Study to support the impact assessment for a revision of the EU Ambient Air Quality Directives

Specific Contract under Framework Contract ENV/F1/FRA/2019/0001

Final Report – Appendix

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Under Framework Contract ENV/F1/FRA/2019/0001
Economic Analysis of Environmental Policies and Analytical Support in the Context of Better Regulation

In association with:

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Appendix 2 – Stakeholder consultation summary report

Appendix 3 - Integrated assessment modelling

Methodology

Overview

Quantitative model analyses for this service contract, in particular of air pollutant emissions, concentrations, ecosystem impacts, feasibility to attain particular air quality targets as well as respective measures and their costs, has been conducted with the state of the art regional models including the *Greenhouse gas – Air pollution Interactions and Synergies (GAINS)* model and *MET Norway's chemical transport model (EMEP CTM)* with the *uEMEP downscaling extension* for fine resolution.

The GAINS integrated assessment model, developed at the International Institute for Applied Systems Analysis (IIASA), addresses air pollution impacts on human health from fine particulate matter and ground level ozone, vegetation damage caused by ground level ozone, the acidification of terrestrial and aquatic ecosystems and excess nitrogen deposition of soils. GAINS brings together data on economic development and structure, control potential and costs of emission sources, the formation and dispersion in the atmosphere of - as well as the inter-relations between - pollutants such as SO_2, NO_x, PM, NMVOC and NH_3. In particular, GAINS quantifies the interactions between these pollutant emissions and greenhouse gases, i.e., CO_2, CH4, N_2O and F-gases. GAINS assesses more than 1000 emission control measures for all EU Member States and computes the atmospheric dispersion of pollutants and analyses the costs and environmental impacts of pollution control strategies. In its optimisation mode, GAINS identifies the most cost-effective emission control strategies as a way to inform policy processes and international negotiations on mitigation of atmospheric pollutants. The model's atmospheric calculations, providing concentration and deposition across several species, are consistent with the EMEP CTM that has been used to provide the necessary calculations and outputs to derive source-receptor relationships used in GAINS. In depth description of the GAINS model is available in Amann et al (2011).

Ambient concentrations of $PM_{2.5}$ are calculated using linear transfer coefficients, derived from perturbation simulations of the EMEP Chemistry Transport Model (see below) run at 0.5°x0.25°, coupled with a downscaling of PPM from low-level emission sectors based on simulations with the CHIMERE CTM run at 0.125°x0.0625° or roughly 7x7km resolution. Altogether, GAINS calculates a concentration field of $PM_{2.5}$ at 7x7km resolution from (sector-specific) emissions of PM, SO_2, NOx, NH_3, and VOC from each Member State. Ambient concentrations in GAINS are thus meant to be representative of urban background levels. Details of the calculations are described, and a validation is shown in (Kiesewetter, et al., 2015).

The EMEP CTM is a state-of-the-art atmospheric chemistry transport model, and includes the recently developed novel, but well documented ((Denby, et al., 2020); (EMEP, 2020)), uEMEP downscaling module that allows the estimation of ambient air pollution concentrations down to a grid resolution of approximately 250x250m for the whole of Europe. Downscaling is carried out where suitable high resolution emissions proxies are available. This includes the emission sectors for traffic, shipping and stationary combustion. This methodology makes use of the best available atmospheric modelling tools and constitutes a substantial upgrade of the simplified approach developed within the work for the EU

Thematic Strategy on Air Pollution to assess compliance with NO_2 and PM_{10} ambient air quality limit values in the GAINS model (Kiesewetter et al., 2013).

Annual mean concentrations have been calculated with the EMEP model under different policy scenarios for the following pollutants: sulphur dioxide, nitrogen dioxide and nitrogen oxide, particulate matter (PM_{10}, $PM_{2.5}$), NMVOC, ozone, ammonia, BaP, benzene and carbon mono$_x$ide. Downscaling will be applied to a selection of these pollutants ($PM_{2.5}$, PM_{10}, NO_2, BaP, Benzene, CO and ozone; see Table A-1) on annual mean concentrations so any short term indicators, e.g. hourly or daily means, will need to be statistically implied from an assessment of either modelled or observed hourly data. Benzo(a)pyrene is not normally explicitly modelled by the EMEP modelling suite. However, a BaP emissions inventory is available for present day emissions, though no scenario trends are available. By applying the same trends used for $PM_{2.5}$ emissions to the BaP emissions then BaP can then be modelled explicitly by the EMEP modelling suite for all scenarios. Heavy metals, regulated under the EU Ambient Air Quality Directives cannot be quantitatively assessed with the EMEP CTM modelling suite, but there are only a handful of violations of AAQ limit or target values reported for these substances. We will review existing monitoring data and exceedance levels, perform statistical analysis of the number and range of exceedances, and explore the key reasons for exceedance by overlying the location of exceedances with the sources of PM. A summary of the approach to assessing each of the pollutants, including the 13 pollutants covered by the AAQ Directives, is presented in Table A-1.

Table A-1 - Summary of modelling approach to each pollutant

	$PM_{2.5}$	PM_{10}	SO_2	NO_x	NO_2	NH_3	VOC	CO	O_3	Benz.	BaP	HM*
Ambient background concentrations and optimisation in IIASA's GAINS Model	✓											
Quantify the related emissions in each Member State and economic sector for all scenarios	✓	✓	✓	✓	✓	✓	✓	✓		split in VOC	scale to $PM_{2.5}$	
Modelling of scenarios with the EMEP MSC-W CTM to calculate annual mean ambient concentrations of air pollutants (0.1°)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	
Downscaling of the EMEP MSC-W CTM using uEMEP to calculate annual mean ambient concentrations of air pollutants at fine resolution for exposure (250 m)	✓	✓		✓	✓			✓	✓	✓	✓	
Downscaling of the EMEP MSC-W CTM using uEMEP to calculate annual mean ambient concentrations of air pollutants at monitoring sites for exceedance indicators (50 m)	✓	✓		✓	✓			✓	✓		✓	
Apply statistical relationships from observed and modelled concentrations to infer likely compliance with short-term limit values		✓						✓	✓			
Health impact assessment (1 km) using downscaled annual mean exposure calculations (250 m)	✓				✓				✓			
Health impact assessment using EMEP MSC-W annual exposure indicator calculations (0.1°)									✓			
Review existing monitoring data and exceedance levels.												✓
Perform statistical analyses of the number and range of exceedances at different limit/target values												✓
Analyse how the number of exceedances change with the different limit values and what this might mean for required mitigation												✓
Explore whether monitoring data can be cross-checked to other pollutant data (e.g., E-PRTR, overlay with PM concentration modelling) to identify potential drivers of local exceedances.												✓

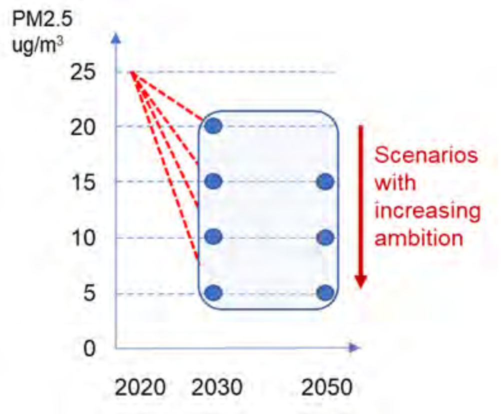
*HM = Heavy metals (Cd, As, Ni, Pb)

All impacts will be assessed compared to the baseline. The impacts will be assessed in the short-term (2025), mid-term (2030) and long-term (2050) time horizon, but not for the years in between.

Application of GAINS

The policy scenarios defined under Policy Area 1 aim to attain closer alignment of air quality standards with the recently published WHO air quality guidelines, which consider the most up-to-date scientific research around the health impacts associated with exposure.

Figure A-1 - Conceptual illustration of the analysed policy scenarios reaching defined annual mean concentration targets for $PM_{2.5}$ with a specific timeline.



We analyse different policy scenarios corresponding to different ambition levels (Figure A-1). In addition, a Maximum (Technically) Feasible Reductions scenario (MTFR or MFR) was generated for both target years, which minimizes emissions irrespective of costs and thus represents the lower limit of emissions achievable with technical measures only. Lifestyle changes and fuel switches beyond the Baseline scenario are not included in the MTFR.

The ‘headline indicator’ of the extent of the alignment with the revised WHO Air Quality Guidelines (and for expressing the level of ambition of different scenarios assessed) is the annual mean concentration of fine particulate matter ($PM_{2.5}$), as this air pollutant at its current levels is associated with the most harmful effects on human health. The scenarios are defined based on assumptions of different $PM_{2.5}$ levels as a headline indicator, but also include assumptions for each pollutant covered by the current Ambient Air Quality Directives.

These emission scenarios have been developed with the optimisation module of the GAINS model, which has been applied to identify cost-optimal strategies to achieve ambient $PM_{2.5}$ concentrations in compliance with ambient air quality standards of different ambition levels in the two target years 2030 and 2050.

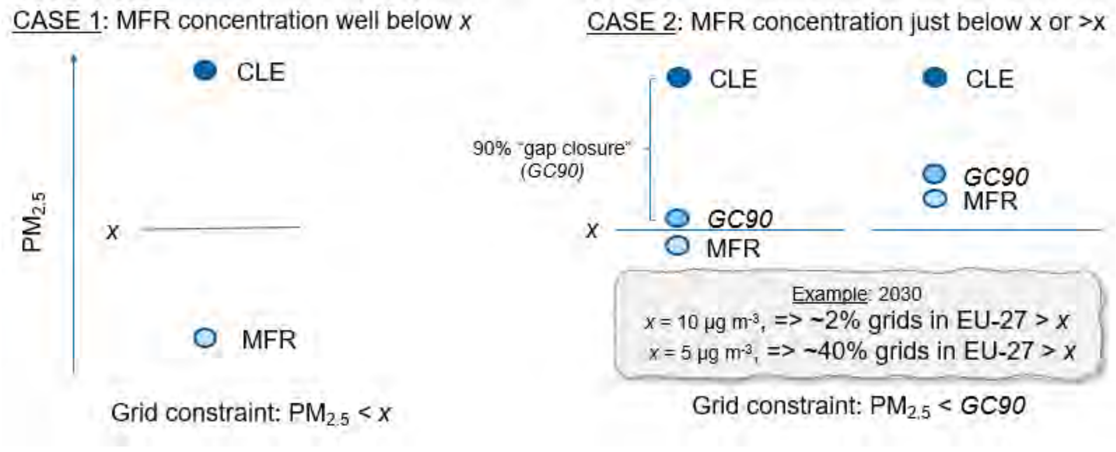
Information box: determine the feasibility of attainment of EU air quality standards

For each scenario specified, we employ the cost optimisation module of the GAINS model to determine the feasibility of attainment of such $PM_{2.5}$ standards at background levels by emission control policies set at the national (or EU) level, and, where attainment of targets is feasible, provide a quantification of emissions and costs by economic sector for achieving this target. The GAINS model includes a linearised approximation of the EMEP atmospheric model relating emissions of PM precursor pollutants to ambient concentrations of $PM_{2.5}$ on a (roughly) 7x7km grid. GAINS can determine the cost optimal solution to achieve certain targets on ambient air quality. In this project, the optimisation analysis is constrained to achieve $PM_{2.5}$ compliance at this grid level. In case the model finds no feasible solution for achieving compliance in all grid cells, the constraints are relaxed to allow for a certain fraction of exceeding areas where additional local policy measures will be needed to achieve compliance. For such grid cells, the optimisation requires at least a 90% improvement of ambient $PM_{2.5}$ concentrations towards the concentration levels attained in the maximum feasible reductions (MTFR) case (see Figure A-2 for illustration of the ‘gap closure’ concept used). The cost optimisation is thus used to suggest the most cost effective national or EU wide emission control measures to bring ambient concentrations close to the ambient air quality limit values. It is important to note that compliance at hot spots, e.g., in busy street canyons, may require supplementary local measures (e.g., traffic restrictions).

For each scenario, the cost optimal solution for $PM_{2.5}$ compliance at background level was quantified in terms of emissions of PM and precursor pollutants by sector and Member State. The emissions were passed on to the full EMEP/uEMEP modelling suite for quantification of ambient concentrations of all pollutants specified in Task 1. For NO_2, NO_x, $PM_{2.5}$, PM_{10}, SO_2, O_3, CO and benzene, concentration levels were calculated at a fine resolution of approx. 250x250m for all of Europe. Population exposure to $PM_{2.5}$, NO_2 and O_3 was quantified using these calculations, and their health impacts in terms of mortality and morbidity analysed. At the same time, for each scenario the cost optimal set of emission control measures and their costs were quantified on national level. In the next stage, the 250x250 m calculations are used to identify monitoring sites that are likely in exceedance. At these sites the uEMEP scheme is further applied at 50x50m resolution to better quantify the potential from local sectoral emission reductions.

While the $PM_{2.5}$ limit values are the driving indicator defining the different scenarios, different ambition levels for $PM_{2.5}$ will have implications for the concentration levels of other air pollutants. Optimising for ambient concentrations of multiple pollutants was not foreseen in this project; however, as described above, from the high-resolution calculations of the EMEP CTM we estimated ambient concentrations of all pollutants covered in the model. This allowed us to quantify the range of feasible concentration limits for other pollutants under each scenario.

Figure A-2: Illustration of the target setting approach in the GAINS optimization at the grid level. The left panel (Case 1) represents the situation where the target level x (=20, 15, 10, 5 µg/m³) lies well between the baseline and MTFR levels for a given grid cell. Case 2 illustrates the target setting approach if the MTFR level lies either above the target (right side of Case 2) or just below it (left side of Case 2). A "gap closure of 90%" towards ensures that the target is feasible, and also ambitious, but not so ambitious that the constraint in a single grid cell can drive the mitigation measures in large parts of Europe.



Legislation and policies included in the baseline

The starting point of the analysis relies on the assumptions in the Clean Air Outlook 2 published in January 2021 but the underlying energy and agriculture projections reflect the further development of the REFERENCE scenarios used for assessing the impacts of recent Commission proposals notably the Fit for 55 package.

EU wide Legislation included in the baseline:

Directive on Industrial Emissions including derogations and opt-outs included according to information provided by national experts (2010/75/EU)

OJ L334/17, 2010: DIRECTIVE 2010/75/EU OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 24 November 2010 on industrial emissions (integrated pollution prevention and control). Official Journal of the European Union

The Medium Combustion Plant directive ((EU) 2015/2193)

OJ L313/1, 2015: Directive (EU) 2015/2193 of the European Parliament and of the Council of 25 November 2015 on the limitation of emissions of certain pollutants into the air from medium combustion plants. Official Journal of the European Union.)

BAT requirements according to European Commission implementing decisions for large combustion plants and industrial production processes according to European Commission implementing decisions

OJ L70/63, 2012: COMMISSION IMPLEMENTING DECISION of 28 February 2012 establishing the best available techniques (BAT) conclusions under Directive 2010/75/EU of the European Parliament and of the Council on industrial emissions for iron and steel production.

OJ L212/1, 2017: COMMISSION IMPLEMENTING DECISION (EU) 2017/1442 of 31 July 2017 establishing best available techniques (BAT) conclusions, under Directive 2010/75/EU of the European Parliament and of the Council, for large combustion plants.

OJ 70/1, 2012: COMMISSION IMPLEMENTING DECISION of 28 February 2012 establishing the best available techniques (BAT) conclusions under Directive 2010/75/EU of the European Parliament and of the Council on industrial emissions for the manufacture of glass.

OJ l 174/32, 2016: COMMISSION IMPLEMENTING DECISION (EU) 2016/1032 of 13 June 2016 establishing best available techniques (BAT) conclusions, under Directive 2010/75/EU of the European Parliament and of the Council, for the non-ferrous metals industries.

OJ L 100/1, 2013: COMMISSION IMPLEMENTING DECISION of 26 March 2013 establishing the best available techniques (BAT) conclusions under Directive 2010/75/EU of the European Parliament and of the Council on industrial emissions for the production of cement, lime and magnesium oxide.

OJ l 284/76, 2014: COMMISSION IMPLEMENTING DECISION of 26 September 2014 establishing the best available techniques (BAT) conclusions, under Directive 2010/75/EU of the European Parliament and of the Council, for the production of pulp, paper and board.

The implementing decisions with regard to Ecodesign requirements for small combustion installations using solid fuels

OJ L 193/1, 2015: Commission Regulation (EU) 2015/1185 of 24 April 2015 implementing Directive 2009/125/EC of the European Parliament and of the Council with regard to Ecodesign requirements for solid fuel local space heaters.

OJ L 193/100, 2015: Commission Regulation (EU) 2015/1189 of 28 April 2015 implementing Directive 2009/125/EC of the European Parliament and of the Council with regard to Ecodesign requirements for solid fuel boilers.

Fuel Quality directive 2009/30/EC on the quality of petrol and diesel fuels, as well as the implications of the mandatory requirements for renewable fuels/energy in the transport sector

Specification of petrol, diesel and gasoil and introducing a mechanism to monitor and reduce greenhouse gas emissions for fuel used by inland waterway vessels: OJ L140/88, 2009

Directive (EU) 2016/802 relating to a reduction in the sulphur content of certain liquid fuels OJ L 121/13, 1999

Directive relating to a reduction in the sulphur content of certain liquid fuels transposing 2008 revision of Annex VI to MARPOL convention: OJ L132/58, 2016.

2008 revision of Annex VI to MARPOL Convention of the IMO regarding NOx emission limit values for ships sailing in emission control areas (including the Baltic and North Seas), becoming mandatory on 1 Jan 2021.

A sulphur emission control area for the entire Mediterranean Sea to start from 1 Jan 2025, thus reducing the maximally allowed sulphur contents to 0.1M% (as opposed to the general 0.5M%). The assumption is that this application will be endorsed by IMO in due time.

For light-duty vehicles: All exhaust emission standards up to Euro 6d, becoming mandatory for new models from 1. Jan. 2020 and 1. Jan. 2021 on (category M1 and N1 respectively) {DIR (692/2008/EC) and ensuing implementing regulations (715/2007/EC)] It is assumed that a stringent Euro 7 stage will become mandatory from the year 2025 onwards.

For heavy-duty vehicles: All exhaust emission standards up to Euro VI, mandatory 31. Dec. 2013 for type approval in the European Union [DIR (595/2009/EC) in conjunction with (582/2011/EU)]

For motorcycles and mopeds: All Euro standards for motorcycles and mopeds in passing through Euro 3 up to and including Euro-5, becoming mandatory for all new registrations from 1. Jan 2021 DIR (2002/51/EC) followed by Reg. (168/2013/EU)

On evaporative emissions for mopeds, motorcycles, light and heavy-duty vehicles: Euro standards up to Euro-5/6 (DIR 692/2008/EC) and fuels directive (RVP of fuels) (EN 228 and EN 590)

For Non-Road Mobile Machinery: All EU emission controls up to Stages IIIA, IIIB and IV, with introduction dates by 2006, 2011, and 2014 (DIR 2004/26/EC) together with (DIR 2005/13/EC), depending on machine category and engine size. Stage V emission standards have been assumed with phasing-in between 2017 and 2021, covering an enlarged scope of machine categories (1628/2016/EU)

Sulphur Emissions Control Area (SECA) in Mediterranean Sea from 2025 (EU DIRECTIVE 2005/33/EC Sulphur content of marine fuel MARPOL Annex VI Air Pollution)

Commission Implementing Decision (EU) 2017/302 of 15 February 2017 establishing best available techniques (BAT) conclusions, under Directive 2010/75/EU of the European Parliament and of the Council, for the intensive rearing of poultry or pigs - OJ L 43/231, 15.2.2017

The Nitrates directive (91/676/EEC) and Water Framework directive (200/60/EC)

Framework Code for Good Agricultural Practice for Reducing Ammonia Emissions (ECE/EB.AIR/120) of the United Nations Economic Commission for Europe

Directive 94/63/EC of 20 December 1994 on the control of volatile organic compound (VOC) emissions resulting from the storage of petrol and its distribution from terminals to service stations - OJ L 365, 31/12/1994

Directive 2009/126/EC on Stage II petrol vapour recovery during refuelling of motor vehicles at service stations - OJ L 285, 31.10.2009

Directive 1999/13/EC of 11 March 1999 on the limitation of emissions of volatile organic compounds due to the use of organic solvents in certain activities and installations) including amendment 2004/42/EC (so called Paints directive) as well as Directive 2008/112/EC on classification, labelling and packaging of substances and mixtures - OJ L 085, 1999

Commission Implementing Decision of 9 October 2014 establishing best available techniques (BAT) conclusions, under Directive 2010/75/EU of the European Parliament and of the Council on industrial emissions, for the refining of mineral oil and gas. (OJ L 307/38, 2014)

National policies

To enable a coherent assessment of the measures reported by Member States, measures listed in the NAPCPs and PAMs database have been clustered into four groups:

Group A: Structural measures that are already included in the PRIMES (energy) and CAPRI (agriculture) activity scenarios. These include, inter alia:

- enhanced energy efficiency,
- accelerated eradication of solid fuels (especially coal) from the residential sector,
- modal shifts in the transport sector,
- more electric cars and/or indicative phase-out of combustion engine (gasoline or diesel) vehicles/cars,
- increasing the share of organic/ecological farming.

Such measures are typically important parts of climate policies and have been reported by Member States in the draft National Energy and Climate Plans (NECPs) and reviewed in the Commission’s analysis. Subsequently, they have been implemented into the energy projection and/or the PRIMES climate policy scenarios, even if the quantification of their impacts remains associated with uncertainties. To avoid double-counting, this analysis considers already adopted measures through the use of the MIX55 scenario as the baseline projection that includes the foreseen additional measures through the PRIMES climate policy scenarios.

Group B: Transposition of EU legislation into national laws and regulations, e.g.,

- implementation of the Ecodesign directive,
- promoting application of the code of good agricultural practice.

These measures are already included in the EU-wide set of measures.

Group C: Other measures whose impacts which can be quantified, even if their quantification is uncertain. These include, e.g.,

- accelerated replacement of old vehicles,
- maintaining stricter emission limit values than EU-wide legislation (e.g., beyond the requirements of the Ecodesign directive).

Introduction schedules have been extracted from the Member States' NAPCP reports or, in absence of these, developed based on comparison with what is assumed in the current legislation baseline. Measures which have already been adopted are considered in the baseline scenario.

Group D: Measures for which a quantification of impacts is difficult in an EU-wide analysis, e.g.,

- low emission zones in cities,
- enhanced in-use surveillance of vehicle emissions,
- information campaigns on eco-friendly driving,
- regional production and consumption,
- challenging industry for stricter NMVOC controls.

As the information provided by Member States does not allow developing robust quantifications of their likely impacts, such measures have not been further considered in the Baseline or the policy scenarios of this report. Thereby, the policy scenarios presented here provide conservative estimates of the possible impacts of reported policies and measures, noting that additional measures that are likely to enhance the effect of these scenarios have been reported by countries.

Concentration modelling methodology

Concentration modelling of the emission scenarios provided by GAINS is carried out using the EMEP MSC-W and uEMEP models. All emission scenarios and all pollutants, see Table A-2, are modelled. uEMEP calculates only annual mean concentrations.

Table A-2 - Modelled pollutants and for which health calculations they were applied. Also included are the calculated bias for the 2015 reference run.

Model	NO_2	$PM_{2.5}$	PM_{10}	O_3	SOMO35	O3 26th 8hday max	BaP	CO	CO MAX 8hday max	Benzine	SO_2
Model applications											
EMEP	CDA	CDA	CDA	CDA	CDA/H2	CDA	CDA	CDA	CDA	CDA	CDA
uEMEP	CA/H1/H2	CA/H1/H2	CA/H2	CA	.	.	CA	CA	.	CA	.
Model validation (2018) bias											
EMEP	-42 %	-23 %	-37 %	+15 %	+1%	-11 %	-13 %	-49 %	-70%	-59%	-26%
uEMEP	-24 %	-19 %	-33 %	+10 %	.	.	+11 %	-44 %	.	-53 %	.

Notes: CA: modelled annual mean concentrations available ; CDA: Modelled daily and annual mean concentrations are available; H1: Applied in health impact study; H2: applied in sensitive group studies at NUTTS2 level; X: not modelled

EMEP modelling

The EMEP MSC-W model version rv4.44 (EMEP model) has been used for these simulations. The horizontal resolution is 0.1ºx0.1º with 20 vertical layers (the lowest with a height of approximately 50 meters). The model domain covers the geographic area between 30N-82N latitude and 30W-60E longitude.

All scenario simulations were using **meteorological conditions for 2018**. In addition, control runs for the 2015 baseline scenario were performed using meteorological data for 2015. The meteorological data to drive the EMEP MSC-W air quality model have been generated by the Integrated Forecast System (IFS) model of the European Centre for Medium-Range Weather Forecasts (ECMWF), hereafter referred to as the ECMWF-IFS model. In the meteorological community the ECMWF-IFS model is considered state-of-the-art, and MSC-W has been using this model in hindcast mode to generate meteorological reanalysis for the year to be studied. The meteorological data for 2018 and 2015 were generated using the IFS Cycle 40r1 version. Sensitivity of the calculated concentrations to the choice of meteorological year was very small. This was true for both the reference 2015 calculation as well as the scenario calculations.

In addition to meteorology other inputs include boundary conditions, anthropogenic emissions and natural emissions from wind-blown dust, forest fires, sea salt and non-anthropogenic VOC's.

All emission scenarios, i.e. national and sectoral total emissions for all GAINS Europe countries, were provided from GAINS by IIASA. The **spatial distribution of emissions**, however, were based on different sources. For EECCA and West-Balkan countries gridded emissions provided by IIASA have been used.[1]

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[1] This applies to Albania, Armenia, Azerbaijan, Belarus, Bosnia and Herzegovina, Georgia, Kazakhstan, Kosovo, Kyrgyzstan, Macedonia, Montenegro, Moldova, Russia, Serbia, Turkey, Ukraine, Tajikistan, Turkmenistan and Uzbekistan.

For EU Member States, EEA countries and for the United Kingdom the spatial distribution of emissions was based on the official gridded EMEP emissions for 2019. The base grid of the EMEP emissions uses the spatial pattern reported on 0.1°x0.1° longitude/latitude resolution by the countries where available[2]. For Italy, Lithuania and Iceland emissions are spatially distributed by expert estimates by CEIP, based mostly on CAMS and EDGAR proxies ((Pinterits, 2021) and (Schindlbacher, 2021)).

Emission totals from **international shipping** in the sea areas within the modelling domain (Baltic Sea, North Sea, North-East Atlantic Ocean, Mediterranean Sea and Black Sea) were provided by IIASA. The emissions were spatially distributed based on the CAMS global shipping dataset (Granier, 2019) for 2019, developed by the Finnish Meteorological Institute (FMI), and provided via the ECCAD (Emissions of atmospheric Compounds and Compilation of Ancillary Data) website (ECCAD, 2022). All international shipping emissions are placed in GNFR sector G (Shipping) in the emission input.

Other sources contributing to the GNFR sector G (Shipping) are emissions from national shipping, which were included in the country emission data provided by IIASA. The spatial distribution of the national shipping emissions is as described above, i.e. for EECCA and West-Balkan countries gridded emissions provided by IIASA were used, while for the EU Member States, EEA countries and for the United Kingdom the emission pattern comes from the EMEP 2019 emissions, thus mostly based on gridded data reported by the countries. The national shipping emissions include both inland waterways and coastal shipping and ports when the country has a coastal border. For a few European countries the reported spatial patterns indicate very high emissions at certain ports. Whether the reported spatial distributions are correct for the year of reporting, is difficult to say. However, since the spatial distribution of national emissions is unchanged for the different scenarios, these coastal ‘hot spots’ appear in all scenarios and might lead to the incorrect conclusions about the effect of shipping emissions, since at coastal areas both national and international shipping emissions contribute to the total.

BaP emissions are normally not included in the emission input of the EMEP MSC-W model but were implemented in the code for the AAQD simulations. However, IIASA could not provide emissions of BaP for the scenarios. Therefore, gridded BaP emissions from the EMEP inventory for 2019 were used as a basis and were scaled following the changes of PM2.5 emissions between the different scenarios.

Benzene emissions are part of the NMVOC emissions, derived from the source dependent speciation split used in EMEP. The NMVOC speciation is based upon data from various CAMS datasets. TNO provided NMVOC speciation data for 25 compounds from each GNFR source sector as part of the CAMS-REG-v3.1.2 database, which were then mapped to the NMVOC species used in the EMEP model (Simpson D. B., 2020).

NMVOC emissions from the agricultural sectors were taken from the EMEP 2019 emissions for all countries, as these are not included in the emissions data provided by IIASA.

Volcanic SOx emissions from passive degassing of Italian volcanoes (Etna, Stromboli and Vulcano) are those reported by Italy.

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[2] This applies to Austria, Belgium, Bulgaria, Croatia, Cyprus, Czechia, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Latvia, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland and the United Kingdom.

Soil NOx emissions were partly based on the new CAMS-GLOB-SOIL v2.2 NOx inventory (Simpson D. a., 2021). Soil-NOx emissions which are related to the use of fertilizers in the agricultural sectors were not taken from the CAMS-GLOB-SOIL inventory, as these were provided as gridded emissions by IIASA for all countries.

Emissions from areas outside the GAINS Europe countries but within the model domain, i.e. North African and Asian areas were from the ECLIPSE v6b dataset provided by IIASA on 0.5⁰ x 0.5⁰ longitude/latitude resolution.

The boundary conditions for the main gaseous and aerosol species were based on climatological observed values with prescribed trends in trans-Atlantic fluxes, while ozone levels have been corrected based on measurements at Mace Head in Ireland (Simpson, 2012). The boundary conditions for natural particles of sea salt and mineral dust were the same as in the status run, namely 5-year monthly average concentrations, derived from EMEP MSC-W global runs.

Daily emissions from forest fires for 2018 were from The Fire Inventory from NCAR (FINN) (Wiedinmyer, 2011), version 5.

uEMEP modelling

The modelled concentrations presented throughout these reports are a combination of both EMEP and uEMEP calculations. Downscaling with uEMEP applies the following methodology with the steps illustrated in Figure A-4 taken from Qing et al. (2022).

- Calculations are made using the EMEP model for all of Europe as described in the previous section. Country based emission totals are provided from the GAINS model and spatially distributed in the EU27 countries using the country submitted 0.1° emission distribution data.
- In addition to concentration outputs, the EMEP model also traces all primary emissions from the 13 GNFR sources using the 'local fractions' methodology from within a defined region surrounding each EMEP grid (EMEP Status Report 1/2017, 2017; Wind et al., 2020). In this application this is within an 8 x 8 EMEP grid region.
- uEMEP is implemented as a post-processing routine to the annual mean output from the EMEP model. EMEP emission grids per sector and per compound are redistributed onto high-resolution sub-grids using the emission proxies.
- uEMEP then calculates the local dispersion from these sub-grid emissions using a dispersion kernel within a moving window region defined to be the size of 2 × 2 EMEP grids.
- uEMEP removes the local fraction contribution from the EMEP grid, within the same moving window region, and replaces these with the uEMEP sub-grid results.
- A frequency-distribution-based chemistry scheme is applied to calculate downscaled NO_2 and O_3 concentrations from annual mean NO_X ($NO+NO_2$) and O_x ($O3+NO_2$) concentrations.
- Resolution of the sub-grids varies according to the application, but maps are made at 250 m and calculations at monitoring sites are made at 25 m.

GAINS vs EMEP/uEMEP

Since the atmospheric calculations in GAINS use transfer coefficients based on the EMEP CTM, calculated concentration fields in GAINS are roughly consistent with EMEP, although differences remain which are related to the model version used (GAINS transfer coefficients were calculated with the 2012

EMEP model), the meteorological year used (5-year average of 2006-2010 in GAINS, 2018 in EMEP) the model resolution (0.1° in EMEP, 0.125°x0.0625° or “7x7km” in GAINS), and the spatial distribution of emissions. The ambient $PM_{2.5}$ target levels set in GAINS are therefore indicative for background concentration levels and are used to create the set of cost-optimal emission control scenarios, while the actual evaluation of concentrations of different pollutants under each scenario is done with the EMEP CTM + uEMEP downscaling.

In general, we find good agreement between EMEP and GAINS, but in individual countries results differ. The emission distribution used in the GAINS transfer coefficients emphasizes cities more strongly than the country reported grids used in the current EMEP model. The linearization used in GAINS also implies that a grid-specific $PM_{2.5}$ constant is included in the calculations, which does not change under strong mitigation scenarios. Both of these factors tend to result in higher ambient PM2.5 concentrations modelled in GAINS than in EMEP, so the GAINS model is more pessimistic than EMEP/uEMEP regarding the attainability of ambitious ambient $PM_{2.5}$ standards.

A comparison of GAINS and uEMEP concentrations modelled for 2020 emissions is shown in Figure A-3.

Figure A-3. Ambient $PM_{2.5}$ concentrations calculated in GAINS (left) and in uEMEP (right) models for 2020. Note that GAINS concentrations are restricted to populated grid cells in the EU-27.

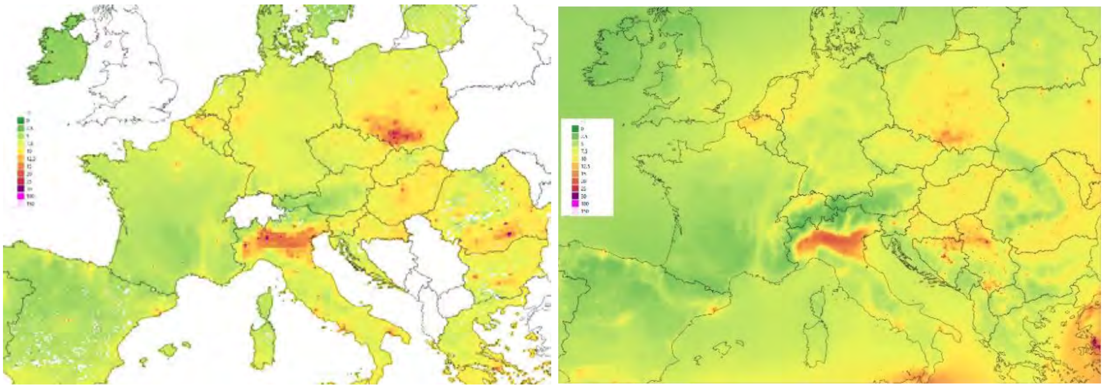
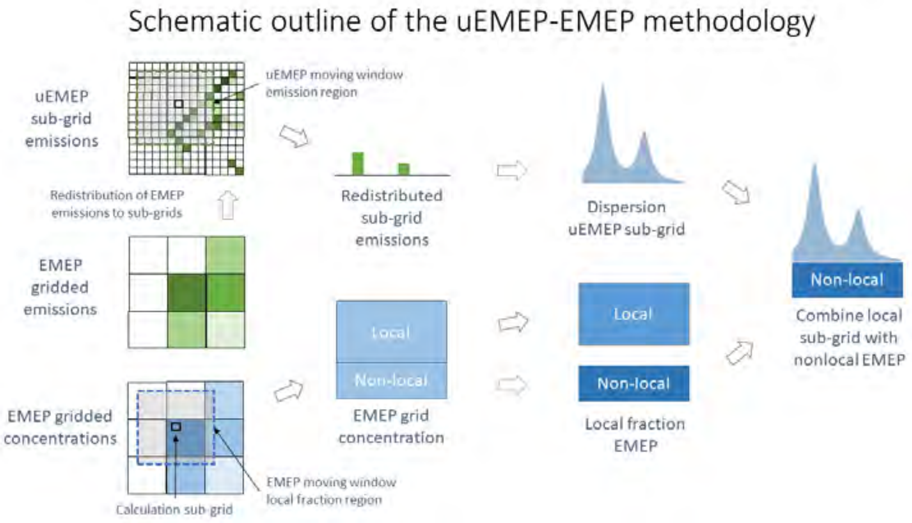


Figure A-4 - Schematic outline of how uEMEP and EMEP are combined



Concentrations at individual stations cannot be expected to be perfectly matched with a Europe wide modelling approach but robust statements about the likely distribution of concentration levels across stations can be made. Although there is no specific street canyon module employed, experience has shown that concentrations generated with uEMEP for $PM_{2.5}$, PM_{10}, NO_x and NO_2 are comparable to measured roadside concentrations. Within this project, the downscaling has been extended to include O_3, benzene and CO. We generally limit the analysis to annual mean concentrations. For SO_2 and the indicators that require temporal resolutions higher than annual mean (SOMO35, 26'th highest O_3 max 8 hour daily mean and highest CO max 8-hour daily mean) then the EMEP model is used without downscaling.

For the downscaled compounds of NO_2, O_3, PM_{10} and $PM_{2.5}$, statistical relationships based on observed concentrations are used to infer statements about likely compliance with short-term daily limit values, such as done previously within the work for the Commission on the Thematic Strategy on Air Pollution. No assessment of hourly indicators is carried out.

Explanation of the EMEP/uEMEP downscaling source contribution methodology

When presenting the source contribution results both downscaled uEMEP and EMEP local fraction calculations are used. This is illustrated in

Figure A-5. In this application of uEMEP the locally downscaled sources include:

- Road transport, which uses Open Street Maps (OSM) ref with a weighted distribution according to road category
- Shipping, which uses AIS emission data provided by the Coastal authorities of Norway
- Residential heating, which uses building density, from OSM, masked by population
- Aviation, which uses the Corine land use airport category
- Off road, which uses a weighted combination of Corine land use categories of urban, suburban, construction and road and rail

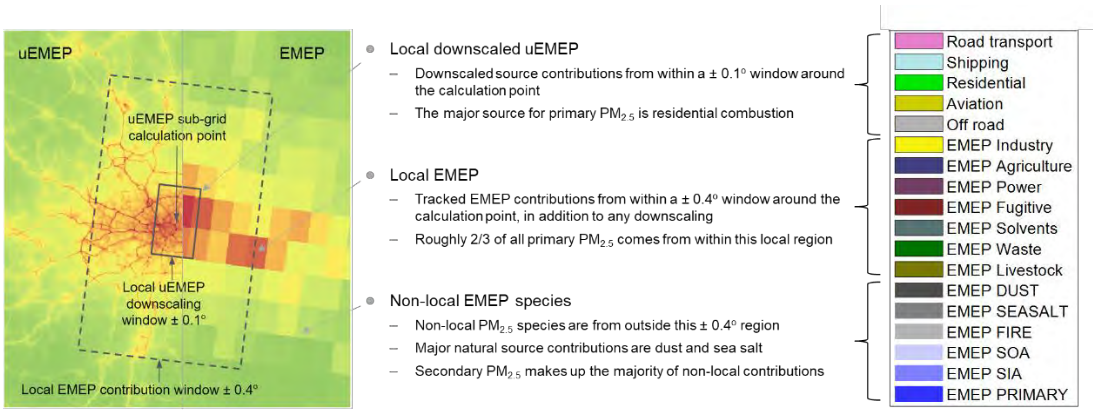
These local sources are calculated with uEMEP using 'local' emissions from within a ± 0.1° window around each uEMEP sub-grid. However, when presenting the source contribution results for these sources the region of contribution is extended using the EMEP local fraction source methodology, including contributions out to a ±0.4° region. The limitation of the region is pragmatic since larger regions require increased computing capacity. All other EMEP source contributions not included in the downscaling, as shown in

Figure A-5, are calculated using EMEP local fractions within the ±0.4º region. Non-anthropological sources and all sources outside the ±0.4º window are allocated to the non-local source contributions. For PM these are further split into species or source sectors, as shown in

Figure A-5.

Figure A-5.

