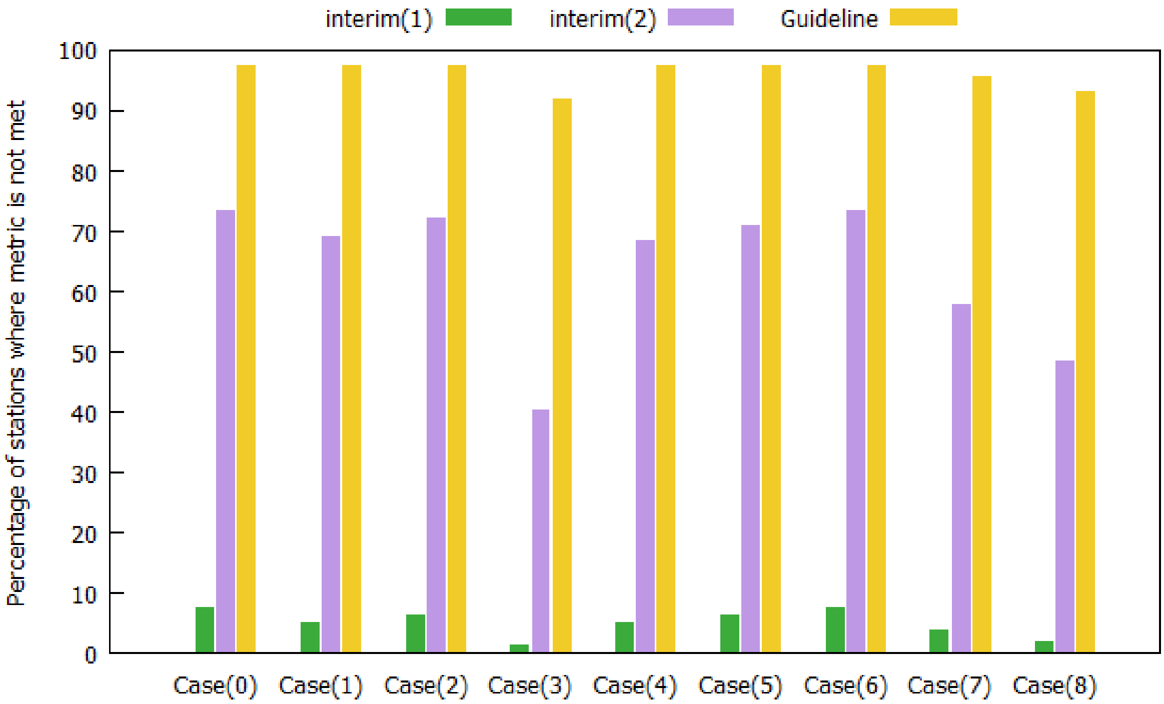

Figure 66 O_3 exceedance - Italy: Scenario comparison for the number of monitoring stations NOT meeting the WHO interim target and guideline values in 2050.

4.6.2. NO_2 Exceedance

Italy has 141 stations with an established record of monitoring hourly concentrations of NO_2 from which the daily mean value and the number of threshold exceedances can be calculated.

Under the baseline scenario (**Figure 67**), all stations are predicted to meet WHO interim target 1 of 120 µg/m^3 in all years, while by 2050 only 4% of stations have four or more exceedances per year of the interim target 2 of 50 µg/m^3. However, meeting the WHO air quality guideline will pose significant challenges as a large proportion of stations (~38%) is predicted to have four or more daily exceedances of the guideline value of 25 µg/m^3 in 2050.

The emission reduction sensitivity scenarios for 2030 and 2050 (**Figure 68** and **Figure 69** respectively) show that there is no dominant sector contribution to NO_2 exceedance. The elimination of emissions from the road transport sector (Case (4)) may have some small effect in 2030 compared to other sectors but this is no longer noticeable in 2050, where NO_2 emissions from transport will be much reduced by current legislation and the natural fleet turnover.

The two control scenarios make a small difference to the proportion of stations meeting the guideline exceedance criteria. The MTFR + 1.5 LIFE (Case (8)) is more effective than MTFR (Case (7)), but even under these scenarios, a significant proportion of stations will not meet the WHO air quality guideline value in 2050 (22% for MTFR + 1.5 LIFE and 28% for MTFR scenario respectively).

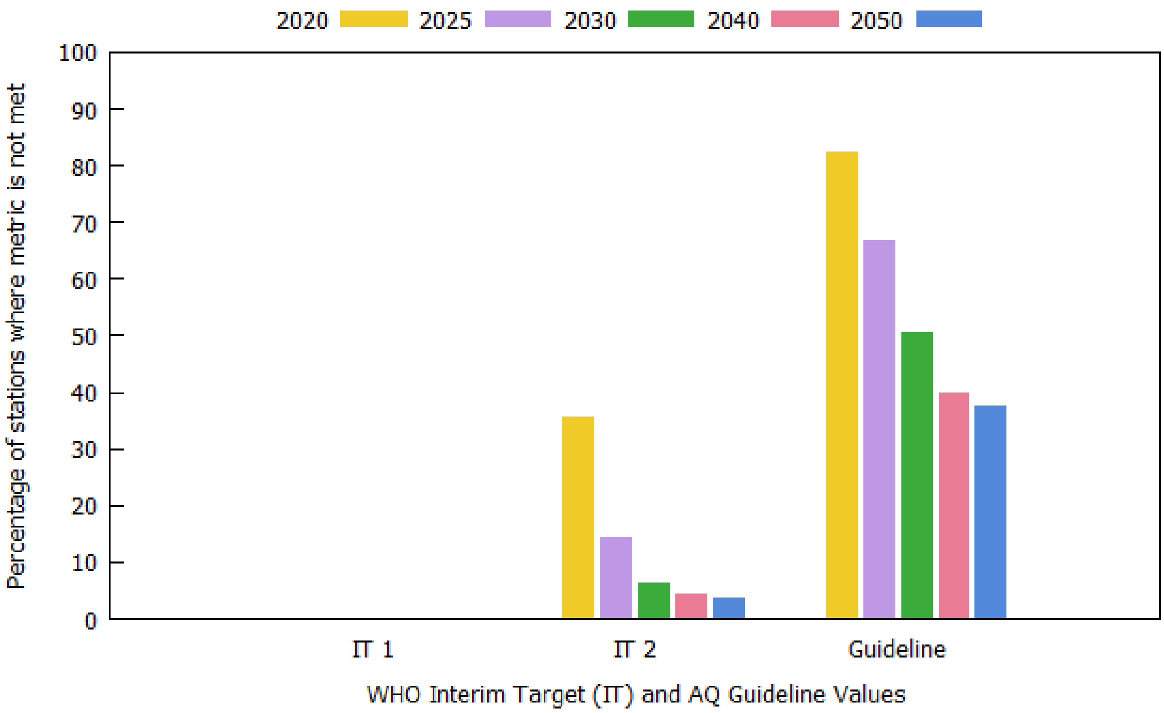

Figure 67 NO_2 exceedance - Italy: Proportion of stations predicted NOT to meet the WHO interim target and guideline values under the baseline scenario (Case (0)).

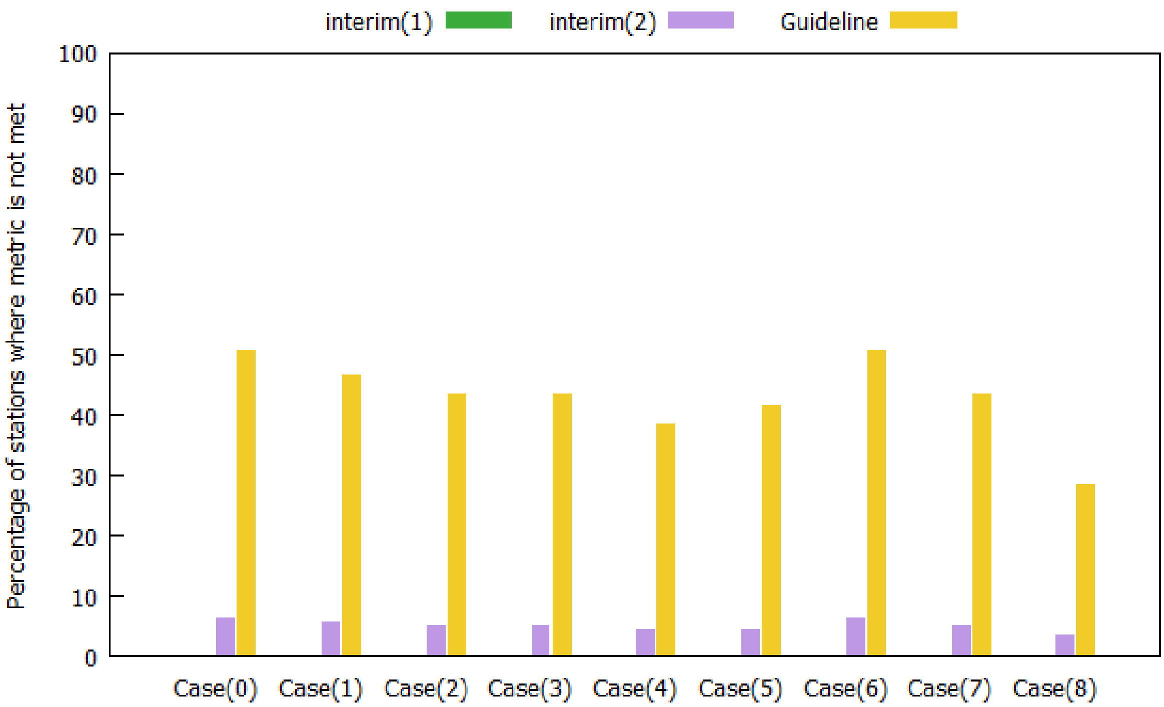

Figure 68 NO_2 exceedance - Italy: Scenario comparison for the number of monitoring stations NOT meeting the WHO interim target and guideline values in 2030.

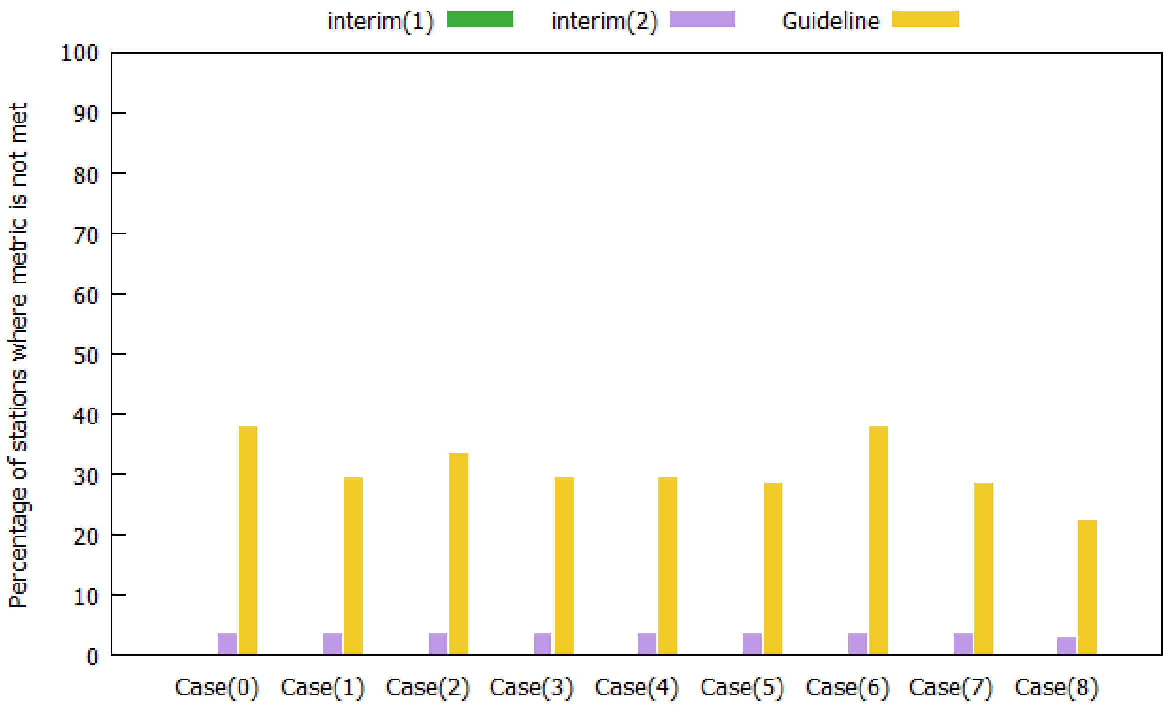

Figure 69 NO_2 exceedance - Italy: Scenario comparison for the number of monitoring stations NOT meeting the WHO interim target and guideline values in 2050.

4.6.3. NO_2 Annual Mean concentration

Italy has 143 stations with an established record of monitoring hourly concentrations of NO_2 from which the annual mean value can be calculated and compared with a limit value.

Under the baseline scenario (**Figure 70**), early all stations are predicted to meet the interim target 2 of 30 μg/m^3 annual mean concentration from 2025 onwards. Regarding the interim target 3 of 20 μg/m^3, less than 10% of stations will not meet the value in 2030 reducing to only 2% in 2050. However, considering the WHO air quality guideline value, a significant proportion of stations is predicted to have concentrations above the value of 10 μg/m^3 (46% in 2030 and 32% in 2050).

The emission reduction sensitivity scenarios for 2030 and 2050 (**Figure 71** and **Figure 72** respectively) show a similar pattern to those for NO_2 exceedance. In 2030, eliminating emissions from road transport (Case (4)) has the largest effect but this is no longer apparent in 2050 when transport emissions will be low under the current regulation.

Of the two control scenarios, MTFR + 1.5 LIFE (Case (8)) has the larger effect in increasing the number of stations meeting the WHO criteria. However, even under this scenario, 9% of the stations in Italy is still predicted to have concentrations above the guideline value in 2050 (18% under MTFR).

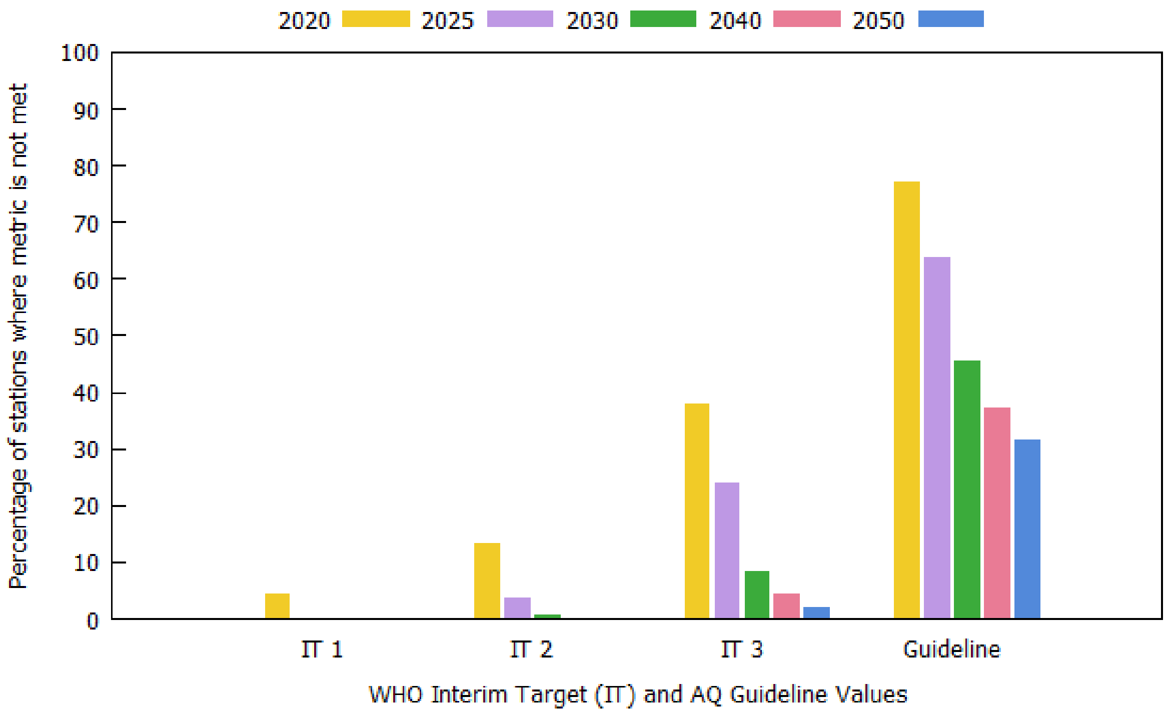

Figure 70 NO_2 annual mean - Italy: Proportion of stations predicted NOT to meet the WHO interim target and guideline values under the baseline scenario (Case (0)).

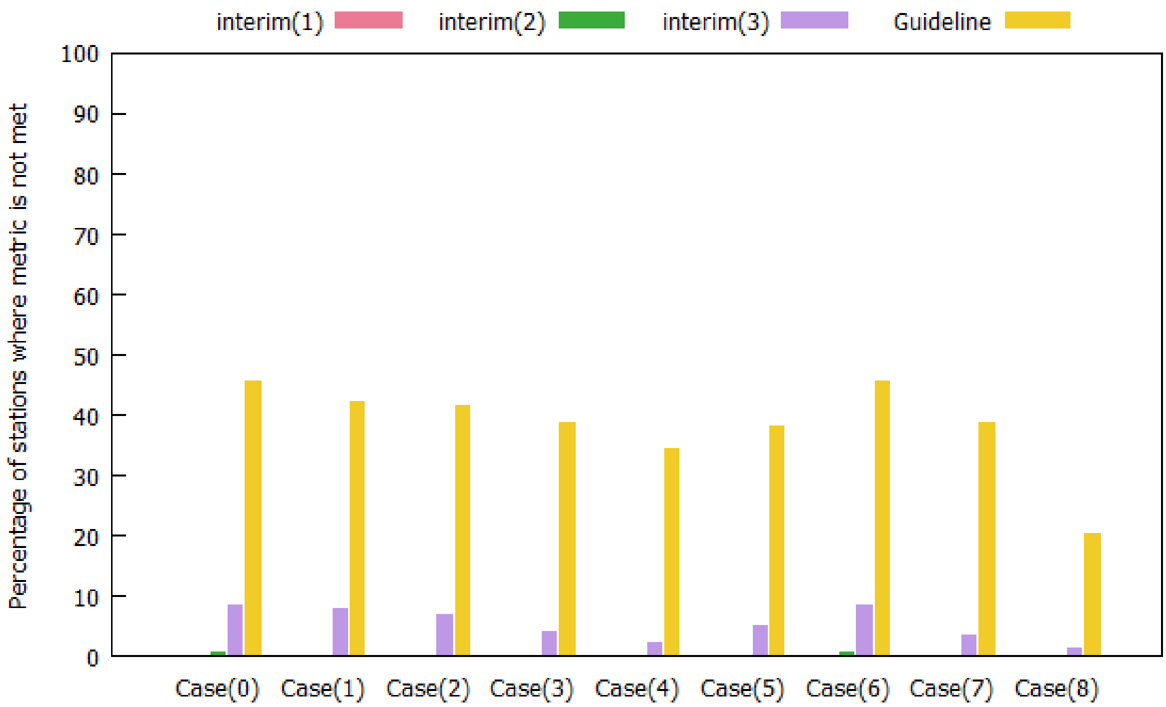

Figure 71 NO_2 annual mean - Italy: Scenario comparison for the number of monitoring stations NOT meeting the WHO interim target and guideline values in 2030.