Figure A-5 - Explanation of how the local and non-local sources from uEMEP and EMEP are combined



- Local downscaled uEMEP
  - Downscaled source contributions from within a ± 0.1° window around the calculation point
  - The major source for primary $PM_{2.5}$ is residential combustion
- Local EMEP
  - Tracked EMEP contributions from within a ± 0.4° window around the calculation point, in addition to any downscaling
  - Roughly 2/3 of all primary $PM_{2.5}$ comes from within this local region
- Non-local EMEP species
  - Non-local $PM_{2.5}$ species are from outside this ± 0.4° region
  - Major natural source contributions are dust and sea salt
  - Secondary $PM_{2.5}$ makes up the majority of non-local contributions

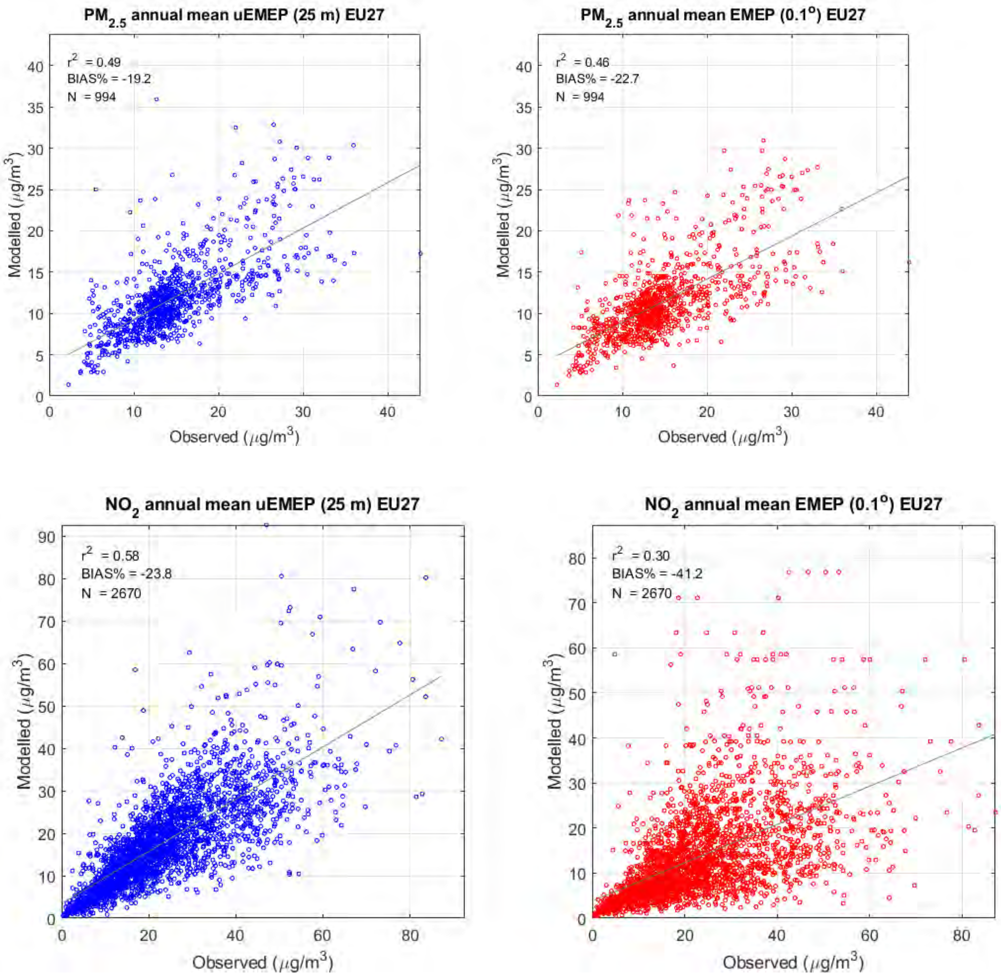
Difference between the EMEP and uEMEP/EMEP calculations

By including the downscaled concentrations then strong emission gradients within each EMEP grid can be resolved. This is most clearly visible with road transport emissions since these are surface emissions well defined in space. The impact of the downscaling will depend on the contributions from local sources compared to non-local sources. For example, on average in Europe the local NO_X contribution from within a ± 0.1° region is around 60% of total NO_X. This increases to 85% for the ±0.4° region. On the other hand, the local contribution of primary $PM_{2.5}$ to the total $PM_{2.5}$ is much less, just 15% from within ± 0.1° and 23% from within ±0.4°. This makes the impact of downscaling less significant for PM than for NO_X.

In

Figure A-8 scatter plots for all Airbase stations in the EU27 are shown comparing the results for uEMEP and EMEP for both $PM_{2.5}$ and NO_2. For $PM_{2.5}$ there is a slight improvement in spatial correlation and bias when using uEMEP. For NO_2 the improvement is more significant for both correlation, almost doubled, and bias, almost halved.

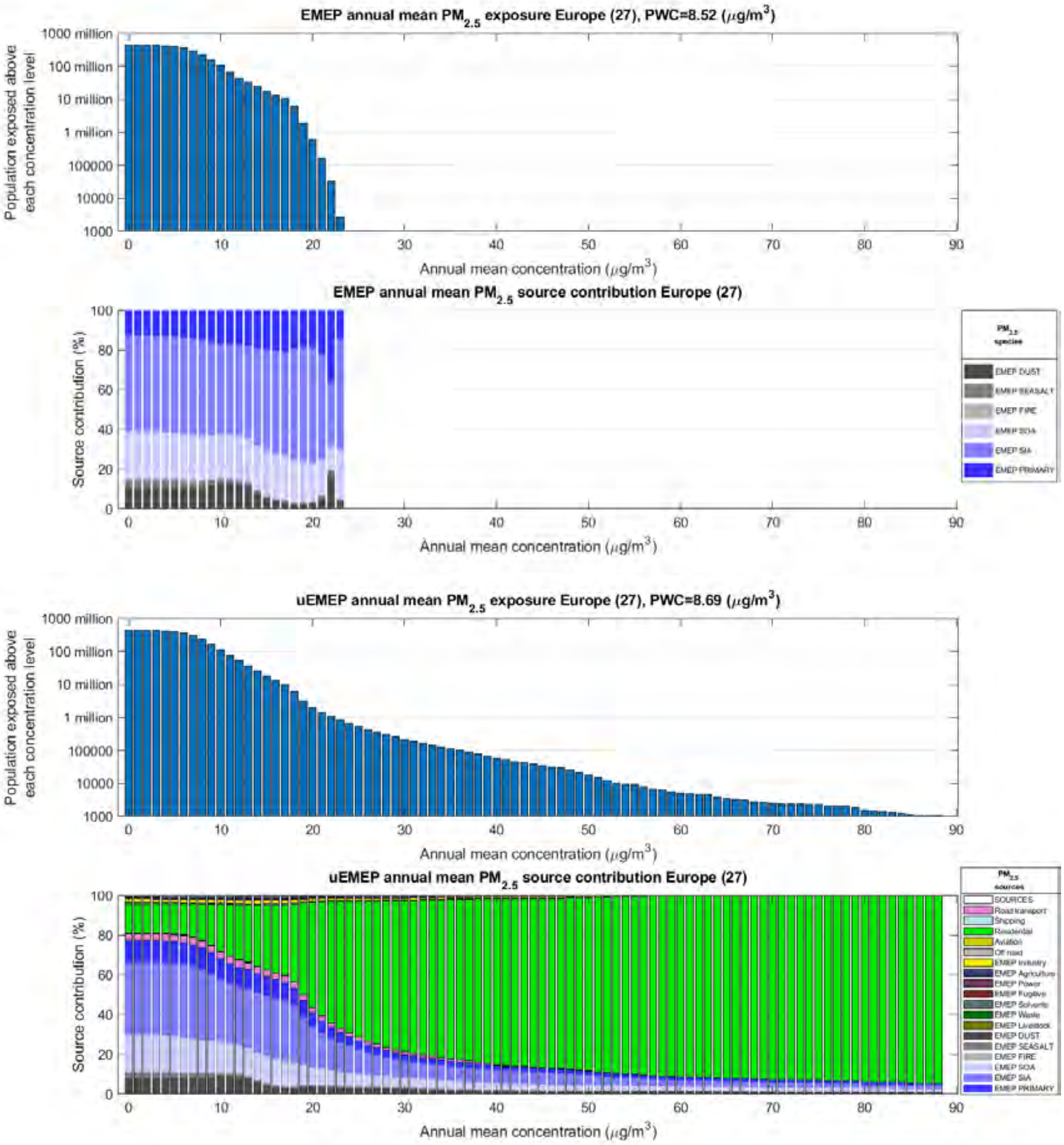
Figure A-6 - Scatter plots for NO_2 and $PM_{2.5}$ showing the difference in concentrations when calculated using uEMEP/EMEP or just EMEP. Reference year 2015.



In

Figure A-7 we show an example of the population exposure calculations, with and without downscaling for $PM_{2.5}$. In this example there are no EMEP concentrations > 23 µg/m^3 whilst the uEMEP downscaling has a much longer tail and indicates that 1 million inhabitants are exposed above this level.

Figure A-7 - Exposure calculations for $PM_{2.5}$ showing EMEP (top) and uEMEP/EMEP (bottom) exposure. This is the 2020 Baseline example.



Validation of concentration modelling

Calculations are made for the reference year 2015 and compared to Airbase observations on a country basis. These calculations are made at a resolution of 25 m to better resolve hot spots. The resulting scatter plots are shown in

Figure A-8 to Figure A-18. All Airbase stations are used in the comparison. The following points can be made:

- NO_2 annual mean bias varies between countries but for all of Europe the bias is –23%. The spatial correlation is high for most countries with $r^2 = 0.58$ for all stations in Europe
- $PM_{2.5}$ annual mean bias varies between countries but for all of Europe the bias is –19%. The spatial correlation is reasonable for most countries with $r^2 = 0.49$ for all stations in Europe
- PM_{10} annual mean bias varies between countries but for all of Europe the bias is poorer than for $PM_{2.5}$ at –33%. The spatial correlation is also poorer than for $PM_{2.5}$ with $r^2 = 0.36$ for all stations in Europe
- O_3 annual mean bias for all of Europe is +10%. The spatial correlation is $r^2 = 0.39$ for all stations in Europe. This indicator is not used in further assessments.
- O_3 SOMO35 bias for all of Europe the bias is +1%. The spatial correlation is $r^2 = 0.42$ for all stations in Europe. This indicator is used for health impacts and is derived directly from EMEP without downscaling.
- O_3 26'th highest daily maximum 8 hour running mean bias varies between countries but for all of Europe the bias is –11%. The spatial correlation is $r^2 = 0.40$ for all stations in Europe. This indicator is derived directly from EMEP without downscaling.
- BaP annual mean bias for all of Europe is +11%. The spatial correlation is $r^2 = 0.70$ for all stations in Europe.
- CO annual mean bias for all of Europe is -44%. The spatial correlation is $r^2 = 0.11$ for all stations in Europe. This indicator is not used in further assessments.
- CO highest daily maximum 8 hour running mean bias for all of Europe is –70%. The spatial correlation is $r^2 = 0.407$ for all stations in Europe. This indicator is derived directly from EMEP without downscaling. These poor modelling results are not used for further analysis.
- Benzene annual mean bias for all of Europe is -53%. The spatial correlation is $r^2 = 0.07$ for all stations in Europe. These poor modelling results are not used for further analysis.

SO_2 annual mean bias for all of Europe is -26%. The spatial correlation is $r^2 = 0.04$ for all stations in Europe. This indicator is not used in further assessments.

Figure A-8 NO₂ annual mean scatter plots for each EU27 country, 2015 reference calculation.

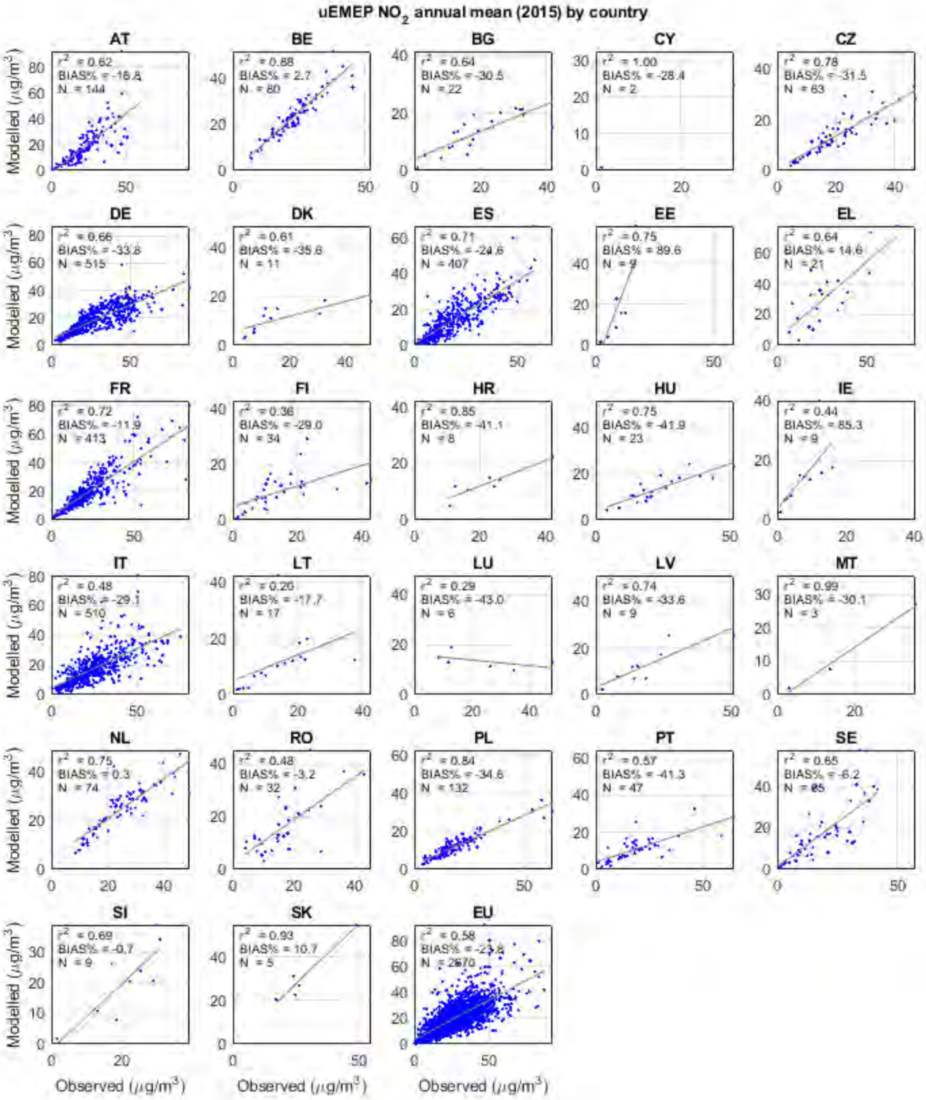


Figure A-9 PM$_{2.5}$ annual mean scatter plots for each EU27 country, 2015 reference calculation.

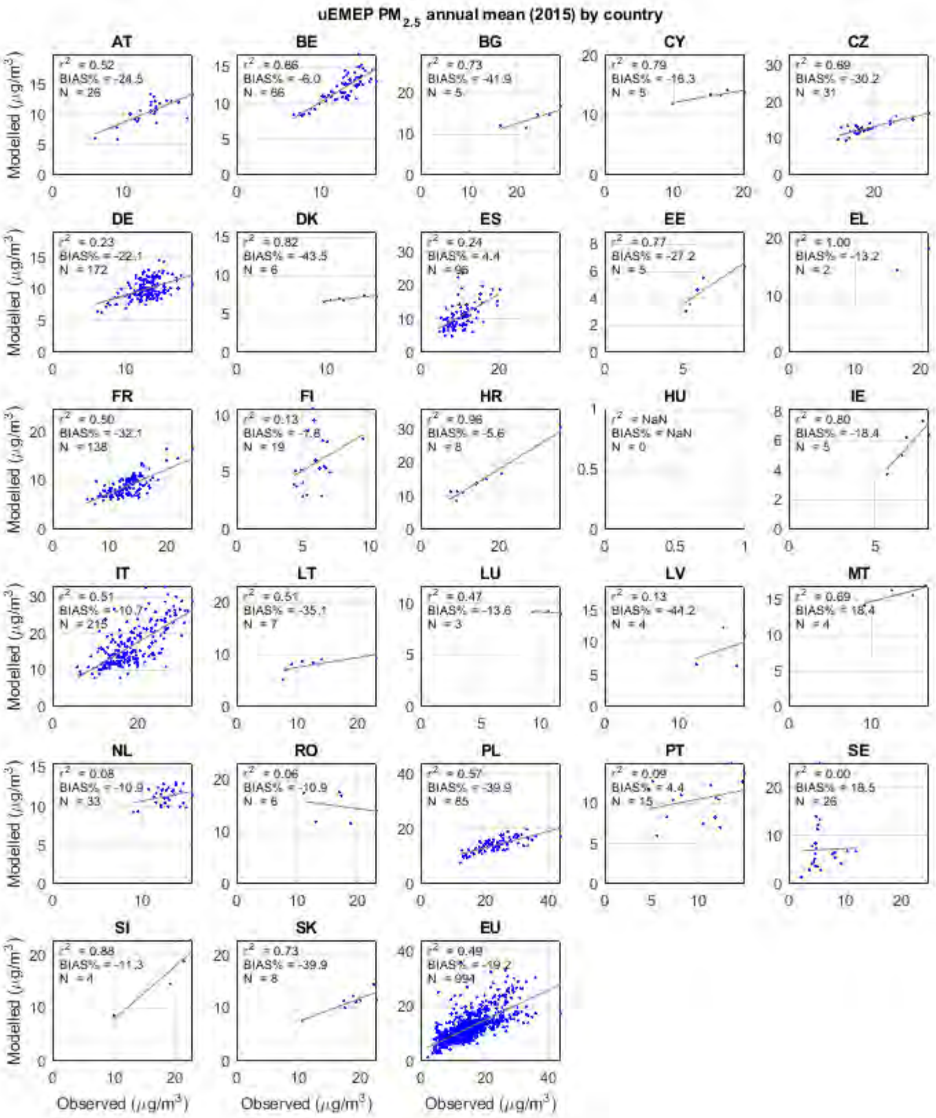


Figure A-10 PM10 annual mean scatter plots for each EU27 country, 2015 reference calculation.

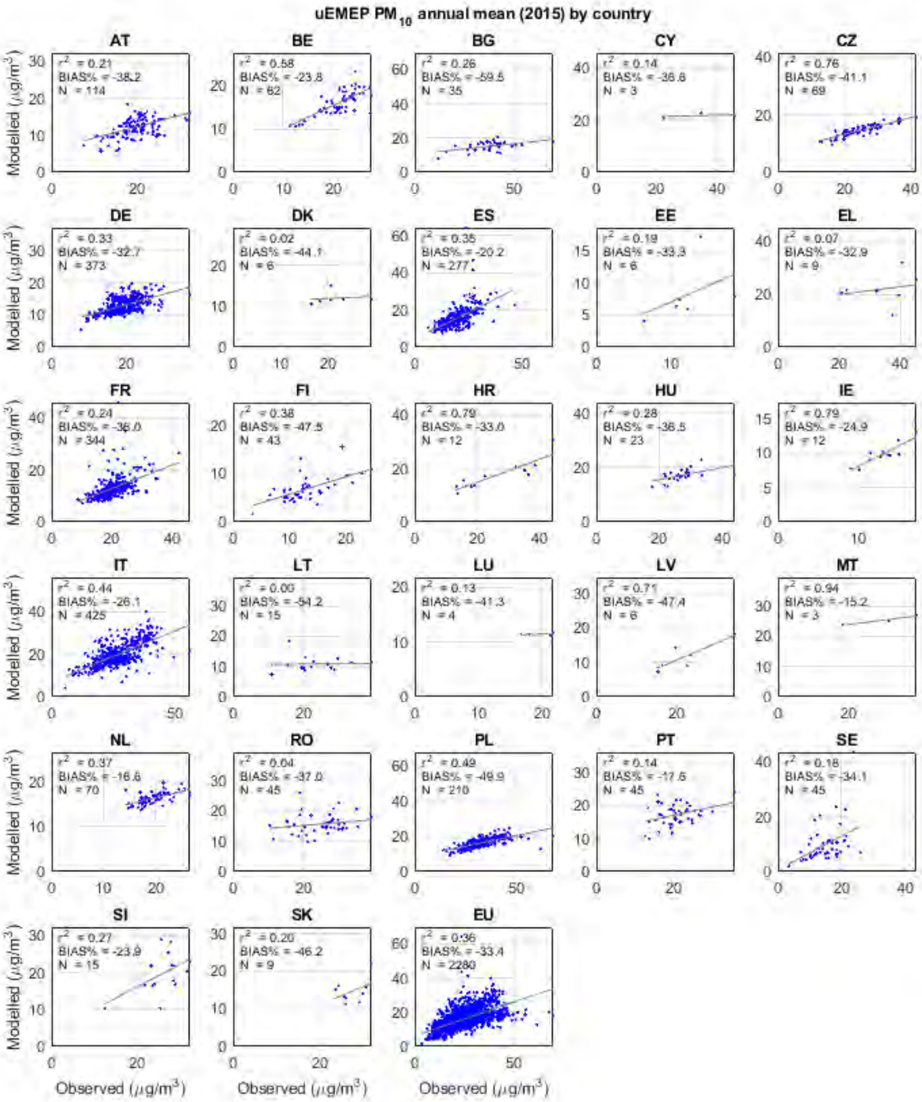


Figure A-11 – O_3 annual mean scatter plots for each EU27 country, 2015 reference calculation.

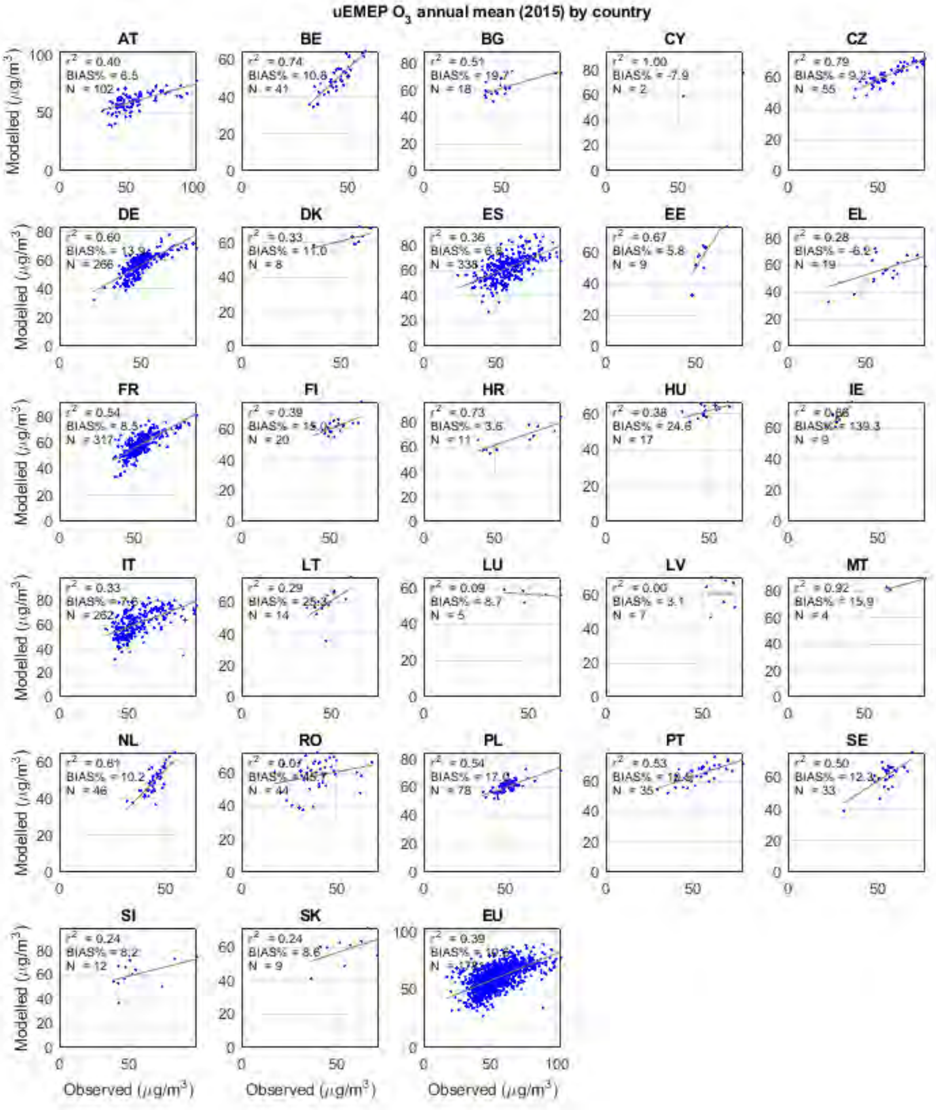


Figure A-12 SOMO35 scatter plots for each EU27 country, 2015 reference calculation.

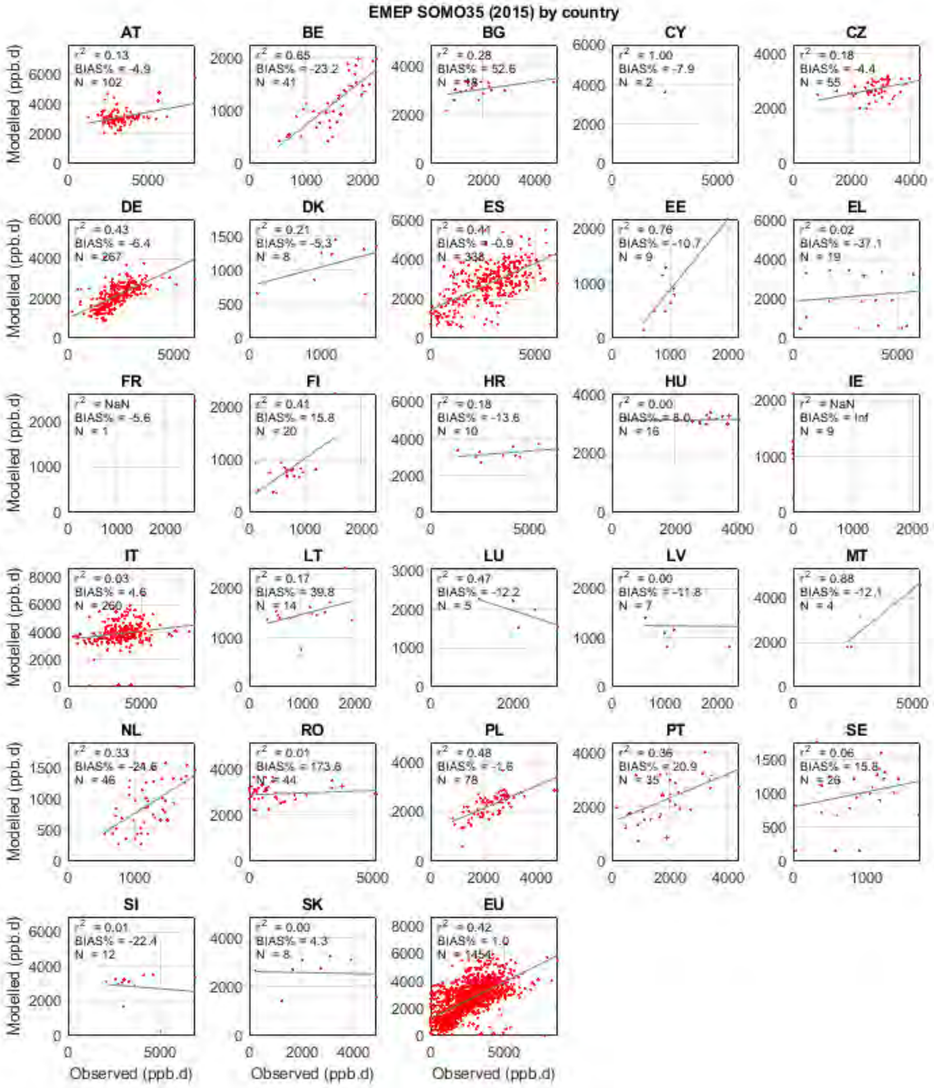


Figure A-13 – O_3 26’th highest daily max 8 hour mean scatter plots for each EU27 country, 2015 reference calculation.

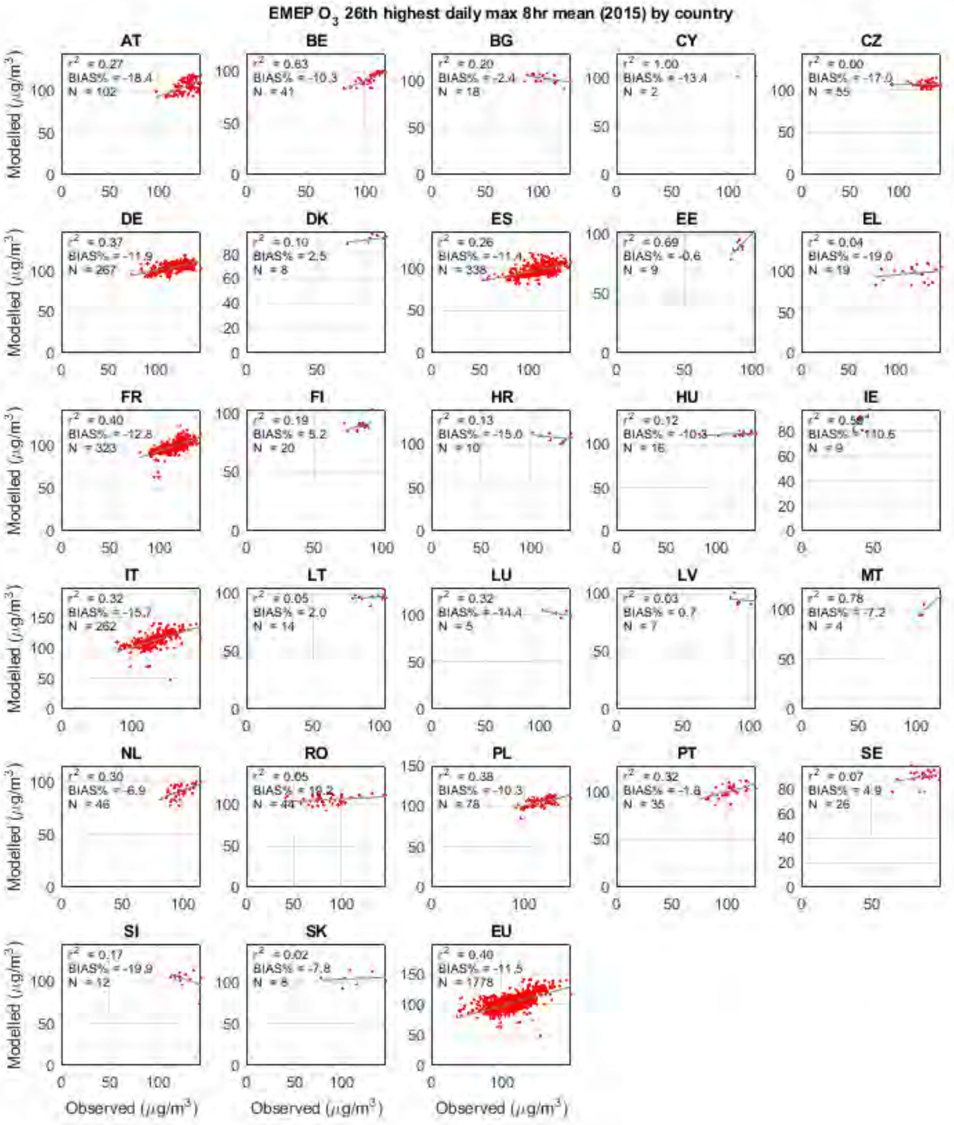


Figure A-14 BaP annual mean scatter plots for each EU27 country, 2015 reference calculation.

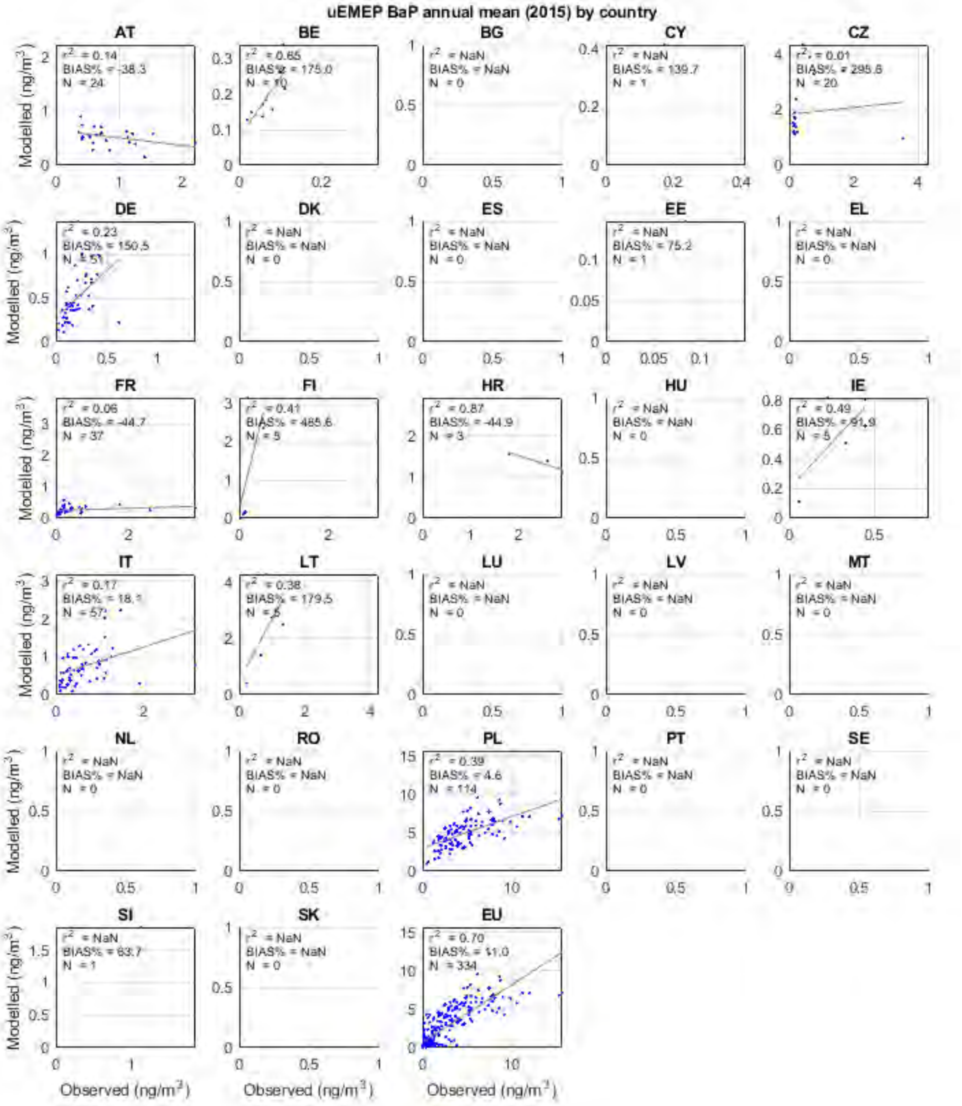


Figure A-15 CO annual mean scatter plots for each EU27 country, 2015 reference calculation.

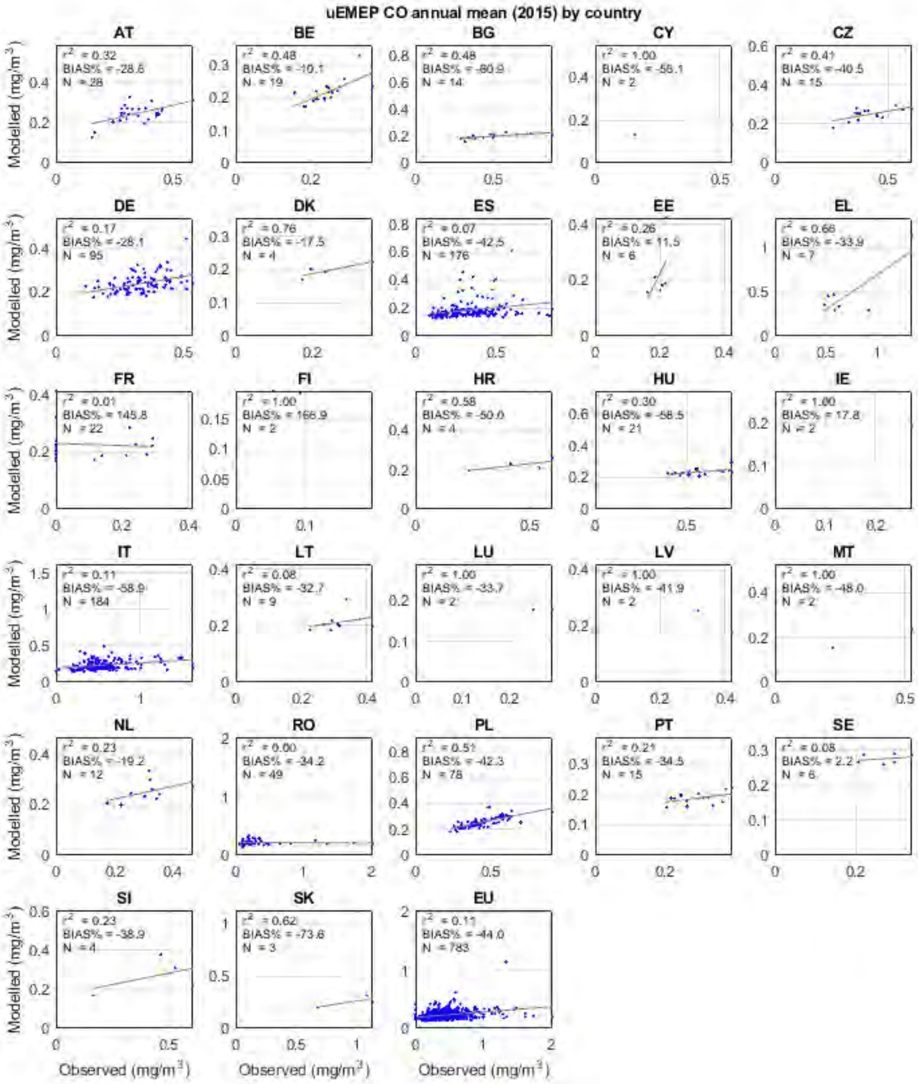


Figure A-16 CO highest daily max 8 hour mean scatter plots for each EU27 country, 2015 reference calculation.

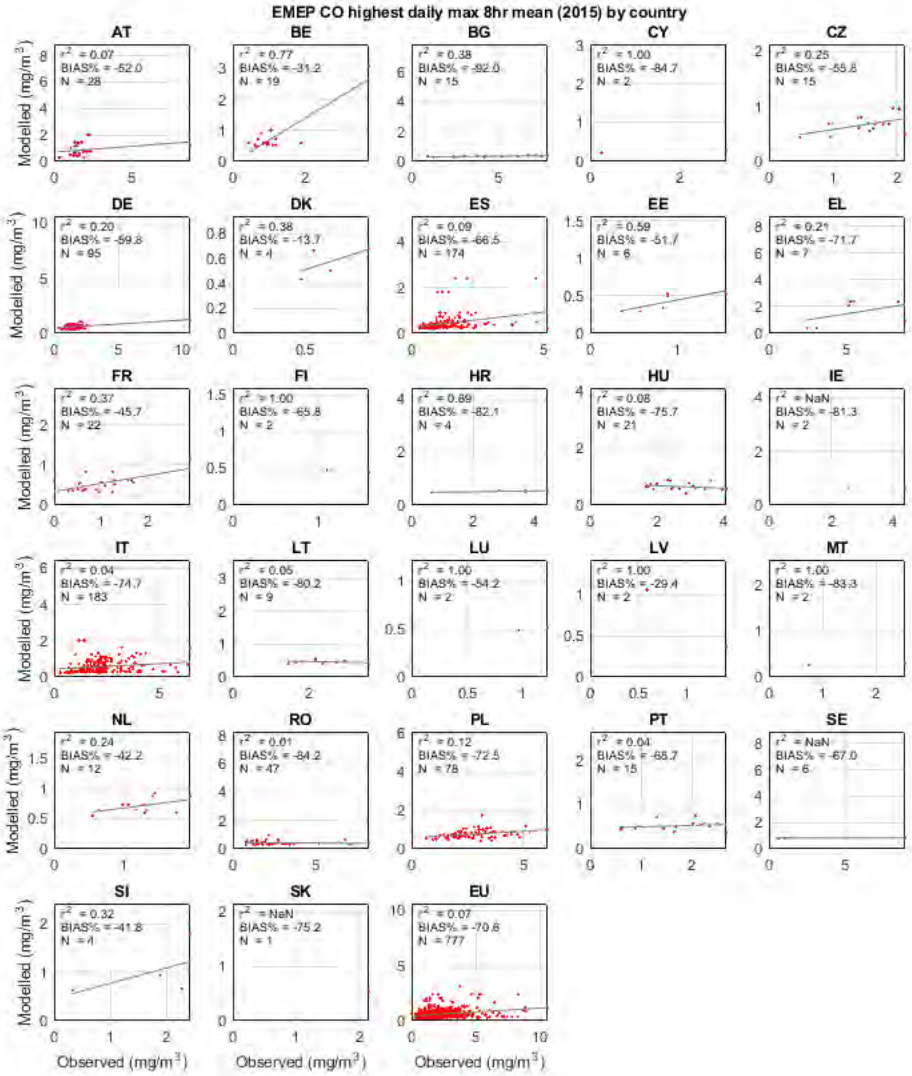


Figure A-17 Benzene annual mean scatter plots for each EU27 country, 2015 reference calculation.