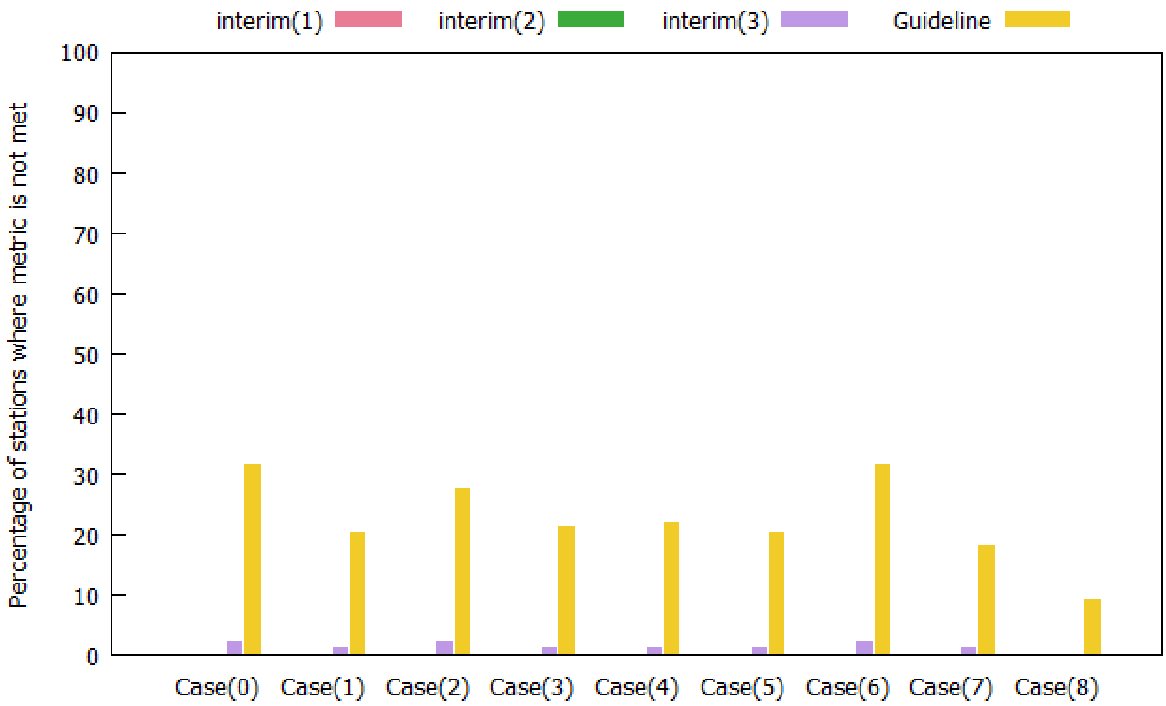

Figure 72 NO_2 annual mean - Italy: Scenario comparison for the number of monitoring stations NOT meeting the WHO interim target and guideline values in 2050.

4.6.4. PM_{10} Exceedance

Italy has 185 stations with an established record of monitoring hourly concentrations of PM_{10} from which the daily mean value and the number of threshold exceedances can be calculated.

Under the baseline scenario (**Figure 73**), there are a very small number of stations with more than four exceedances per year of the interim target 2 of 100 µg/m^3 in 2030 and interim target 3 of 75 µg/m^3 for PM_{10} daily mean concentration in 2050. However, when considering the interim target 4 of 50 µg/m^3 and the air quality guideline value of 45 µg/m^3 a substantial proportion of stations are predicted not to meet the criteria (32% and 40% respectively in 2050).

Among all sectoral emission reduction scenarios for 2030 and 2050 (**Figure 74** and **Figure 75** respectively), the elimination of agricultural emissions (Case (6)) has the most noticeable effect and being comparable with the effects associated to the control scenario MTFR + 1.5 LIFE (Case (8)). Nevertheless, none of the scenarios is expected to result in all stations having concentrations that do meet the air quality guideline value. In particular, the proportion of stations not meeting the guideline value in 2050 is 34% under MTFR and 28% for MTFR + 1.5 LIFE.

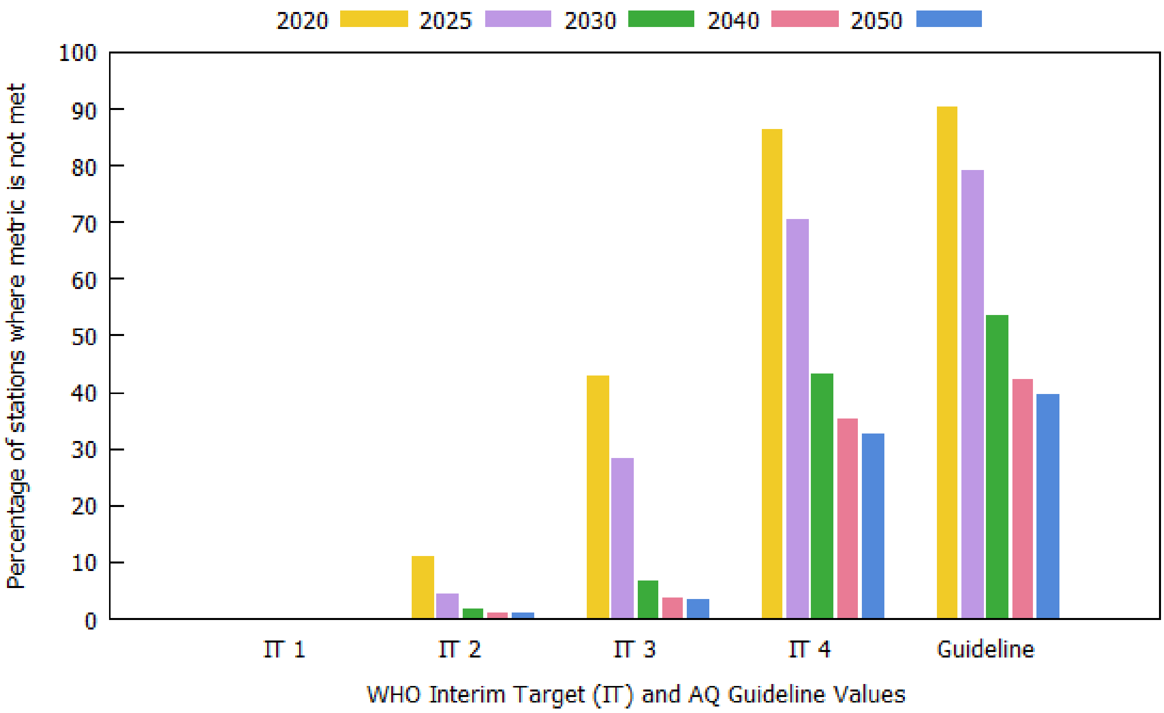

Figure 73 PM_{10} exceedance - Italy: Proportion of stations predicted NOT to meet the WHO interim target and guideline values under the baseline scenario (Case (0)).

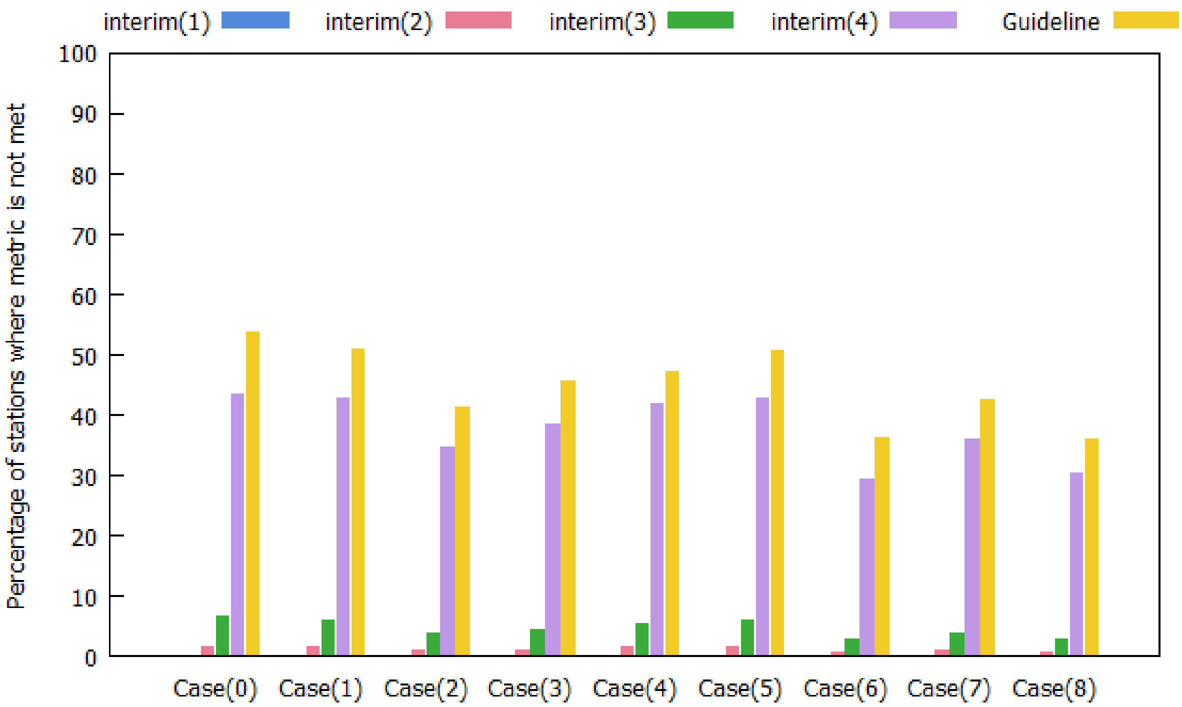

Figure 74 PM_{10} exceedance - Italy: Scenario comparison for the number of monitoring stations NOT meeting the WHO interim target and guideline values in 2030.

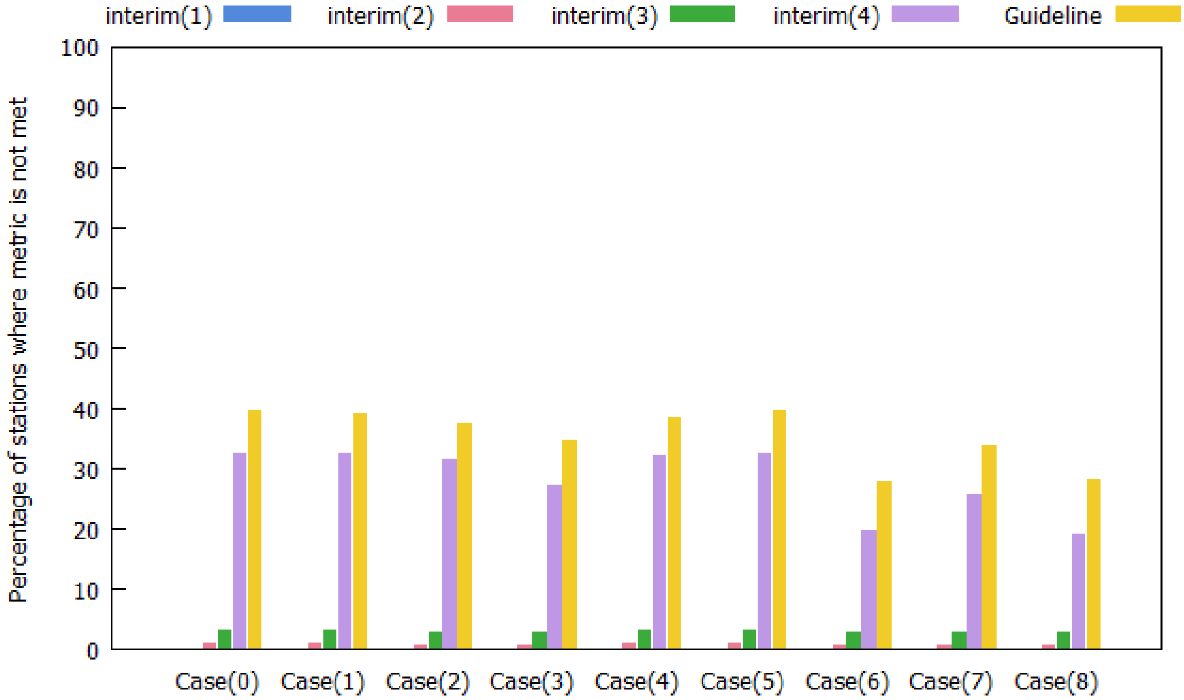

Figure 75 PM_{10} exceedance - Italy: Scenario comparison for the number of monitoring stations NOT meeting the WHO interim target and guideline values in 2050.

4.6.5. PM_{10} Annual Mean

Italy has 187 stations with an established record of monitoring hourly concentrations of PM_{10} from which the annual mean value can be calculated and compared with a limit value.

Under the baseline scenario (**Figure 76**), by 2030 nearly all stations meet the interim target 3 value of 30 µg/m^3. However, when considering the interim target 4 value of 20 µg/m^3, more than 21% of the stations have concentrations above the value. The proportion is doubled when considering the guideline value of 15 µg/m^3 with 53% of the stations not meeting the value.

The emission reduction sensitivity scenarios for 2030 and 2050 (**Figure 77** and **Figure 78** respectively) show that eliminating agricultural emissions (Case (6)) makes the largest change in increasing the number of stations meeting the interim target and guideline values. Eliminating domestic and commercial emissions (Case (2)) is also predicted to have an effect but this is only noticeable in 2030.

The two control scenarios considered, MTFR (Case (7)) and MTFR + 1.5 LIFE (Case (8)) are similar in effect, with the latter having a slightly higher impact in the proportion of stations meeting the WHO criteria. However, in both scenarios, a significant proportion of stations is predicted to have concentrations above the WHO air quality guideline value in 2050 (44% under MTFR and 36% under MTFR + 1.5 LIFE scenario respectively).

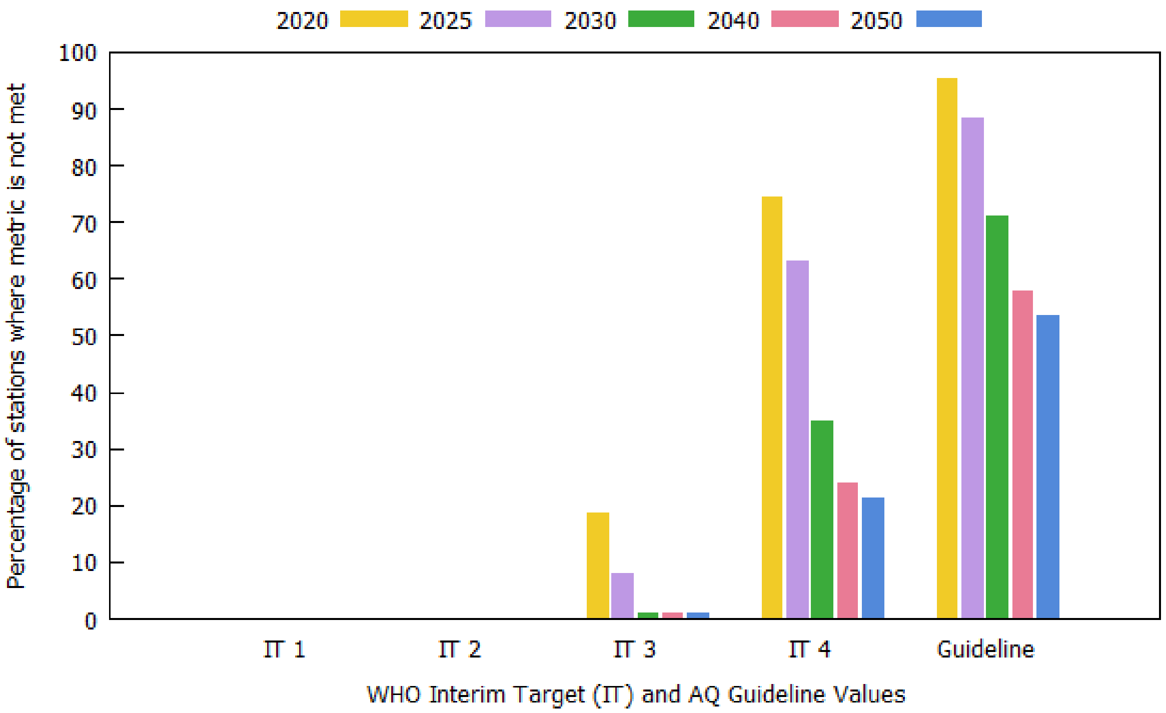

Figure 76 PM$_{10}$ annual mean - Italy: Proportion of stations predicted NOT to meet the WHO interim target and guideline values under the baseline scenario (Case (0)).