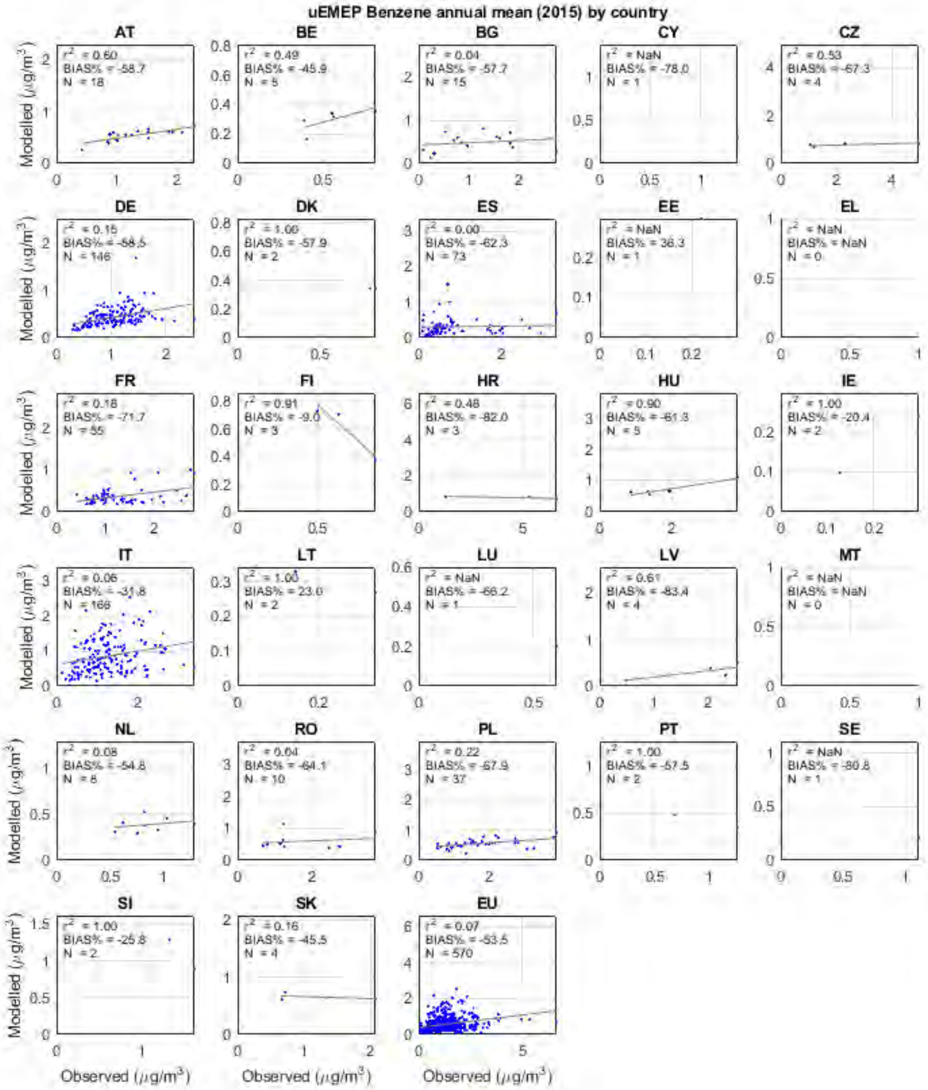
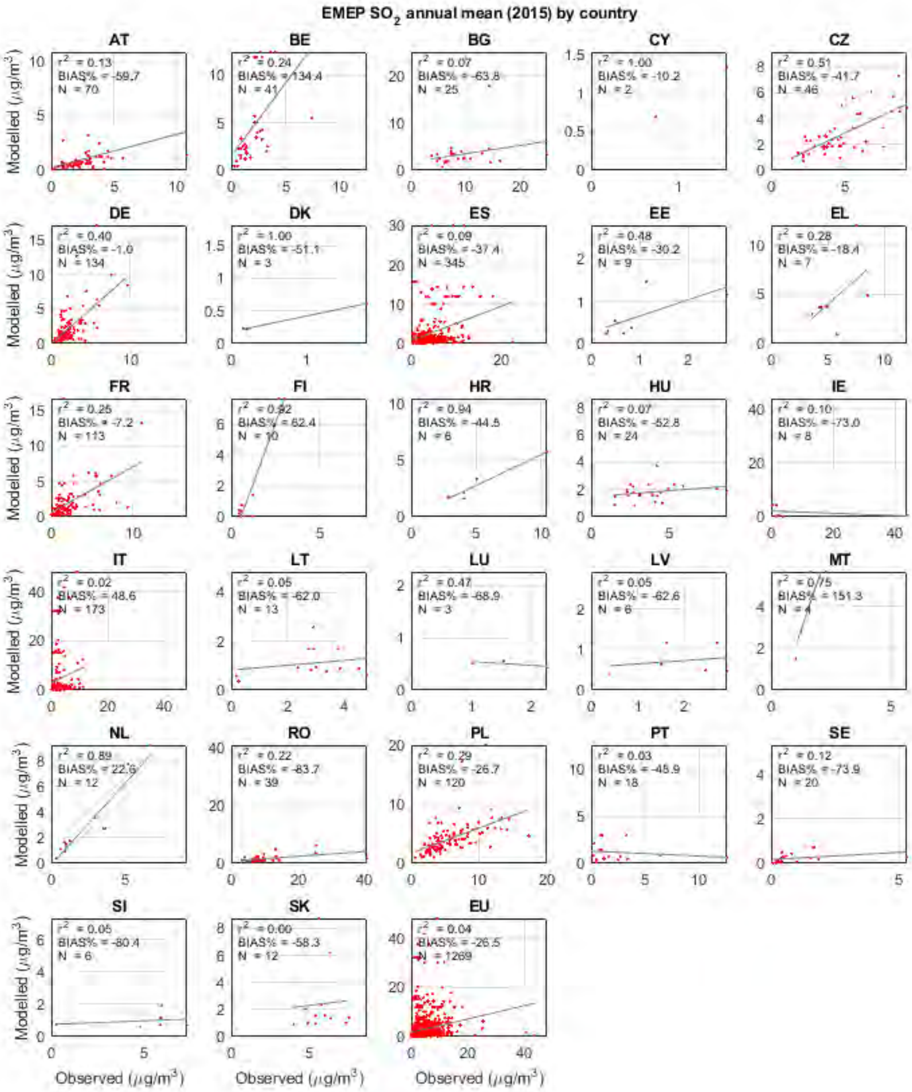


Figure A-18 SO₂ annual mean scatter plots for each EU27 country, 2015 reference calculation.



Bias adjustment

A sensitivity study has been carried out to evaluate the possible impact of model bias on the calculated scenarios at station sites. Bias adjustment was implemented in the modelling to assess the impact of model bias on future scenarios, assuming that the bias was caused either by downscaling dispersion bias or bias in emissions on a country basis. This was intended as a sensitivity test but will likely give more realistic results than calculations without bias adjustment. This has been applied to annual mean $PM_{2.5}$, PM_{10} and NO_2 concentrations.

As a default, bias adjusted concentrations are not used in the assessment. This is because without bias adjustment the contribution of the various sources is known. With bias adjustment it is not known which sources are responsible for the bias so this adjustment must be made homogeneously across all downscaled sources.

A 'bias adjustment' was implemented to some of the modelling to calibrate modelled concentrations and concentration monitored at sampling points for the year 2015 (i.e. at Airbase station sites). Notably, such bias adjustment was implemented for the station exceedance calculations for PM2.5 and NO2. This is based on the assumption that such bias is caused either by downscaling dispersion bias, or residual bias in emissions reported on a country basis. For the population exposure estimates this bias adjustment has not been applied. See the underpinning support study on the revision of the Ambient Air Quality Directives.

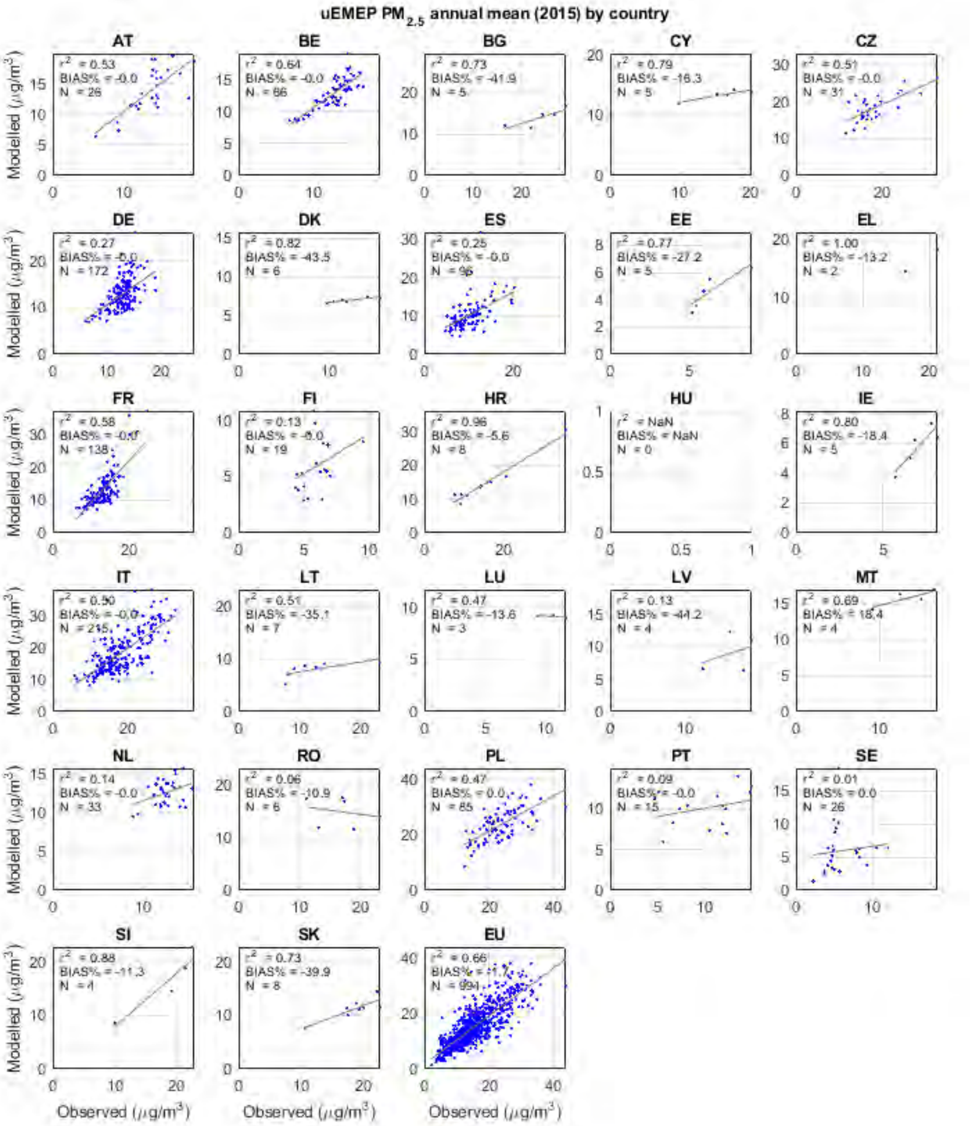
Bias adjustment has been applied for the pollutants $PM_{2.5}$, PM_{10} and NO_2. These pollutants have sufficient measurement data on a country basis to apply the adjustment. The bias in O_3 indicators were not large and, as a secondary pollutant, bias adjustment was not relevant.

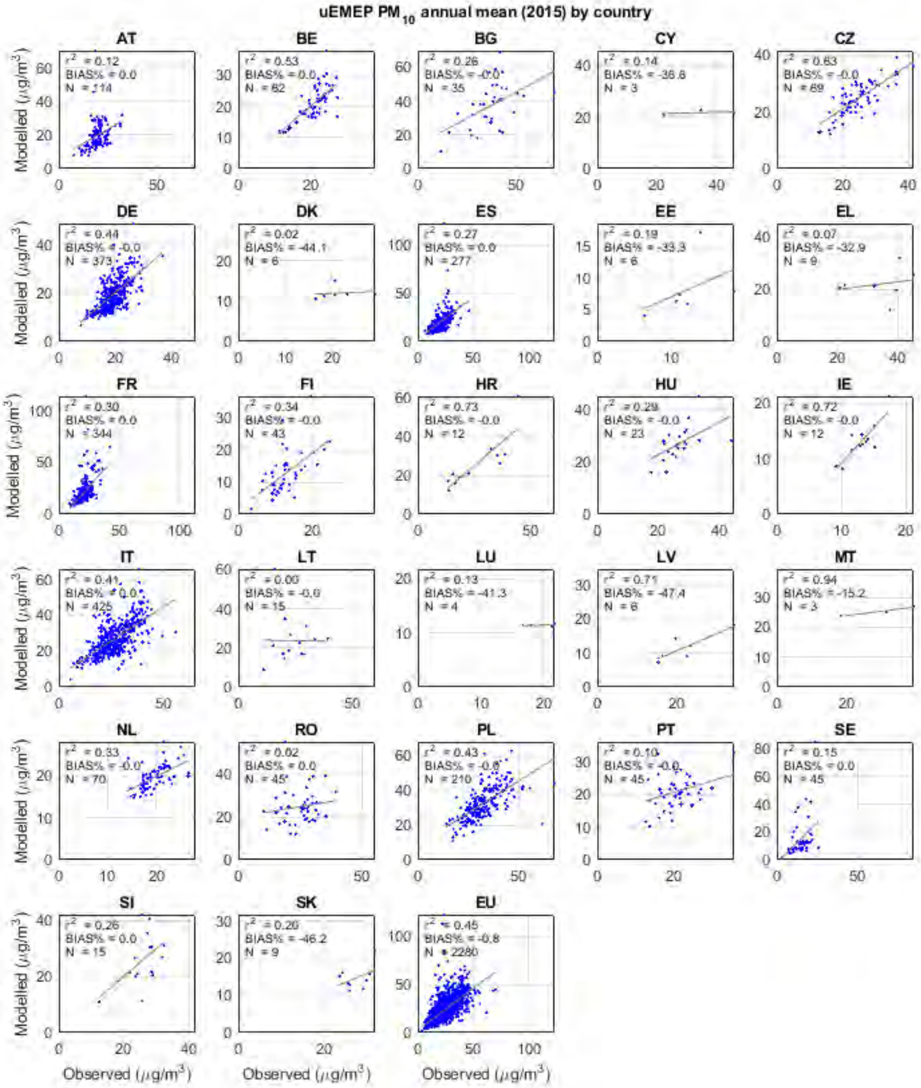
In Figure A-19, there are differences in bias between countries. Since the modelling methodology is consistent for all countries, including the downscaling, it is likely the inter country variation in bias is due to differences in submitted emissions. We thus apply a bias adjustment for each country individually. It is not possible to know which sources may be leading to the bias so the bias adjustment is applied to the source contributions from within the ±0.4° region surrounding each station site. Since 85% of the NO_x comes from within this region then bias adjustment of NO_2 will likely reflect emission bias. For primary $PM_{2.5}$ only 60% of primary emissions come from within this area so the bias adjustment for $PM_{2.5}$ and PM_{10} will overcorrect the primary contribution.

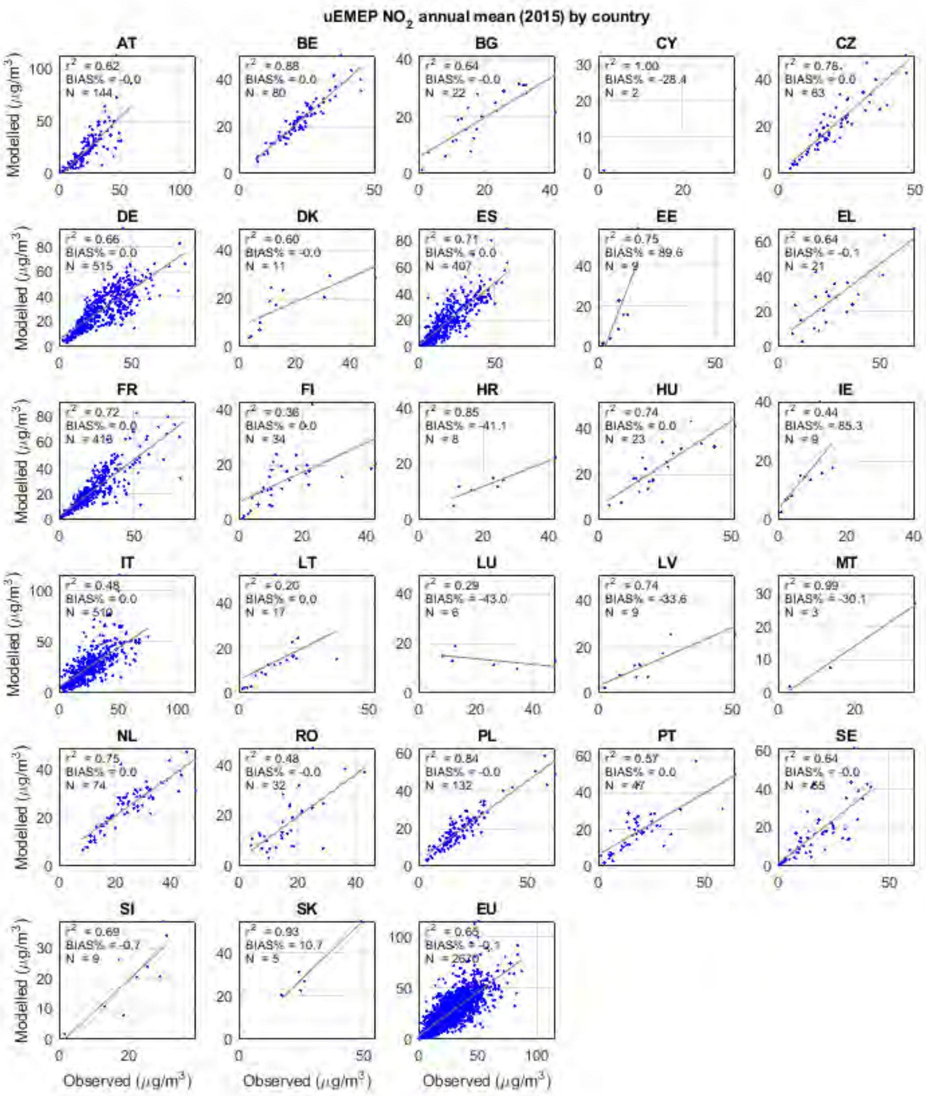
In Figure A-19, the resulting scatter plots of the country based bias adjustment is shown for $PM_{2.5}$, PM_{10} and NO_2. Only countries with more than 10 stations are adjusted in this way. For both $PM_{2.5}$, PM_{10} and NO_2 the overall European spatial correlation is improved with the country based adjustment, reinforcing that the variability between countries may be due to differences in emissions.

The effect of the bias adjustment on the station exceedances for all scenarios is shown and discussed in Section 7.1.2 (ref: 'Sensitivity to bias adjustment of station concentrations') in the main part of the report.

Figure A-19 Bias adjusted annual mean scatter plots of $PM_{2.5}$, PM_{10} and NO_2 for each EU27 country, 2015 reference calculation.




uEMEP PM_{10} annual mean (2015) by country
AT
r^2 = 0.12
BIAS% = 0.0
N = 114
BE
r^2 = 0.53
BIAS% = 0.0
N = 82
BG
r^2 = 0.26
BIAS% = -0.0
N = 35
CY
r^2 = 0.14
BIAS% = -36.8
N = 3
CZ
r^2 = 0.63
BIAS% = -0.0
N = 69
DE
r^2 = 0.44
BIAS% = -0.0
N = 373
DK
r^2 = 0.02
BIAS% = -44.1
N = 6
ES
r^2 = 0.27
BIAS% = 0.0
N = 277
EE
r^2 = 0.19
BIAS% = -33.3
N = 6
EL
r^2 = 0.07
BIAS% = -32.9
N = 9
FR
r^2 = 0.30
BIAS% = 0.0
N = 344
FI
r^2 = 0.34
BIAS% = -0.0
N = 43
HR
r^2 = 0.73
BIAS% = -0.0
N = 12
HU
r^2 = 0.29
BIAS% = -0.0
N = 23
IE
r^2 = 0.72
BIAS% = -0.0
N = 12
IT
r^2 = 0.41
BIAS% = 0.0
N = 425
LT
r^2 = 0.00
BIAS% = -0.0
N = 15
LU
r^2 = 0.13
BIAS% = -41.3
N = 4
LV
r^2 = 0.71
BIAS% = -47.4
N = 6
MT
r^2 = 0.94
BIAS% = -15.2
N = 3
NL
r^2 = 0.33
BIAS% = -0.0
N = 70
RO
r^2 = 0.02
BIAS% = 0.0
N = 45
PL
r^2 = 0.43
BIAS% = -0.0
N = 210
PT
r^2 = 0.10
BIAS% = -0.0
N = 45
SE
r^2 = 0.15
BIAS% = 0.0
N = 45
SI
r^2 = 0.26
BIAS% = 0.0
N = 15
SK
r^2 = 0.20
BIAS% = -46.2
N = 9
EU
r^2 = 0.45
BIAS% = -0.8
N = 2280
Modelled ($\mu g/m^3$)
Observed ($\mu g/m^3$)



Maps

Maps are shown for the following pollutants and indicators using both uEMEP and EMEP models (indicated in brackets)

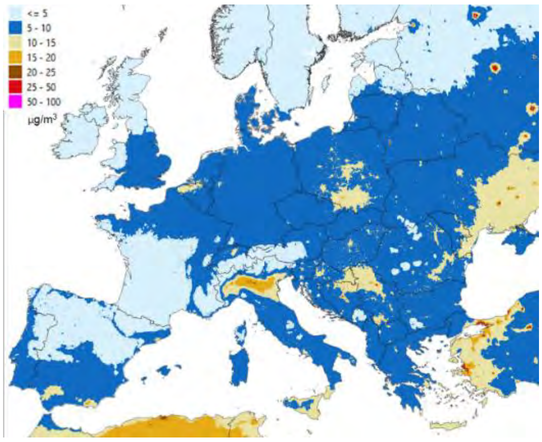
- Annual mean PM$_{2.5}$: All calculated scenarios except 2015 (uEMEP)
- Annual mean PM$_{10}$, NO$_2$, BaP and Benzene: All baseline and MTFR scenarios for 2020, 2030 and 2050 (uEMEP)
- O$_3$ 26'th highest daily maximum 8 hour running mean: All baseline and MTFR scenarios for 2020, 2030 and 2050 (EMEP)
- CO highest daily maximum 8 hour running mean: All baseline and MTFR scenarios for 2020, 2030 and 2050 (EMEP)
- SO$_2$ 99'th percentile, 3'rd highest daily mean: All baseline and MTFR scenarios for 2020, 2030 and 2050 (EMEP, converted from annual mean to percentile)

A number of pollutants show modelled bias and these biases are indicated in the figures.
In addition to the European maps a number of maps of specific regions with specific pollutants of interest are presented. These include:

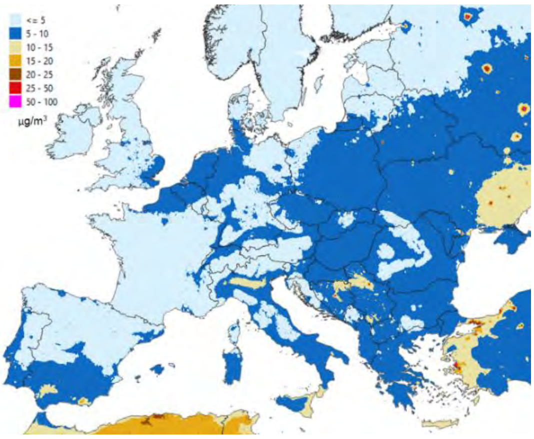
- North-western Europe NO_2 annual mean: 2020 and all scenarios for 2030
- Eastern Europe $PM_{2.5}$ annual mean: 2020 and all scenarios for 2030
- Northern Europe Sweden (Stockholm) PM_{10} annual mean: 2020 and all scenarios for 2030
- Po Valley region Northern Italy $PM_{2.5}$ annual mean: 2020 and all scenarios for 2030.

Figure A-20 $PM_{2.5}$ concentrations for base line 2020 and a range of optimised (OPT) scenarios, including Maximum Technical Feasible Reduction (MTFR) for 2030. Calculations are made on the uEMEP 250 m grid. (WITHOUT bias adjustment - Bias is -19% in the 2015 reference calculation).

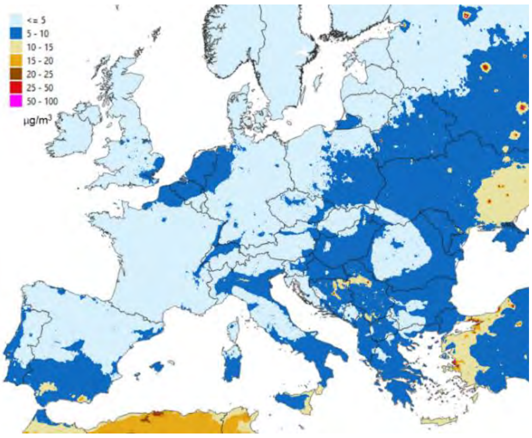
Base 2020



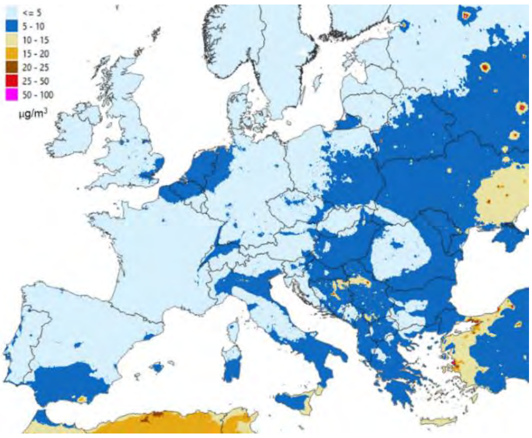
Base 2030



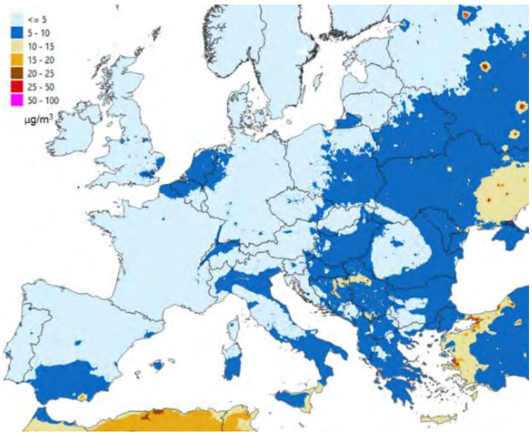
OPT-15 2030



OPT-10 2030



OPT-05 2030



MTFR 2030

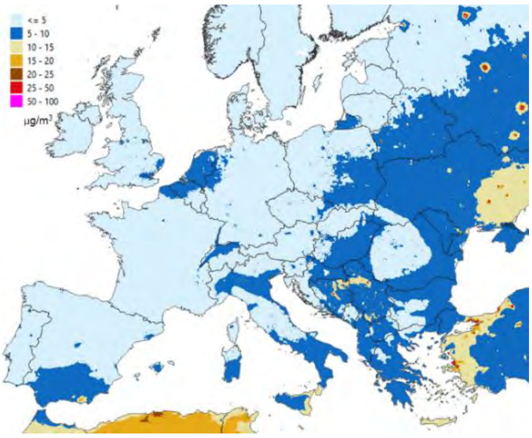
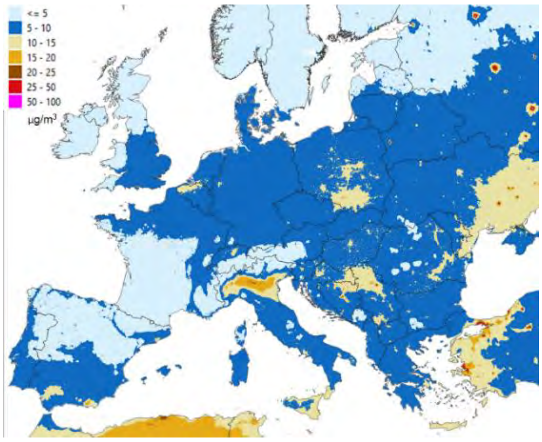
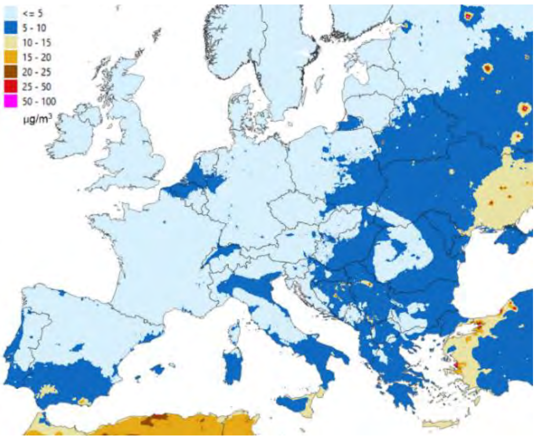


Figure A-21 $PM_{2.5}$ concentrations for base line 2020 and a range of optimised (OPT) scenarios, including Maximum Technical Feasible Reduction (MTFR) for 2050. Calculations are made on the uEMEP 250 m grid. (WITHOUT bias adjustment - Bias is -19% in the 2015 reference calculation).

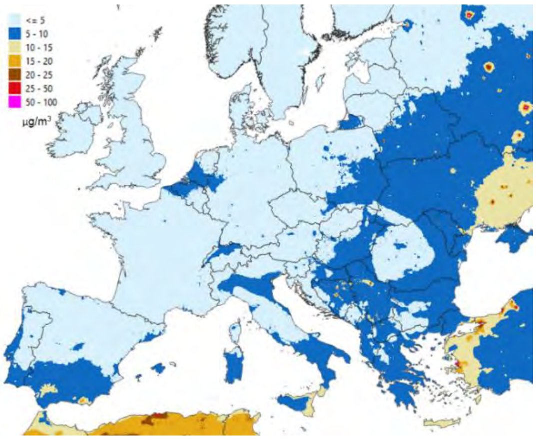
Base 2020



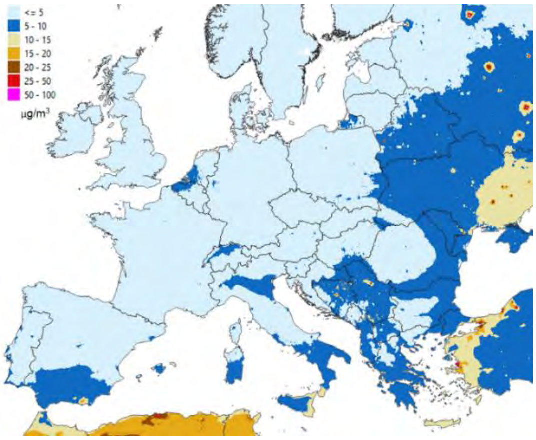
Base 2050



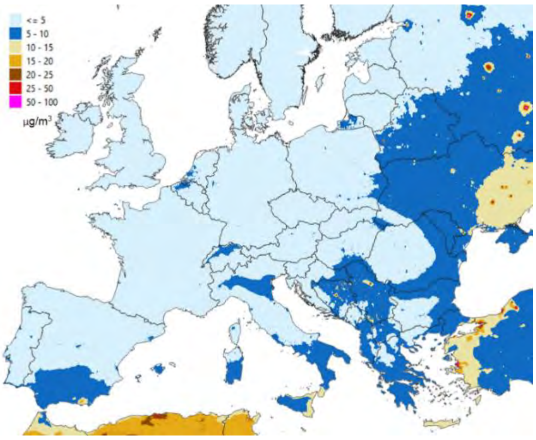
OPT-15 2050



OPT-10 2050



OPT-05 2050



MTFR 2050

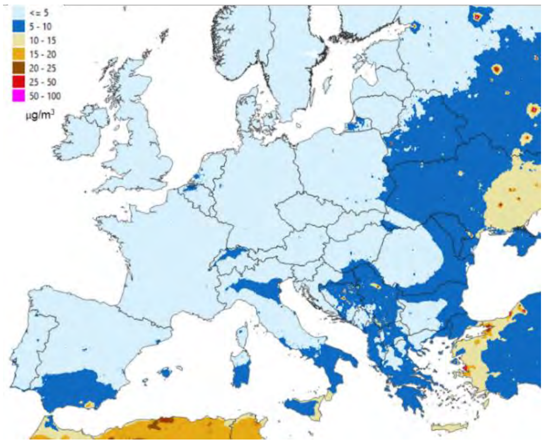
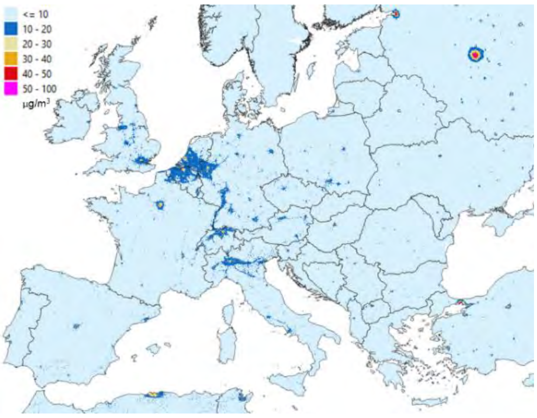
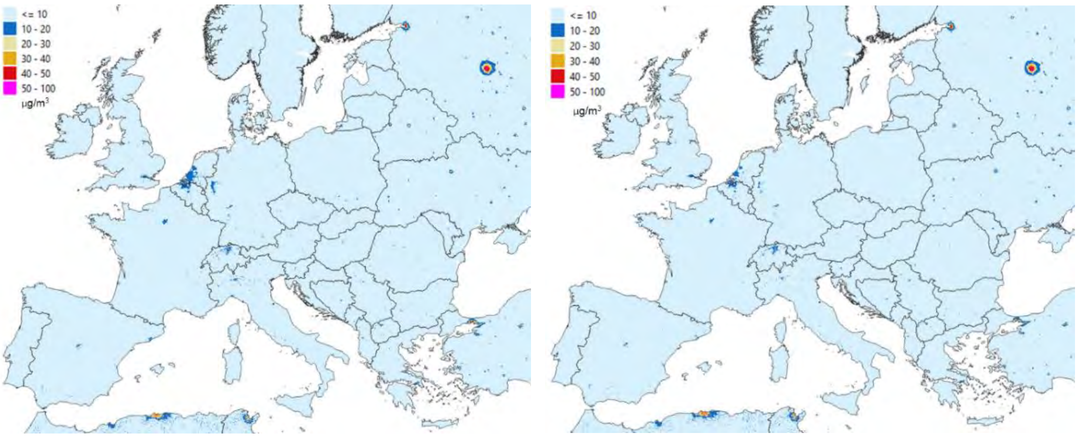


Figure A-22 NO$_2$ concentrations for base line (Base) and Maximum Technical Feasible Reduction (MTFR) for 2020, 2030 and 2050. Calculations are made on the uEMEP 250 m grid. (WITHOUT bias adjustment - Bias is -23% in the 2015 reference calculation).

Base 2020



Base 2030 **MTFR 2030**



Base 2050 **MTFR 2050**

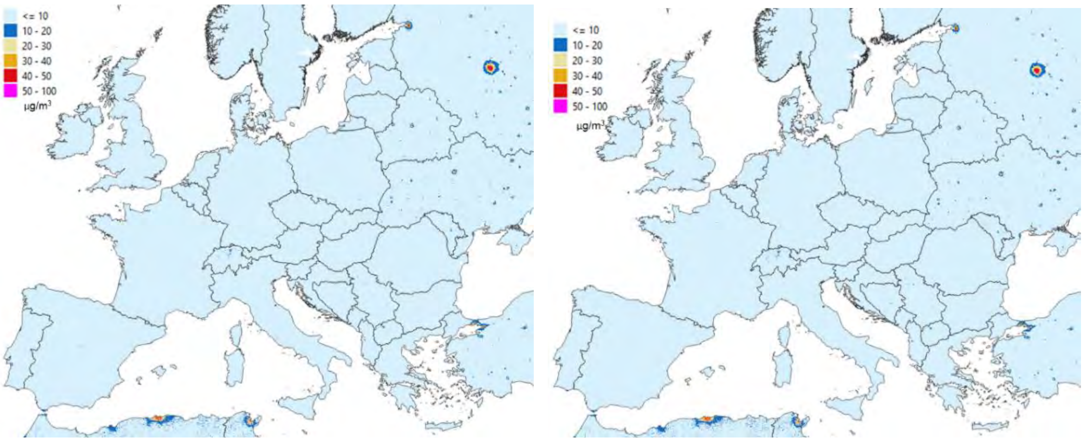
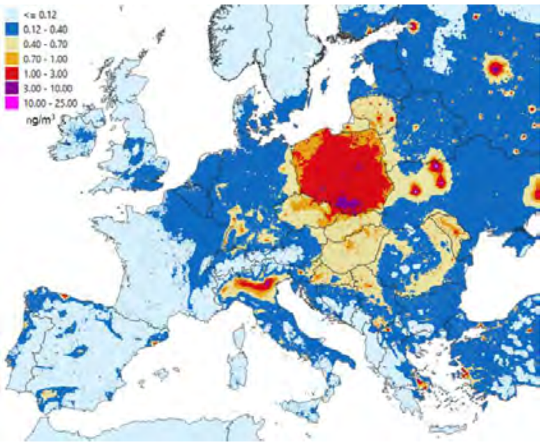
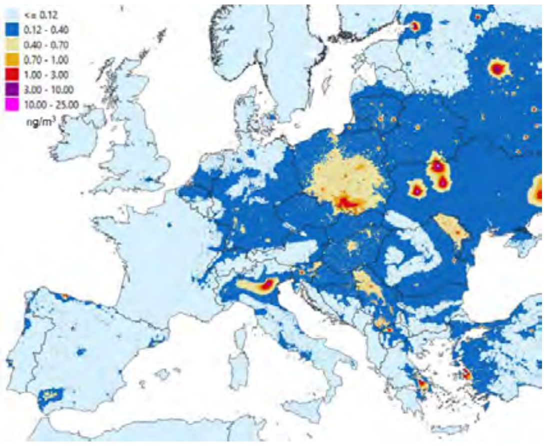


Figure A-23 BaP annual mean concentrations for base line (Base) and Maximum Technical Feasible Reduction (MTFR) for 2020, 2030 and 2050. Calculations are made on the uEMEP 250 m grid. (WITHOUT bias adjustment - Bias is +11% in the 2015 reference calculation).

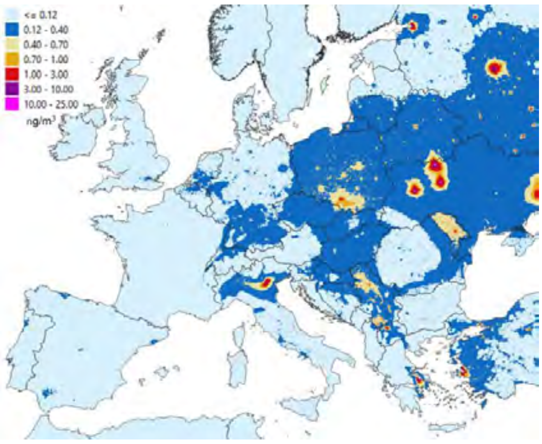
Base 2020



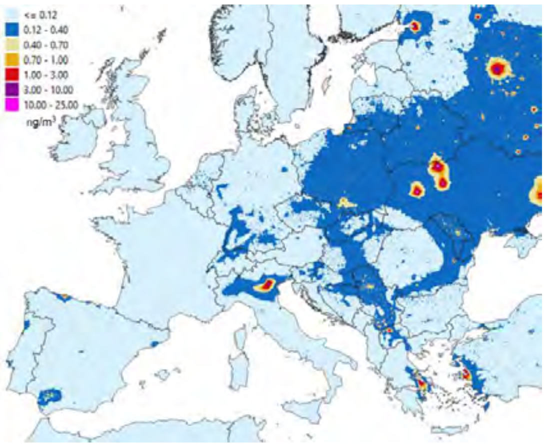
Base 2030



MTFR 2030



Base 2050



MTFR 2050

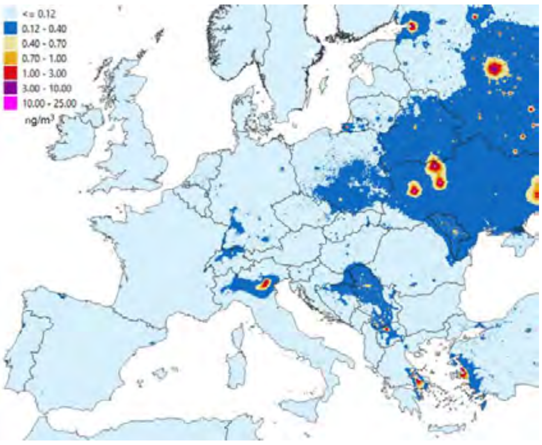
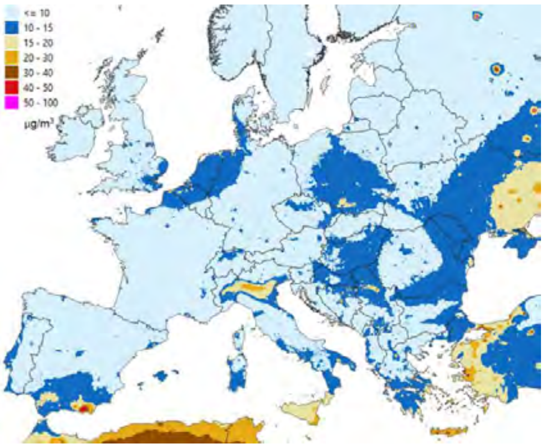
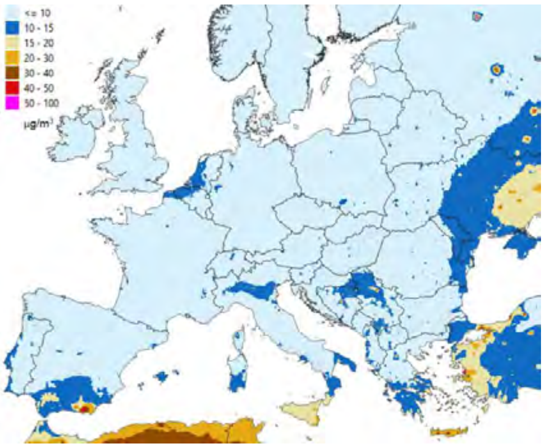


Figure A-24 PM$_{10}$ annual mean concentrations for base line (Base) and Maximum Technical Feasible Reduction (MTFR) for 2020, 2030 and 2050. Calculations are made on the uEMEP 250 m grid. (WITHOUT bias adjustment - Bias is -33% in the 2015 reference calculation).

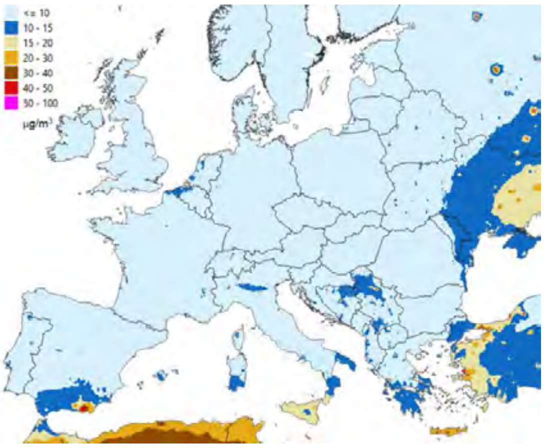
Base 2020



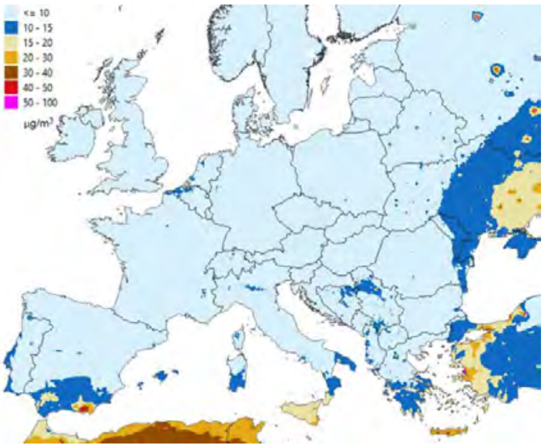
Base 2030



MTFR 2030



Base 2050



MTFR 2050

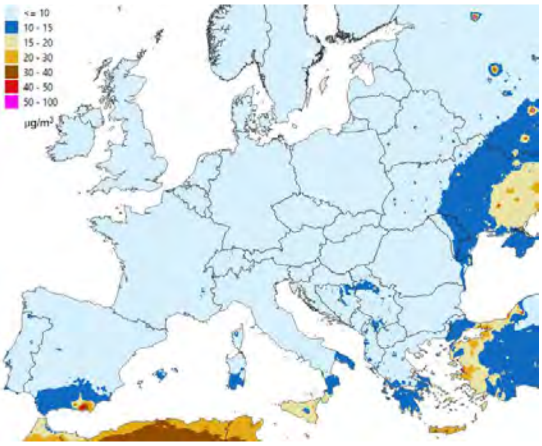
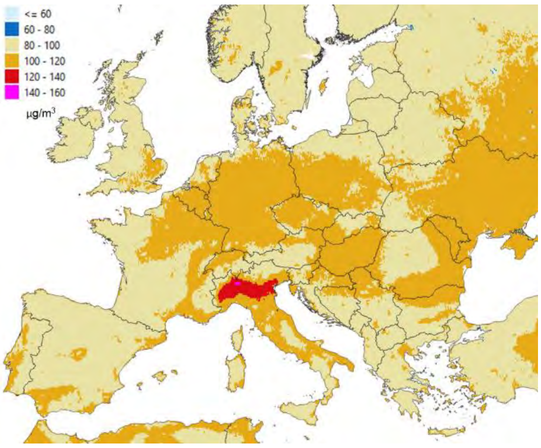
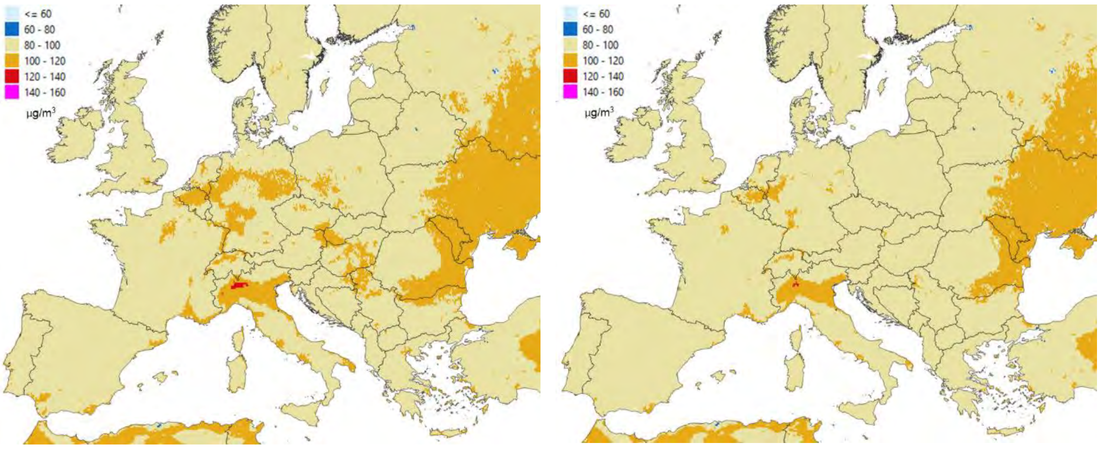


Figure A-25 O₃ (26’th highest maximum 8 hour daily running mean) concentrations for base line (Base) and Maximum Technical Feasible Reduction (MTFR) for 2020, 2030 and 2050. Calculations are made on the EMEP 0.1° grid. (WITHOUT bias adjustment - Bias is -11% in the 2015 reference calculation).

Base 2020



Base 2030 **MTFR 2030**



Base 2050 **MTFR 2050**

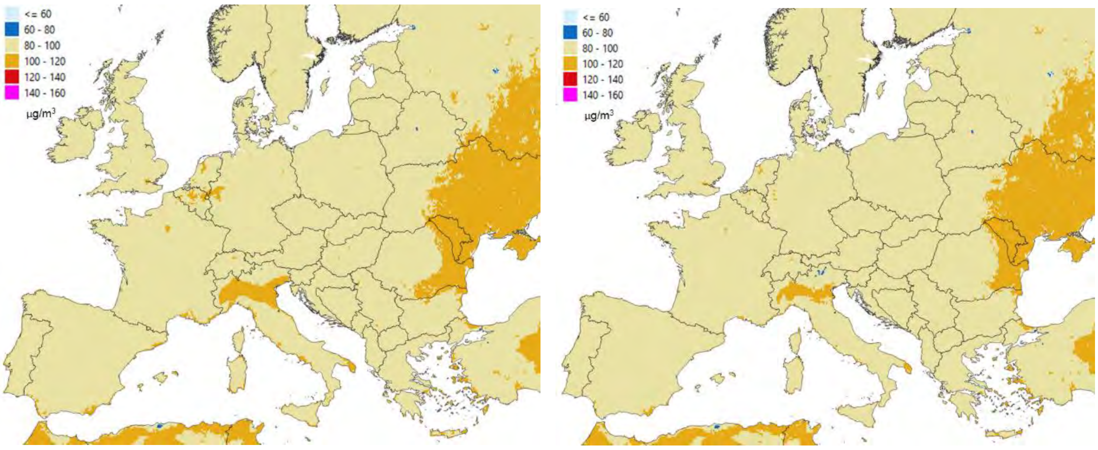
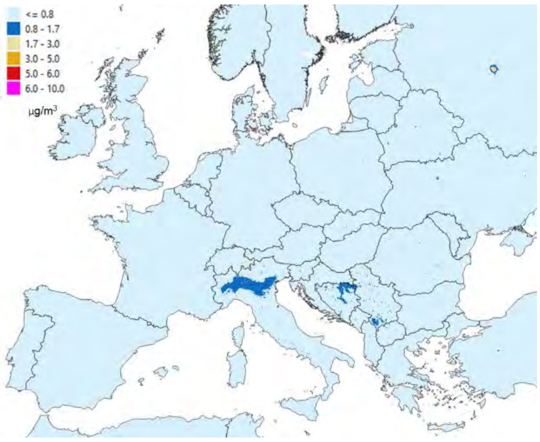
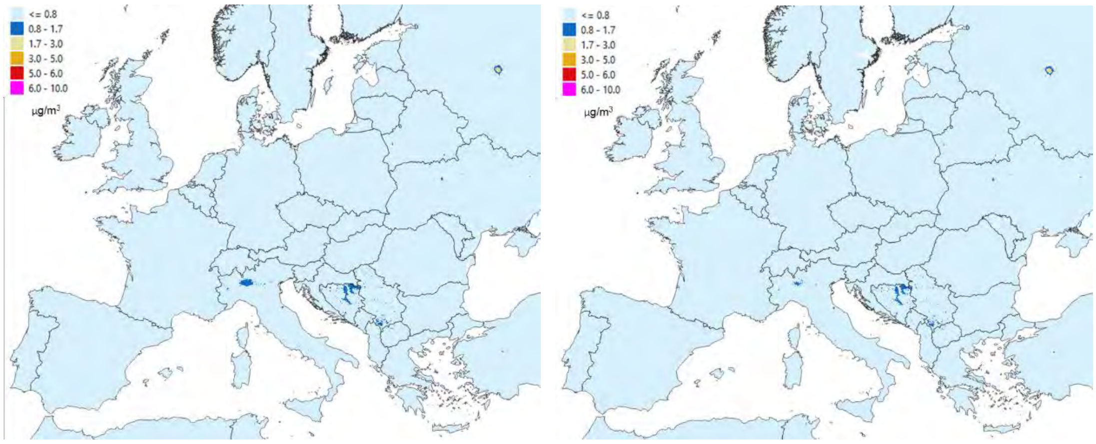
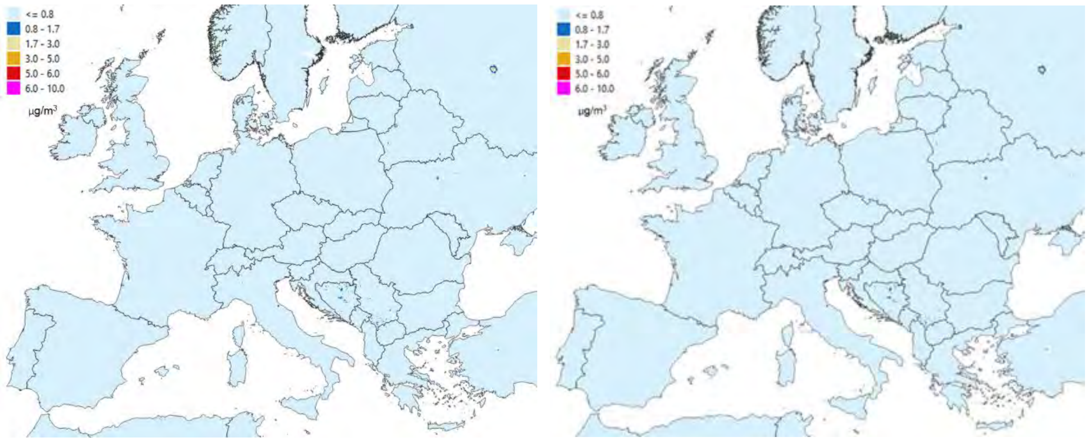


Figure A-26 Benzene annual mean concentrations for base line (Base) and Maximum Technical Feasible Reduction (MTFR) for 2020, 2030 and 2050. Calculations are made on the uEMEP 250 m grid. (WITHOUT bias adjustment - Bias is -55% in the 2015 reference calculation).


Base 2020


Base 2030

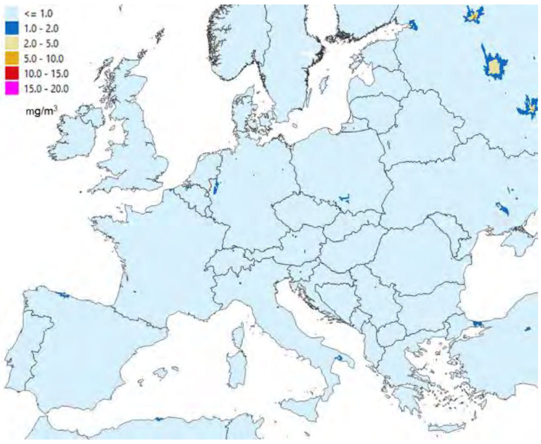
MTFR 2030


Base 2050

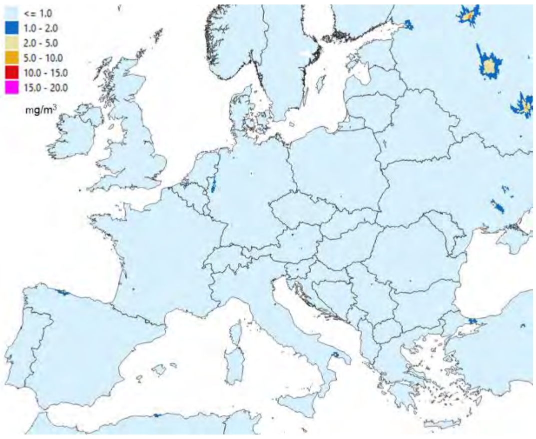
MTFR 2050

Figure A-27 CO (highest maximum 8 hour daily running mean) concentrations for base line (Base) and Maximum Technical Feasible Reduction (MTFR) for 2020, 2030 and 2050. Calculations are made on the EMEP 0.1° grid. (WITHOUT bias adjustment - Bias is -70% in the 2015 reference calculation).

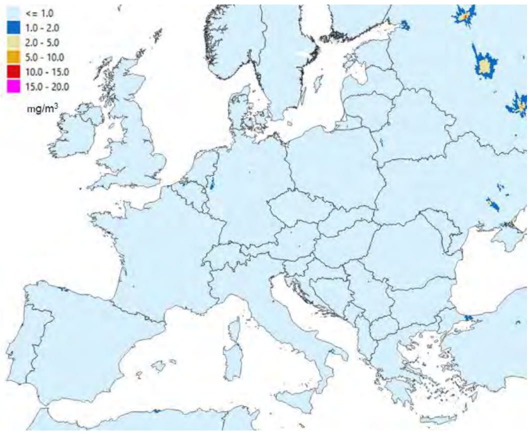
Base 2020



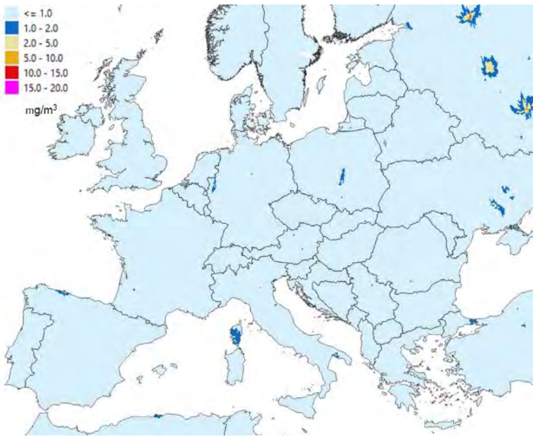
Base 2030



MTFR 2030



Base 2050



MTFR 2050

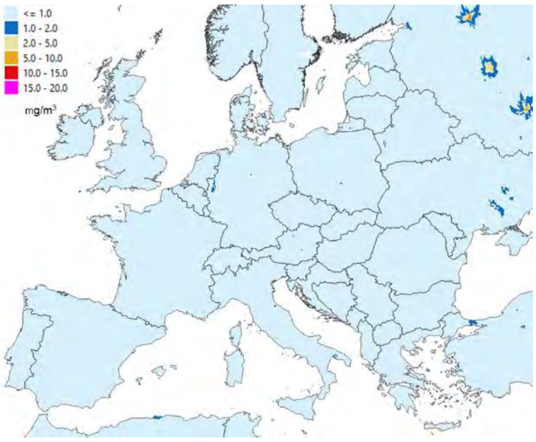
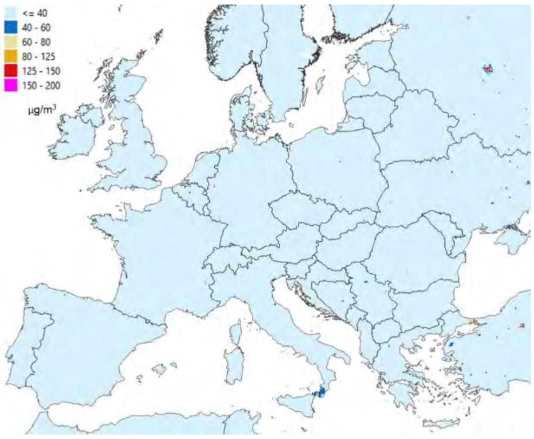


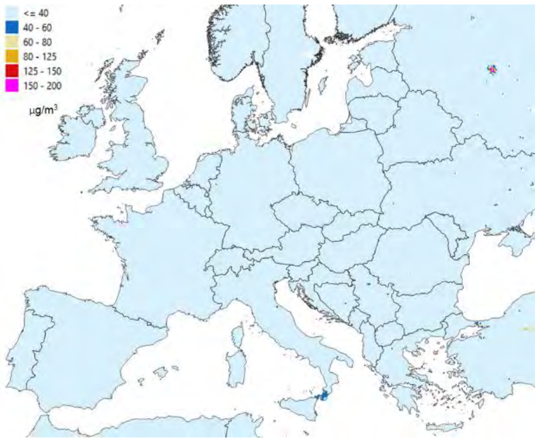
Figure A-28 SO_2 (99'th percentile daily mean) concentrations for base line (Base) and Maximum Technical Feasible Reduction (MTFR) for 2020, 2030 and 2050. Calculations are made on the EMEP 0.1° grid. Annual means are calculated and converted to 99'th percentiles using the scaling factor provided in

Table A-4. (WITHOUT bias adjustment - Calculated annual mean bias is -26% in the 2015 reference calculation).

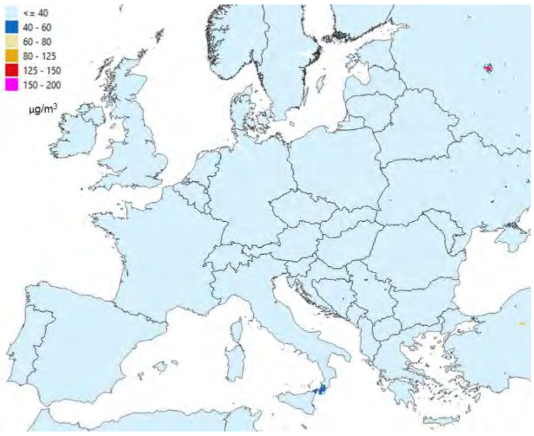
Base 2020



Base 2030



MTFR 2030

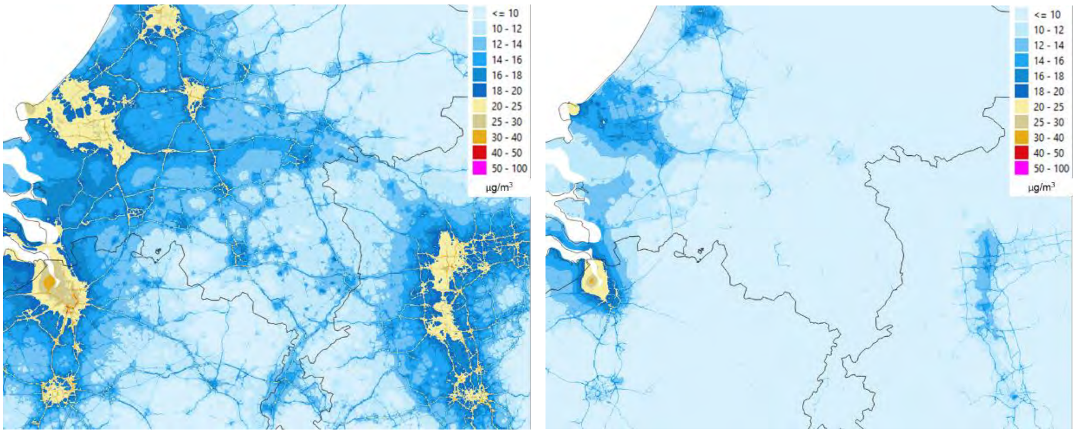


Base 2050

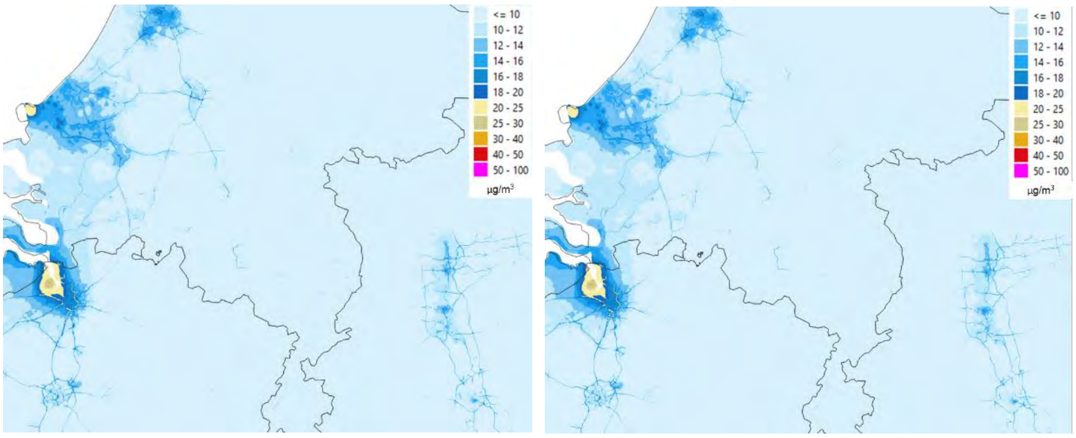
MTFR 2050

Figure A-29 NO_2 annual mean concentrations for base line 2020 and a range of optimised (OPT) scenarios, including Maximum Technical Feasible Reduction (MTFR) for 2030. Calculations are made on the uEMEP 250 m grid. (WITHOUT bias adjustment - Bias -23% in 2015 reference calculation for all of Europe. Region in North-Western Europe including Belgium (Bias +2.7%), Germany (Bias -33%) and The Netherlands (Bias +0.3%)). Note the change in colour scale to emphasize concentrations between 10 and 25 µg/m³.

Base 2020 **Base 2030**



OPT-15 2030 **OPT-10 2030**



OPT-05 2030 **MTFR 2030**

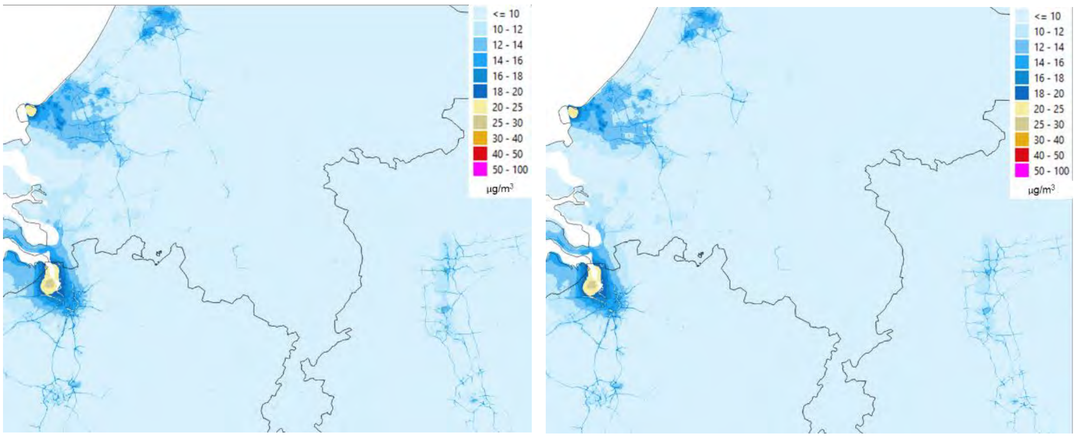
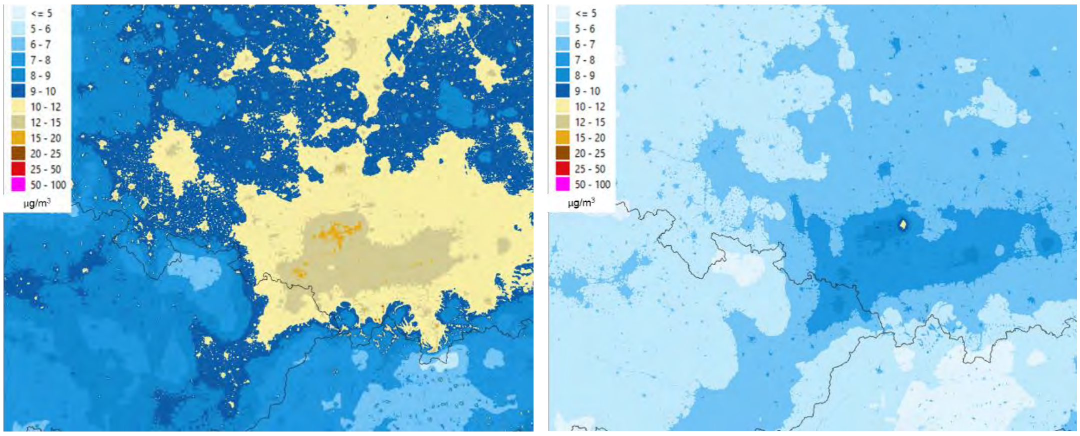
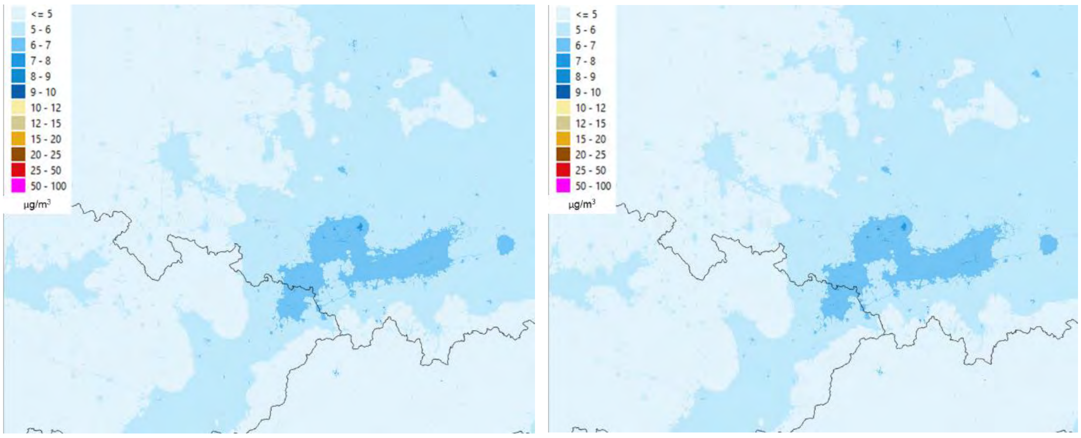


Figure A-30 $PM_{2.5}$ annual mean concentrations for base line 2020 and a range of optimised (OPT) scenarios, including Maximum Technical Feasible Reduction (MTFR) for 2030. Calculations are made on the uEMEP 250 m grid. (WITHOUT bias adjustment - Bias -19% in 2015 reference calculation for all of Europe. Region in North-Western Europe including Poland (Bias -40%), Czech Republic (Bias -30%) and Slovakia (Bias -40%)). Note the change in colour scale to emphasize concentrations between 5 and 12 µg/m^3.

Base 2020 **Base 2030**



OPT-15 2030 **OPT-10 2030**



OPT-05 2030 **MTFR 2030**

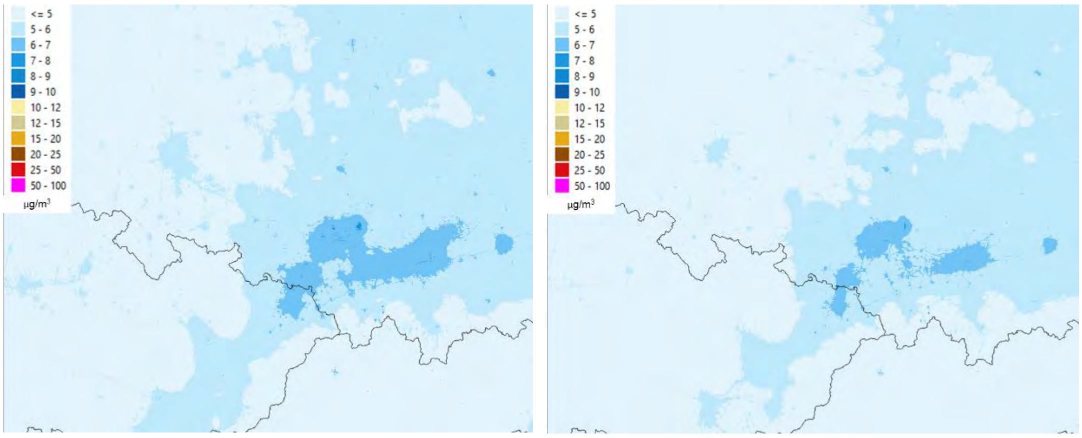
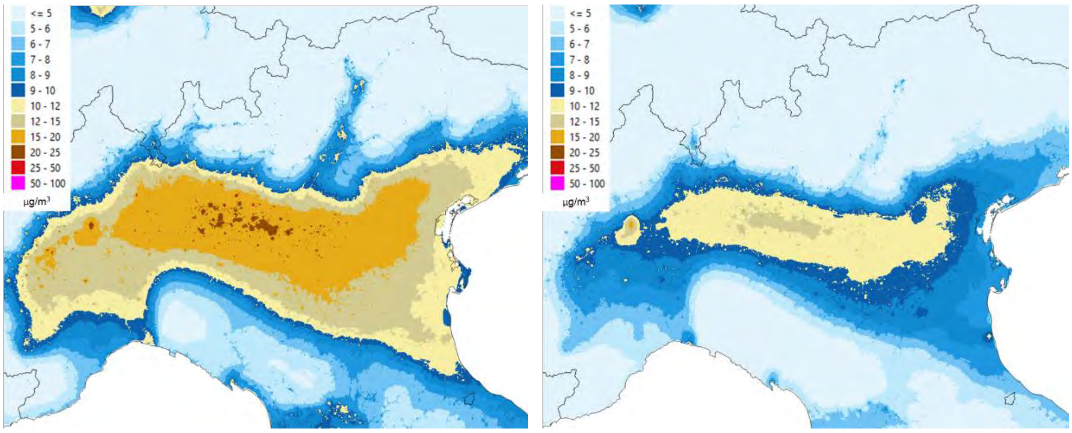
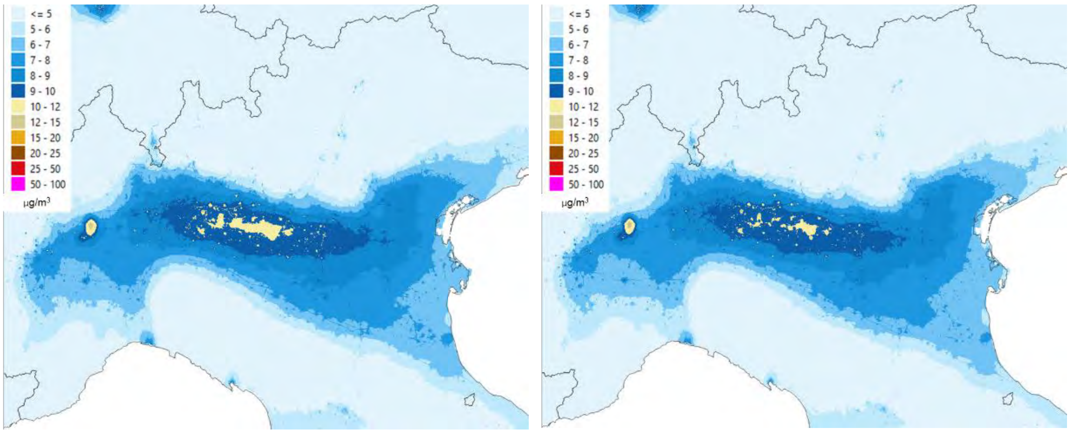


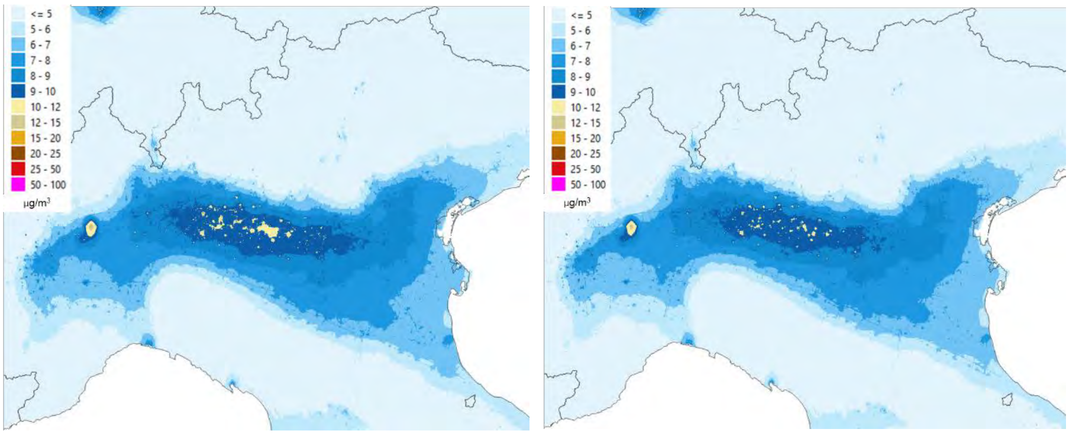
Figure A-31 $PM_{2.5}$ annual mean concentrations for base line 2020 and a range of optimised (OPT) scenarios, including Maximum Technical Feasible Reduction (MTFR) for 2030. Calculations are made on the uEMEP 250 m grid. (WITHOUT bias adjustment - Bias -19% in the 2015 reference calculation for all of Europe. Region shown is the Po Valley in Northern Italy (Bias -11%)). Note the change in colour scale to emphasize concentrations between 5 and 12 µg/m³.


Base 2020

Base 2030


OPT-15 2030

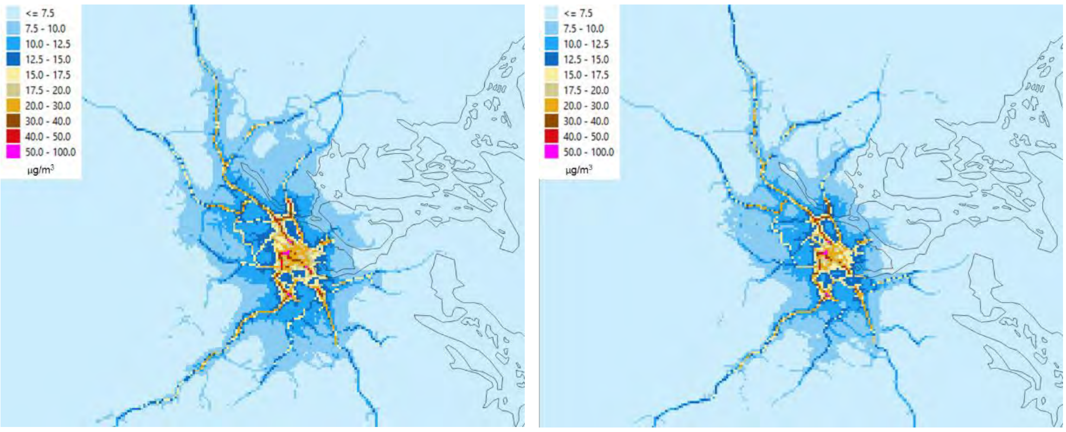
OPT-10 2030


OPT-05 2030

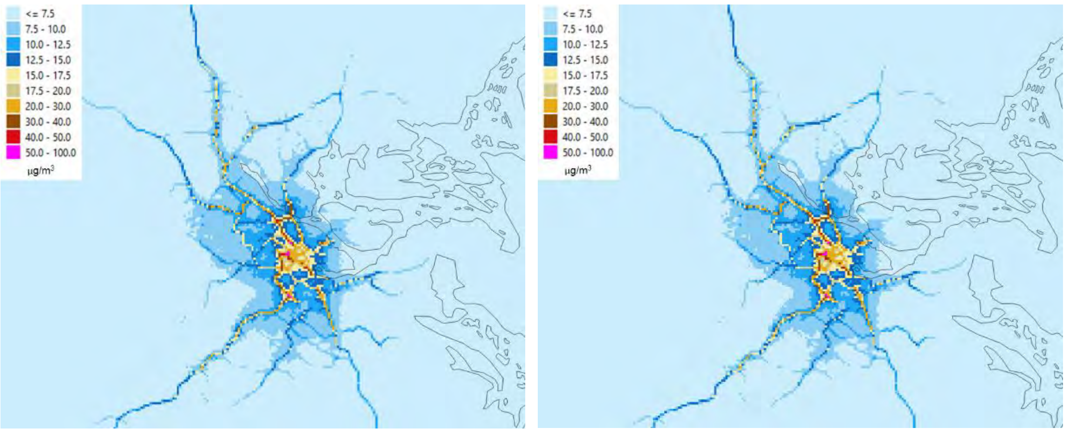
MTFR 2030

Figure A-32 PM_{10} annual mean concentrations for base line 2020 and a range of optimised (OPT) scenarios, including Maximum Technical Feasible Reduction (MTFR) for 2030. Calculations are made on the uEMEP 250 m grid. (WITHOUT bias adjustment - Bias -19% in the 2015 reference calculation for all of Europe. Region shown is the city of Stockholm in Sweden (Bias -34%)). Note the change in colour scale to emphasize concentrations between 7.5 and 20 µg/m^3.