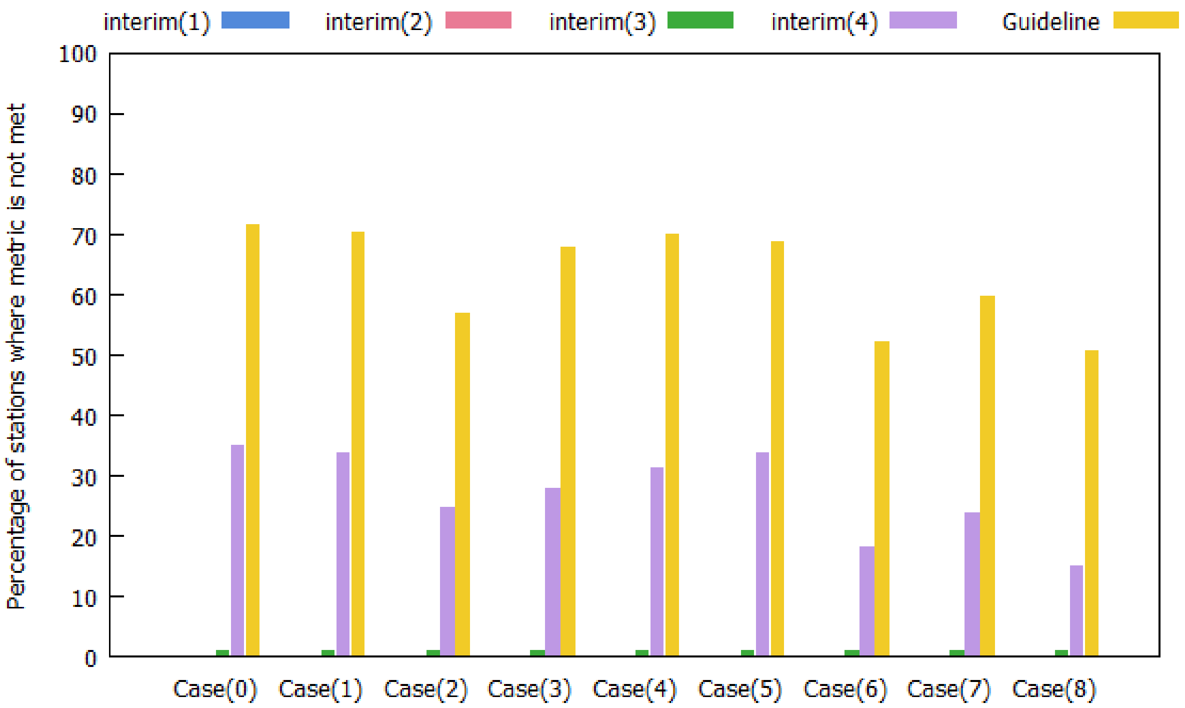

Figure 77 PM$_{10}$ annual mean - Italy: Scenario comparison for the number of monitoring stations NOT meeting the WHO interim target and guideline values in 2030.

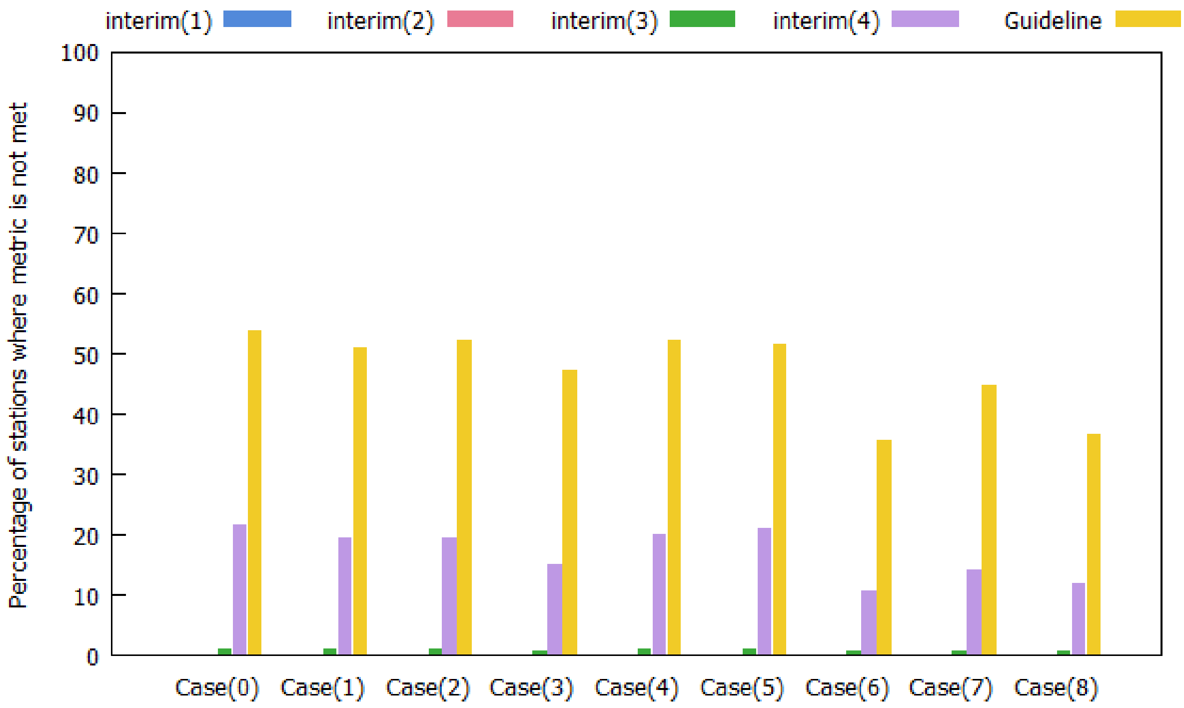

Figure 78 PM_{10} annual mean - Italy: Scenario comparison for the number of monitoring stations NOT meeting the WHO interim target and guideline values in 2050.

4.6.6. $PM_{2.5}$ Exceedance

In Italy there are 227 stations with an established record of monitoring hourly concentrations of $PM_{2.5}$ from which the daily mean value and the number of threshold exceedances can be calculated.

Under the baseline scenario (**Figure 79**), almost all stations meet the interim target 2 of 50 μg/m^3 for the daily mean concentration by 2040. In 2050, the interim target 3 of 37.5 μg/m^3 is exceeded on four or more days per year by 9% of the stations, and the interim target 4 of 25 μg/m^3 by 30% of the stations. Regarding the air quality guideline value of 15 μg/m^3, more than half of the stations (57%) have concentrations above the value during four or more days per year.

The emission reduction sensitivity scenarios for 2030 and 2050 (**Figure 80** and **Figure 81** respectively) show a similar pattern to the PM_{10} results to which $PM_{2.5}$ contributes. Similarly, the removal of agricultural emissions (Case (6)) has the largest effect, while eliminating domestic and commercial emissions (Case (2)) is predicted to also have a rather short-term effect (by 2030). The remaining sectoral emission reduction scenarios are predicted not to have a substantial effect.

The two control scenarios MTFR (Case (7)) and MTFR + 1.5 LIFE (Case (8)) show similar results with the latter being slightly more effective in increasing the number of stations meeting the WHO criteria. However, in all scenarios a significant proportion of stations will continue to show exceedances of the WHO air quality guideline of 15 μg/m^3 on four or more days a year (~50% under MTFR, 45% under MTFR + 1.5 LIFE scenario).

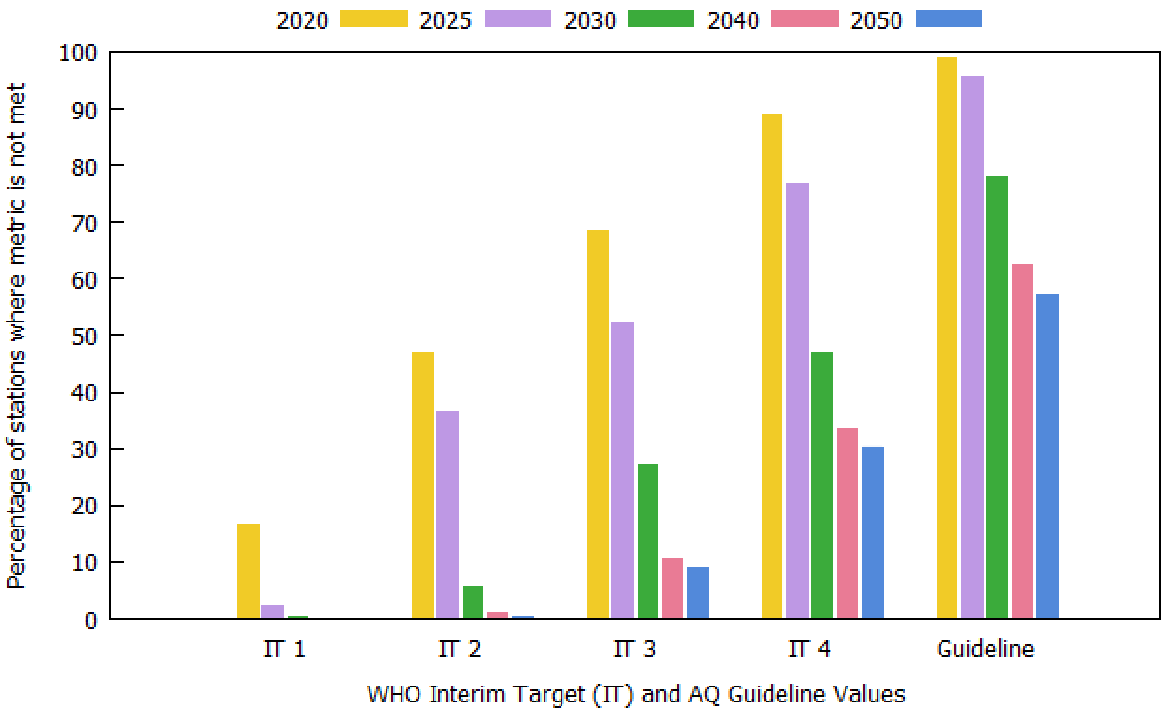

Figure 79 $PM_{2.5}$ exceedance - Italy: Proportion of stations predicted NOT to meet the WHO interim target and guideline values under the baseline scenario (Case (0)).

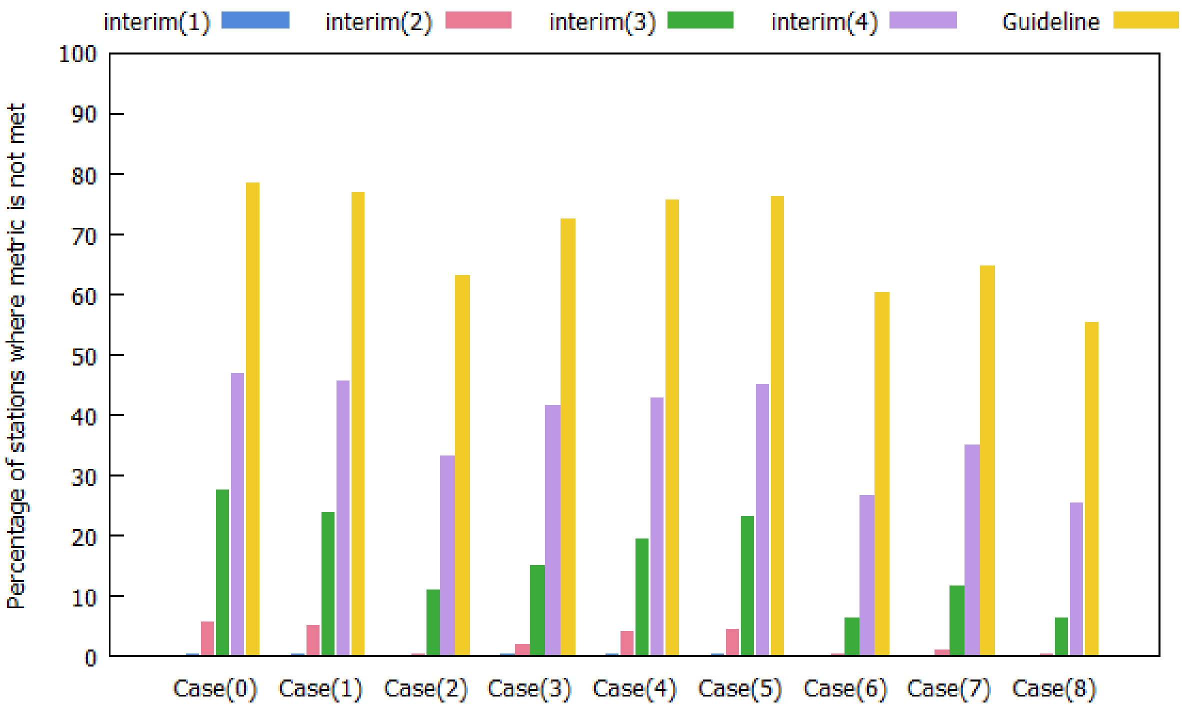

Figure 80 $PM_{2.5}$ exceedance - Italy: Scenario comparison for the number of monitoring stations NOT meeting the WHO interim target and guideline values in 2030.

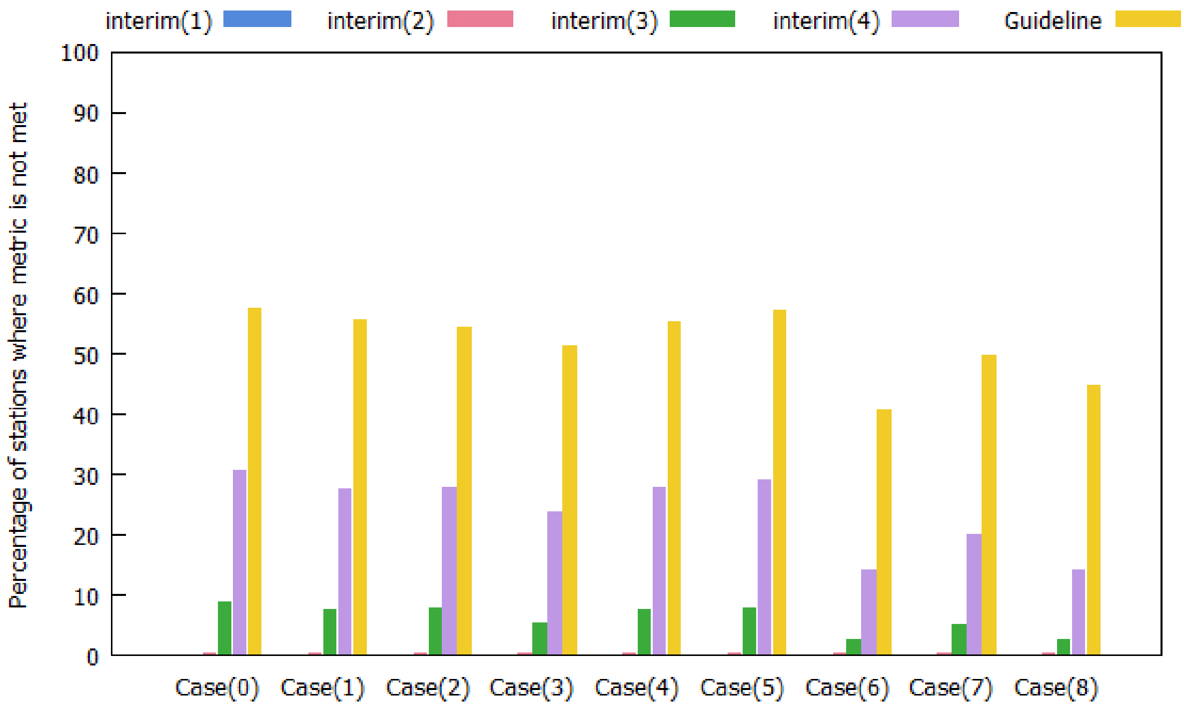

Figure 81 $PM_{2.5}$ exceedance - Italy: Scenario comparison for the number of monitoring stations NOT meeting the WHO interim target and guideline values in 2050.

4.6.7. $PM_{2.5}$ Annual Mean

Italy has 233 stations with an established record of monitoring hourly concentrations of $PM_{2.5}$ from which the annual mean value can be calculated and compared with a limit value.

Under the baseline scenario (**Figure 82**), the WHO interim target 3 of 15 μg/m^3 is met at all stations by 2050 and only 6% of the stations have higher annual mean concentrations in 2030. At the interim target 4 of 10 μg/m^3, 42% of the stations have higher annual mean concentrations in 2030 reducing to 17% in 2050. At the WHO guideline value of 5 μg/m^3, 97% of the stations have higher annual mean concentrations in 2030 reducing to 82% in 2050.

The emission reduction sensitivity calculations for 2030 and 2050 (**Figure 83** and **Figure 84** respectively) show similar behaviour to that of the $PM_{2.5}$ exceedance calculations. Compared to the baseline, the most effective sector for emission reductions is agriculture (Case (6)), while by 2050 all other sector emission reduction scenarios have only a small effect. The elimination of agricultural emissions is predicted to have comparable (and even higher by 2050) effects to those associated with the two control scenarios MTFR (Case (7)) and MTFR + 1.5 LIFE (Case (8)). However, even under these scenarios, more than 30% of the stations is predicted to have concentrations above the annual mean WHO air quality guideline value of 5 μg/m^3 (reaching up to almost 80% depending on the scenario considered).