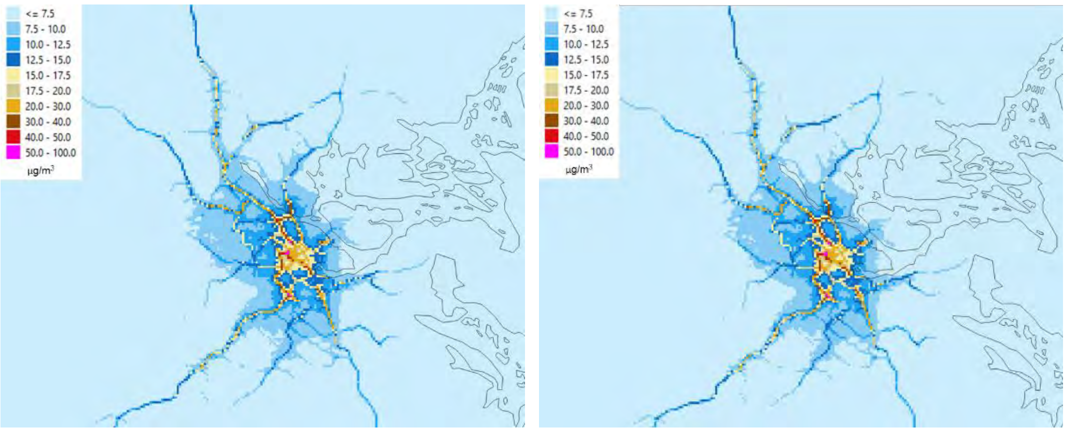
Base 2020 **Base 2030**



OPT-15 2030 **OPT-10 2030**



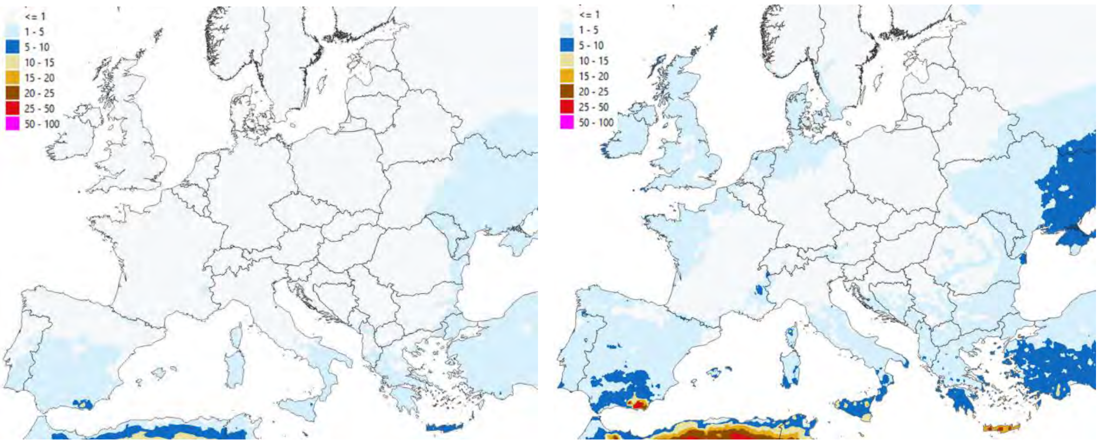
OPT-05 2030 **MTFR 2030**



Natural contributions of wind-blown dust and sea salt

In the source contributions presented in the previous sections a significant contribution can be seen to come from the natural sources of wind-blown dust and sea salt. In Figure A-33 the contribution of these two natural sources to $PM_{2.5}$ and PM_{10} are presented as a map. Since the same meteorology is used for all scenarios then the natural contributions are also calculated to be the same for all scenarios.

Figure A-33 $PM_{2.5}$ (left) and PM_{10} (right) contribution from the natural sources of wind blown dust and sea salt



As a sensitivity assessment, the natural contributions of wind-blown dust and sea salt are subtracted from the total calculated $PM_{2.5}$ and PM_{10} concentrations. The resulting concentrations fields for 2020 baseline and 2030 MTFR are shown in Figure A-34 and

Figure A-35. These can be compared to Figure A-20 and Figure A-24.

Figure A-34 $PM_{2.5}$ (left) and PM_{10} (right) with the contribution from the natural sources of wind blown dust and sea salt subtracted for the 2020 baseline

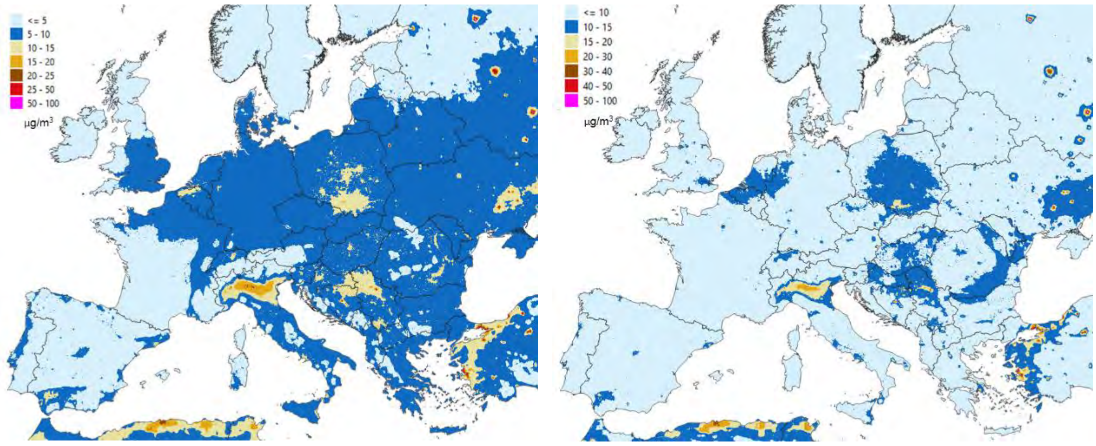
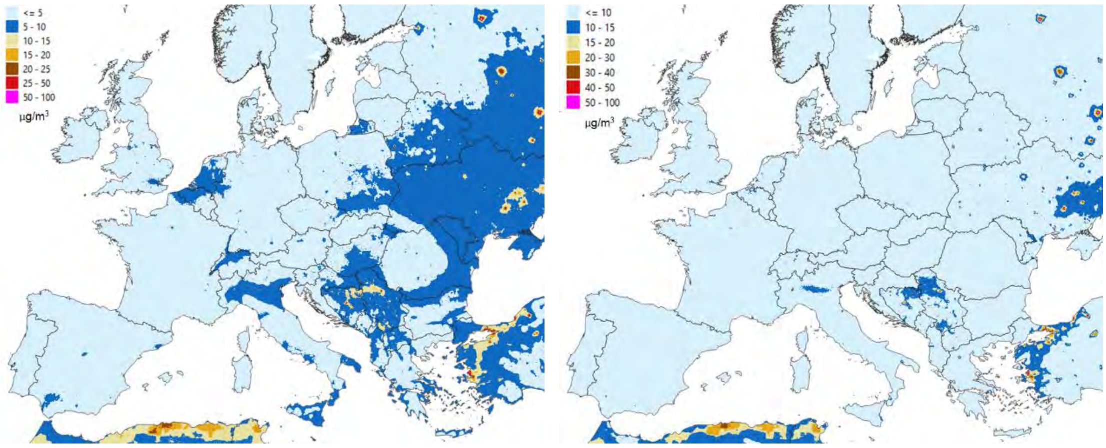


Figure A-35 $PM_{2.5}$ (left) and PM_{10} (right) with the contribution from the natural sources of wind blown dust and sea salt subtracted for the 2030 MTFR



Limitations and uncertainties

One of the major uncertainties in air quality modelling remains the emissions. Not just total emissions per country, but also how they are distributed in space. When further applying sub-grid emission proxies for the downscaling to gridded emissions then inconsistencies between the gridded and sub-grid methodologies can increase uncertainties. Optimally the same emission proxies should be used for both the gridded data and the sub-gridded data. This is not possible when 27 countries independently provide gridded emissions, even when methodologies may be very similar.

When applying European wide emission proxies for downscaling it cannot be expected that every individual station is correctly modelled. However, statistically the results should be robust. This is important to remember when just a few stations remain over particular thresholds. This may mean that local reductions can be usefully implemented but it may also mean that the emission or emission proxies are not correct at those few sites.

The general problem with negative bias, or any bias, even after downscaling also places a limitation on the usefulness of the calculations. If emissions are underestimated or unknown emission sources are not included then the impact of the emission scenarios may be different. The bias adjustment will provide improved mapping for at least the year that it is applied for, but there is no guarantee of the validity of the adjustment for the further scenario calculations. The bias adjustment results are thus an indicator of the uncertainty one can expect in future scenarios. Even so the results for Benzene and CO, with a -50% bias indicate important deficiencies in the emissions inventory.

Modelling uncertainties in methodologies also lead to limitations. It is worth noting the EMEP and uEMEP models have been applied in countries where emissions are better known. Under these conditions the model performance is much improved.

During the course of the modelling some clear challenges in emissions have been found. These include:

- Separation and spatial distribution of national and international shipping emissions
- Individual industries with large and uncertain emissions that can dominate the exposure in a whole city
- Incorrect allocation of some residential heating emissions

- Reported non-exhaust emissions that may not be adequately spatially distributed or quantified.

Results for 2030

The figures below present the reduction of emissions of $PM_{2.5}$ precursors as calculated in the GAINS model for policy scenarios and the MTFR case showing finer sector/measure resolution than in the main report.

Figure A-36 - Reduction of SO_2 emissions, split by MS (2030)

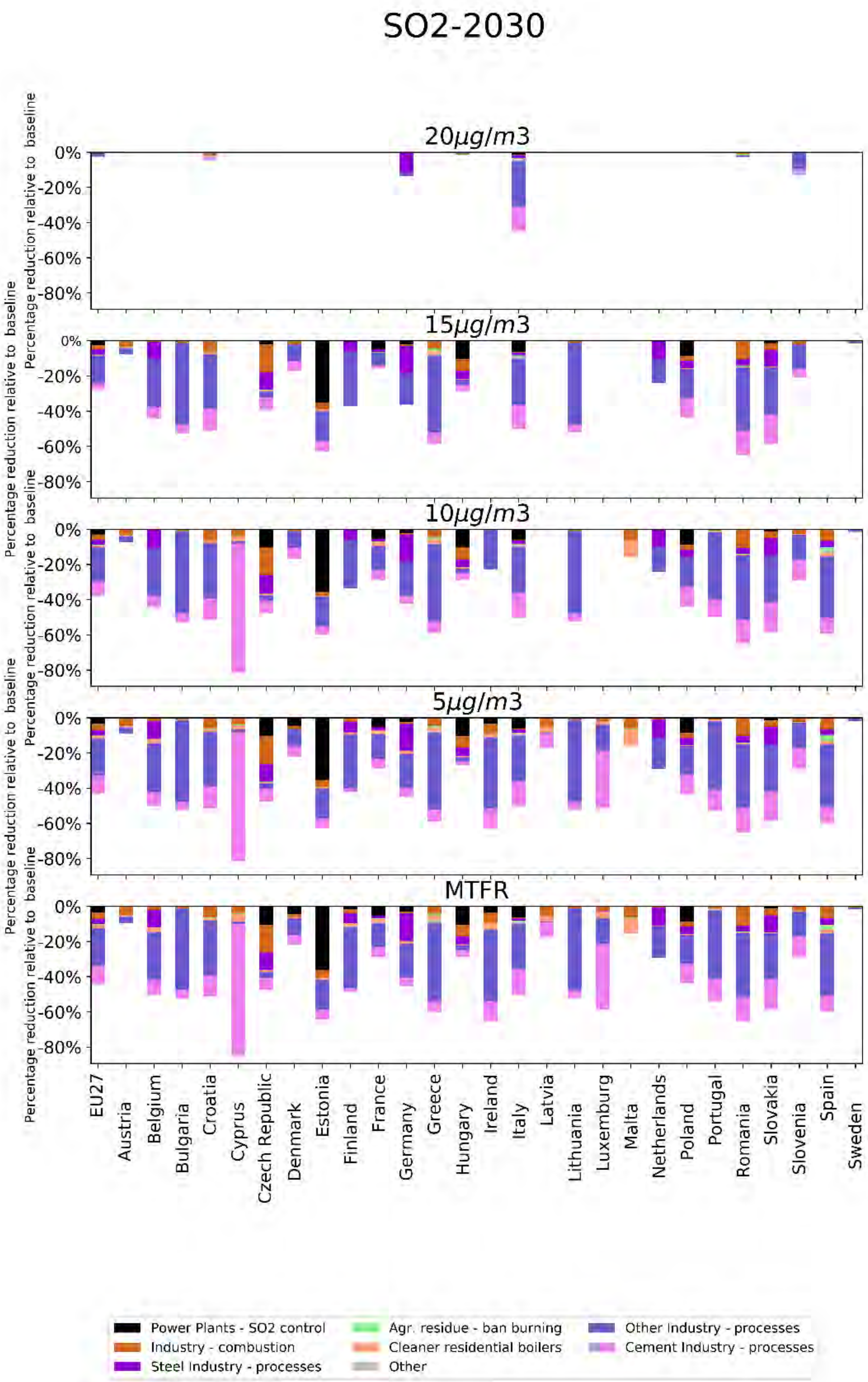


Figure A-37 - Reduction of NOx emissions, split by MS (2030)

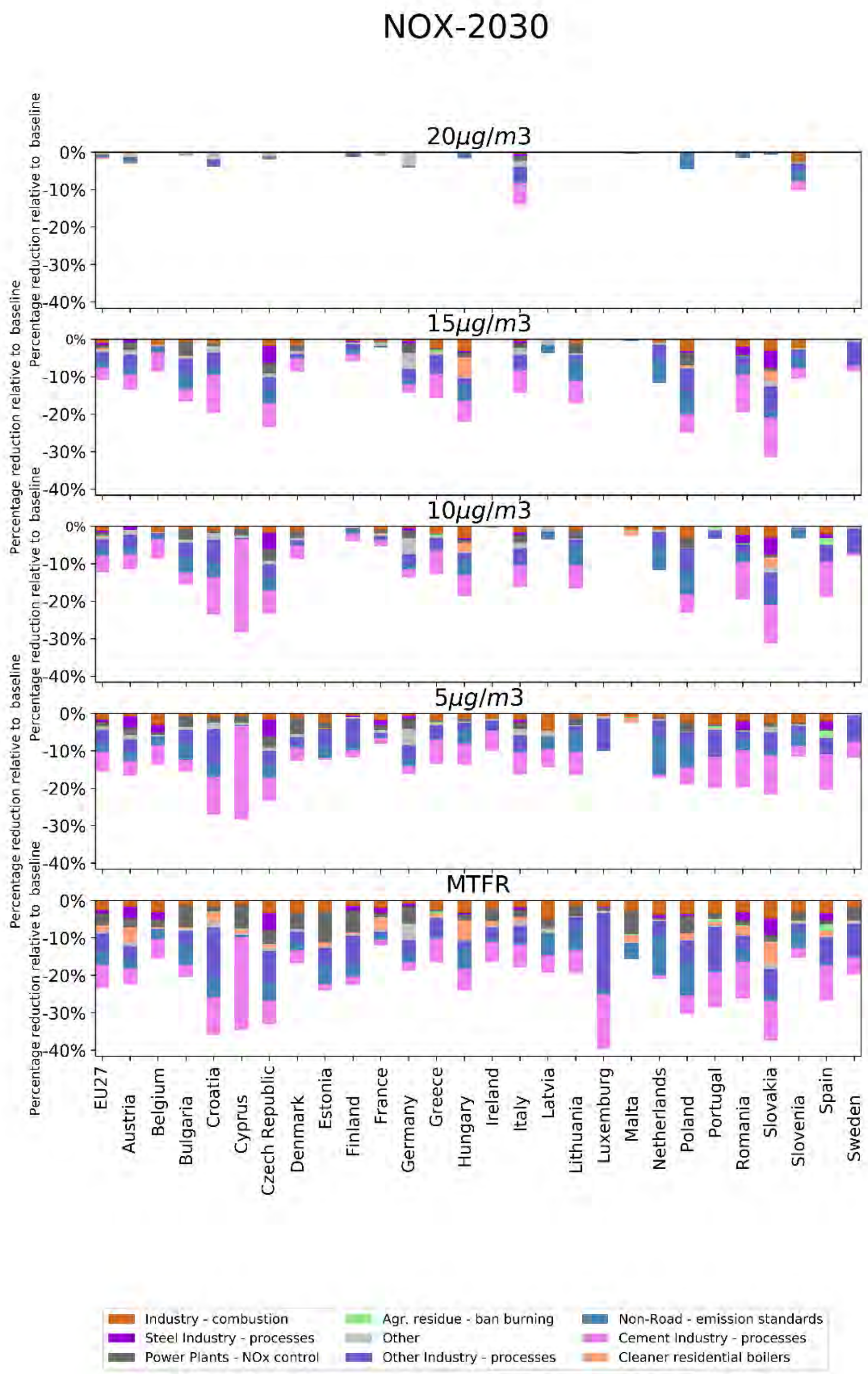


Figure A-38 - Reduction of NH_3 emissions, split by MS (2030)

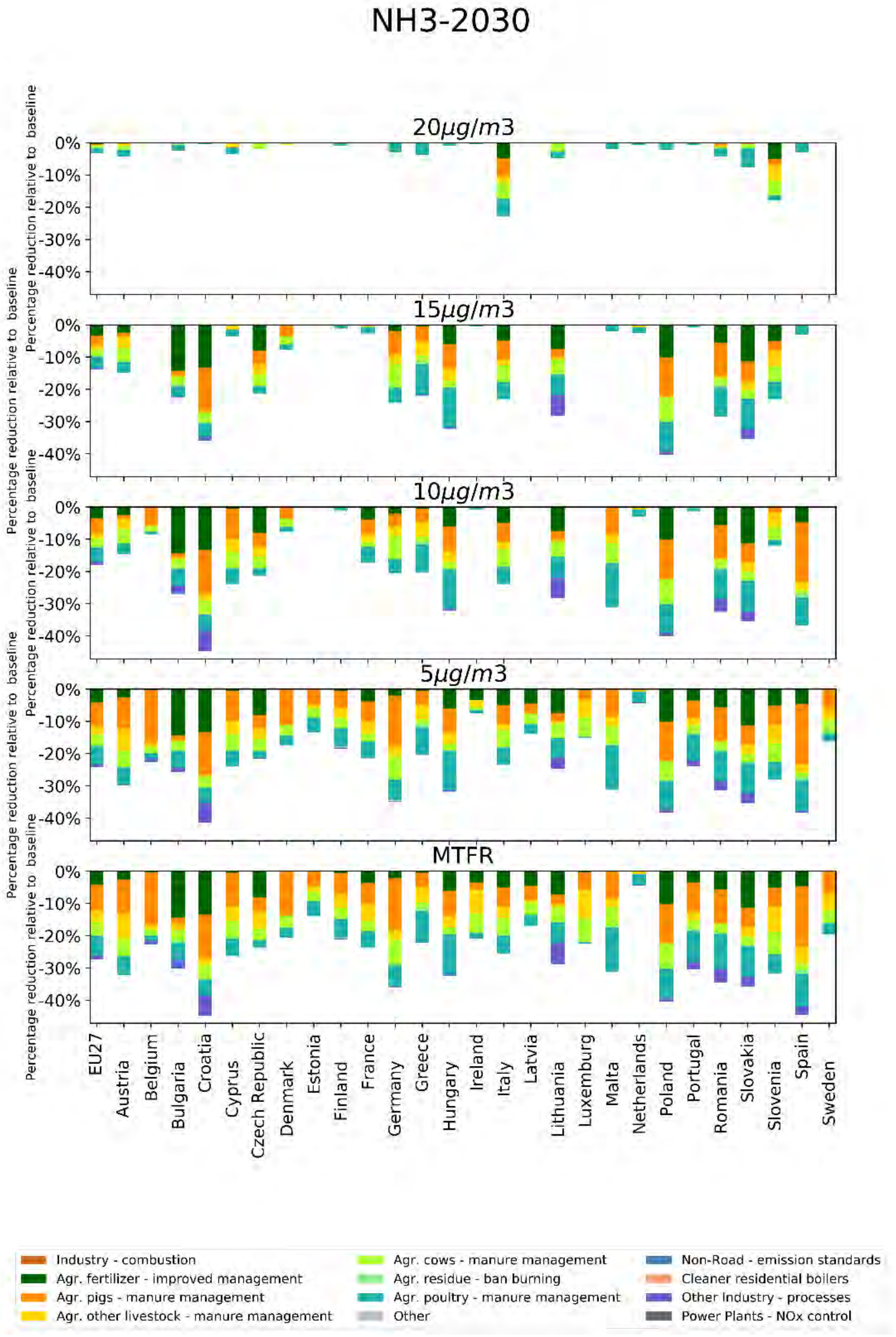


Figure A-39 – Reduction of VOC emissions, split by MS (2030)

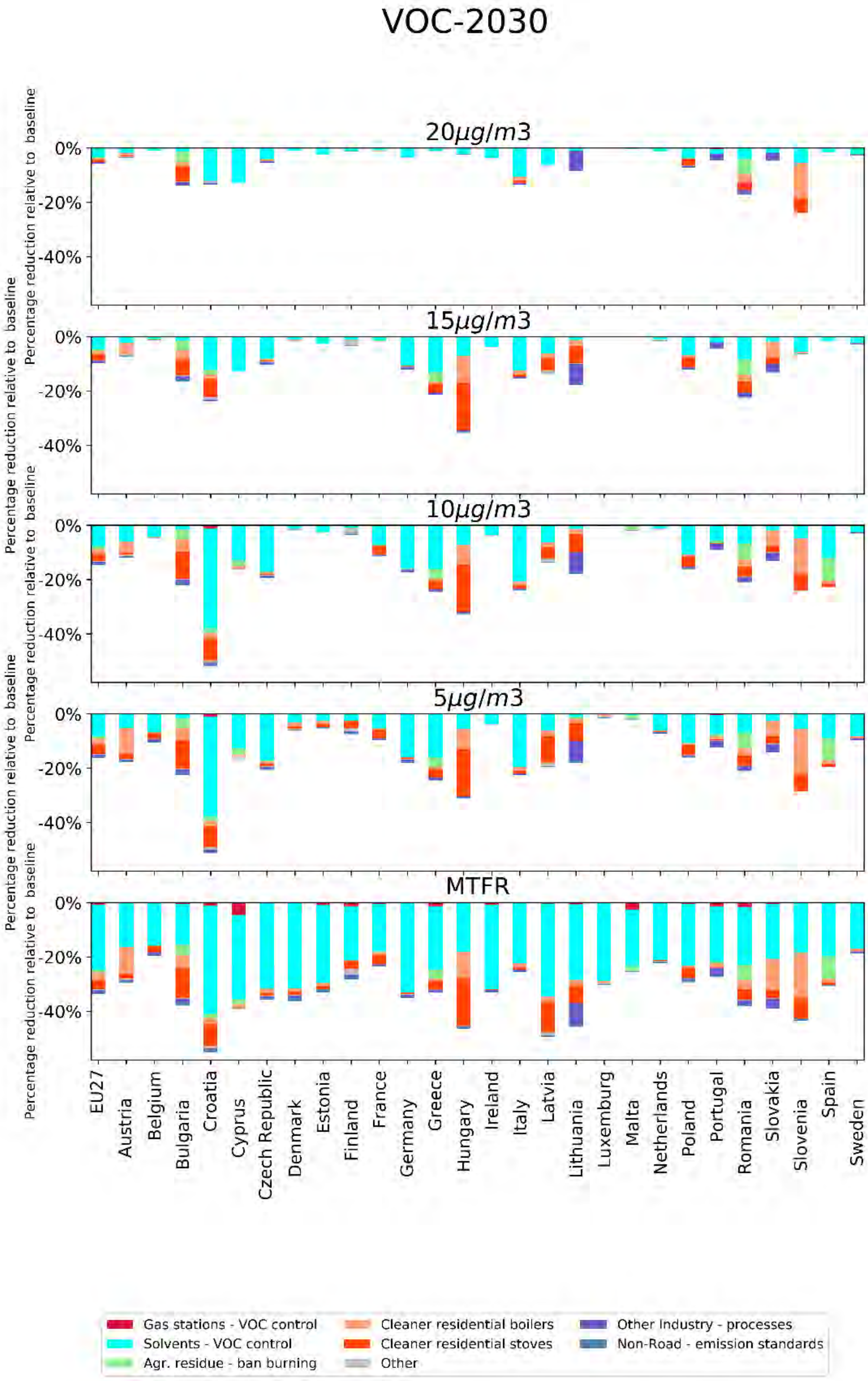
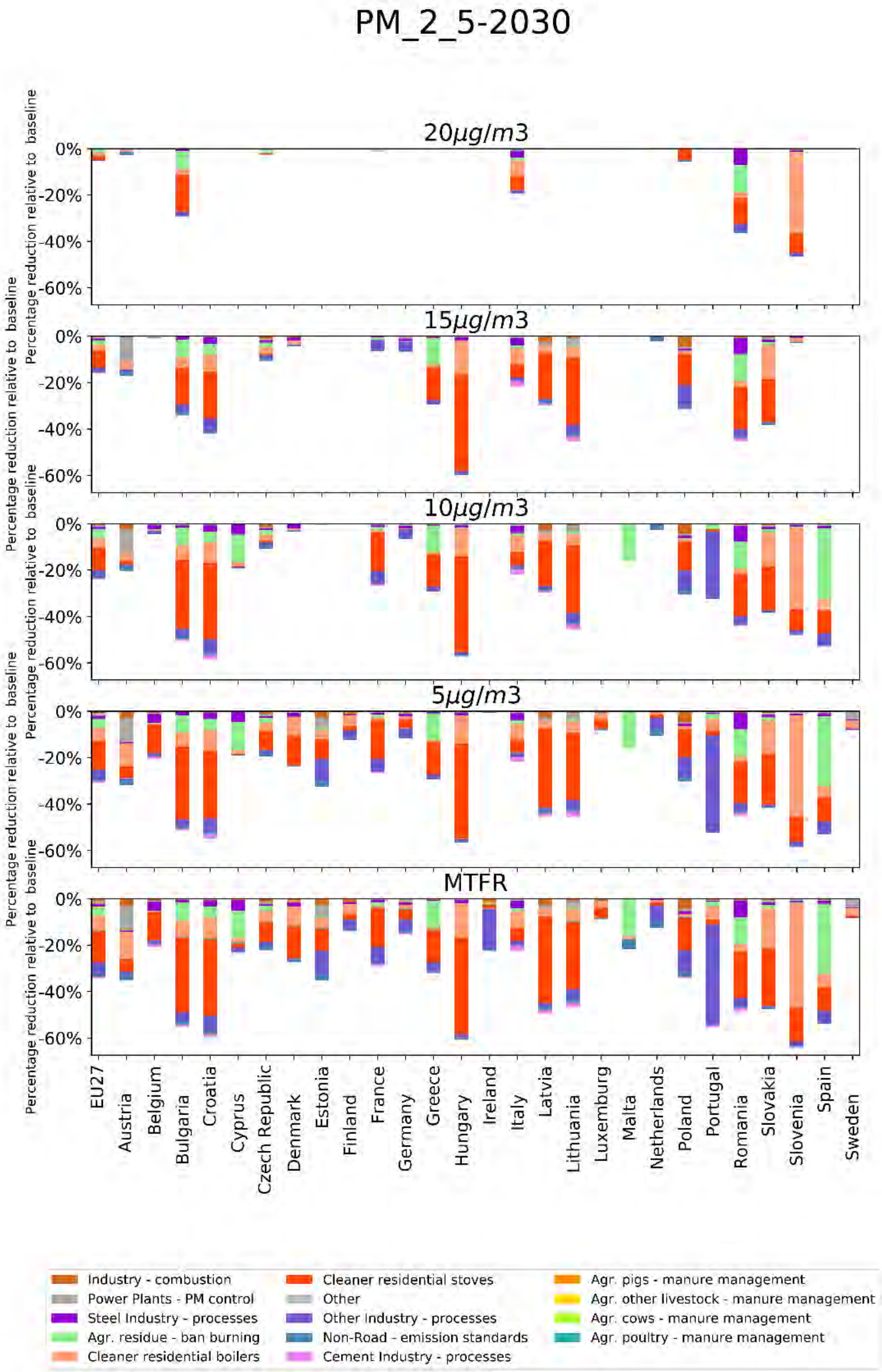


Figure A-40 - Reduction of $PM_{2.5}$ emissions, split by MS (2030)



The following figures show a comparison of pollutant mitigation efforts across the policy scenarios and MTFR for each member states and at the EU-27 level, also providing a finer sector/measure resolution.

Figure A-41 – Reduction of SO_2 emissions, split by MS (2030) [Alternative]

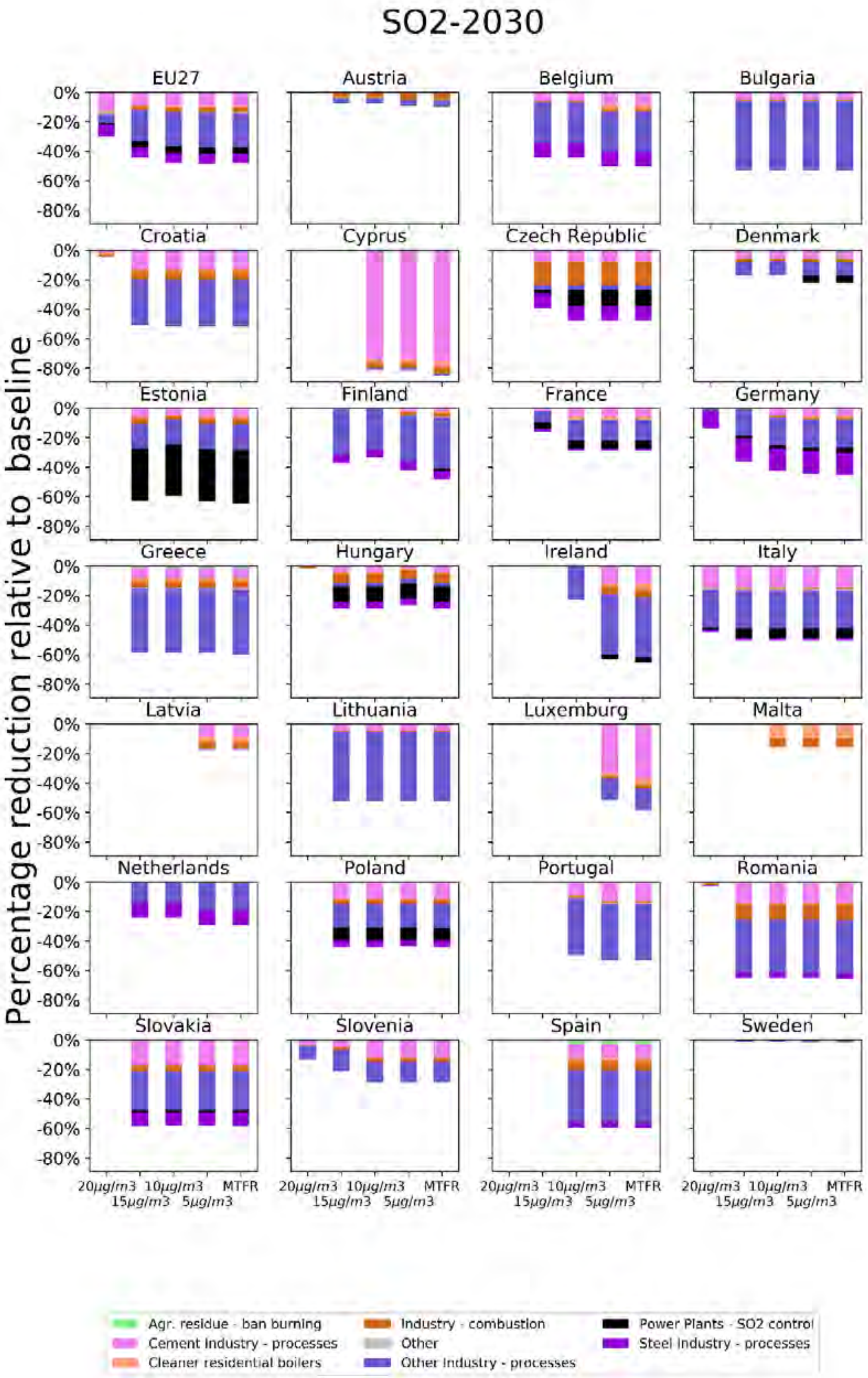


Figure A-42 - Reduction of NOx emissions, split by MS (2030) [Alternative]

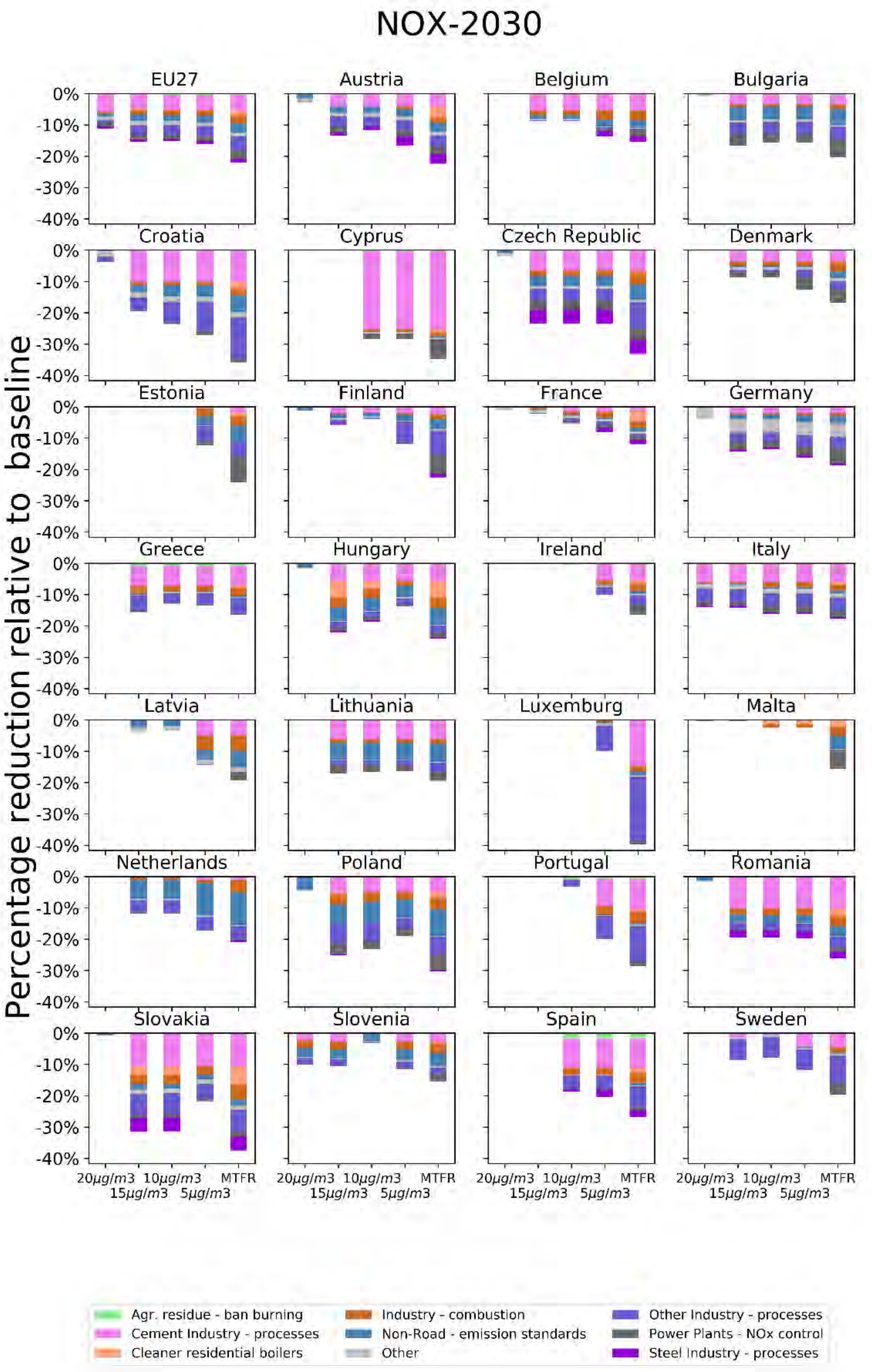


Figure A-43 – Reduction of NH_3 emissions, split by MS (2030) [Alternative]

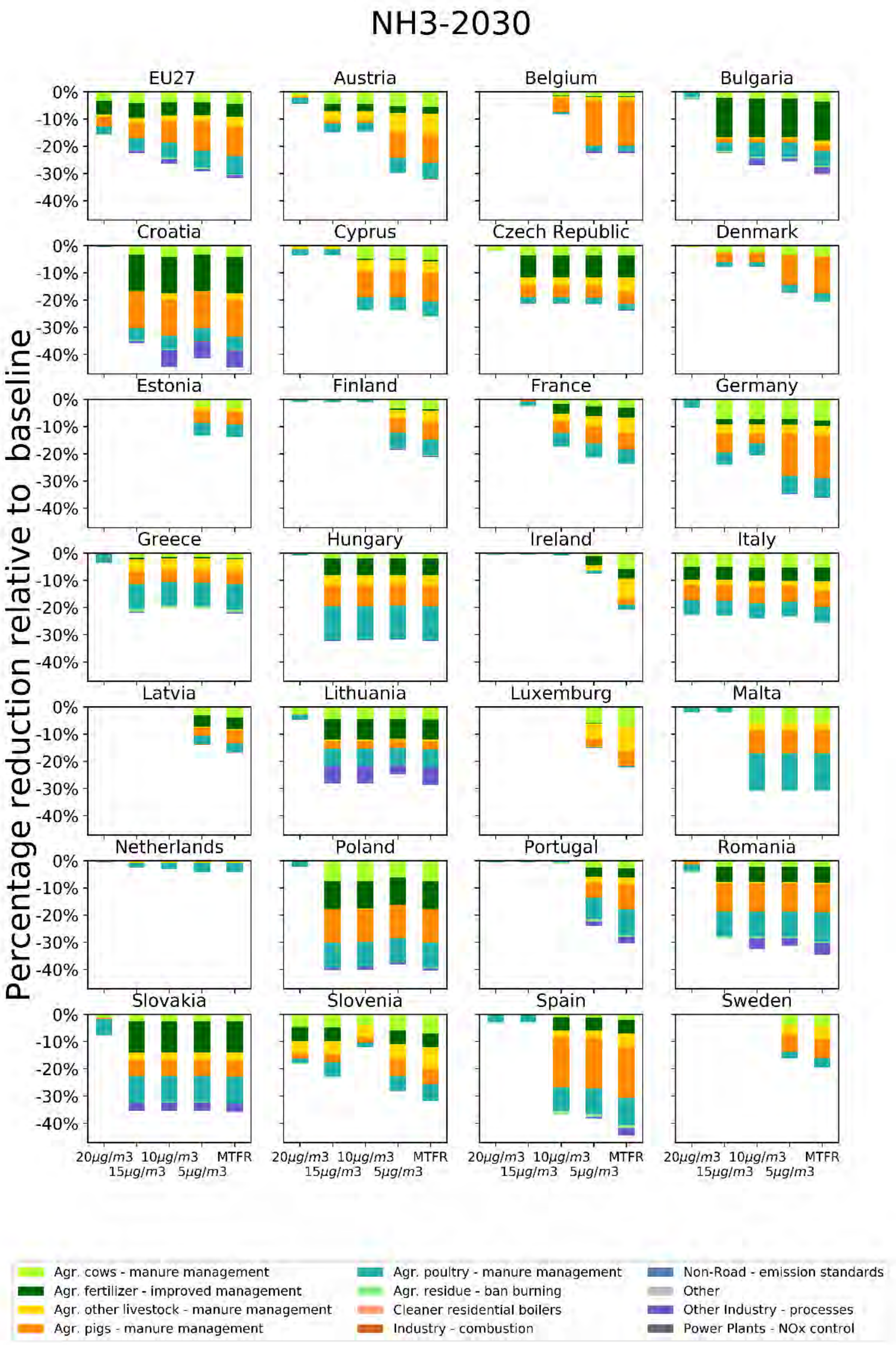


Figure A-44 - Reduction of VOC emissions, split by MS (2030) [Alternative]