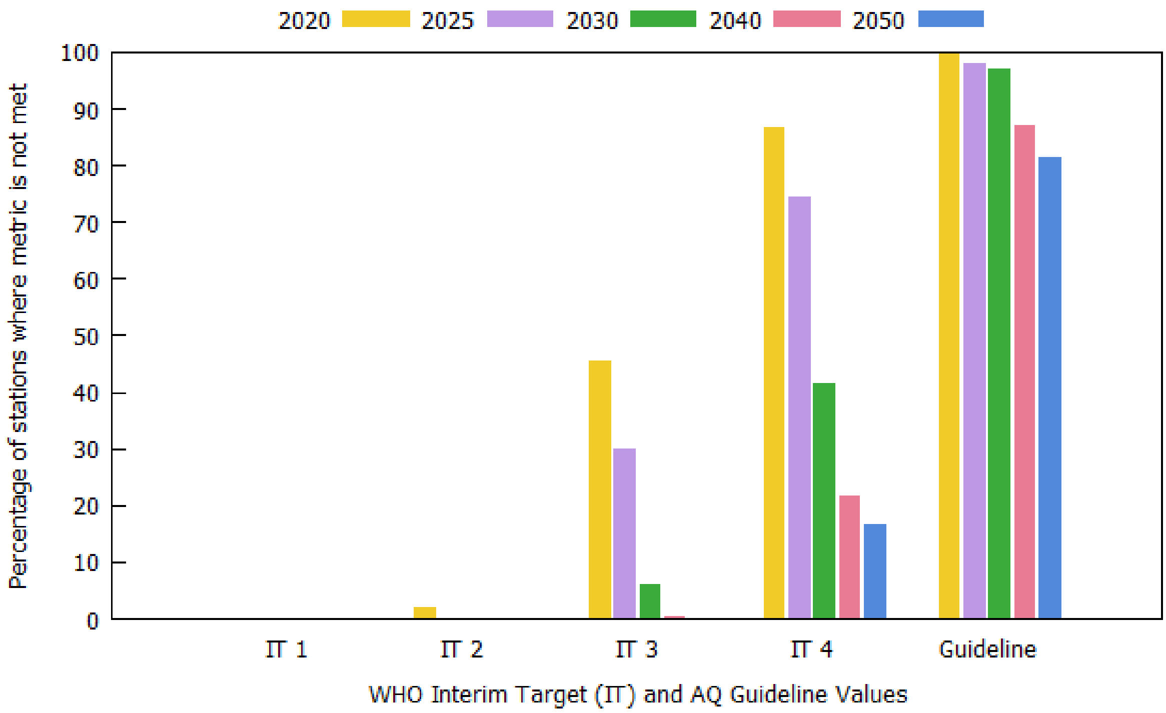

Figure 82 PM$_{2.5}$ annual mean - Italy: Proportion of stations predicted NOT to meet the WHO interim target and guideline values under the baseline scenario (Case (0)).

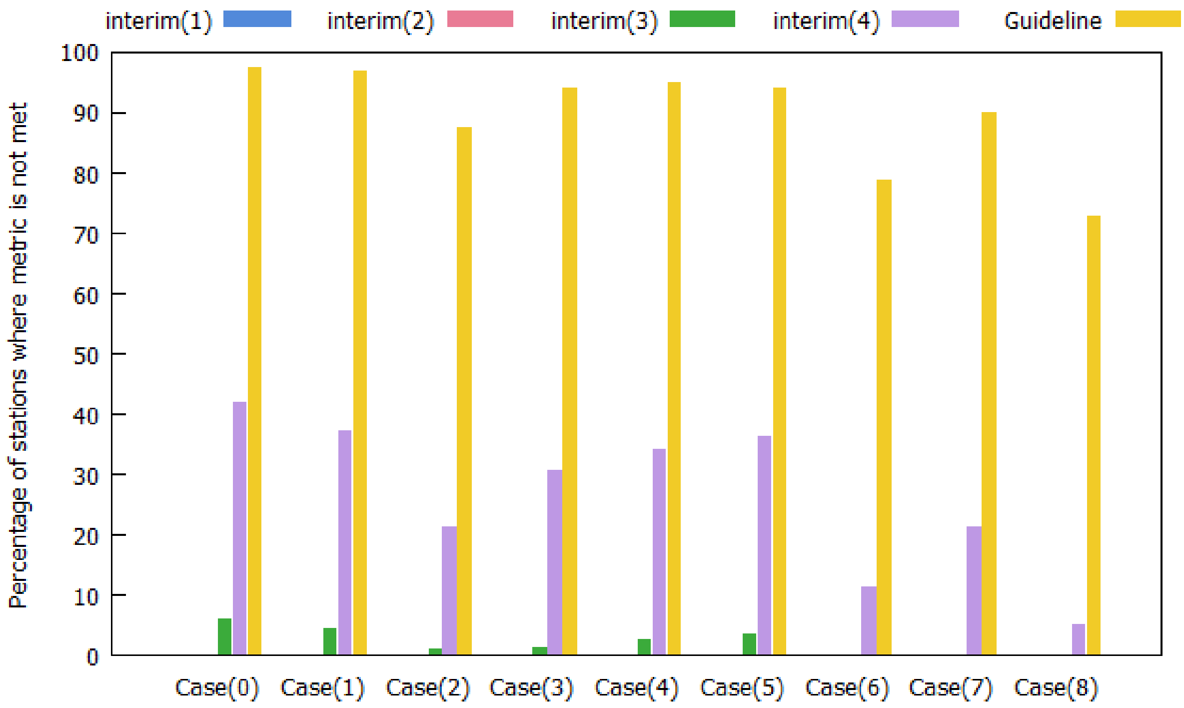

Figure 83 PM$_{2.5}$ annual mean - Italy: Scenario comparison for the number of monitoring stations NOT meeting the WHO interim target and guideline values in 2030.

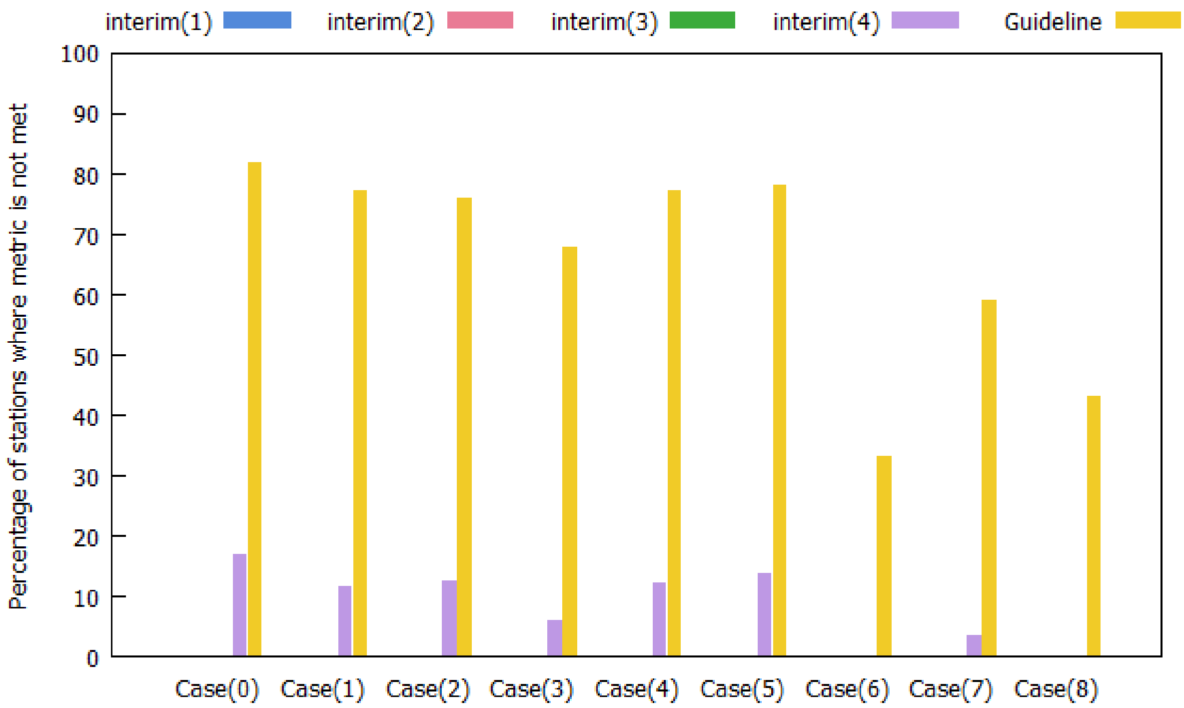

Figure 84 PM$_{2.5}$ annual mean - Italy: Scenario comparison for the number of monitoring stations NOT meeting the WHO interim target and guideline values in 2050.

4.7. SPAIN

4.7.1. Ozone Exceedance

Spain has 188 stations with an established record of monitoring hourly concentrations of ozone from which the maximum daily 8-hr mean concentration and the number of threshold exceedances can be calculated.

In 2050, under the baseline scenario (**Figure 85**), there remains a small proportion of stations (6%), which will not meet the WHO interim target 1 of 160 µg/m^3 daily mean of the 8-hr highest concentration hours not to be exceeded on four or more days per year. However, this proportion significantly increases when considering the interim target 2 of 120 µg/m^3 and mainly the air quality guideline value. In particular, in 2050, 94% of the stations will not meet the air quality guideline exceedance value of 100 µg/m^3.

The emission reduction sensitivity scenarios for 2030 and 2050 are shown in **Figure 86** and **Figure 87** respectively. Similar to the results shown for other countries, the elimination of industry combustion/process and solvent produce/use emissions (Case (3)) has the largest effect in increasing the stations that meet the WHO interim target and guideline values. However, the vast majority of stations is still predicted to record exceedances above the WHO air quality guideline value (more than 80% in 2050). Eliminating emissions from other sectors is ineffective.

The two control scenarios MTFR (Case (7)) and MTFR + 1.5 LIFE (Case (8)) also have a fairly minor effect. The proportion of stations having O_3 max daily 8-hr mean concentrations above the guideline exceedance threshold on four or more days a year in 2050 is 90% for MTFR and 88% for MTFR + 1.5 LIFE respectively.

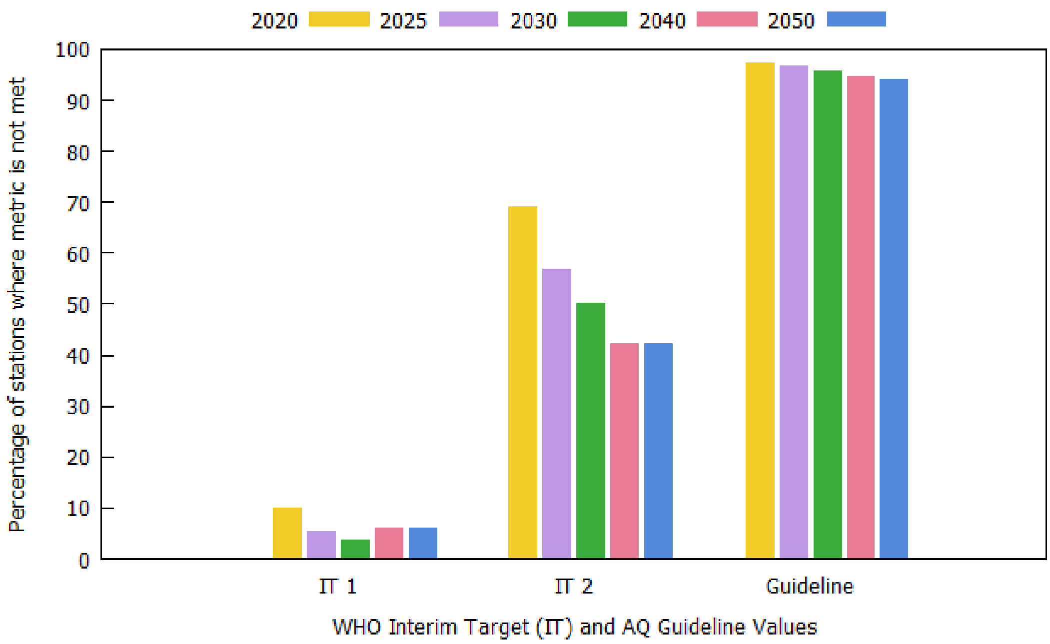

Figure 85 O_3 exceedance - Spain: Proportion of stations predicted NOT to meet the WHO interim target and guideline values under the baseline scenario (Case (0)).

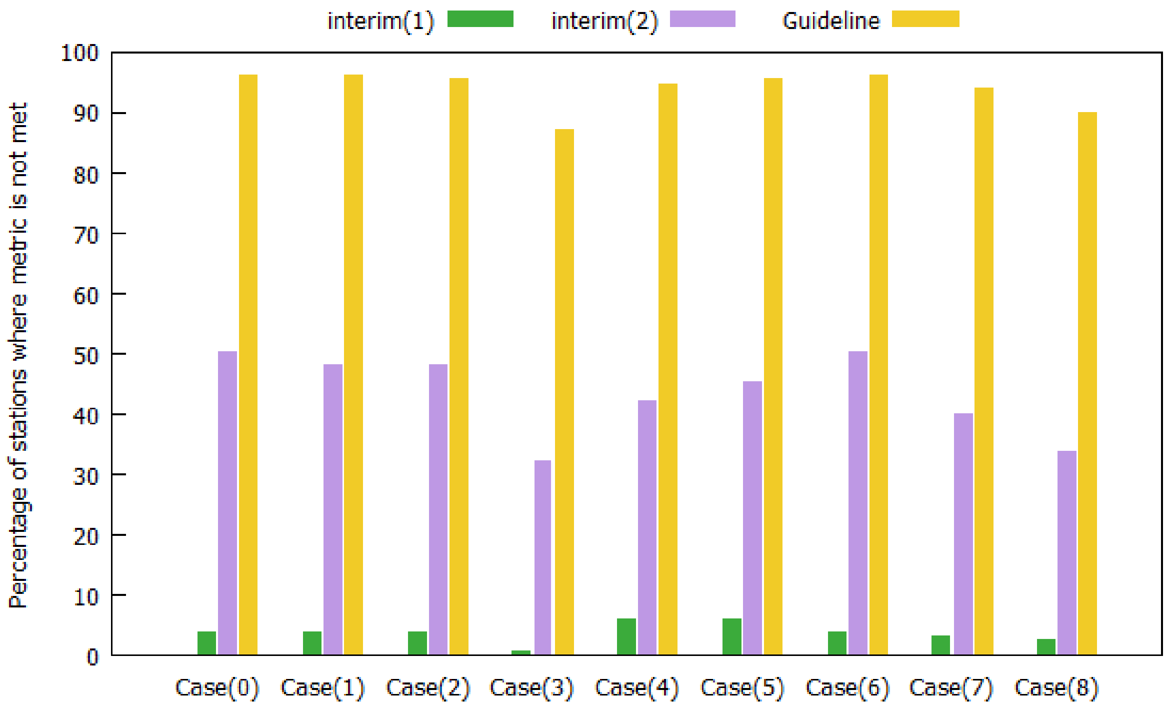

Figure 86 O_3 exceedance - Spain: Scenario comparison for the number of monitoring stations NOT meeting the WHO interim target and guideline values in 2030.

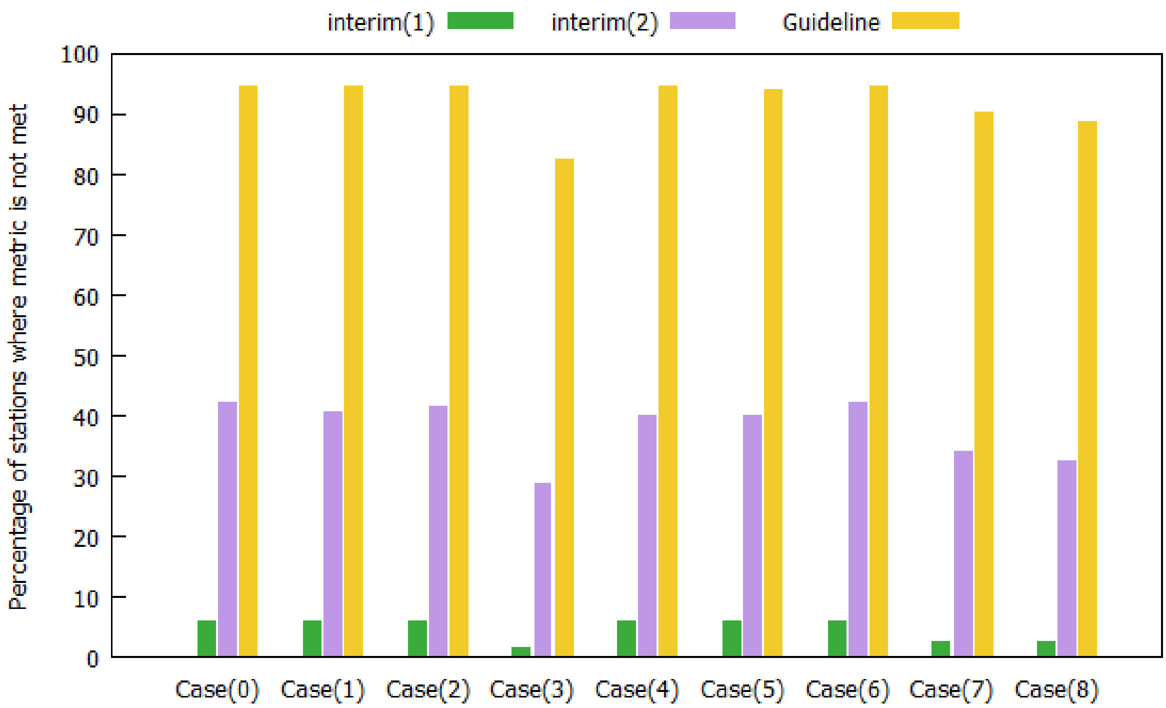

Figure 87 O_3 exceedance - Spain: Scenario comparison for the number of monitoring stations NOT meeting the WHO interim target and guideline values in 2050.

4.7.2. NO_2 Exceedance

Spain has 232 stations with an established record of monitoring hourly concentrations of NO_2 from which the daily mean value and the number of threshold exceedances can be calculated.

Under the baseline scenario (**Figure 88**), by 2050, all monitoring stations meet the WHO interim target 2 of no more than four or more exceedances per year of 50 µg/m^3 daily mean NO_2 concentration. A proportion of stations will not meet the WHO guideline exceedance threshold of 25 µg/m^3. This proportion amounts to 30% in 2030, reducing to 13% by 2050.

The emission reduction sensitivity calculations for 2030 and 2050 (**Figure 89** and **Figure 90** respectively) show that emission reductions from the transport sector (road and non-road) (Cases (4) and (5)) as well as the industry combustion/process and solvent produce/use (Case (3)) are having the largest effect. By 2050, all stations are predicted to meet the interim target 2 for all sectoral emissions reduction scenarios. However, in all scenarios, around 8% to 13% of the stations will not meet the guideline value in 2050.

Of the two control scenarios, MTFR reduces the proportion of stations not meeting the guideline value to 9% by 2050, while the MTFR + 1.5 LIFE scenario achieves a slightly better reduction with 8% of stations showing four or more exceedances per year of the guideline value of 25 µg/m^3.