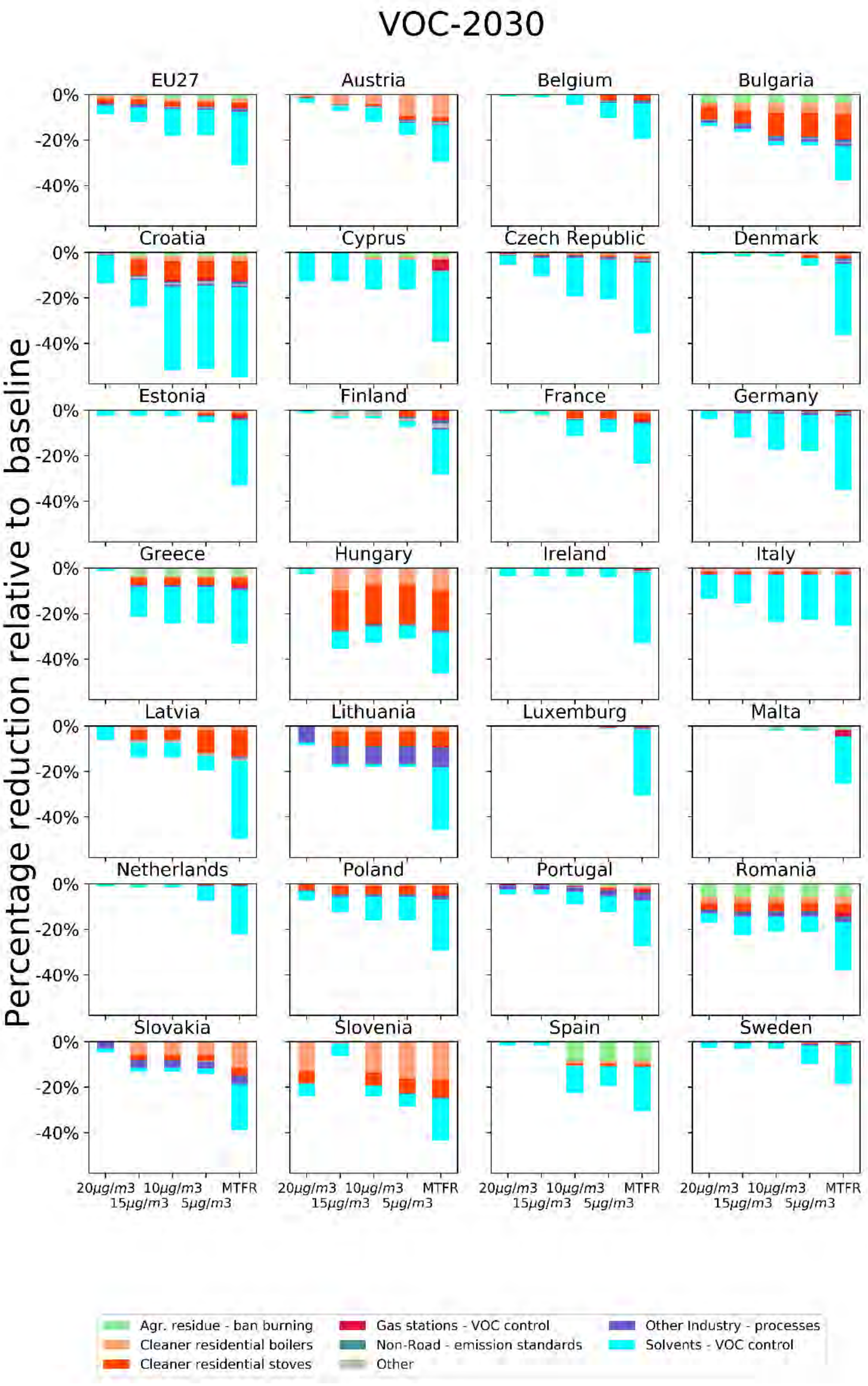
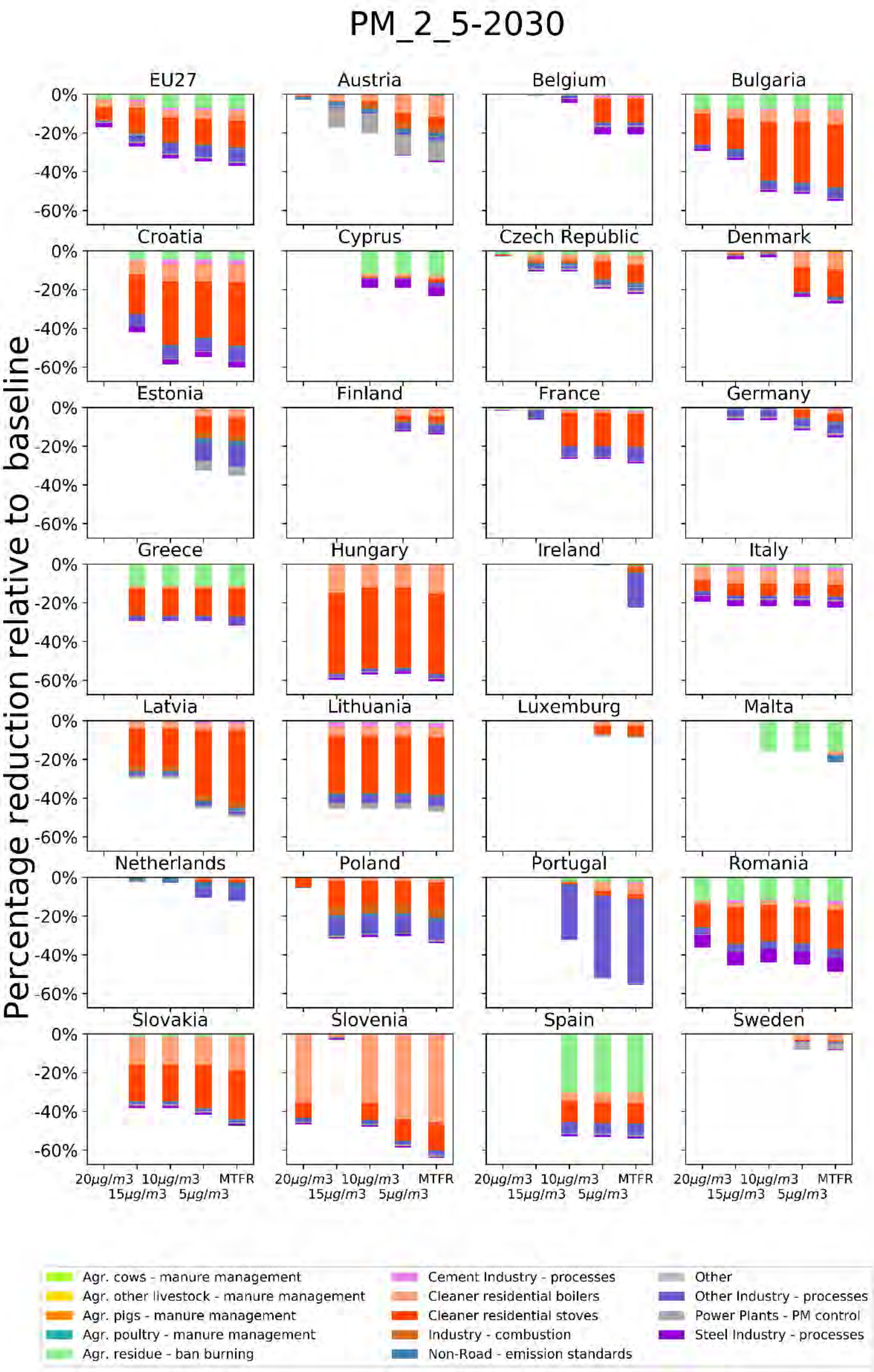


Figure A-45 - Reduction of $PM_{2.5}$ emissions, split by MS (2030) [Alternative]



Results for 2050

Figures below show the emission reductions by MS for policy scenario in 2050 as well as impact on concentration and distribution of mitigation costs.

Figure A-46 - Reduction of SO_2 emissions, split by MS (2050)

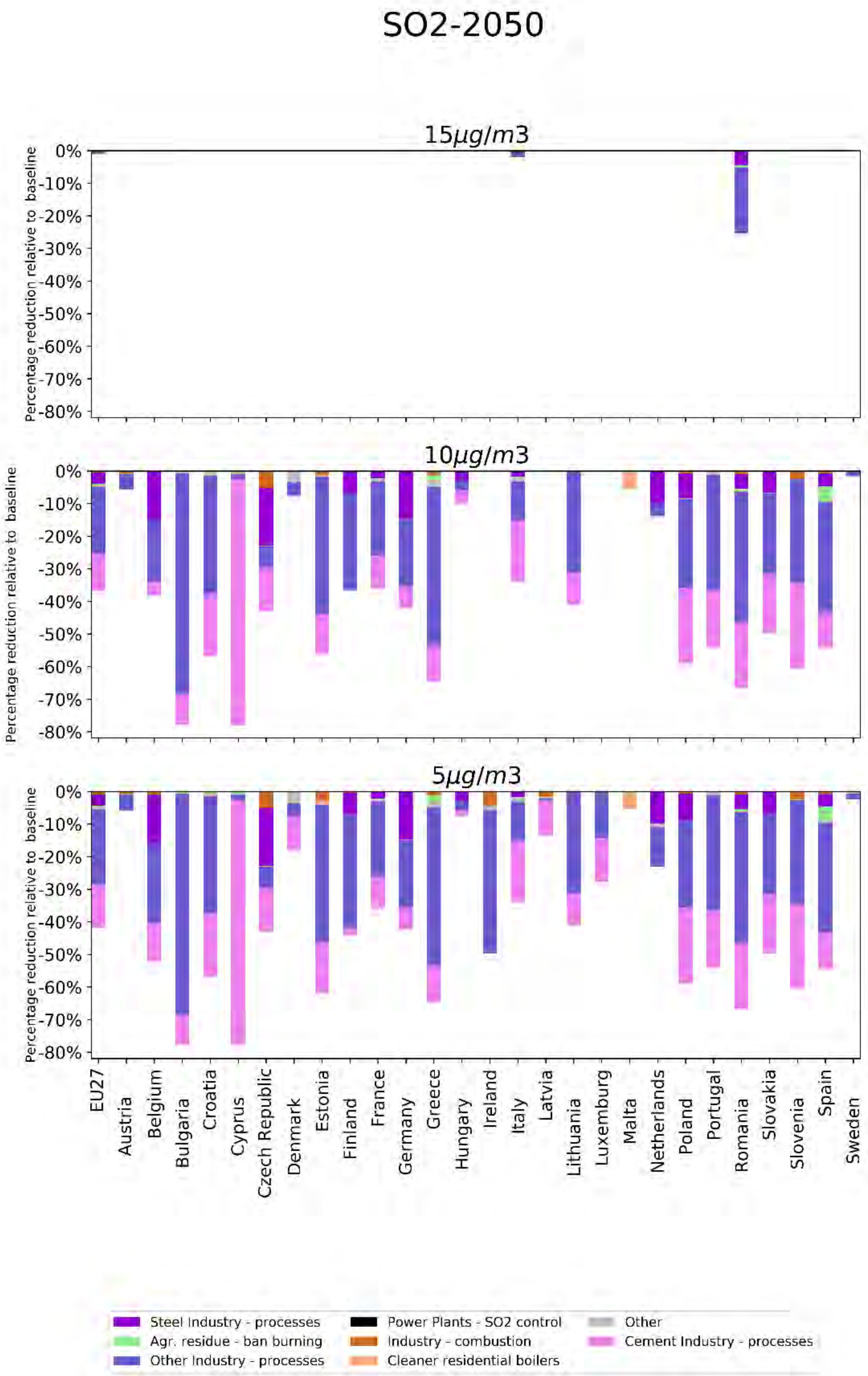


Figure A-47 - Reduction of NOx emissions, split by MS (2050)

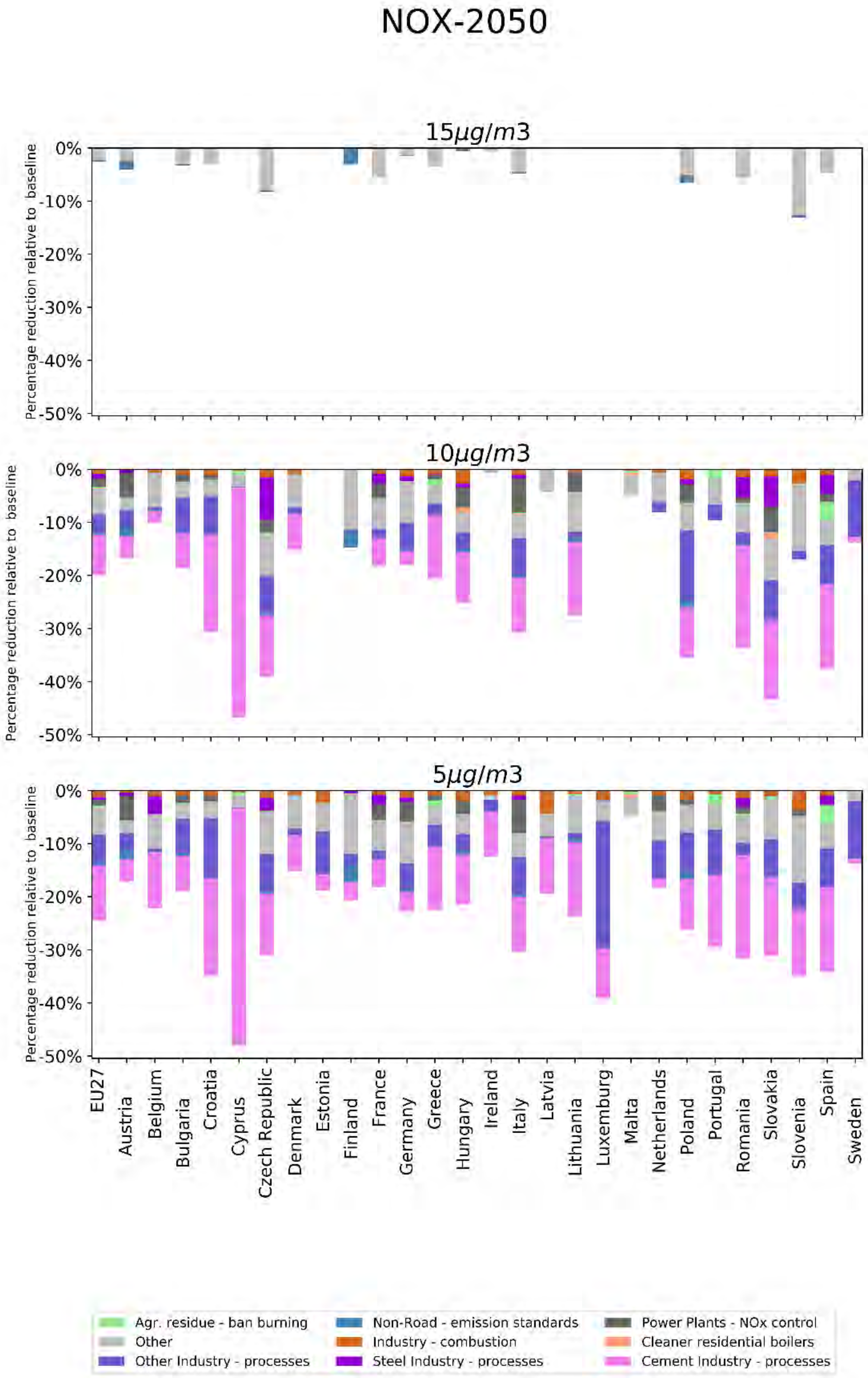


Figure A-48 – Reduction of NH_3 emissions, split by MS (2050)

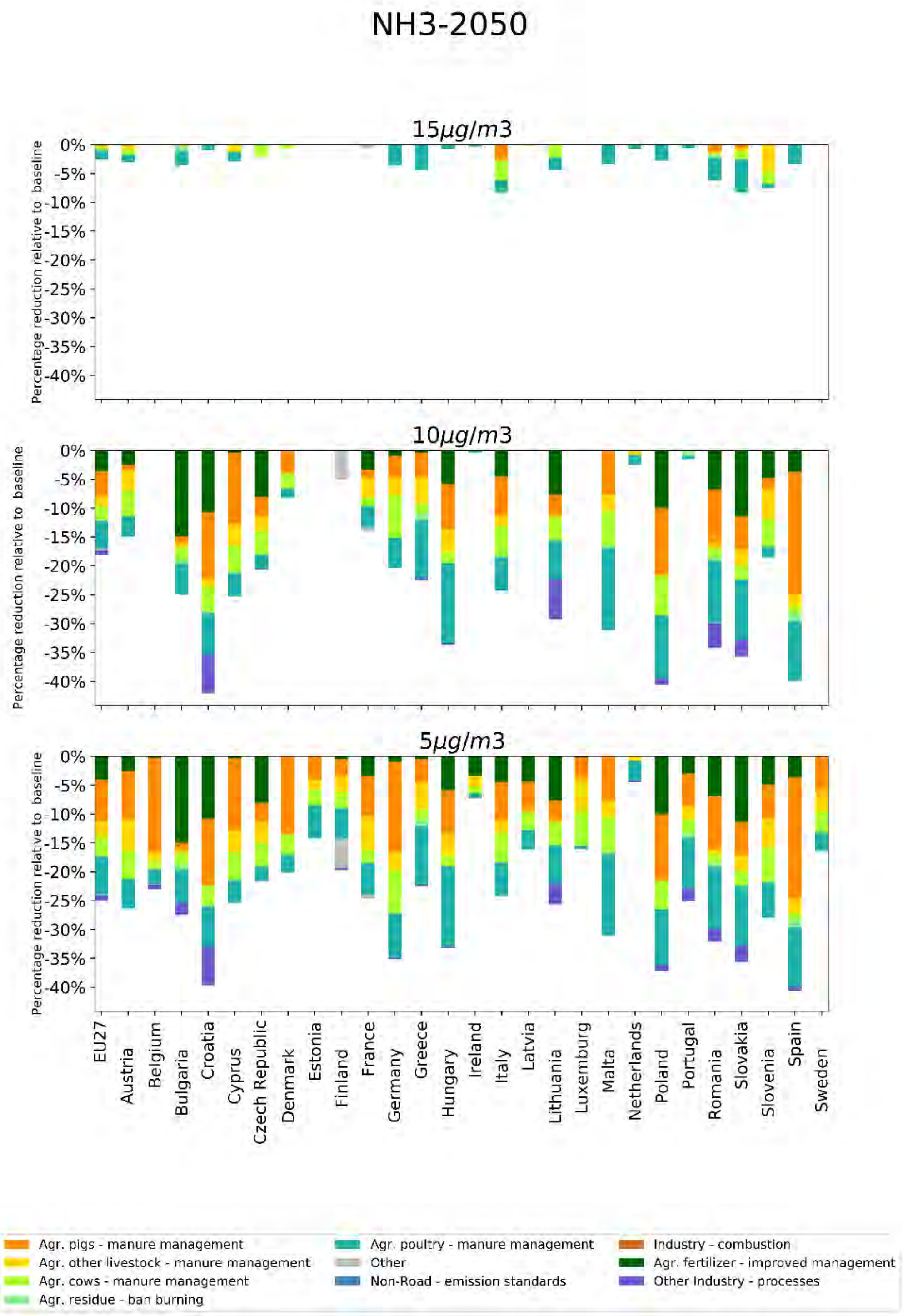


Figure A-49 – Reduction of VOC emissions, split by MS (2050)

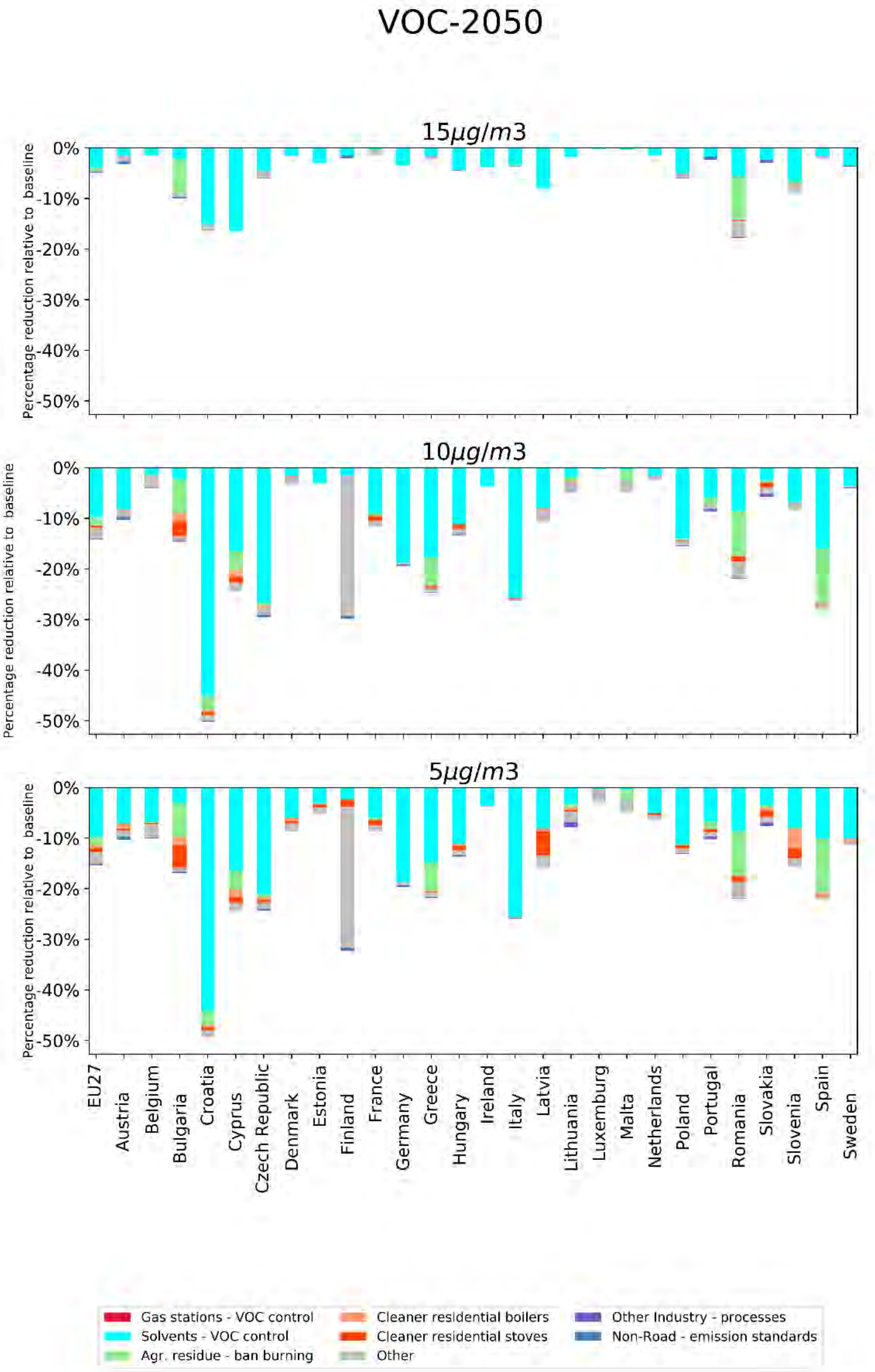


Figure A-50 – Reduction of $PM_{2.5}$ emissions, split by MS (2050)

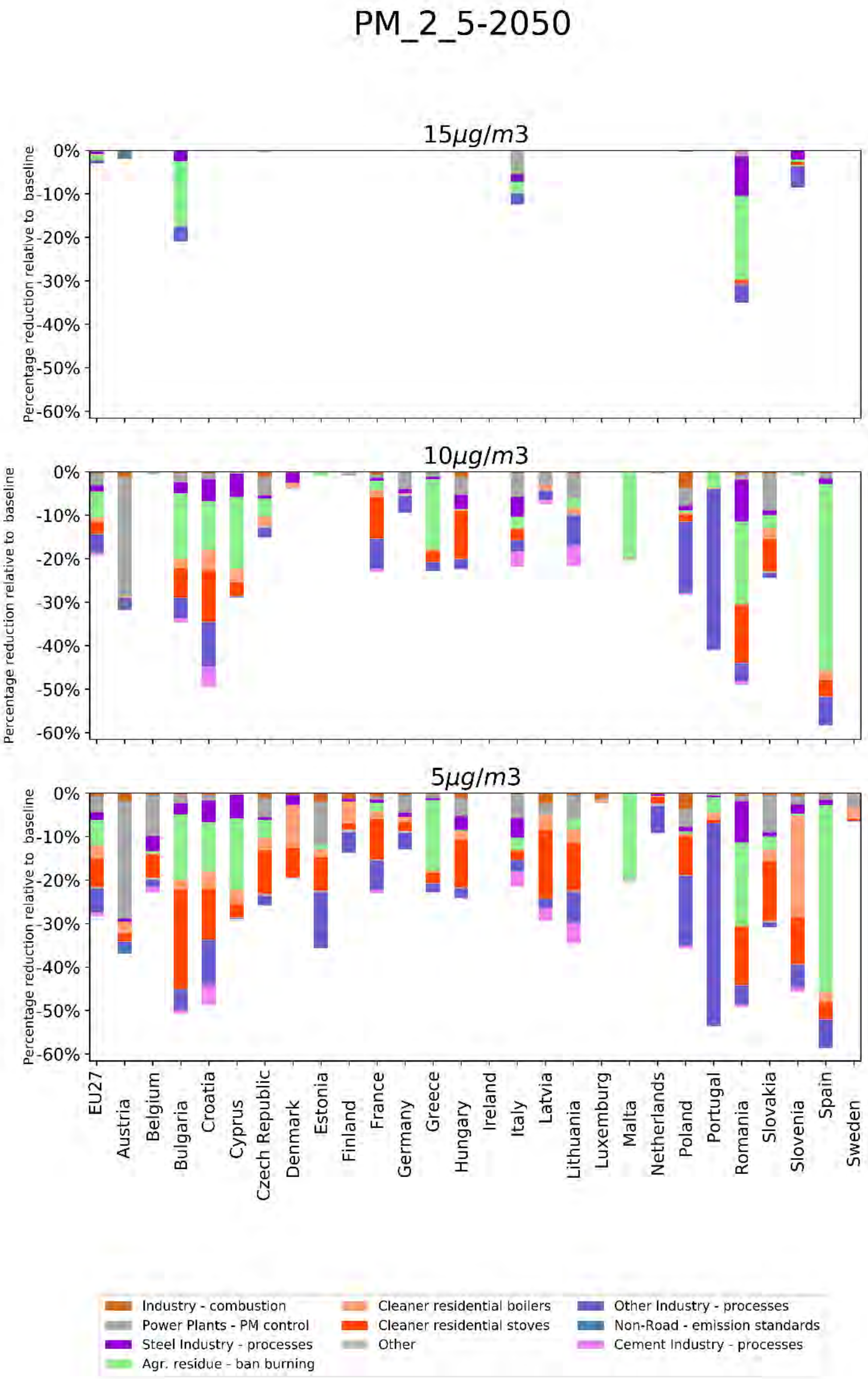


Figure A-51 - Reduction of SO_2 emissions, split by MS (2050) [Alternative]

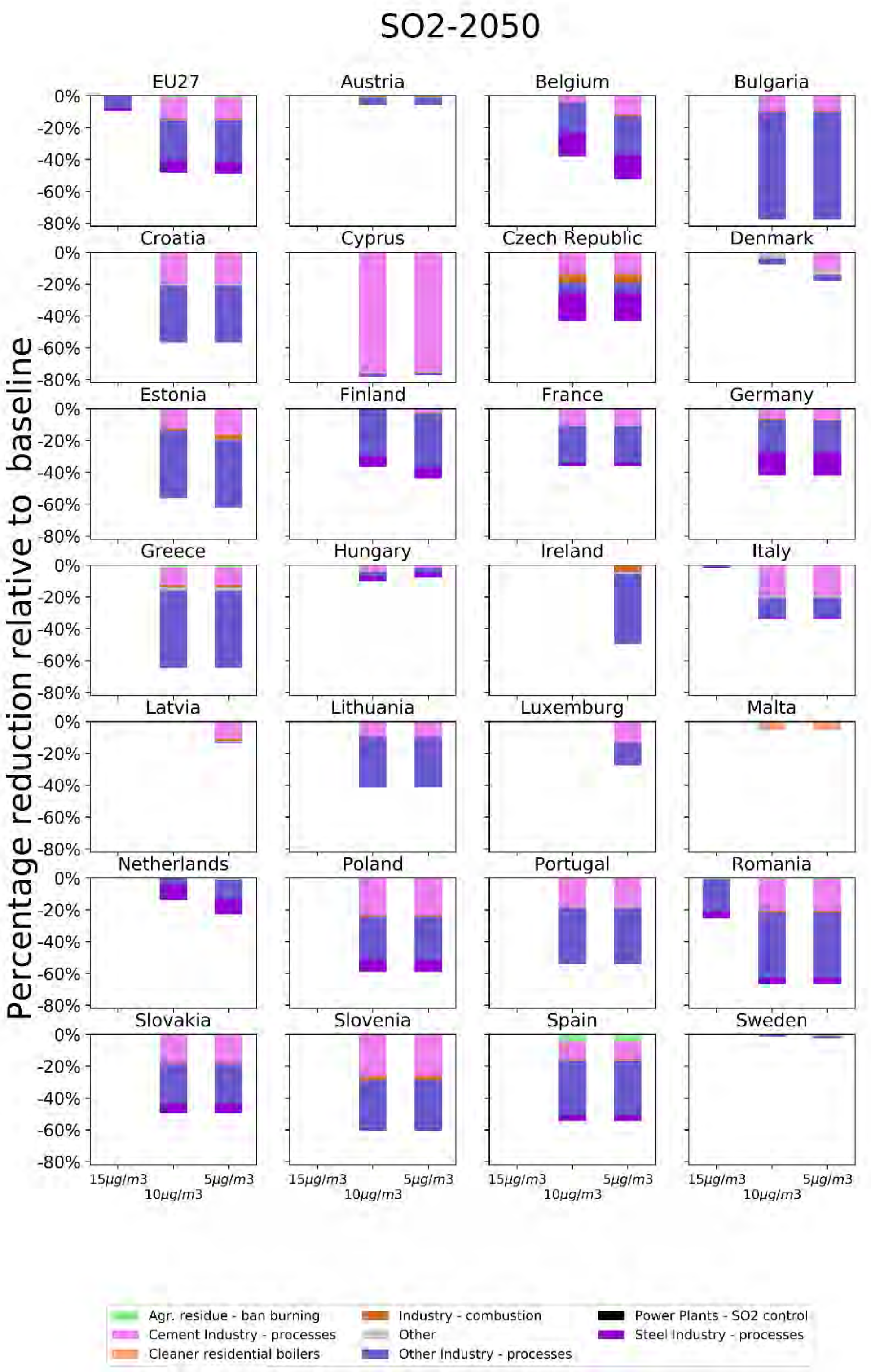


Figure A-52 - Reduction of NOx emissions, split by MS (2050) [Alternative]

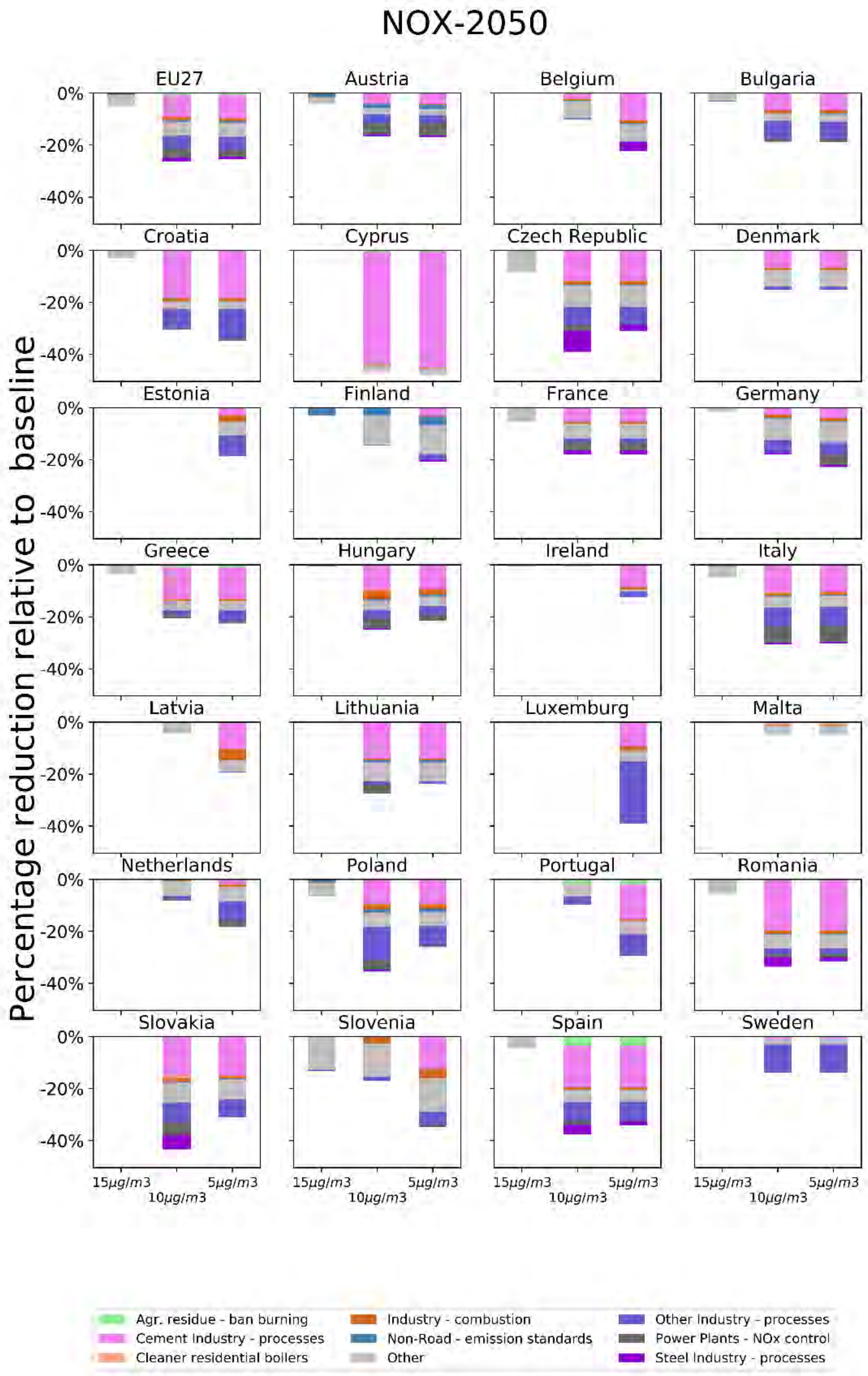


Figure A-53 - Reduction of NH_3 emissions, split by MS (2050) [Alternative]

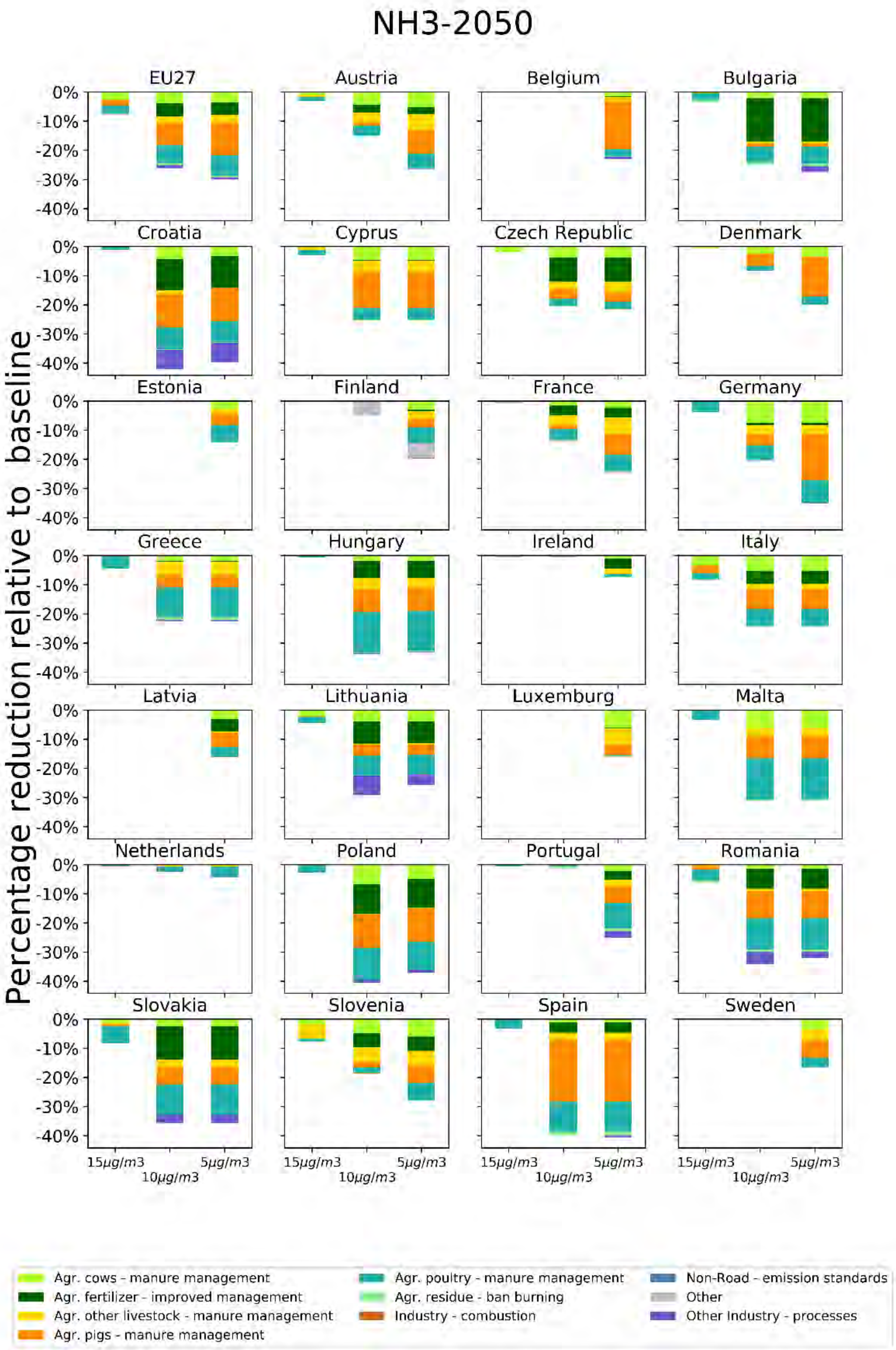


Figure A-54 – Reduction of VOC emissions, split by MS (2050) [Alternative]