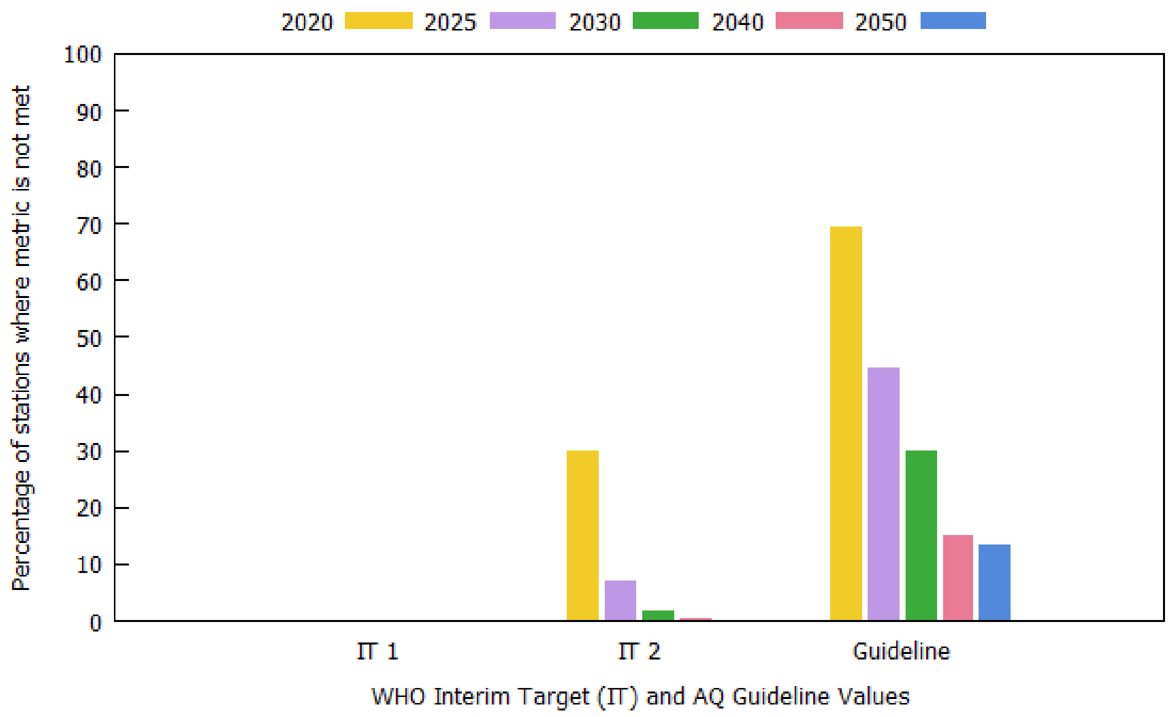

Figure 88 NO_2 exceedance - Spain: Proportion of stations predicted NOT to meet the WHO interim target and guideline values under the baseline scenario (Case (0)).

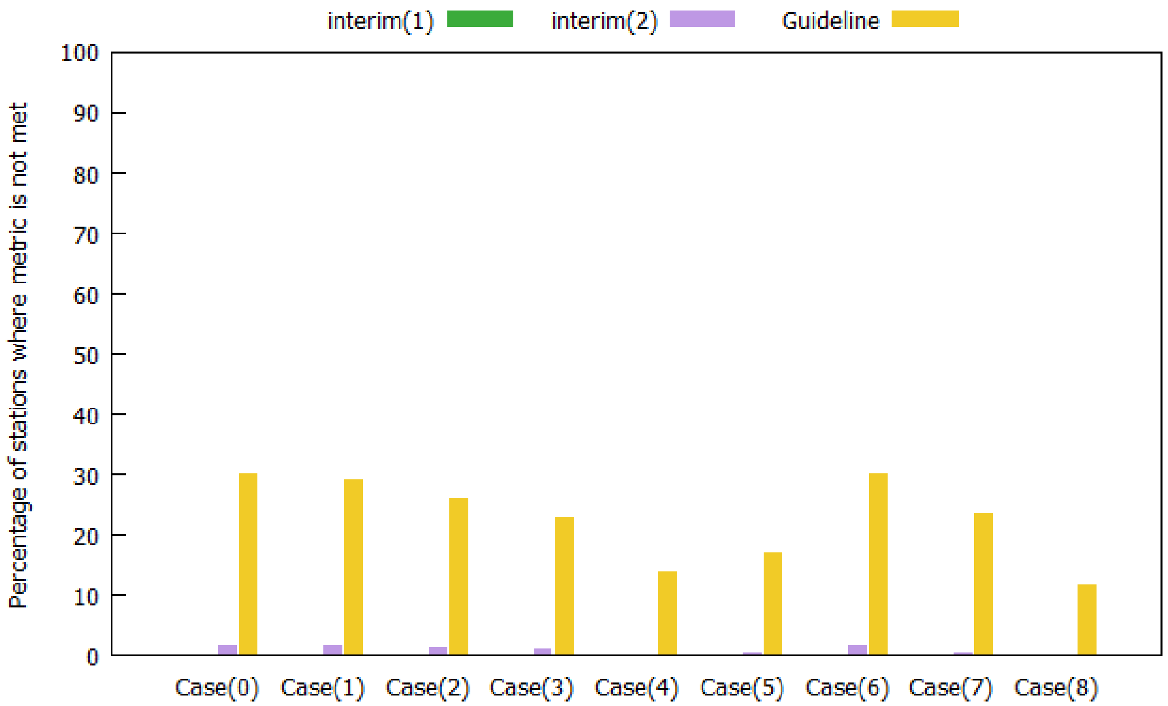

Figure 89 NO_2 exceedance - Spain: Scenario comparison for the number of monitoring stations NOT meeting the WHO interim target and guideline values in 2030.

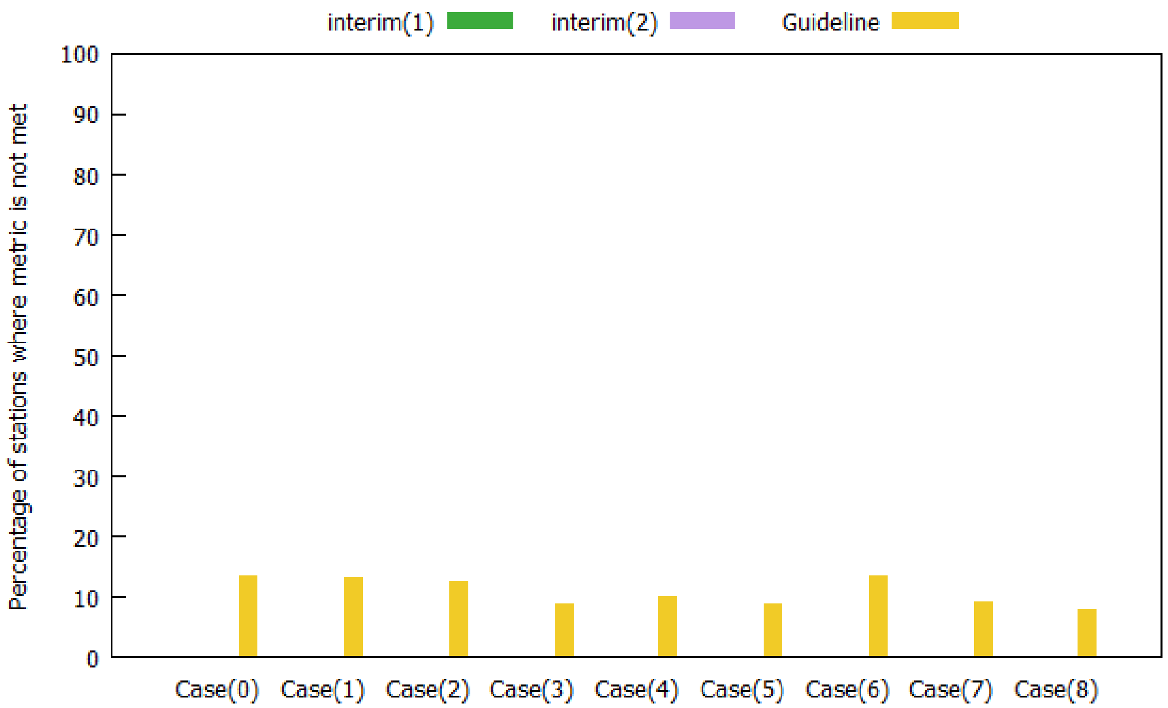

Figure 90 NO_2 exceedance - Spain: Scenario comparison for the number of monitoring stations NOT meeting the WHO interim target and guideline values in 2050.

4.7.3. NO_2 Annual Mean

Spain has 233 stations with an established record of monitoring hourly concentrations of NO_2 from which the annual mean value can be calculated and compared with a limit value.

Under the baseline scenario (**Figure 91**), all stations meet the WHO interim target 3 of 20 µg/m^3 by 2040. However, meeting the air quality guideline value of 10 µg/m^3 appears to be challenging in around 10% of the stations in 2050 (33% in 2030).

The emission reduction sensitivity scenarios for 2030 and 2050 (**Figure 92** and **Figure** 93 respectively) show that eliminating transport emissions (Case (4) and Case (5)) have the largest effect on annual mean NO_2 concentration in 2030 whereas in 2050 it is the elimination of process emissions (Case (3)) and non-road transport (Case (5)). This reflects the low contribution made by on-road transport to NO_2 by that date.

Of the two control scenarios, MTFR (Case (7)) has relatively little effect in 2030 with 28% of the stations having higher annual NO_2 concentrations than the WHO guideline value and a small proportion of 2% not meeting the interim target 3. In comparison, for the baseline scenario (Case (0)) the proportions are 33% and 4% respectively. The MTFR + 1.5 LIFE scenario (Case (8)) results in 9% of the stations in 2030 having a higher annual mean NO_2 concentration than the guideline value and all stations meeting the interim target 3 threshold. In 2050, the proportion of stations having concentrations above the WHO guideline is only 1%.

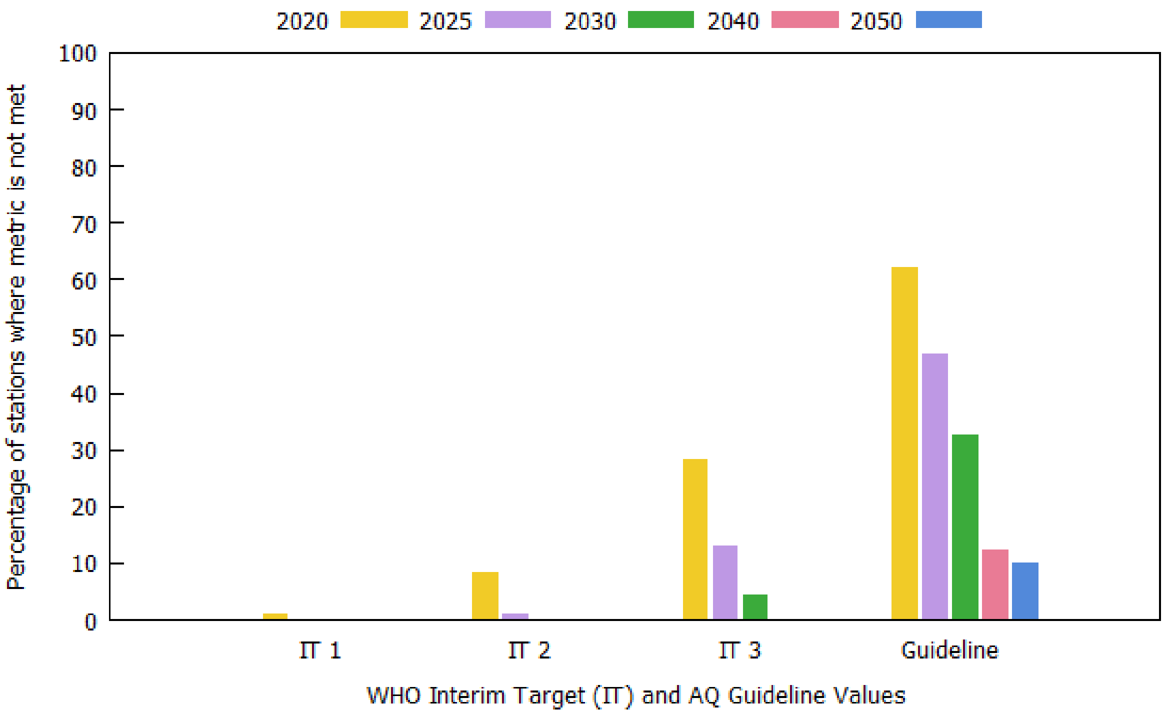

Figure 91 NO_2 annual mean - Spain: Proportion of stations predicted NOT to meet the WHO interim target and guideline values under the baseline scenario (Case (0)).

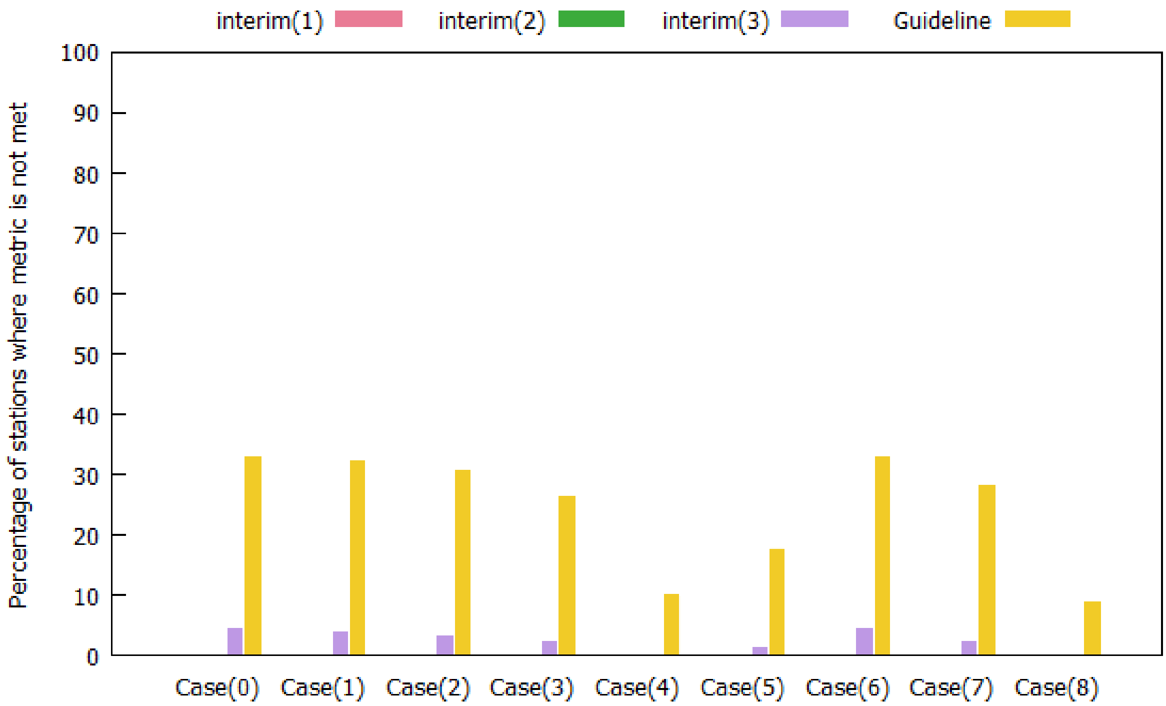

Figure 92 NO_2 annual mean - Spain: Scenario comparison for the number of monitoring stations NOT meeting the WHO interim target and guideline values in 2030.

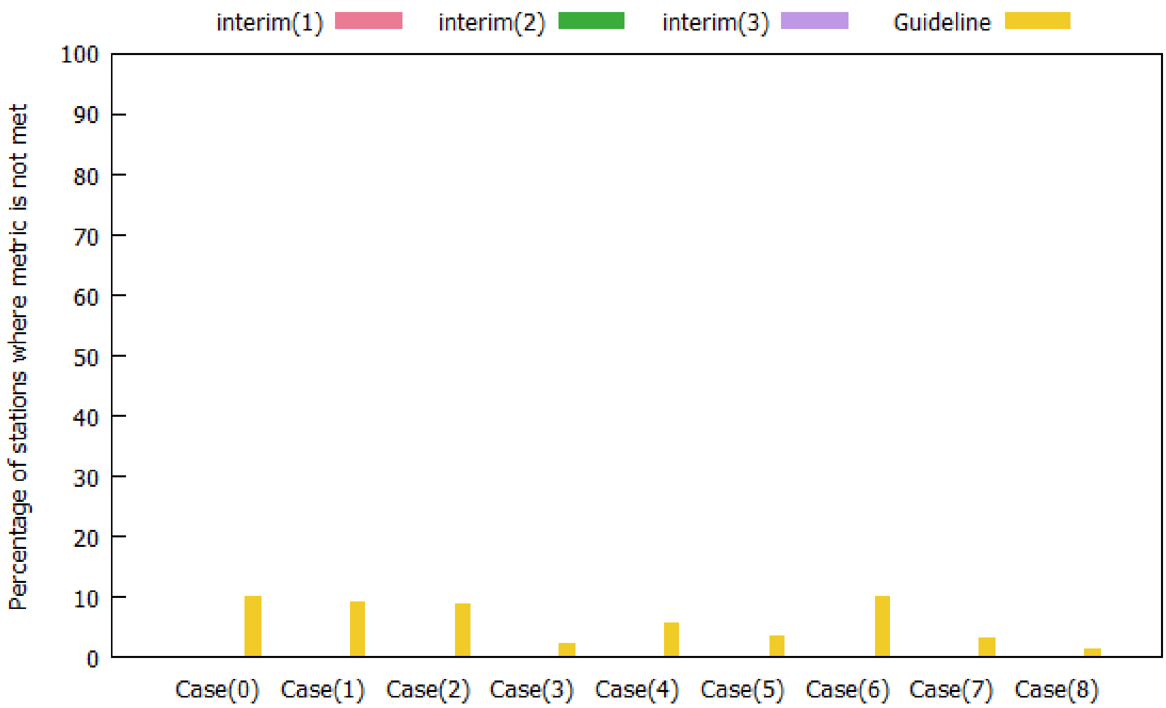

Figure 93 NO_2 annual mean - Spain: Scenario comparison for the number of monitoring stations NOT meeting the WHO interim target and guideline values in 2050.