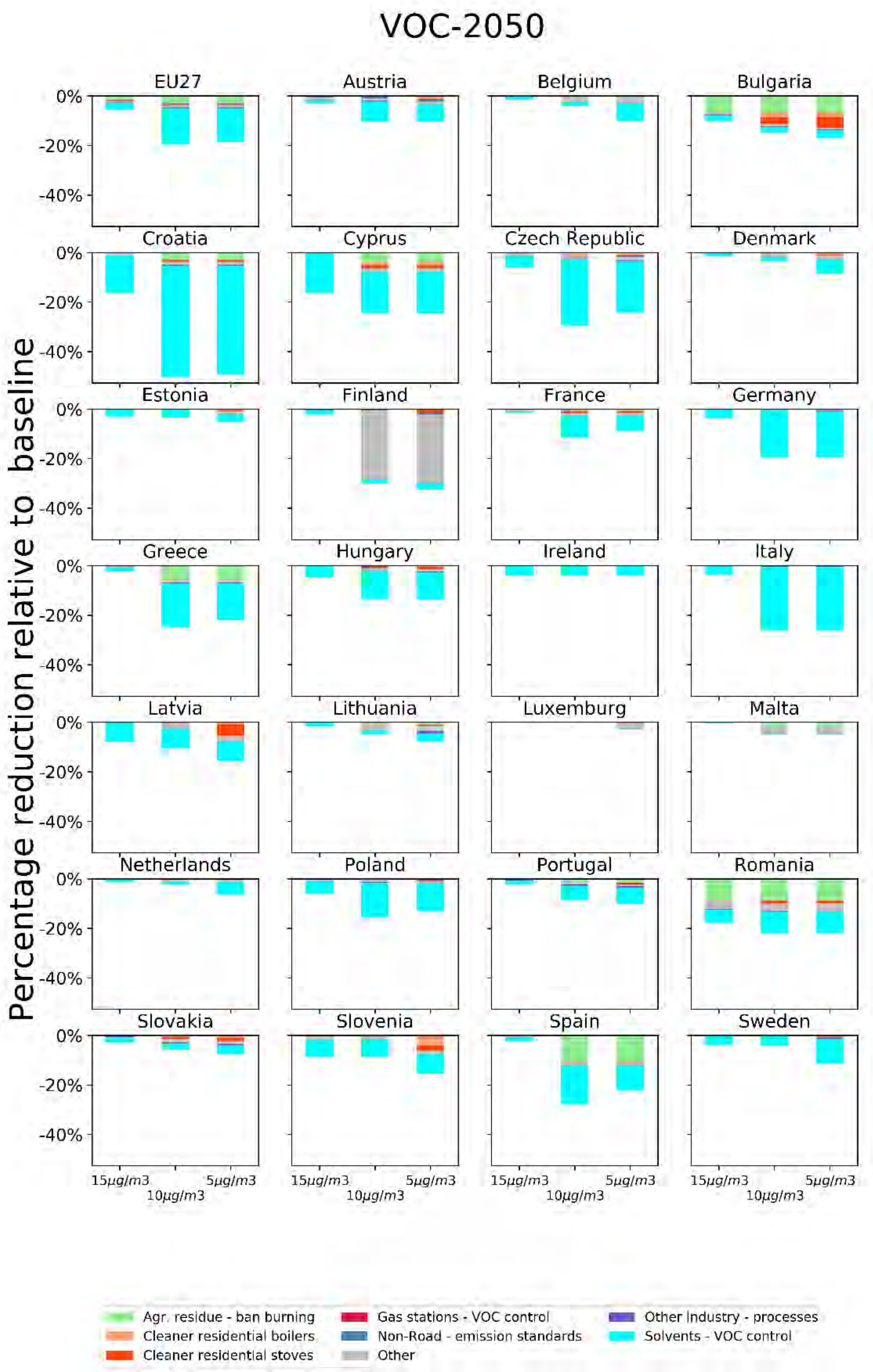
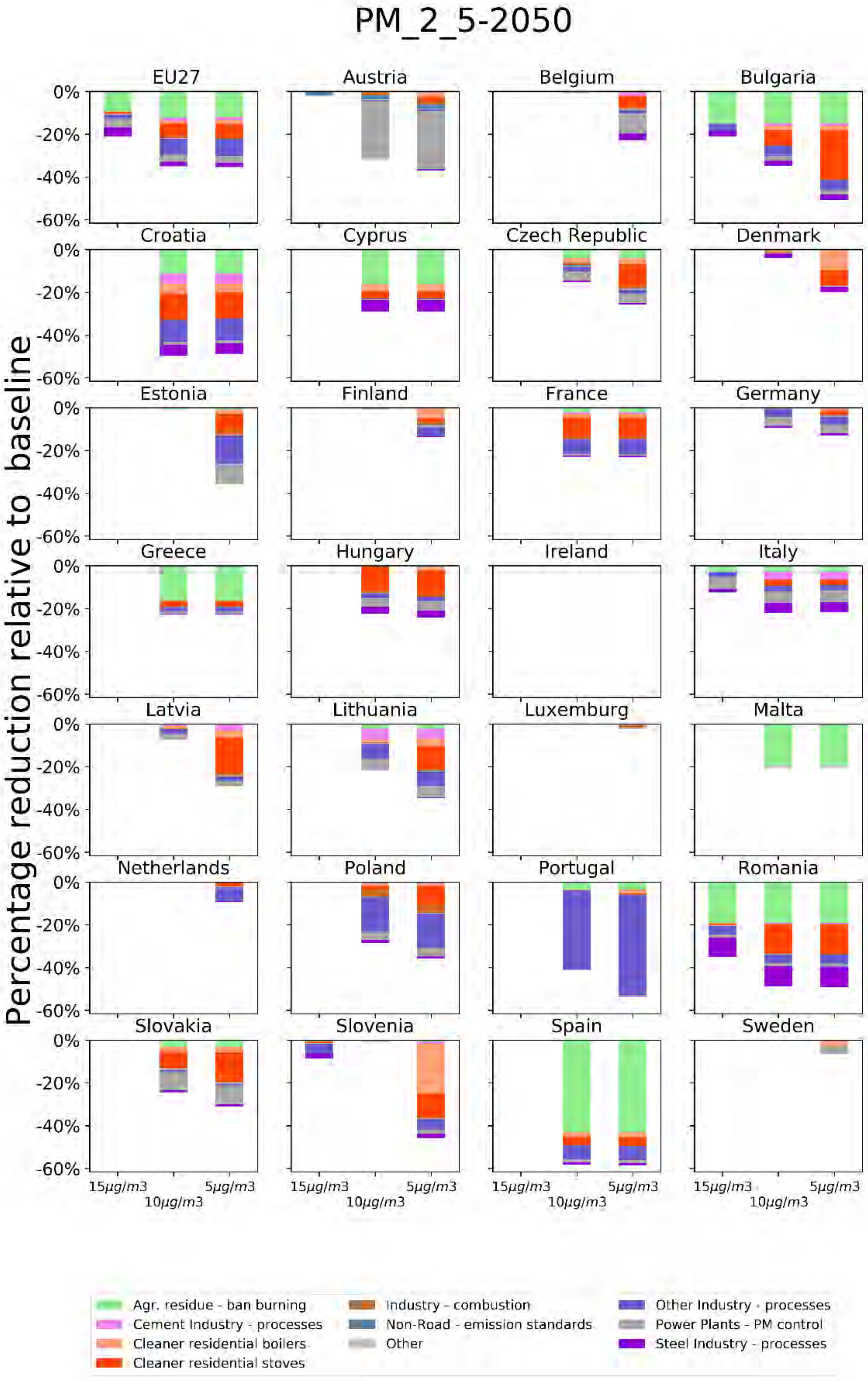
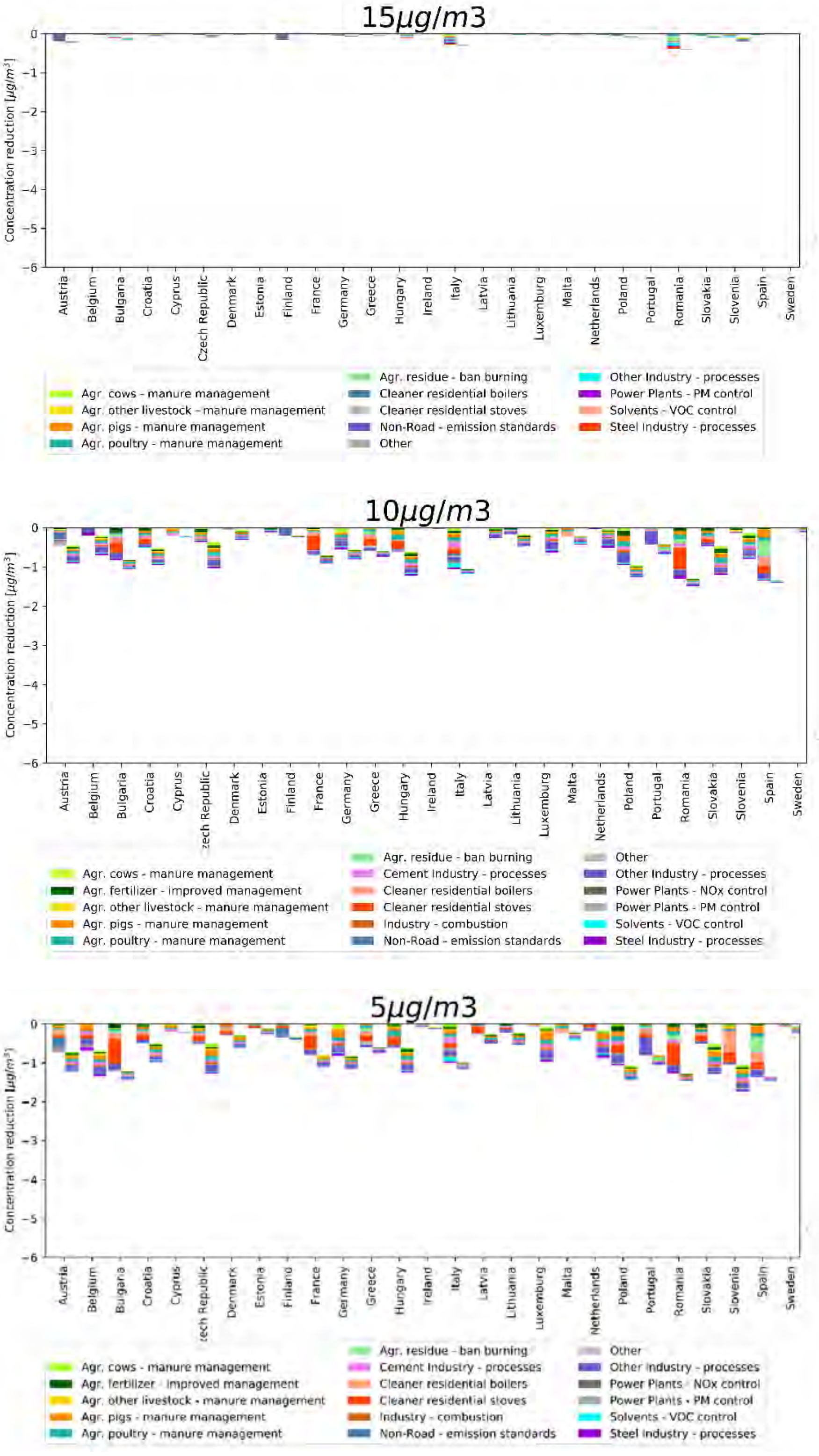


Figure A-55 - Reduction of PM2.5 emissions, split by MS (2050) [Alternative]



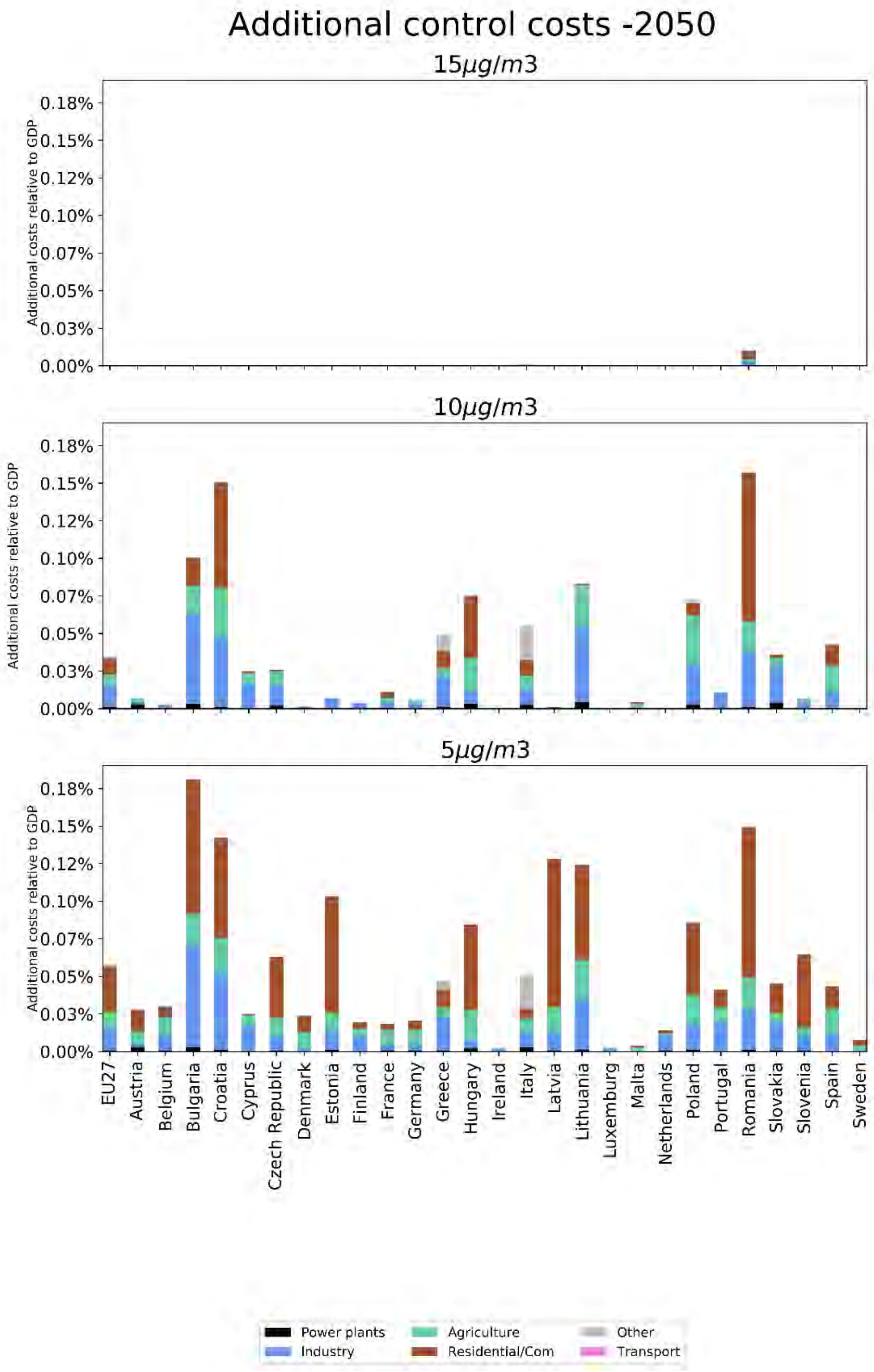
The three Figures below show the contribution of various sectors (measures) to the reduction in population mean exposure across the Member States (also including transboundary impact – right hand extension to each bar) for three policy cases in 2050. Whilst achieving a 15 µg/m^3 target does not necessitate significant additional efforts (as shown also in previous figures in this section), strengthening target to 10 µg/m^3 and then 5 µg/m^3 requires all MS to contribute with additional mitigation efforts spread across several sectors but mostly benefiting from action in residential heating and agricultural sources.

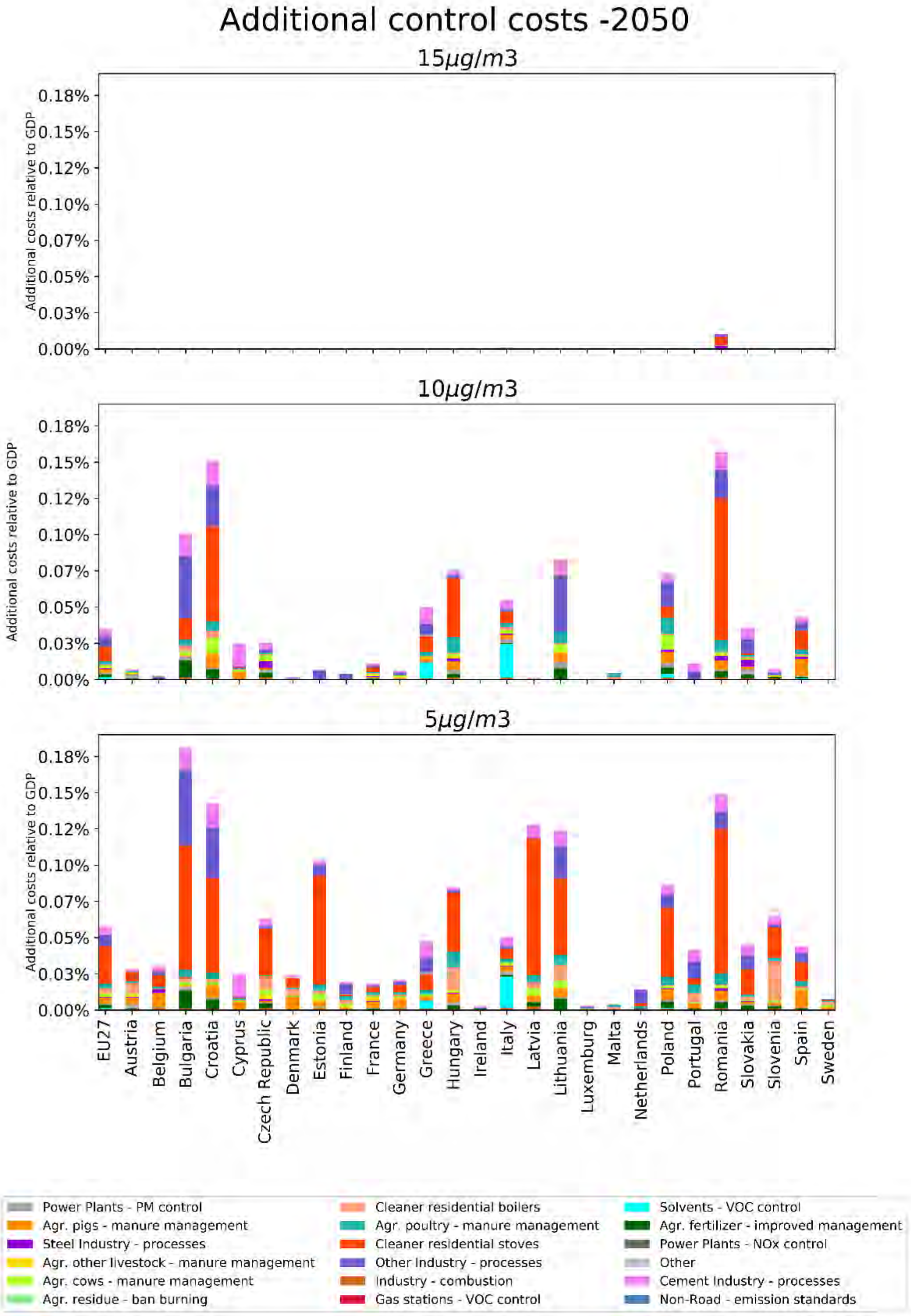
Figure A-56 - Contribution of various sectors (measures) to the reduction in population mean exposure across the MS in 2050



Finally, the figures below show additional air pollution control costs in 2050 (shown as percentage of GDP) for the policy scenarios. As indicated earlier in this section, OPT15 does not entail significant additional costs, meaning that this target is nearly achieved in the Baseline. Costs increase significantly under OPT10 and even more so for OPT5 where all countries would need to introduce additional measures. Most of the additional costs is associated with accelerating transition to clean residential heating appliances, measures in agriculture, and industry. The first figure aggregates costs to key sector while the next one shows higher source/measure resolution highlighting key areas where mitigation is achieved.

Figure A-57 - Additional air pollution control costs in 2050 (shown as percentage of GDP) for the policy scenario




Additional control costs -2050
15µg/m3
10µg/m3
5µg/m3
Additional costs relative to GDP
0.18%
0.15%
0.12%
0.10%
0.07%
0.05%
0.03%
0.00%
EU27
Austria
Belgium
Bulgaria
Croatia
Cyprus
Czech Republic
Denmark
Estonia
Finland
France
Germany
Greece
Hungary
Ireland
Italy
Latvia
Lithuania
Luxemburg
Malta
Netherlands
Poland
Portugal
Romania
Slovakia
Slovenia
Spain
Sweden
Power Plants - PM control
Agr. pigs - manure management
Steel Industry - processes
Agr. other livestock - manure management
Agr. cows - manure management
Agr. residue - ban burning
Cleaner residential boilers
Agr. poultry - manure management
Cleaner residential stoves
Other Industry - processes
Industry - combustion
Gas stations - VOC control
Solvents - VOC control
Agr. fertilizer - improved management
Power Plants - NOx control
Other
Cement Industry - processes
Non-Road - emission standards

Appendix 4 – Measurement data and additional heavy metal analysis

Measurement data

Count of current exceedances

Alongside the detailed pollutant modelling, a further key data input was an analysis of recent monitoring data for various pollutants and averaging periods. The analysis was based on historic measurement data, and as such gives a picture of the 'current status' of air pollution and compliance with various standards.

The data was sourced from the EEA's Airbase database (EEA, 2022) (accessed March and April 2022). The year selected for the analysis was 2019, to exclude the effects of the pandemic on measured data.

The results of the analysis are presented in the following table. This presents, for different pollutants over different averaging periods, the number of measurement sites reporting in the EEA AirBase data set that are above a given air pollutant concentration threshold.

The dataset was refined to focus only on monitoring sites in the EU27, and to consider sites with a data aggregation only over 85%.

Table A-3- Results of analysis of 2019 EEA Airbase monitoring data

Pollutant	Averaging period	Data aggregation process*	Metric	Total sites**	Illustration 1			Illustration 2		
					Standard	Count sites exceeding	% of all sites exceeding	*Standard*	Count sites exceeding	% of all sites exceeding
$PM_{2.5}$	24 hour	1 year 50 %ile of daily values in a year	50th percentile	1256	*25 µg/m3*	0	0%	*15 µg/m3*	109	9%
$PM_{2.5}$	24 hour	1 year 99 percentile of daily means (P1D) or .../aq/primaryObservation/day	99th percentile (WHO AQG)	1256	*25 µg/m3*	1,060	84%	*15 µg/m3*	1,227	98%
$PM_{2.5}$	24 hour	1 year day max	Max	1256	*25 µg/m3*	1,172	93%	*15 µg/m3*	1,246	99%
PM_{10}	24 hour	1 year 50 %ile of daily values in a year	50th percentile	2635	*50 µg/m3*	0	0%	*45 µg/m3*	0	0%
PM_{10}	24 hour	1 year 90.4 percentile - COMPLIANCE	90.4th percentile (EU compliance)	2635	*50 µg/m3*	273	10%	*45 µg/m3*	430	16%
PM_{10}	24 hour	1 year 99 percentile of daily means (P1D) or .../aq/primaryObservation/day	99th percentile (WHO AQG	2635	*50 µg/m3*	1,454	55%	*45 µg/m3*	1,816	69%
NO_2	24 hour	1 year 50 %ile of daily values in a year	50th percentile	2941	*50 µg/m3*	29	1%	*25 µg/m3*	768	26%
NO_2	24 hour	1 year 99 percentile of daily means (P1D) or .../aq/primaryObservation/day	99th percentile (WHO AQG)	2941	*50 µg/m3*	1,092	37%	*25 µg/m3*	2,441	83%
NO_2	1 hour	1 year hour max19	19th highest value in a year (EU compliance)	2641	*200 µg/m3*	1	0%	*120 µg/m3*	229	9%
SO_2	Annual	Annual mean / 1 calendar year	N/A	1307	*20 µg/m3*	4	0%	-	-	-
SO_2	24 hour	P1Y-day-max-per99.18	99.18th percentile (EU compliance)	1314	*125 µg/m3*	2	0%	*40 µg/m3*	49	3.7%
SO_2	1 hour	1 year hour max 25	25th highest value in a year (EU compliance)	1278	*350 µg/m3*	1	0%	*50 µg/m3*	147	12%
CO	8 hour daily maximum	1 year [8 hour] daymax exceed 10	(EU compliance)	792	*10 mg/m3*	1	0%	*0.01 µg/m3*	2	0%
CO	24 hour	1 year day max	Max. (WHO AQG)	792	-	-	-	*4 mg/m3*	39	5%
CO	24 hour	1 year 99 percentile of daily means (P1D) or .../aq/primaryObservation/day	99th percentile	804	-	-	-	*4 mg/m3*	1	0%
CO	1 hour	1 year hour max	Max.(WHO AQG)	794	-	-	-	*35 mg/m3*	1	0%
C6H6	Annual	Annual mean / 1 calendar year	N/A	591	*5 µg/m3*	1	0%	*1.7 µg/m3*	65	11%
BaP	Annual	Annual mean / 1 calendar year	N/A	401	*1 ng/m3*	149	37%	*0.12 ng/m3*	338	84%
O_3	AOT40 5yr	AOT40 vegetation protection averaged over 5 years	(EU Compliance - vegetation)	1516	*18000 µg/m3*	752	50%	-	-	-
O_3	8hr M 6months	Yearly highest six monthly average of daily maximum 8-hour mean concentration	(WHO AQG - peak season)	1768	*100*	437	25%	*60*	1,745	99%
O_3	8hr M	1 year 93.15 percentile daily 8h maximum	93.15th percentile (EU Compliance)	1826	*120*	568	31%	*100*	1,528	84%
O_3	8hr M	1 year 99 percentile daily 8h maximum	99th percentile (WHO AQG)	1826	*120*	1,450	79%	*100*	1,739	95%

Notes : *as defined in the Airbase dataset; **Total sites reporting data in the data set for the specific pollutant and time period combination ; '-' denotes no entry

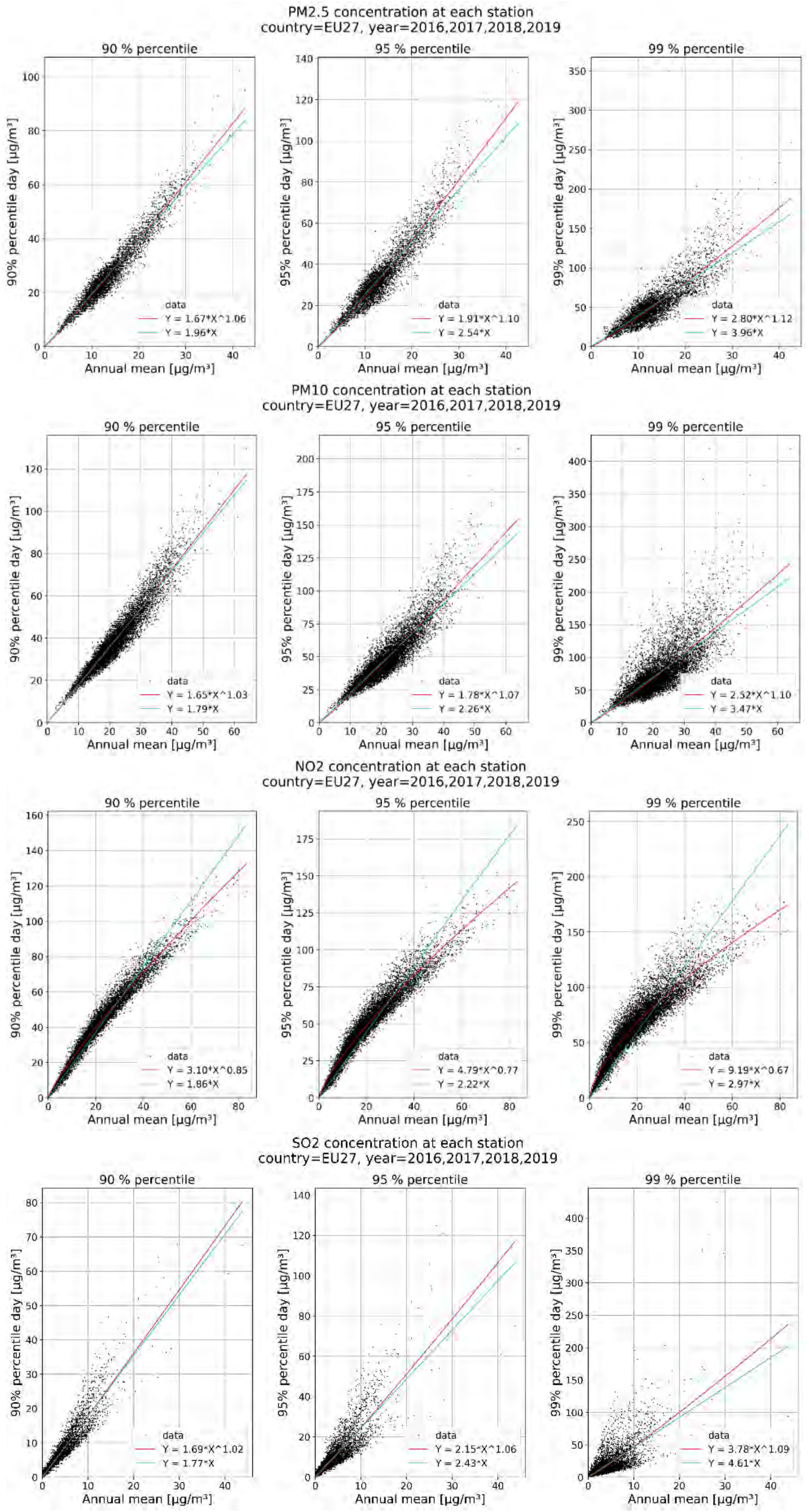
Statistical relationship between annual means and daily mean percentiles

Calculations carried out with uEMEP provide annual mean concentrations. There is also a need to address higher temporal resolutions. In this section, measurement data is analysed to provide an empirical relationship between annual means and daily mean percentiles.

In Figure A-58 scatter plots for $PM_{2.5}$, PM_{10}, NO_2 and SO_2 show the relationship between annual mean and the daily mean 90'th, 95'th and 99'th percentiles, respectively 26, 18 and 3 days per year. Scatter is significantly lower for the 90'th percentile in all cases. Both a linear and a power law fit are applied. For simplicity the linear fit provides a single number that can be used to relate an annual mean concentration to any of the percentiles.

This number can be used in two ways. Firstly, calculated annual mean concentrations can be converted to daily mean percentiles, providing a new set of indicators either at stations sites or for mapping purposes. Alternatively, if an annual mean threshold concentration is to be set then a consistent percentile threshold can be derived.

Figure A-58 Scatter plots of annual mean versus 90'th. 95'th and 99'th daily mean percentiles for PM$_{2.5}$, PM$_{10}$, NO$_2$ and SO$_2$. Data are from Airbase from 2016-2019. Fitted curves, linear and power law, are shown.



The results are summarized in

Table A-4.

Table A-4 - Conversion parameters based on linear fit converting from annual mean concentrations to 90'th, 95'th and 99'th daily mean percentiles for $PM_{2.5}$, PM_{10}, NO_2 and SO_2. Data used are from Airbase 2016 - 2019.

Pollutant	90'th	95'th	99'th
$PM_{2.5}$	1.96	2.54	3.96
PM_{10}	1.79	2.26	3.47
NO_2	1.86	2.22	2.97
SO_2	1.77	2.43	4.61

Measurement data and further analysis - Benzene

For this assessment, the data reported by each of the 27 member states for annual mean measurements of Benzene in 2019 was obtained through the European Environment Agencies air quality annual statistics for all EEA reporting countries tool (EEA, 2022). This dataset was filtered to remove rows relating to non-EU member states and included only data marked as verified from monitoring locations with data capture above 85%. This analysis does not include data relating to Romania as this information was not provided in the EEA reporting countries tool.

Table A-5 - Reference standards for Benzene

Thresholds considered	Benzene (µg/m³)
Threshold 2: EU standard	5

Table A-5 shows only the current EU standard set for concentrations of Benzene as an annual mean. The current WHO air quality guidelines does not set a standard for this pollutant.

To show the distribution of air quality values across all the identified monitoring sites in 2019, a boxplot was produced for Benzene. The whiskers show the minimum and maximum values, the box extends from the lower to upper quartiles with a line at the median, and the 95% and 99% quartiles are also represented. The grid at the top shows the metal concentrations on a logarithmic scale.

Figure A-59 - Measured concentrations of Benzene at the 354 stations in EEA reporting countries tool 2019 dataset

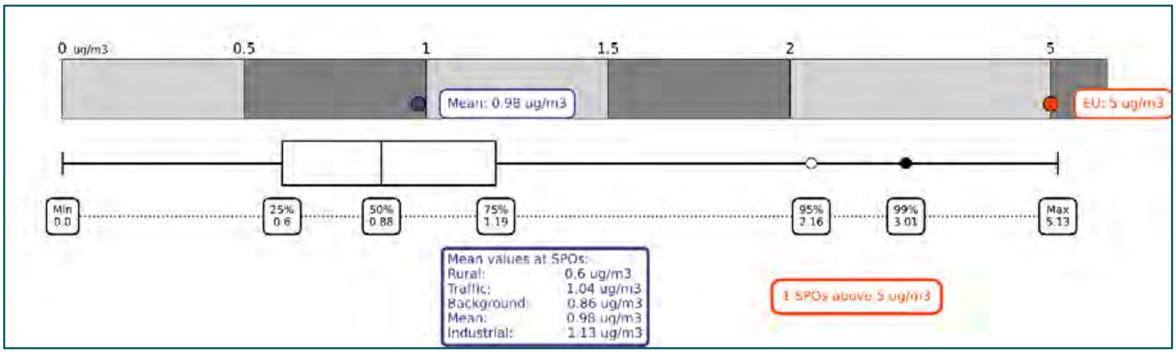


Figure A-59 shows that almost all monitoring locations measuring concentrations of Benzene are compliant with the current objective, with only one location in exceedance of this objective value. The data shows that approximately half of the locations measure concentrations below 1 µg/m³ as an annual mean.

Table A-6- tabulated statistics of annual mean Benzene measurements, disaggregated by site location type

	Background	Industrial	Traffic
Mean	0.86	1.13	1.04
Minimum	0.00	0.00	0.00
Maximum	3.03	5.13	4.58
Total Count	267	259	100
Count above EU standard	0	0	1

Measurement data and further analysis – Carbon Monoxide

For this assessment, data was collected and processed using the same source and approach undertaken for the Benzene analysis. As found in the Benzene analysis, this assessment was limited as data for Romania was not provided in the EEA reporting countries tool dataset.

Table A-7- Proposed and existing standards for Carbon Monoxide

Thresholds considered	CO (µg/m³)
Threshold 1: WHO guideline for concentrations of Carbon Monoxide as a 24 hour mean	4

Figure A-60 – Measured max 1-hour concentrations of Carbon Monoxide at the 728 monitoring stations reported in the EEA reporting countries tool 2019 dataset

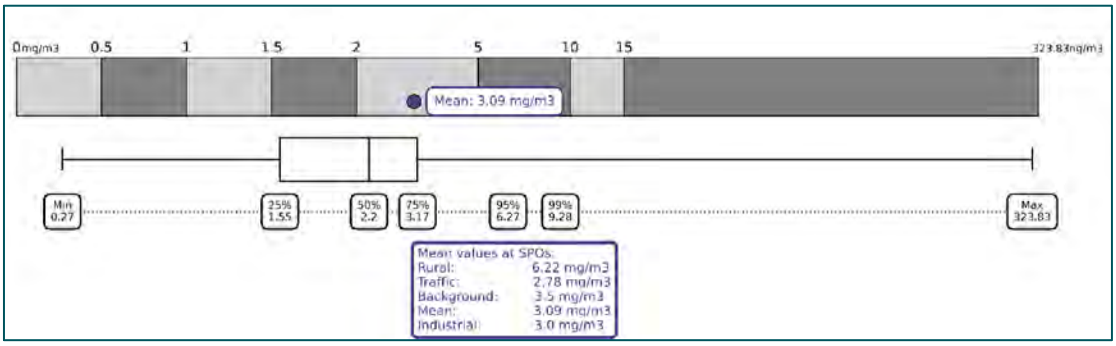
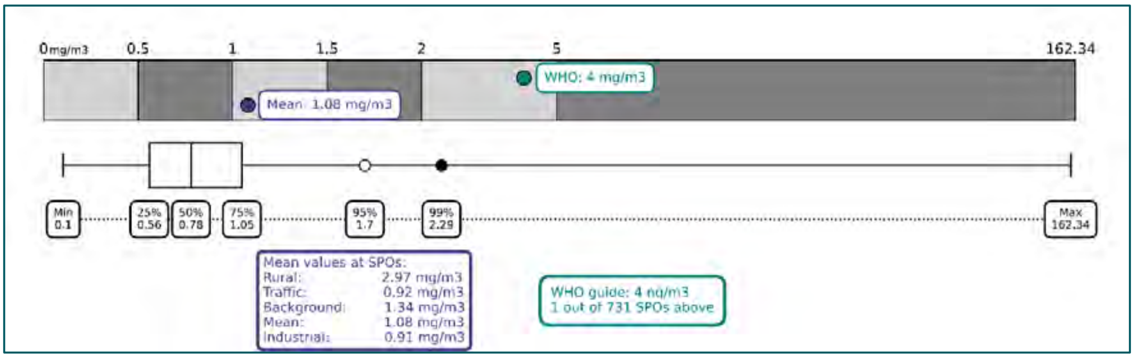


Figure A-60 shows that maximum hourly concentration of Carbon Monoxide was below 10 mg/m^3 (WHO AQG) at nearly all the monitoring stations reported in the database, with half of the stations recording below 2.2 mg/m^3. The data shows that one station measured 323.8 mg/m^3, further analysis shows that this is a clear outlier as the next highest max value was 19.7 mg/m^3.

Figure A-61 - Measured 24-hour concentrations of Carbon Monoxide as the 99th percentile at the 728 monitoring stations reported in the EEA reporting countries tool 2019 dataset



The data displayed in Figure A-61 shows that concentrations at the 99th percentile of 24 hour measurements are far below the WHO guidance value of 4 mg/m^3 at almost all monitoring locations. The data shows that the highest 99th percentile value is 162.3 mg/m^3 was far higher than the WHO guidance value, which was exceeded at one location only. The data shows that the second highest 99th percentile value was recorded as 3.9 mg/m^3, which is just below the guidance value.

Table A-8- Tabulated statistics of max hourly measurements Carbon Monoxide, disaggregated by site location type

	Background	Industrial	Traffic
Mean	3.50	3.00	2.78
Minimum	0.27	0.47	0.70
Maximum	323.83	19.7	18.60
Total Count	284	343	101

Table A-9- Tabulated statistics of measurements of Carbon Monoxide at the 99th percentile, disaggregated by site location type

	Background	Industrial	Traffic
Mean	1.34	0.91	0.92
Minimum	0.10	0.1	0.27
Maximum	162.34	3.99	2.40
Total Count	284	343	101
Count above EU standard	1	0	0

Effects of climate change on ozone

Being a secondary air pollutant, ozone is formed through chemical reactions in the atmosphere rather than being emitted directly. As many of these reactions are temperature dependent and require sunlight, climate change has important effects on ozone concentrations. More specifically, increases in air temperature enhance ozone formation via associated photochemical processes (Peel et al., 2013; Schnell and Prather, 2017). Thus, more ozone is formed during high pressure periods and stagnant conditions, which are likely to occur more often and to be longer-lasting and in a warming climate (Horton et al., 2014; Vautard et al., 2018).

Interactions between climate change and ozone are further complicated by a large number of indirect couplings (Jacob and Winner, 2009; (Fiore, 2012)), involving ozone in particular emissions of ozone precursors as well as ozone loss mechanisms which depend on temperature, soil moisture, boundary layer height, vegetation and land use. For example, emissions of NOx from lighting and emissions of isoprene and other biogenic VOCs from vegetation are likely to increase in a warming climate (Langner et al., 2012; Simpson et al., 2014), while the uptake of ozone on soil and vegetation can be affected by meteorology in both directions (Anderson and Enghardt, 2010). Aerosols altering radiative transfer in the atmosphere, and thus ozone chemistry, respond to climate change too, further modifying the picture.

According to the ozone Air Quality Standard in the EU, the Maximum daily 8-hour mean should not exceed 120 µg/m^3 (about 60 ppb at the surface) for more than 25 days in a year, averaged over 3 years. The concept of 'climate penalty' means that future climatic conditions in a warming world will exacerbate the challenge in reaching air quality targets or standards (Schneidemesser et al., 2020) because ozone will be enhanced due to climate change. Greater emission reductions will thus be necessary to attain the same air quality target in a warmer climate in comparison to a stationary climate scenario (Wu et al., 2012).

As noted in the IPCC AR6 report (Naik et al., 2021), future air quality will mainly depend on precursor emissions, with climate change projected to have mixed effects. Because of the uncertainty of how natural processes will respond, there is low confidence in the projections of surface ozone under climate change according to the IPCC.