4.7.4. PM_{10} Exceedance

Spain has 52 stations with an established record of monitoring hourly concentrations of PM_{10} from which the daily mean value and the number of threshold exceedances can be calculated.

Under the baseline scenario (**Figure 94**), PM_{10} exceedances decrease steeply with time but there are some stations that continue to register high daily mean concentrations on four or more days per year. In 2050, the proportion of stations not meeting the interim target 3 of 75 µg/m^3 is 2%, the interim target 4 of 50 µg/m^3 is 6% and the guideline value of 45 µg/m^3 is almost 10%.

The emission reduction sensitivity calculations for 2030 and 2050 (**Figure 95** and **Figure 96** respectively) show that there is no single sector determining the annual concentrations and eliminating emissions from each sector in turn makes very little difference when compared to the baseline scenario for any of the interim target and guideline values.

Of the two control scenarios, neither one makes a substantial difference to the base case and under either, there remain a few stations where the interim target 3 threshold is not met. For the AQ guideline threshold of 45 µg/m^3 in 2050, both the MTFR scenario (Case (7)) and the MTFR + 1.5 LIFE scenario (Case (8)) result in almost 10% of the stations not meeting the exceedance target. This is the same as for the baseline scenario (Case (0))

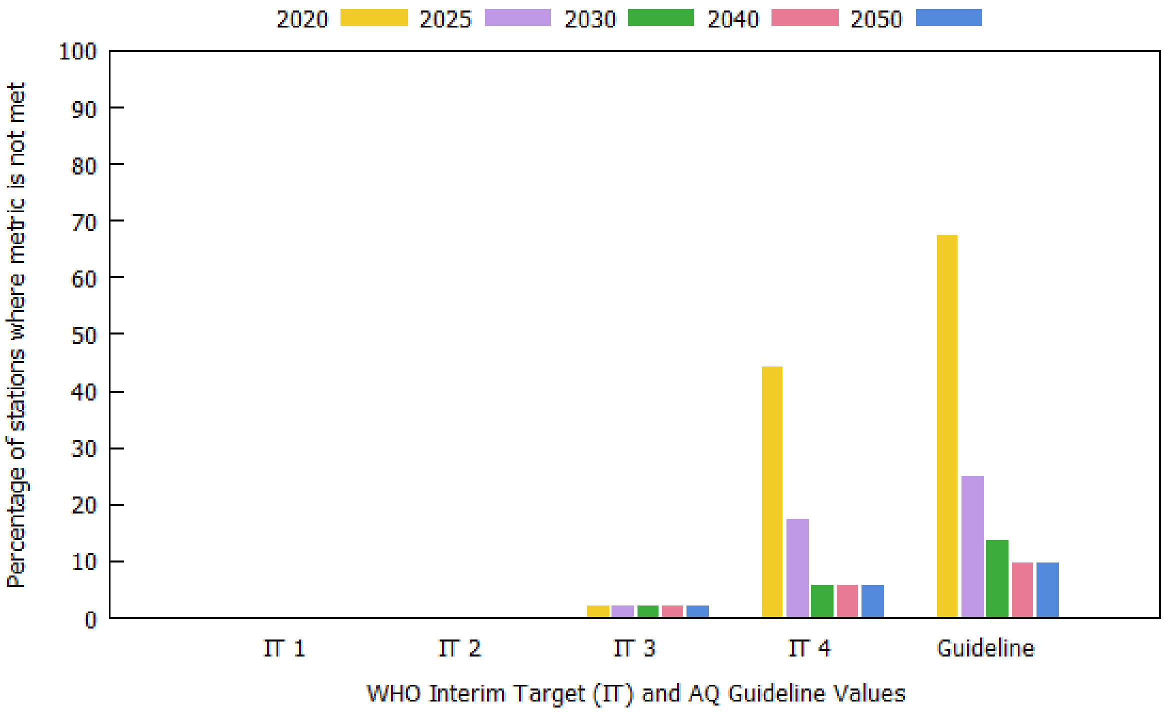

Figure 94 PM_{10} exceedance - Spain: Proportion of stations predicted NOT to meet the WHO interim target and guideline values under the baseline scenario (Case (0)).

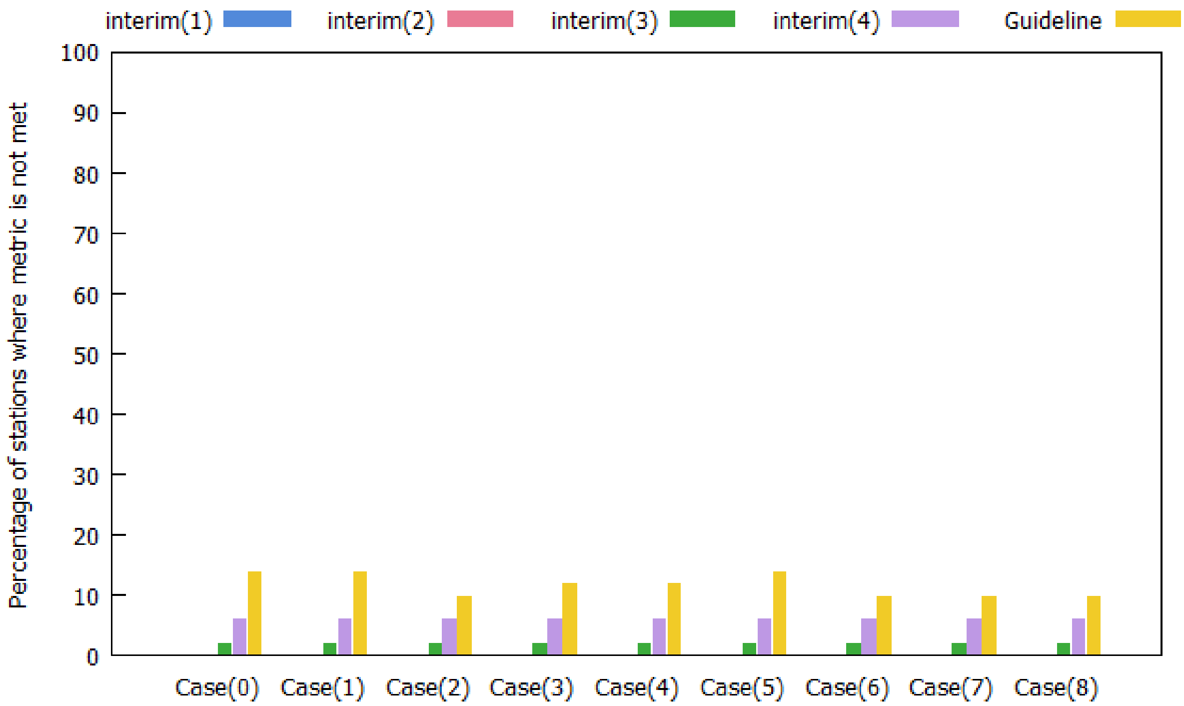

Figure 95 PM$_{10}$ exceedance - Spain: Scenario comparison for the number of monitoring stations NOT meeting the WHO interim target and guideline values in 2030.

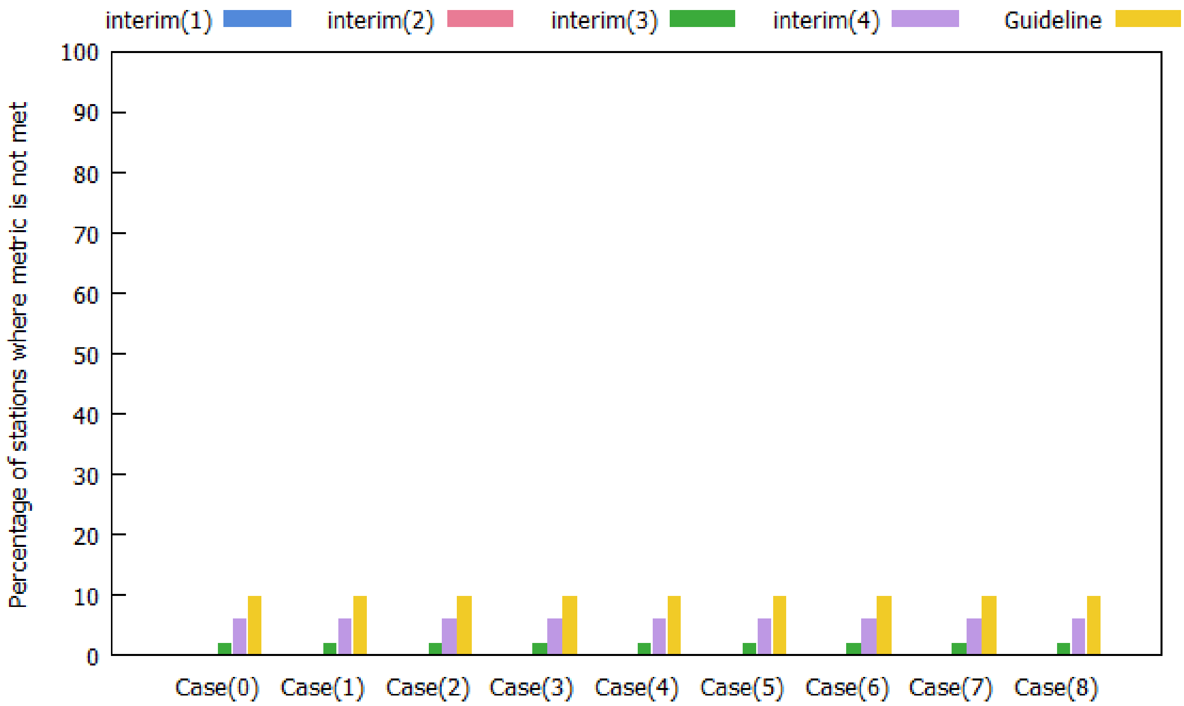

Figure 96 PM$_{10}$ exceedance - Spain: Scenario comparison for the number of monitoring stations NOT meeting the WHO interim target and guideline values in 2050.

4.7.5. PM_{10} Annual Mean

Spain has 58 stations with an established record of monitoring hourly concentrations of PM_{10} from which the annual mean value can be calculated and compared with a limit value.

Under the baseline scenario (**Figure 97**), a small proportion of stations is predicted to have higher annual PM_{10} concentrations in 2030 and in 2050 than the interim target 4 of 20 µg/m^3. The proportions are 7% and 5% respectively. For the guideline value of 15 µg/m^3, the proportions are 19% in 2030 and 17% in 2050.

The emission reduction sensitivity scenarios for 2030 and 2050 (**Figure 98** and **Figure 99** respectively) show that no single sector dominates the PM_{10} results. As for the other countries, eliminating agricultural emissions (Case (6)) has a slightly higher impact and this is through the contribution that (secondary) $PM_{2.5}$ makes to PM_{10}. However, meeting the guideline value in all stations will remain challenging.

The two control scenarios MTFR (Case (7)) and MTFR + 1.5 LIFE (Case (8)) are both predicted to have similar results and there is no substantial change between 2030 and 2050 in the proportion of stations (16%) having higher PM_{10} annual mean concentrations than the guideline value of 15 µg/m^3.

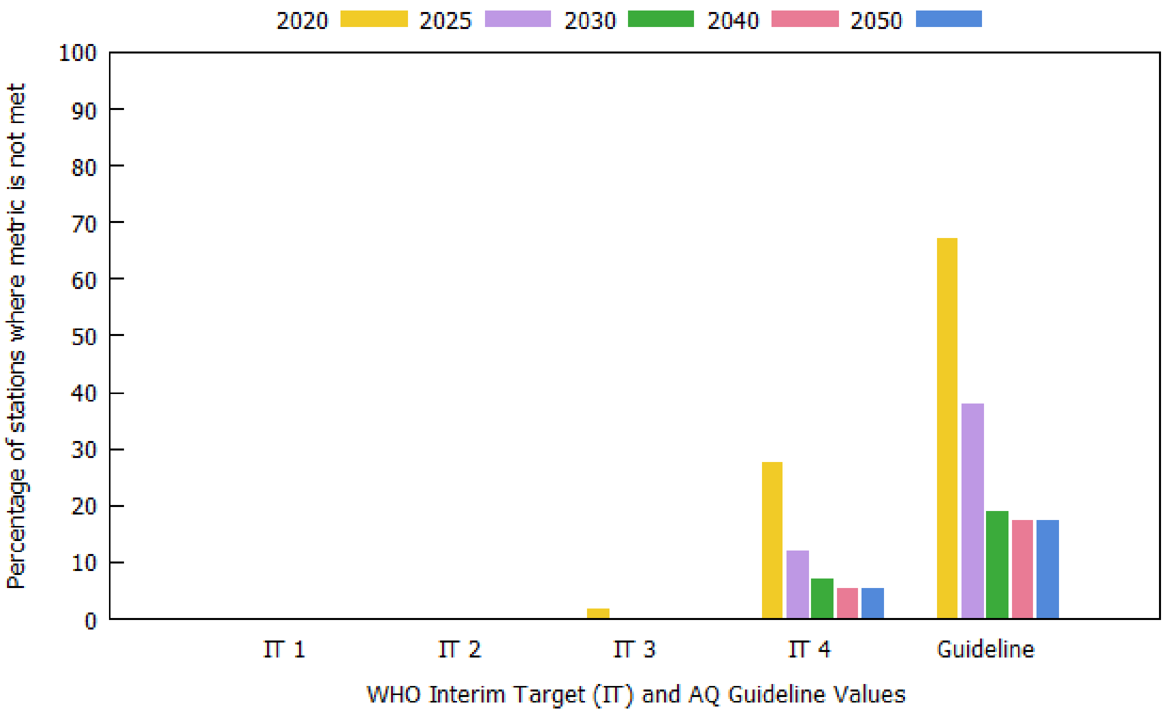

Figure 97 PM_{10} annual mean - Spain: Proportion of stations predicted NOT to meet the WHO interim target and guideline values under the baseline scenario (Case (0)).

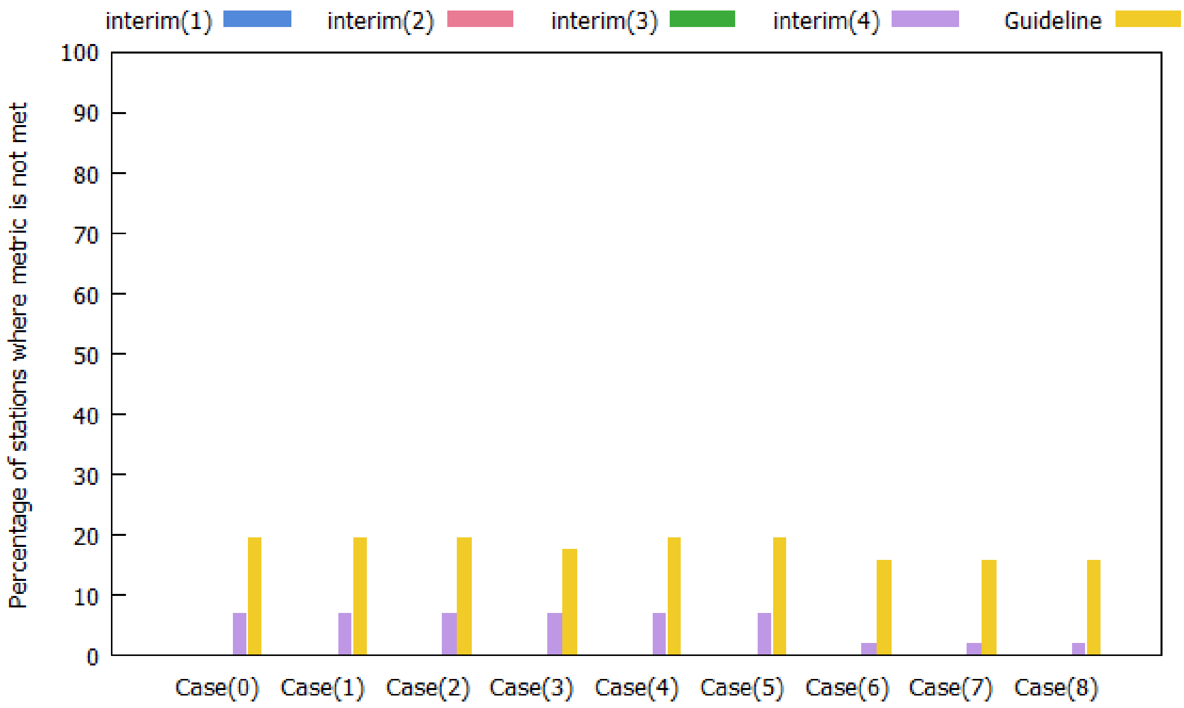

Figure 98 PM$_{10}$ annual mean - Spain: Scenario comparison for the number of monitoring stations NOT meeting the WHO interim target and guideline values in 2030.

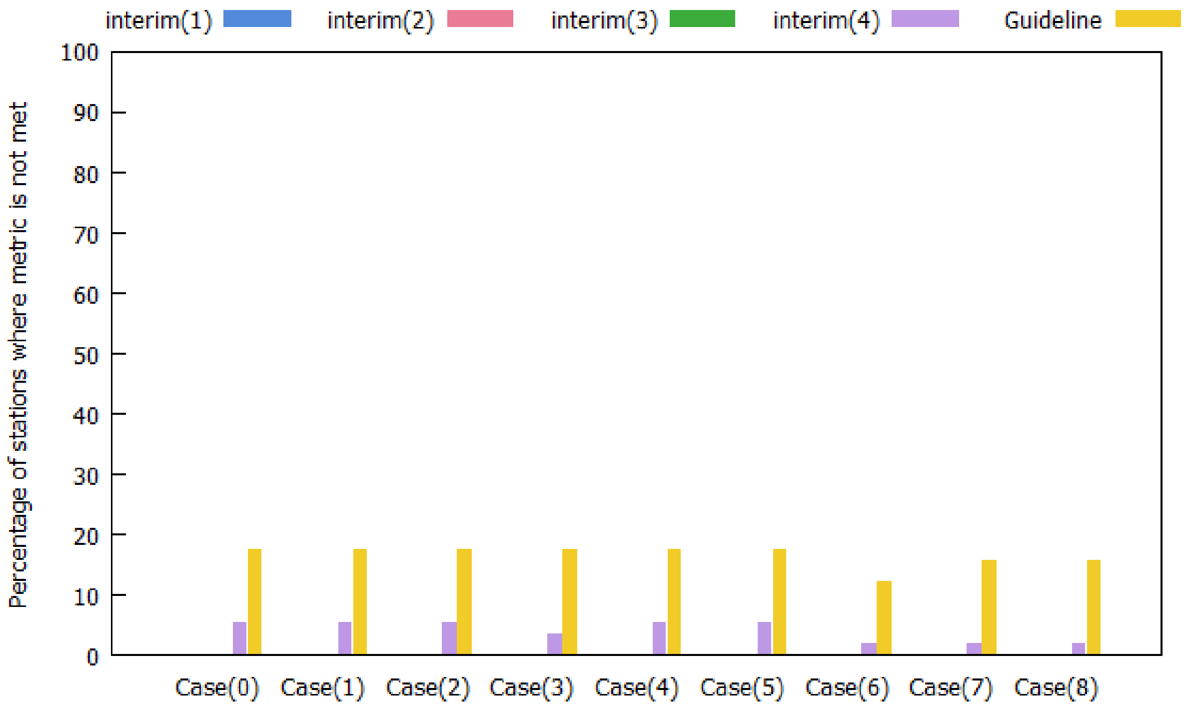

Figure 99 PM$_{10}$ annual mean - Spain: Scenario comparison for the number of monitoring stations NOT meeting the WHO interim target and guideline values in 2050.

4.7.6. $PM_{2.5}$ Exceedance

Spain has 83 stations with an established record of monitoring hourly concentrations of $PM_{2.5}$ from which the daily mean value and the number of threshold exceedances can be calculated.

Under the baseline scenario (**Figure 100**), the number of stations where $PM_{2.5}$ exceeds both the interim target 4 (25 µg/m^3) and guideline value (15 µg/m^3) on four or more days per year decreases significantly in time up to mainly 2030 and with a small further reduction by 2050. In 2050, there are only 2% of the stations exceeding the interim target 4 and 15% exceeding the guideline value.

The emission reduction sensitivity calculations for 2030 and 2050 (**Figure 101** and **Figure 102** respectively) show that eliminating agricultural emissions (Case (6)) has the largest effect and results in all stations meeting the guideline value by 2050.

Both control scenarios have a similar effect in 2030 and reduce the proportion of stations not meeting the guideline criteria to 4%. MTFR (Case (7)) has no further change by 2050 but MTFR + 1.5 LIFE (Case (8)) results in all stations meeting the guideline criteria. It seems likely that this is through associated changes in agricultural emissions.

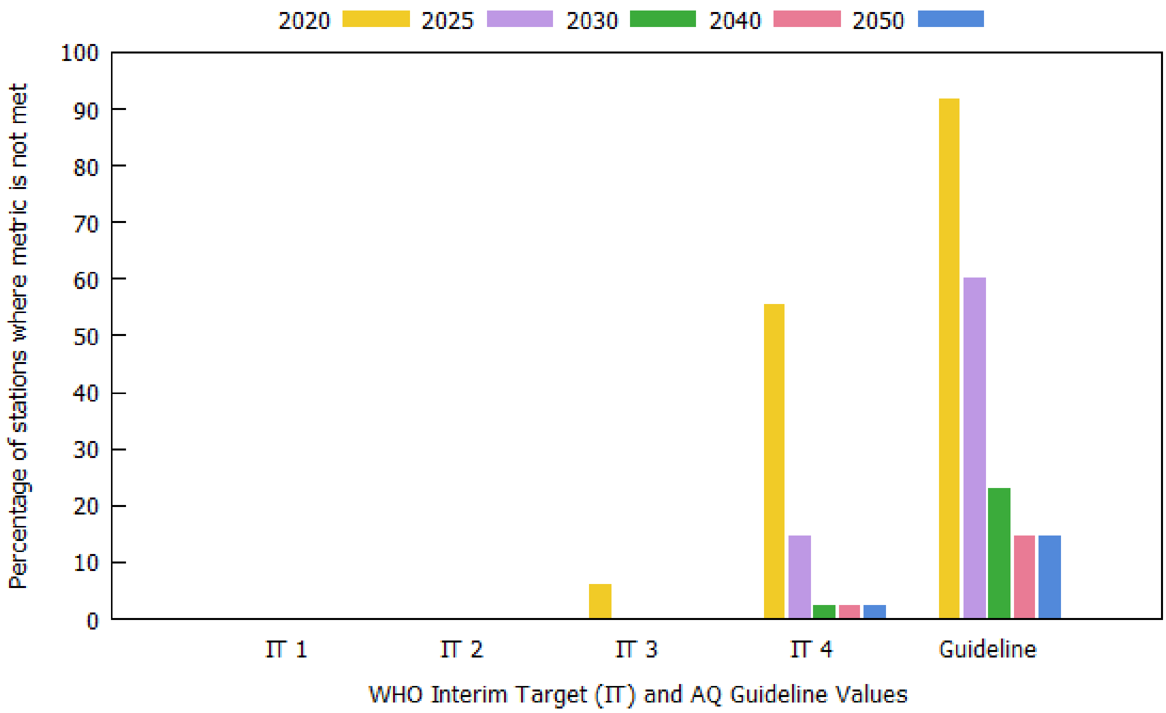

Figure 100 PM$_{2.5}$ exceedance - Spain: Proportion of stations predicted NOT to meet the WHO interim target and guideline values under the baseline scenario (Case (0)).

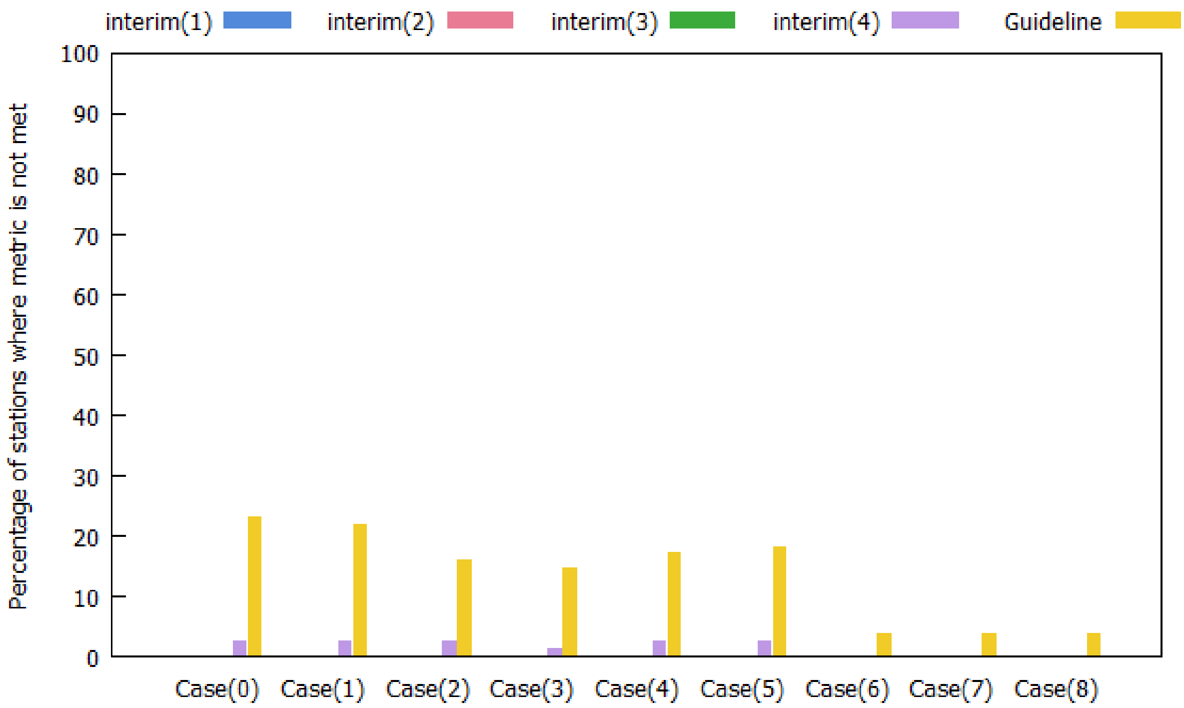

Figure 101 PM$_{2.5}$ exceedance - Spain: Scenario comparison for the number of monitoring stations NOT meeting the WHO interim target and guideline values in 2030.

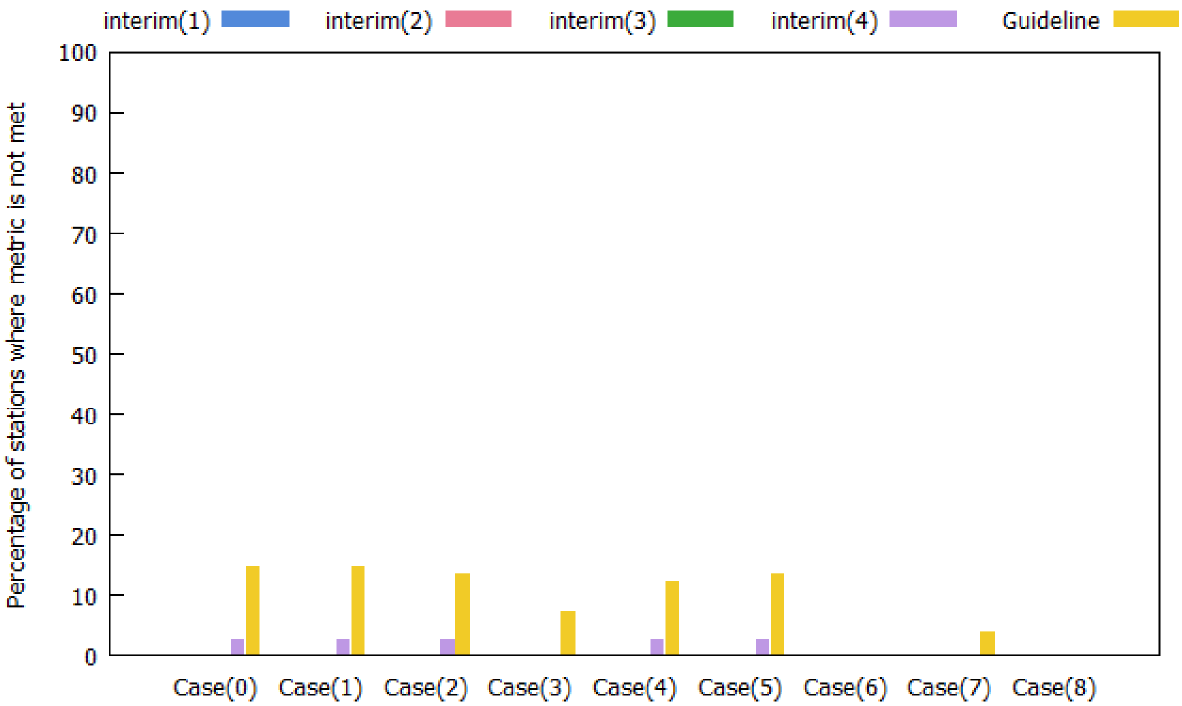

Figure 102 $PM_{2.5}$ exceedance - Spain: Scenario comparison for the number of monitoring stations NOT meeting the WHO interim target and guideline values in 2050.

4.7.7. $PM_{2.5}$ Annual Mean

Spain has 83 stations with an established record of monitoring hourly concentrations of $PM_{2.5}$ from which the annual mean value can be calculated and compared with a limit value.

Under the baseline scenario (**Figure 103**), there is just one station that has a higher concentration than the interim target 4 of 10 $\mu g/m^3$ in 2030. However, the proportion of stations having annual $PM_{2.5}$ concentrations higher than the guideline value of 5 $\mu g/m^3$ is quite significant, with 48% of the stations above the guideline value in 2030 and 31% in 2050.

The emission reduction sensitivity calculations for 2030 and 2050 (**Figure 104** and **Figure 105** respectively) show that eliminating agricultural emissions (Case (6)) has the largest effect on annual mean concentrations at the monitoring stations. In particular, by 2050, only a few stations (3%) are predicted not to meet the guideline value, when removing agricultural emissions.

Of the two control scenarios, MTFR + 1.5 LIFE (Case (8)) has the largest impact. However, several stations will still exceed the guideline value of 5 $\mu g/m^3$, amounting to 12% in 2030 and 7% in 2050. Under MTFR (Case (7)), the equivalent proportions are 19% and 11% respectively.

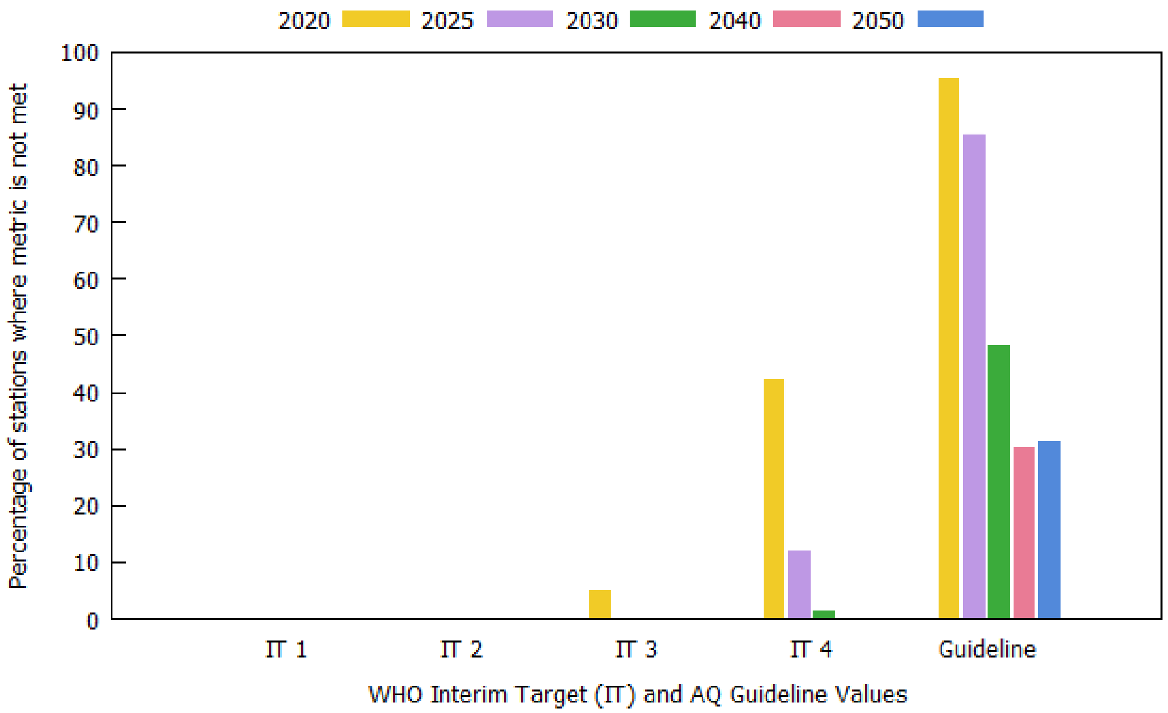

Figure 103 PM$_{2.5}$ annual mean - Spain: Proportion of stations predicted NOT to meet the WHO interim target and guideline values under the baseline scenario (Case (0)).

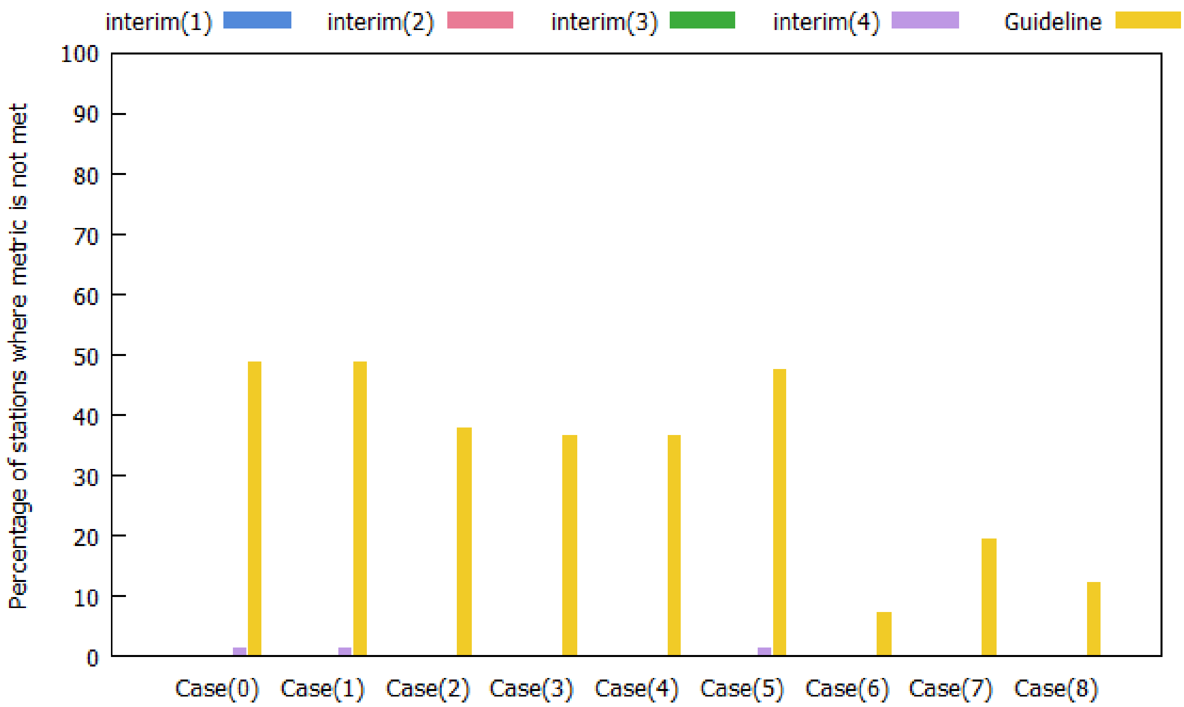

Figure 104 PM$_{2.5}$ annual mean - Spain: Scenario comparison for the number of monitoring stations NOT meeting the WHO interim target and guideline values in 2030.

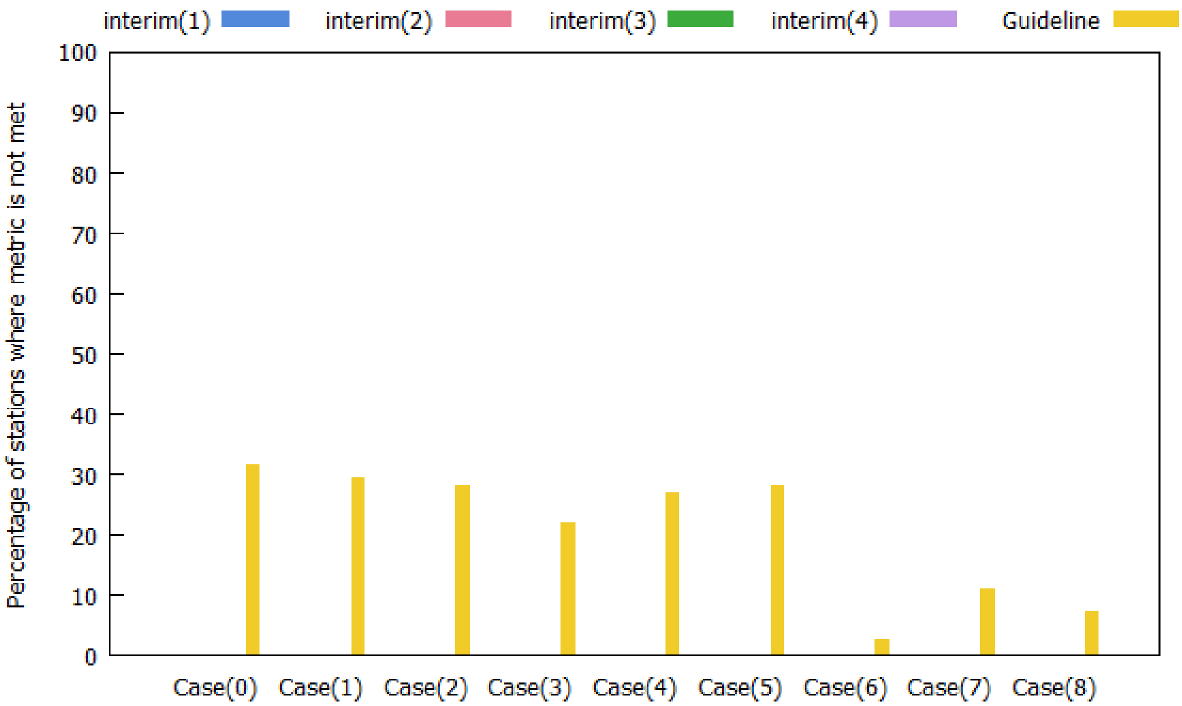

Figure 105 $PM_{2.5}$ annual mean - Spain: Scenario comparison for the number of monitoring stations NOT meeting the WHO interim target and guideline values in 2050.

5. SUMMARY AND CONCLUSIONS

Concawe commissioned a study to carry out sets of forward predictions of air quality across the European monitoring network for the period 2015 to 2050. These were based on the economic activity scenario developed for the Second Clean Air Outlook [6]. These model predictions have been compared with the air quality interim target and guideline values proposed by WHO in its recent revision [4]. Specifically, the annual exceedance frequency of thresholds set for O_3, NO_2, PM_{10} and $PM_{2.5}$ daily mean concentrations were examined as were the annual mean concentration thresholds for NO_2, PM_{10} and $PM_{2.5}$.

Three activity scenarios of the Second Clean Air Outlook (CAO2) were explored as well as some illustrative emission reduction scenarios were considered. These were simple cases where emissions from key sectors were set to zero in turn. The purpose was to determine if emissions from any of the sectors had, individually, a dominating effect on future air quality.

The study finds that, by pollutant, for the EU-27 as a whole:

<u>Ozone (O_3)</u>

- The WHO Air Quality Guidelines (AQG) recommend an exceedance frequency of less than four days a year (99th percentile) for the maximum daily 8-hour mean O_3 concentration, with thresholds of 160 (IT 1), 120 (IT 2) and 100 µg/m^3 (guideline). The current AAQS is 120 µg/m^3 not to be exceeded on more than 25 days per year, averaged over 3 years.

- Overall in EU-27, under the CLE scenario of the Second Clean Air Outlook, the proportion of stations not meeting the WHO exceedance thresholds in 2050 is 3% for IT 1, 58% for IT 2 and 95% for the guideline value.

- Under the maximum emission reduction scenarios MTFR and MTFR + 1.5 LIFE, the proportion of stations not meeting the exceedance guideline value in 2050 slightly reduces to 93% and 92% respectively.

- The Concawe sensitivity scenarios suggest that the effective measures within those control scenarios are likely to be those on the reduction of emissions from industry combustion/process and solvent/product use due mainly to the removal of VOC emissions. However, the improvement is predicted to be marginal.

<u>Nitrogen Dioxide (NO_2)</u>

- The WHO AQG recommend an exceedance frequency of less than four days a year (99th percentile) for the NO_2 daily mean concentration, with thresholds of 120 (IT 1), 50 (IT 2) and 25 µg/m^3 (guideline). Under the current AAQD, there is no AAQS for the exceedance frequency of a daily threshold.

- Under the CLE scenario, the proportion of stations in Europe not meeting the WHO exceedance thresholds in 2050 is 0% for IT 1, 1% for IT 2 and 17% for the guideline value.

- Under the maximum emission reduction scenarios MTFR and MTFR + 1.5 LIFE, the proportion of stations not meeting the exceedance guideline value in 2050 reduces to 15% and 13% respectively.

- The WHO AQG recommend a limit on the annual mean concentration of NO_2 with limit values of 40 (IT 1), 30 (IT 2), 20 (IT 3) and 10 $\mu g/m^3$ (guideline). The current AAQS is 40 $\mu g/m^3$.

- Under the CLE scenario, the proportion of stations not meeting the WHO annual mean thresholds in 2050 is 1% or less for the interim target values and 11% for the guideline value.

- Under the maximum emission reduction scenarios MTFR and MTFR + 1.5 LIFE, the proportion of stations not meeting the annual mean guideline value in 2050 reduces to 7% and 3% respectively.

- The Concawe sensitivity scenarios suggest that the effective measures within these scenarios are likely to be those on the reduction of NOx emissions from transport, without however achieving full compliance.

Particulate Matter - PM_{10}

- The WHO AQG recommend an exceedance frequency of less than four days a year (99^{th} percentile) for the PM_{10} daily mean concentration, with thresholds of 150 (IT 1), 100 (IT 2), 75 (IT 3), 50 (IT 4) and 45 $\mu g/m^3$ (guideline). The current AAQS is 50 $\mu g/m^3$ not be exceeded on more than 35 days per year.

- Under the CLE scenario, all stations in Europe are able to meet the WHO exceedance threshold IT 1, and very closely meet IT 2 and IT 3 (1% and 3% of stations not meeting the targets respectively). The proportion of stations not meeting the WHO exceedance thresholds in 2050 is 17% for IT 4 and 22% for the guideline value.

- Under the maximum emission reduction scenarios MTFR and MTFR + 1.5 LIFE, the proportion of stations not meeting the WHO exceedance threshold IT 1 in 2050 is 13% and 10% respectively, while considering the exceedance guideline value in 2050, the proportion increases to 17% and 15% respectively.

- The WHO AQG recommend a limit on the annual mean concentration of PM_{10} with limit values of 70 (IT 1), 50 (IT 2), 30 (IT 3), 20 (IT 4) and 15 $\mu g/m^3$ (guideline). The current AAQS is 40 $\mu g/m^3$.

- Under the CLE scenario, the proportion of stations not meeting the WHO annual mean thresholds in 2050 is less than 1% for IT 3, 10% for IT 4 and 35% for the guideline value.

- Under the maximum emission reduction scenarios MTFR and MTFR + 1.5 LIFE, the proportion of stations not meeting the annual mean threshold IT 4 is 7% and 6% respectively, while considering the annual mean guideline in 2050, the proportion of stations not meeting the guideline value remains significant at 26% and 21% respectively.

- The Concawe sensitivity scenarios suggest that the effective measures within these scenarios are likely to be those on the reduction of emissions from agriculture (NH_3) and domestic/commercial heating.

Particulate Matter - $PM_{2.5}$

- The WHO AQG recommend an exceedance frequency of less than four days a year (99^{th} percentile) for the $PM_{2.5}$ daily mean concentration, with thresholds of 75 (IT 1), 50 (IT 2), 37.5 (IT 3), 20 (IT 4) and 15 $\mu g/m^3$ (guideline). Under the current AAQD, there is no AAQS for the exceedance frequency of a daily threshold.

- Under the CLE scenario, the proportion of stations not meeting the WHO exceedance thresholds in 2050 is less than 6% for IT 3, 19% for IT 4 and 62% for the guideline value.
- Under the maximum emission reduction scenarios MTFR and MTFR + 1.5 LIFE, the proportion of stations not meeting the IT 4 is 12% and 9% respectively, while considering the exceedance guideline value in 2050 the proportion increases to 43% and 35% respectively.
- The WHO AQG recommend a limit on the annual mean concentration of $PM_{2.5}$ with limit values of 35 (IT 1), 25 (IT 2), 15 (IT 3), 10 (IT 4) and 5 $\mu g/m^3$ (guideline). The current AAQS is 25 $\mu g/m^3$ with the long-term objective that average concentrations should fall below 20 $\mu g/m^3$.
- Under the CLE scenario, the proportion of stations not meeting the WHO annual mean thresholds in 2050 is less than 1% for IT 3, 10% for IT 4 and 75% for the guideline value.
- Under the maximum emission reduction scenario MTFR, the proportion of stations not meeting the annual mean threshold IT 4 is less than 3% while under MTFR + 1.5 LIFE almost all stations are able to meet the IT 4 threshold. The proportion of stations not meeting the annual mean guideline value in 2050 is significant in both scenarios being, 52% for MTFR and 37% for MTFR + 1.5 LIFE respectively.
- The Concawe sensitivity scenarios suggest that the effective measures within these scenarios are likely to be those on the reduction of emissions from agriculture (NH_3) and domestic/commercial heating.

To test the representativeness of these findings, the results for four countries were examined. These are France, Poland, Italy and Spain. For ozone exceedance of a daily threshold, which represents the highest ozone concentrations, the results are similar to those of the EU-27 taken as a whole. The highest ozone concentrations occurring during climatic conditions on a geographic scale are commensurate with the majority of the EU-27 countries.

For the other pollutant metrics there are differences. Poland and Italy generally experience higher particulate matter concentrations, both peak and average, and the monitoring stations in those countries have more frequent exceedances of daily thresholds and higher annual average concentrations, compared with the WHO interim and guideline values, than the EU-27 as a whole.

The same pattern is observed for PM_{10} and for $PM_{2.5}$ (which makes up part of PM_{10}) although the variation between countries is larger for $PM_{2.5}$.

For NO_2, there is also variation between countries with Italy generally having a larger proportion of stations not meeting the WHO guideline criteria than for the EU-27 as a whole.

In conclusion, the study finds that air quality in Europe, represented by the pollutants and metrics tested and determined across the air quality monitoring network, improves over time towards the horizon of 2050. This is due to the reduction in emissions already legislated within the economic outlook of the Second Clean Air Outlook.

The study shows that air quality in Europe will not meet the guideline criteria set out in the 2021 WHO AQG under the Second Clean Air Outlook forecast energy/activity pathway as determined by the network of monitoring stations set out in 2015. It is worth noting that, by design, monitoring stations are located at positions where air quality is a concern and to verify that ambient air quality standards are complied with.

Although air quality will not meet the WHO AQG criteria, the forecasted air quality under the current pathway is largely consistent with the more ambitious of the interim target criteria. However, there is variability within countries and the distribution of air quality is not uniform over Europe.

The effect of emission controls was explored using two maximal emission reduction scenarios. Under the MTFR scenario, controls that are technically (but not necessarily economically) feasible are applied to the baseline economic/activity pathway. Broadly, these extend controls on already regulated sources. MTFR leads to some improvement in air quality but the WHO guideline values are not achieved.

The scenario MTFR + 1.5 LIFE results overall in improved air quality compared to MTFR alone with mainly benefits to particulate matter concentrations.

Concawe sensitivity calculations, comprising the setting to zero of emissions from sectors in turn, show that there is no single sector emission that has a dominant effect on how air quality at monitoring stations will compare with the interim target and guideline criteria. While reduction of NOx emissions from transport are influencing the NO_2, prediction calculations show that agricultural emissions have a strong effect on particulate matter concentrations. This is primarily an influence on (secondary) $PM_{2.5}$ formation but, because $PM_{2.5}$ makes up a significant part of PM_{10}, the concentrations of PM_{10} are also affected. Road transport emissions lose importance after 2030 because of the drop in older vehicles within the fleet. Non-road emissions for transport and construction play a growing role as their contribution becomes larger relative to on-road. Reductions in domestic emissions associated with the use of fuel for heating of homes and commercial premises also have an impact on particulate matter concentrations. 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.

These sensitivity calculations support the findings of the control scenarios, namely that the MTFR + 1.5 LIFE is more effective than MTFR alone in improving air quality, because it takes a broader approach to reducing emissions from a whole range of sectors.

The outlook for 2030 and for 2050 is therefore 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, air quality in Europe is unlikely to meet the WHO guideline values at many locations in Europe covered by the current monitoring networks.

6. REFERENCES

1. European Commission (2008). Directive 2008/50/EC of the European Parliament and of the Council of 21 May 2008 on ambient air quality and cleaner air for Europe. https://eur-lex.europa.eu/legal-content/en/ALL/?uri=CELEX%3A32008L0050.

2. European Commission (2004). Directive 2004/107/EC of the European Parliament and of the Council of 15 December 2004 relating to arsenic, cadmium, mercury, nickel and polycyclic aromatic hydrocarbons in ambient air. https://eur-lex.europa.eu/legal-ontent/EN/TXT/?qid=1575558618688&uri=CELEX:32004L0107.

3. World Health Organization (2006). Air Quality Guidelines. Global Update 2005. Particulate matter, ozone, nitrogen dioxide, and sulfur dioxide. https://www.euro.who.int/en/health-topics/environment-and-health/air-quality/publications/pre2009/air-quality-guidelines.-global-update-2005.-particulate-matter,-ozone,-nitrogen-dioxide-and-sulfur-dioxide.

4. World Health Organization (2021). WHO global air quality guidelines: particulate matter ($PM_{2.5}$ and PM_{10}), ozone, nitrogen dioxide, sulfur dioxide and carbon monoxide. https://www.who.int/publications/i/item/9789240034228.

5. European Commission (2022). Proposal for a Directive of the European Parliament and of the Council on ambient air quality and clean air for Europe. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM%3A2022%3A542%3AFIN.

6. M. Amann, J. Borken-Kleefeld, J. Cofala, C. Heyes, L. Hoglund-Isaksson, G. Kiesewetter, Z. Klimont, P. Rafaj, W. Schöpp, F. Wagner, W. Winiwarter, M. Holland, T. Vandyck (2020). Support to the development of the Second Clean Air Outlook – Final Report. https://circabc.europa.eu/ui/group/cd69a4b9-1a68-4d6c-9c48-77c0399f225d/library/79bf53a9-b6d9-4a4a-a4b5-433101462e42/details.

7. M. Amann, J. Borken-Kleefeld, J. Cofala, C. Heyes, L. Hoglund-Isaksson, G. Kiesewetter, Z. Klimont, P. Rafaj, W. Schöpp, F. Wagner, W. Winiwarter, M. Holland, T. Vandyck (2020). Support to the development of the Second Clean Air Outlook – Final Report, Annex. https://circabc.europa.eu/ui/group/cd69a4b9-1a68-4d6c-9c48-77c0399f225d/library/fd58ae9b-6b7d-44bb-ba55-4e982390928b/details.

8. Norwegian Meteorological Institute (2022). "Transboundary particulate matter, photo-oxidants, acidifying and eutrophying components", EMEP Status Report 1/2022. https://emep.int/publ/reports/2022/EMEP_Status_Report_1_2022.pdf.

9. European Commission (2016). Directive (EU) 2016/2284 of the European Parliament and of the Council of 14 December 2016 on the reduction of national emissions of certain atmospheric pollutants, amending Directive 2003/35/EC and repealing Directive 2001/81/EC. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv:OJ.L_.2016.344.01.0001.01.ENG&toc=OJ:L:2016:344:TOC

10. European Topic Centre on Air Emissions (1996). CORINAIR90 Comprehensive Summary Report. Corinair 90 - Comprehensive summary report — European Environment Agency (europa.eu).

11. E3 Modelling. PRIMES (Price-Induced Market Equilibrium System) model (website). https://e3modelling.com/modelling-tools/primes/.

12. International Institute for Applied Systems Analysis (IIASA). ‘Greenhouse Gas and Air Pollution Interactions and Synergies (GAINS)’ (website). https://iiasa.ac.at/models-and-data/greenhouse-gas-and-air-pollution-interactions-and-synergies.

13. European Environment Agency (2018). ‘Air Quality e-Reporting’ (website). https://www.eea.europa.eu/data-and-maps/data/aqereporting-8.

14. Concawe (2016). Urban Air Quality Study. Concawe report No. 11/16. https://www.concawe.eu/wp-content/uploads/2017/01/rpt_16-11.pdf.

15. Concawe (2018). A comparison of real driving emissions from Euro 6 diesel passenger cars with zero emission vehicles and their impact on urban air quality compliance. Concawe report No. 8/18. https://www.concawe.eu/wp-content/uploads/2018/04/Rpt_18_8.pdf.

16. European Topic Centre on Air Pollution and Climate Change Mitigation (2017). Long-term air quality trends in Europe. Contribution of meteorological variability, natural factors and emissions. Technical Paper 2016/7. https://www.eionet.europa.eu/etcs/etc-atni/products/etc-atni-reports/etcacm_tp_2016_7_aqtrendseurope.

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