As climate-induced ozone change depends on the geographic location, the chemical regime (i.e. other species that affect ozone), vegetation, land use, and the metric in question (ozone mean, Maximum daily 8-hour mean, SOMO35, number of days exceeding the limit value, etc.), the season and the time horizon of interest (2030, 2050, etc.), it is impossible to suggest one single value for the ozone climate penalty for ozone.

Nonetheless, a rich literature exists on annual-mean or summer-time ozone changes in different locations under different climate change scenarios. For example, Lacressonniere et al. (2016) calculated changes in SOMO35 in under 2-degree warming and identified increases in temperature and isoprene emissions as main drivers of summer ozone, but the spread among models was large, so that no quantitative conclusion was drawn. (Fortems-Cheiney, 2017) gave a range of climate-only driven change in SOMO35 from about -200 to +1000 ppb.days for Europe under 2 and 3 degree warmings.

Fu and Tian (2019) summarized results from a large number of model studies and derived ranges for several world regions. For summertime mean ozone in Europe by 2050, they indicate an increase of up to 2 ppb by 2050, and of up to 1000 ppb.day increase in SOMO35, due to climate change alone. Varatsos et al. (2019) found (for a European heatwave in 2014) that the ozone-temperature relationship in Sweden and Finland was mostly driven by the temperature-dependent isoprene emissions with the highest correlation coefficient during the heatwave period attributed to the increased isoprene emission fluxes. However, the clear response of ozone to temperature perturbations in 2003 was better manifested when the mean anomalies of the two variables between two periods that were examined: the calculated slopes were around 5.3 ppb/°C and around 4.75 ppb/°C for the 16 June - 14 August and 1–14 August periods, respectively.

Meehl et al. (2018) calculated that in a future with stabilized ozone precursors, surface ozone concentrations increase on heat wave days compared to non-heat wave days in most regions except in areas where there is ozone suppression that contributes to decreases in ozone in future heat waves. They attribute these findings to changes in isoprene emissions at high temperatures (e.g. in Eastern Europe).

Schnell et al. (2016) conducted a multi-model study with coupled climate chemistry models, concluding that climate change shifts the seasonal surface ozone peak to earlier in the year and increases the amplitude of the annual cycle. *Increases* in mean summertime and high-percentile ozone are generally found in polluted environments, while *decreases* are found in clean environments, broadly consistent with other studies (e.g., Johnson et al.,1999; Wu et al., 2008, Garrido-Perez et al., 2019) which suggest ozone enhancements in large parts of central Europe but much lower increases, or even decreases due to climate change in Northern Europe. Schnell et al. (2016) hypothesize that warmer temperatures increase the efficiency of precursors to produce ozone in polluted regions, consequently reducing precursor availability in neighbouring, cleaner, downwind locations, where nitrogen oxides are usually more efficient in producing ozone. On a much broader scale, (Doherty, 2013) use one model to show that the more rapid thermal decomposition of organonitrates expected in a warming climate can lead to a few ppb increase in the annual average of surface ozone over land and a corresponding decrease over the oceans. Even with constant biogenic emissions, climate change would cause the largest ozone increases at high percentiles. In most cases, air quality extreme episodes become larger and contain higher ozone levels relative to the rest of the distribution.

(Colette A, 2015) reviewed results from 25 model simulations and concluded that summertime ozone may be enhanced by up to 5 ppbv in the worst case/locations by the end of this century (with a 95% confidence interval between about 1 and 1.5 ppb).

However, as Archibald et al. pointed out recently (Archibald, 2020), chemical mechanisms are a large uncertainty in the response of ozone to changes in temperature, and so climate, in the future, which underscores the need for more work to be performed to better understand the response of ozone to changes in temperature and constrain how well this relationship is simulated in models.

Based on current knowledge **we suggest that emission reductions should aim at summertime ozone concentrations that are at least 2 ppb below the Air Quality Standard** in order to meet that Standard even in a warmer climate by mid-century.

A multi-model study taking into account all relevant chemistry-climate couplings, natural emission changes, land-use change, etc. would be necessary to give a more temporally/spatially resolved quantitative estimate.

Average exposure and percentage reductions in concentrations

Analysis was undertaken to understand the potential impacts of the OPT10 scenario on concentrations of $PM_{2.5}$ and NO_2 across the EU.

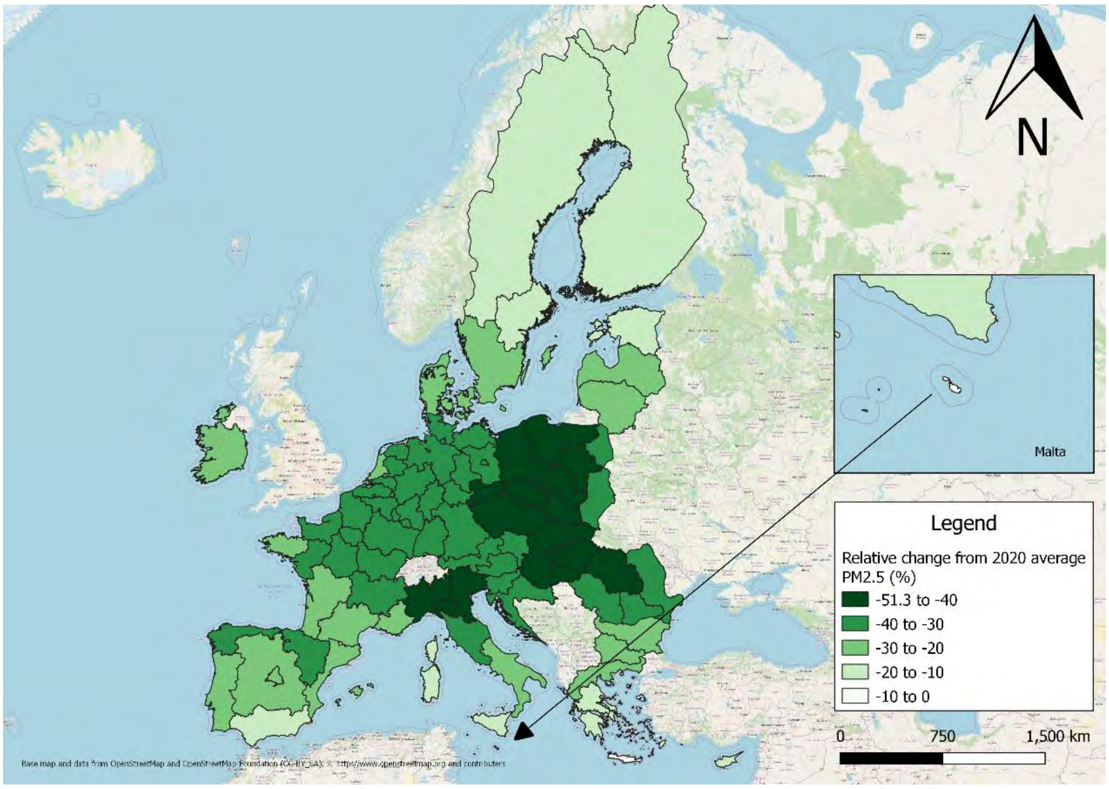
The maps below show the percentage reduction of annual average NO_2 and $PM_{2.5}$ concentrations in 2030 under the OPT10 scenario, relative to the 2020 baseline. These are based on the modelled, bias unadjusted outputs, averaged at the NUTS 1 spatial level (note: as explored further in the health impact assessment modelling, when looking at the relative change between baseline and scenarios, there is an insignificant difference between using bias unadjusted or bias adjusted modelling outputs). Contributions from non-anthropogenic emission sources were not deducted, i.e. all figures represent absolute concentrations including both anthropogenic and non-anthropogenic sources.

These calculations were made using the 2020 and 2030 outputs from the air pollution uEMEP dispersion model for the central analysis, which were resampled to the 1km population grid of Eurostat. The outputs were then aggregated to provide an average concentration for each NUTS 1 spatial region using GIS software. The percentage change was then calculated between the 2020 baseline and 2030 OPT10 scenario for each pollutant.

Assessing the impacts on $PM_{2.5}$ as an annual mean concentration

Figure A-62 shows the impact of OTP10 scenario on $PM_{2.5}$ across the EU in 2030 compared to levels modelled for 2020.

Figure A-62 Relative change (%) in annual mean $PM_{2.5}$ in 2030 compared to the 2020 baseline across EU member states aggregated to NUTS 1 spatial resolution



The figure shows that concentrations of $PM_{2.5}$ are predicted to fall by as much as 40 - 51% in regions located in Poland, Czechia, Slovakia, Hungary, Romania and northern Italy. The figure also shows that the relative reduction is between 10 - 40% in almost all other areas. The reductions are lowest in regions located in Southern Europe where non-anthropogenic (in some cases transboundary) sources are more important (e.g. Saharan desert which is not impacted by the mitigation measures). The figure also shows that the level of reduction is smaller in the Scandinavian countries where 2020 baseline concentrations were predicted to be much lower in comparison to other regions and therefore not likely to have the same level of benefits than those in regions with higher concentrations initially.

Figure A-63 Absolute change in $PM_{2.5}$ reduction across NUTS 1 regions between 2020 and 2030 (μg/m^3)

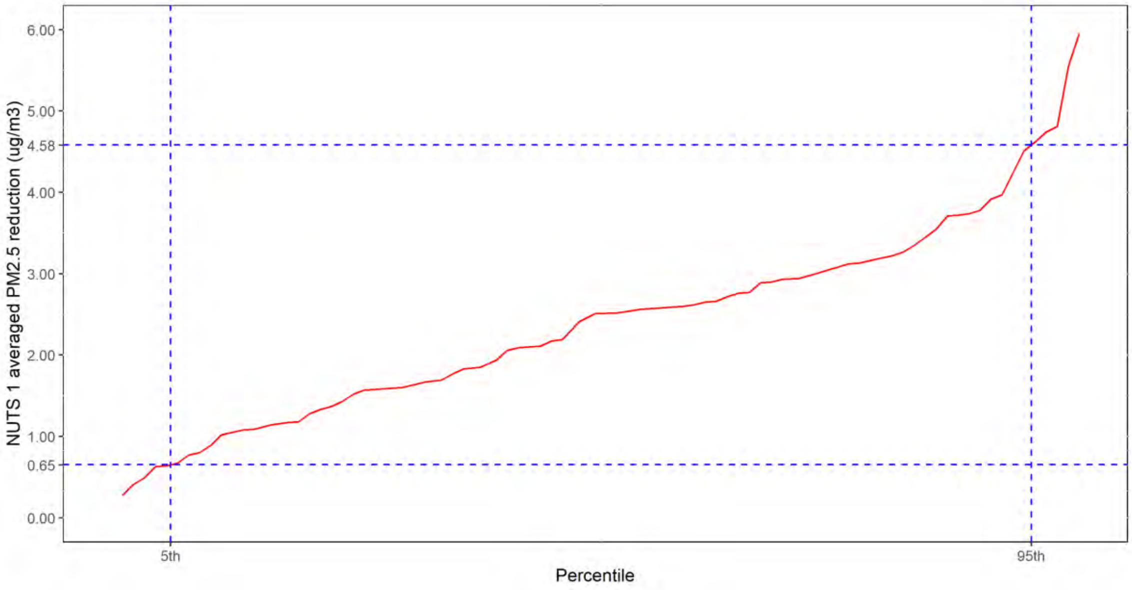


Figure A-63 shows a representation of how the absolute level of change in $PM_{2.5}$ across NUTS 1 regions between 2020 baseline and 2030 OPT10. The figure shows that the level of reduction across these spatial areas to be 0.65 μg/m^3 at the 5th percentile (i.e. the statistical point amongst the smaller reduction in concentrations relative the baseline) and 4.58 μg/m^3 at the 95th percentile.

Figure A-64 Relative change in $PM_{2.5}$ reduction across NUTS 1 regions between 2020 and 2030 (μg/m^3)

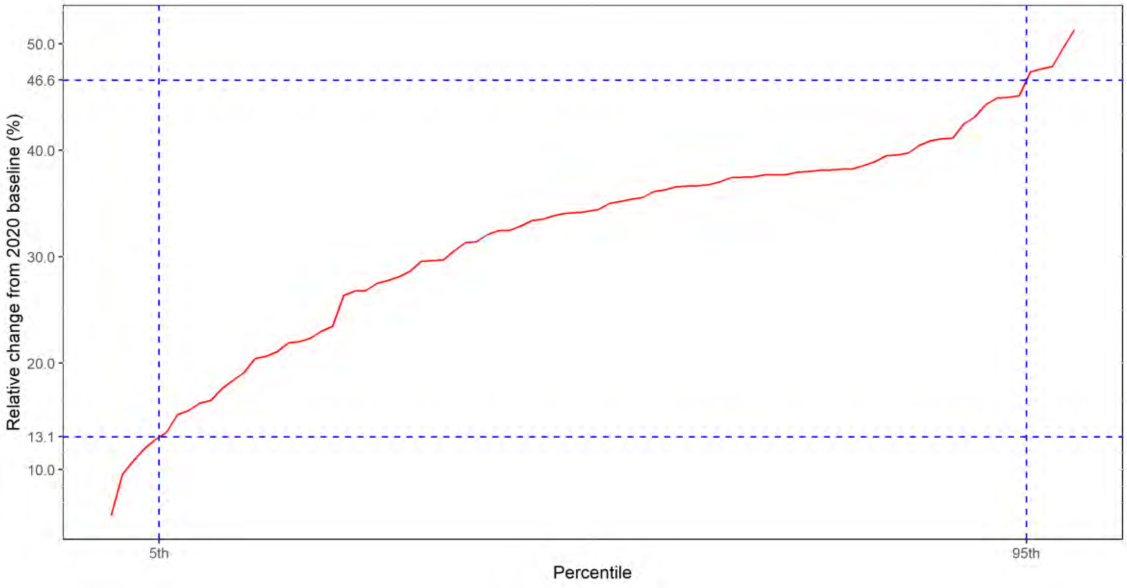


Figure A-64 shows a representation of the relative level of change in $PM_{2.5}$ across NUTS 1 regions between 2020 baseline and 2030 OPT10. The figure shows that the level of reduction across these spatial areas at the 5th percentile to be 13.1% and 46.6% at the 95th percentile relative to the values calculated for 2020.

Table A-10: Comparison of the number of NUTS 1 regions in each concentration range for $PM_{2.5}$

Concentration range (µg/m^3)	NUTs 1 regions				Relative change (%) from 2020
	2020 count	2020 % of total	2030 count	2030 % of total	
0.0 - 2.5	1	1	2	2	100
2.5 – 5.0	15	17	53	60	253
5.0 - 7.5	31	35	28	32	-10
7.5 - 10.0	31	35	2	2	-94
10.0 - 12.5	9	10	2	2	-78
12.5 - 15.0	1	1	1	1	0

Table A-10 shows the number of regions with an average $PM_{2.5}$ concentration within six 2.5 increment groupings that divide the smallest and the highest 2020 averaged annual mean. The table shows that in 2020, 41 regions had a concentration of 7.5 µg/m^3 or higher; this number fell in 2030 to five regions. The table shows that biggest change in the number of zones in an increment grouping to be in the 2.5 – 5.0 µg/m^3 range, where the absolute number increased by 53 in 2030, a relative change of 253% of the 2020 figure.[3] Overall, the table shows that there is a greater proportion of regions within the lowest two increments in 2030 (62%) compared to the proportion in the same two increments in 2020 (18%).

Figure A-65 Changes in $PM_{2.5}$ concentration (%) from increment grouping (positive changes represent reduction in concentrations)

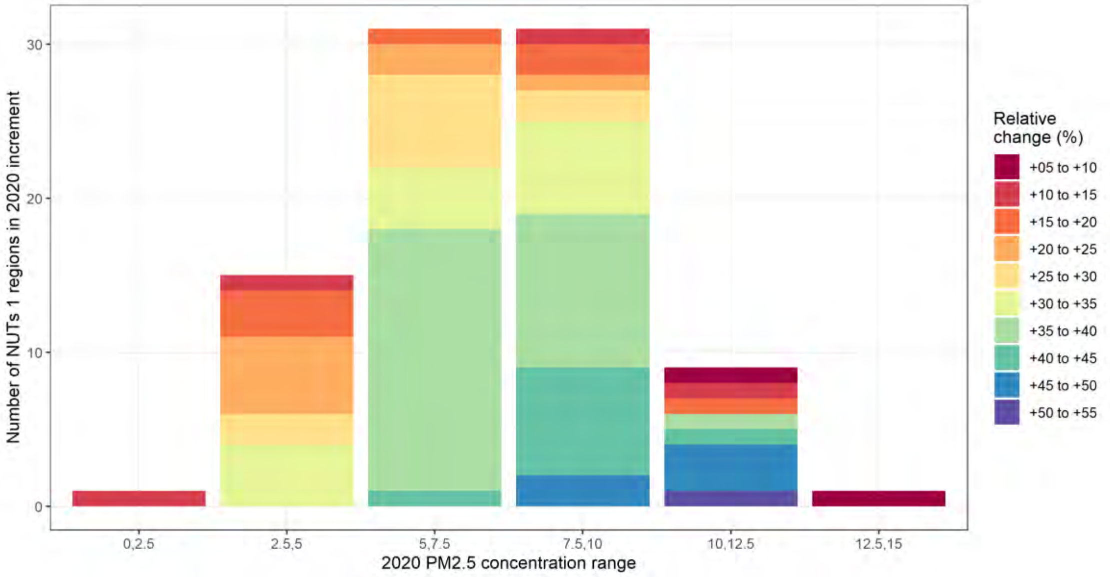


Figure A-65 shows the relative percentage change of NUTS 1 regions relative to their 2020 annual averaged concentration grouping (shown on the x-axis). The data shows that the regions with a concentration value between 5 -10 µg/m^3 were most abundant in 2020 and these regions generally had a reduction (relative changes with a positive value) of between 35 – 40% in 2030. The figure shows that NUTS 1 regions with the lowest concentrations in 2020 corresponded with the lowest level of relative change in 2030, whilst regions with bigger relative changes tended to occur in regions with the highest level of concentrations in 2020 baseline (with the caveat that the zone with the highest 2020 concentration value also had one of the lowest relative reductions in 2030. This zone is 'MT0' or the

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[3] Note that this relative change figure relates to the number of NUTs 1 regions in each concentration class and does not reflect the relative change in pollutant concentration

NUTS region covering Malta. This result is likely driven by the high contribution of non-anthropogenic sources which are more challenging to address).

Table A-11: Summary of changes in $PM_{2.5}$ concentration (%) from increment grouping

2020 $PM_{2.5}$ concentration range (µg/m^3)	Number of regions	Min % reduction vs 2020	25th percentile % reduction vs 2020	Average % reduction vs 2020	75th percentile % reduction vs 2020	Max % reduction vs 2020
0 - 2.5	1	-12.83	-12.83	-12.83	-12.83	-12.83
2.5 - 5	15	-13.5	-19.41	-24.12	-30.12	-34.18
5 - 7.5	31	-15.19	-28.66	-33.22	-37.83	-40.48
7.5 - 10	31	-11.95	-33.14	-35.44	-40.98	-49.62
10 - 12.5	9	-9.54	-17.61	-34.56	-47.65	-51.34
12.5 - 15	1	-5.74	-5.74	-5.74	-5.74	-5.74

Table A-11 shows a summary of the relevant changes in concentrations with respect to the 2020 increment groupings. The data further shows that although the biggest relative changes occurred in zones where the 2020 annual averaged concentration was greater than 5 but smaller than 12.5 µg/m^3, the average values in these zones were relatively consistent between these groupings.

The table below presents the distribution of $PM_{2.5}$ concentration reductions between 2030 OPT10 and 2020 baseline, for those NUTS1 regions with $PM_{2.5}$ concentrations above the WHO AQG in 2020. In the 2020 baseline, 72 of 88 NUTS1 regions have an AEI in excess of the WHO AQG in 2020. The majority of these 72 regions then achieve a reduction of more than 25% in concentrations under the 2030 OPT10 scenario (61 regions achieve a reduction of 25% or more). However, this leaves 11 NUTS1 regions which do not achieve at least a 25% reduction.

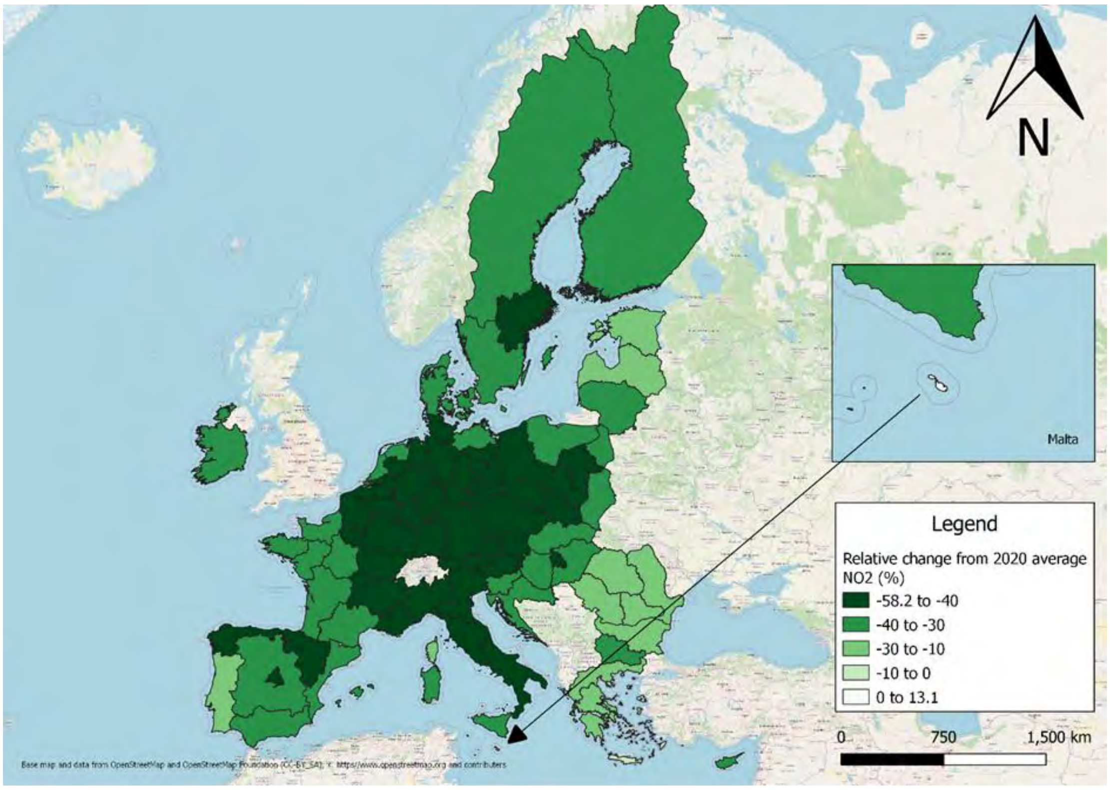
Table A-12: Distribution of reductions in $PM_{2.5}$ concentration under OPT10 2030 relative to baseline 2020, for those NUTS1 regions that are above the WHO AQG in 2020

	0% to 5%	5% to 10%	10% to 15%	15% to 20%	20% to 25%	25% to 30%	30% to 35%	35% to 40%	40% to 45%	45% to 50%	50% to 55%
Count of regions	0	2	2	4	3	8	11	27	9	5	1

Assessing the impacts on NO_2 as an annual mean concentration

Figure A-66 shows the impact of OTP10 scenario on NO_2 across the EU in 2030 compared to levels modelled for 2020 baseline.

Figure A-66 Relative change (%) in annual mean NO_2 in 2030 compared to the 2020 baseline across EU member states aggregated to NUTS 1 spatial resolution



The figure shows that concentrations of NO_2 are predicted to fall 40 - 58% in the majority of NUTS1 regions, in particular those located across the central member states and almost all of Italy in the south. The relative reduction is 10 - 40% in almost all other areas.

The reductions are shown to be lowest in regions located in south-eastern regions (Greece, Bulgaria, Romania) where levels of reduction are shown to be between 1 - 30%.

The model outputs suggest that the scenario will not be beneficial (as a regional mean) in Malta, where annual average concentrations are predicted to increase by 13% in 2030 from the 2020 baseline. As noted in the main report, this is due to the influence of shipping (see Section 7.1.2): *In 2020 the Mediterranean countries of Malta and Cyprus have two of the lowest NO_2 exposures. However, an increase in shipping contributions from 2020 to 2030 and a strongly reduced road transport contribution in many other countries results in Malta having one of the highest exposures to NO2 of any European country.*

Figure A-67 Absolute change in NO_2 reduction across NUTS 1 regions between 2020 and 2030 (μg/m^3)

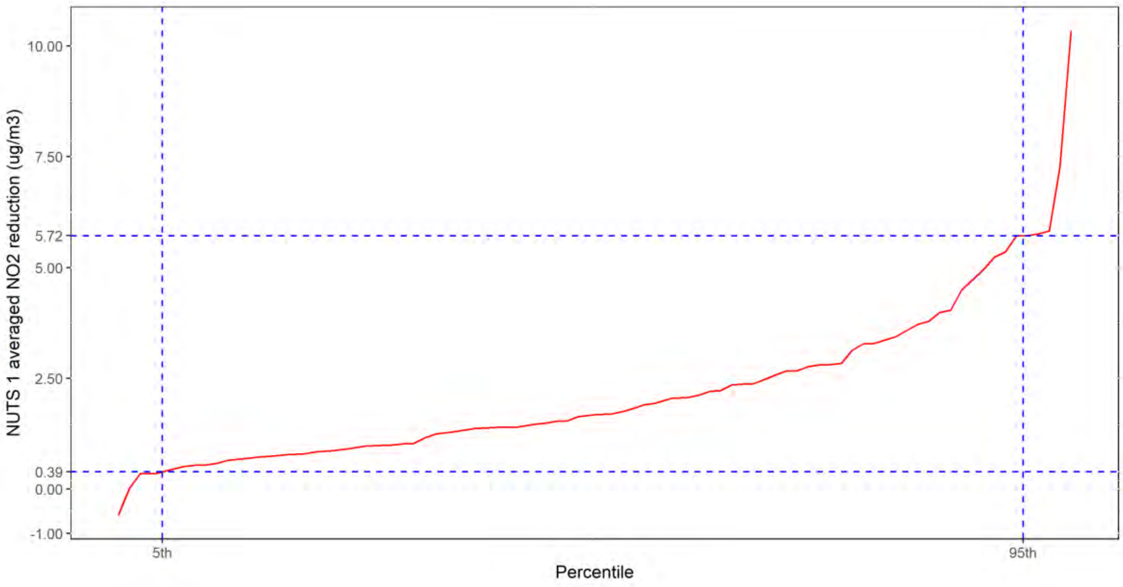


Figure A-67 shows a representation of how the absolute level of change in NO_2 across NUTS 1 regions between 2020 and 2030. The figure shows that the level of reduction across these spatial areas at the 5th percentile to be 0.39 µg/m^3 and 5.72 µg/m^3 at the 95th percentile.

Figure A-68 Relative change in NO_2 reduction across NUTS 1 regions between 2020 and 2030 (µg/m^3)

Figure A-68 shows a representation of the relative level of change in NO_2 across NUTS 1 regions between 2020 and 2030. The figure shows that the level of reduction across these spatial areas at the 5th percentile to be 21.4% and 52.6% at the 95th percentile relative to the values calculated for 2020.

Table A-13: Comparison of the number of NUTS 1 regions in each concentration range for NO_2

Concentration range (µg/m^3)	NUTs 1 regions				Relative change (%) from 2020
	2020 count	2020 % of total	2030 count	2030 % of total	
0.0 - 2.5	15	17	42	48	180
2.5 – 5.0	40	45	36	41	-10
5.0 - 7.5	18	20	7	8	-61
7.5 - 10.0	7	8	2	2	-71
10.0 - 12.5	3	3	1	1	-67
12.5 - 15.0	3	3	0	0	0
15.0 - 17.5	1	1	0	0	0
20.0 - 22.5	1	1	0	0	0

Table A-13 shows the number of regions with an average NO_2 concentration in the eight 2.5 increment groupings that divide the smallest and the highest 2020 averaged annual mean. The table shows that in 2020, eight regions had a concentration of 10 µg/m^3 or higher; this number fell in 2030 to one region having a concentration of between 10 - 12.5 µg/m^3. The table shows that biggest change in the number of zones in an increment grouping to be in the 0 – 2.5 µg/m^3 range, where the absolute number increased by 27 in 2030, a relative change of 180% of the 2020 figure. Overall, the table shows that there is a greater proportion of regions within the lowest two increments in 2030 (89%) compared to the proportion in the same two increments in 2020 (62%).

Figure A-69 Changes in NO_2 concentration (%) from increment grouping (positive changes represent reduction in concentrations)

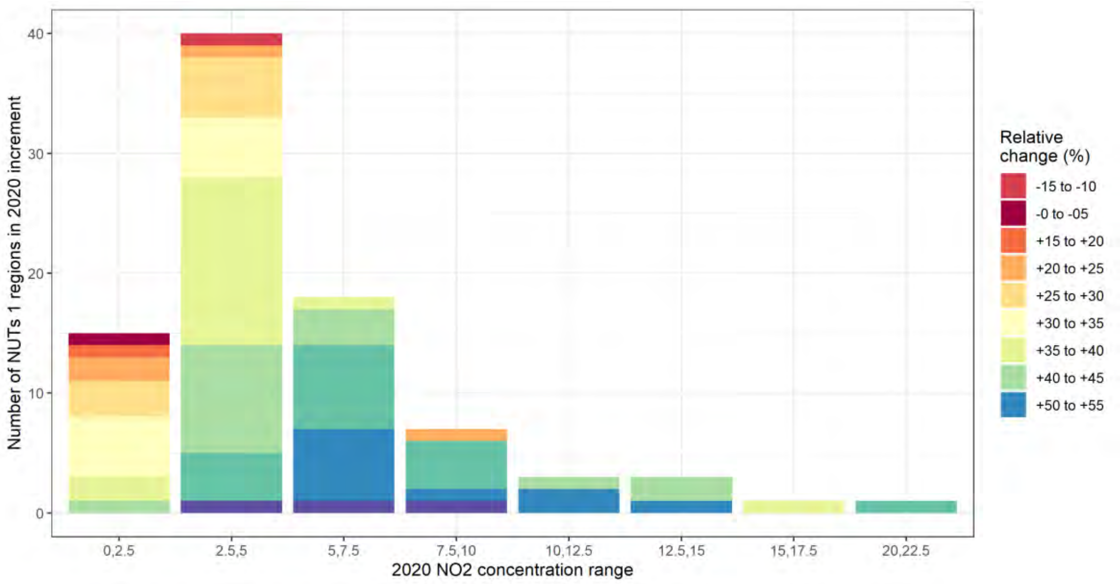


Figure A-69**Error! Reference source not found.** shows the relative percentage change of NUTS 1 regions relative to their 2020 annual averaged concentration grouping (shown on the x-axis). The data shows that the regions with a concentration value between 2.5 -10 µg/m^3 were most abundant in 2020 and these regions generally had a reduction of between 40 – 55% in 2030. The figure shows that NUTS 1 regions with the lowest concentrations in 2020 corresponded with the lowest level of relative change in 2030, whilst regions were the biggest relative change occurred is shown in the regions with the highest level of concentrations in 2020.

Table A-14: Summary of changes in NO_2 concentration (%) from increment grouping

2020 NO_2 concentration range (µg/m^3)	Number of regions (2020)	Min % reduction vs 2020	25th percentile % reduction vs 2020	Average % reduction vs 2020	75th percentile % reduction vs 2020	Max % reduction vs 2020
0 - 2.5	15	-0.86	-24.73	-28.51	-34.22	-42.39
2.5 - 5	40	13.12	-33.8	-36.74	-43.6	-56.59
5 - 7.5	18	-37.88	-45.44	-47.46	-50.92	-55.48
7.5 - 10	7	-23.47	-45.87	-45.97	-50.2	-58.22
10 - 12.5	3	-44.89	-47.94	-49.66	-52.05	-53.1
12.5 - 15	3	-41.04	-42.49	-45.94	-48.39	-52.85

Table A-14 shows a summary of the relevant changes in concentrations with respect to the 2020 increment groupings. The data further shows that average and max level of reduction were reasonably consistent in regions where the 2020 annual averaged concentration value was between 2.5 and 15.0 µg/m^3.

As for $PM_{2.5}$, it is also informative to place the concentration reductions achieved in light of the different starting positions of the NUTS1 regions relative to the WHO AQGs. In the 2020 baseline, only 8 of 88 NUTS1 regions have an AEI in excess of the WHO AQG. Under the OPT10 scenario, all 8 regions achieve a relative reduction in NO_2 concentrations of 35% or more, with 3 achieving a reduction of over 50%.

Measurement data and further analysis - heavy metals

Monitoring Dataset

The data was sourced from the European Environment Agency who recently published updated air quality annual statistics for all EEA reporting countries (EEA, 2022). This dataset reports various atmospheric pollutants across all EU Member States as well as the UK, Turkey, Serbia, Montenegro, Kosovo, Georgia, Bosnia & Herzegovina, Norway, Iceland, and North Macedonia.

The measured annual mean concentrations at every monitoring site for arsenic, nickel, lead, and cadmium in the form of PM_{10} aerosol for the year 2019 were extracted. Some reported data points that are published in the EEA dataset were categorised as 'Not verified' as they did not go through sufficient checks by the data provider. These data points were excluded from any further analysis, so that the analysis included only those that had been through a full QA/QC process. The monitoring sites also ranged in coverage. Only monitoring sites with greater than 85% data coverage per year are valid for air quality assessments and compliance checks[4]. However, for the purposes of this analysis, monitoring sites with less than 85% data coverage were also examined to investigate all potential exceedances. To show the distribution of air pollutant concentration values across all the identified monitoring sites in 2019, boxplots were produced for each heavy metal.

Concentration Thresholds

The concentration thresholds were taken from the Directive 2004/107/EC[5] and the WHO guidelines from 2005 (WHO, 2005), as well as from proposed thresholds considered for the AAQ Directives Revision. The values in Table A-15 refer to the heavy metal when in the form of PM_{10} aerosol. The aim of the analysis is to examine which types of monitoring sites were not in compliance with the concentration thresholds considered in this analysis, to further understand the types of monitoring sites which would be most affected by adopting the proposed lower concentration limit values considered within this impact assessment.

Table A-15: Concentration thresholds proposed for nickel, lead, arsenic, and cadmium. WHO guideline levels or 1/100,000 lifetime risk levels are presented in bold font. Existing EC standards are shown in blue font. 1/1,000,000 lifetime risk levels are shown in *italic font*.

Thresholds considered	Nickel ng/m³	Lead µg/m³	Arsenic ng/m³	Cadmium ng/m³
Threshold 1: WHO guideline	**25**	**0.5**	**6.6**	**5**
Threshold 2: EU standard	20	0.5	6	5
Threshold 3: Low	10	0.25	4	2.5
Threshold 4: Mid	*2.5*	0.15	2	1.5
Threshold 5: High	-	0.05	*0.66*	*0.5*

E-PRTR Dataset

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[4] Data coverage refers to the annual average percentage of valid measurement. The EEA (EEA, 2022) states that annual statistics with coverage less than 75% averaged over a year should not be included in air quality assessments. Annual statistics with coverage less than 85% averaged over a year should not be included in compliance checks.

[5] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32004L0107

Levels of some metals were found to exceed EU standards at some monitoring sites in the EEA reporting countries. To identify the likely contributing sources at stations located in the EU, GIS modelling was used to overlay pollutant release data from industrial sites in the European Pollutant Release and Transfer Registry (E-PRTR) database (EEA, 2021) with the EEA monitoring site data. This was carried out to understand whether high concentrations of heavy metals could be associated with the presence of industrial sites.

The E-PRTR database provides annual pollutant release data from industrial facilities in all EU Member States as well as Iceland, Liechtenstein, Norway, Switzerland, Serbia, and the UK. Information on facility activities, annual pollutant release data for the four heavy metals, and BAT conclusions and derogations for the year 2019 was extracted from this database. This information was overlayed with the EEA monitoring site data. Both a 2 and 10 km radius was drawn around each EEA monitoring site to determine whether there are any E-PRTR sites within this radius which reported heavy metal releases in 2019, and which could be influencing concentrations at the monitoring site. A 2 and 10 km zone was chosen because the E-PRTR industrial sites are typically on a larger scale, which tend to have taller stacks, vents and release points. Using both distances helps account for variability in pollution dispersion. A plume from a higher release point may result in significant ground-level concentrations compared to the peak concentration at distances of up to 10 km.

Results

Boxplot Distributions of Heavy Metals

To show the distribution of air quality values across all the identified monitoring sites in 2019, boxplots were produced for each heavy metal. The whiskers show the minimum and maximum values, the box extends from the lower to upper quartiles with a line at the median, and the 95% and 99% quartiles are also represented. Each metal has additional disaggregation of the monitored concentration ranges by nominated station type: background stations (green), and industrial stations (brown). The grid at the top shows the metal concentrations on a logarithmic scale.

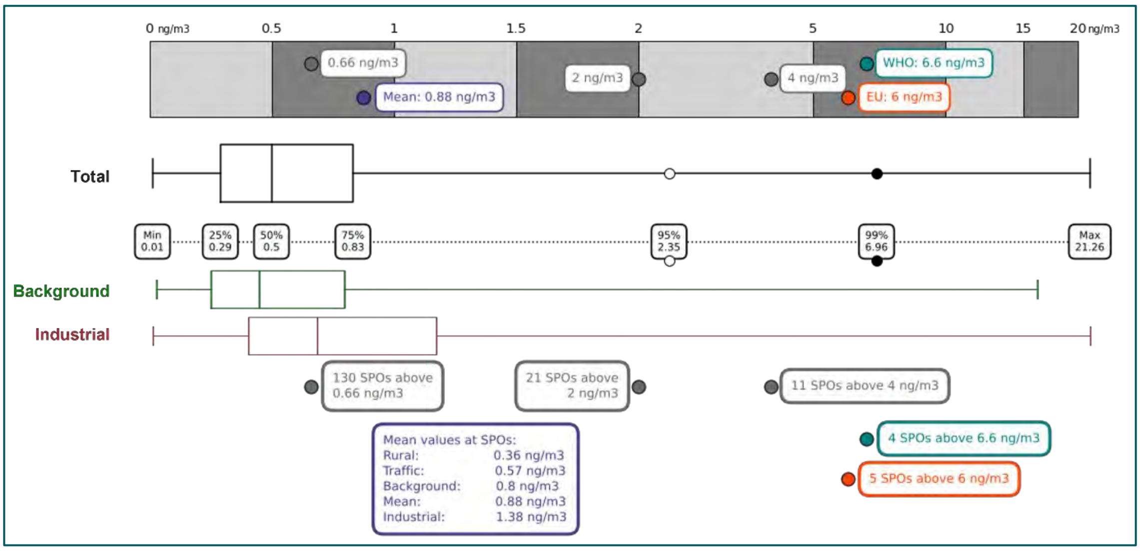
The markers on the grid above the boxplots represent the WHO guideline, the current EU standard, the mean concentration, and the proposed concentration thresholds (Table A-17). Along the bottom of the boxplot are coloured boxes which show how many of the monitoring sites in 2019 were not in compliance with the given thresholds. Finally, the purple box lists the average measured concentrations at rural, traffic, background, industrial monitoring sites, and the mean of all the sites, in ascending order.

Arsenic

Figure A-70 shows that:

- 5 monitoring sites out of those with over 85% data coverage do not meet the current EU standard for arsenic of 6 ng/m^3.
- 11 monitoring sites recorded concentrations above 4 ng/m^3.
- 21 monitoring sites recorded concentrations above 2 ng/m^3.
- 130 monitoring sites recorded concentrations above 0.66 ng/m^3.
- Monitoring sites in industrial areas show the highest arsenic concentrations with an average of 1.38 ng/m^3.
- The median, lower and upper quartiles, and maximum value are lower for background sites compared to industrial sites.

Figure A-70 - Distribution of arsenic concentrations in PM_{10} monitored at 354 stations in EEA reporting countries in 2019. Total (black), background (green), and industrial (brown). Monitoring sites are above 85% data coverage.

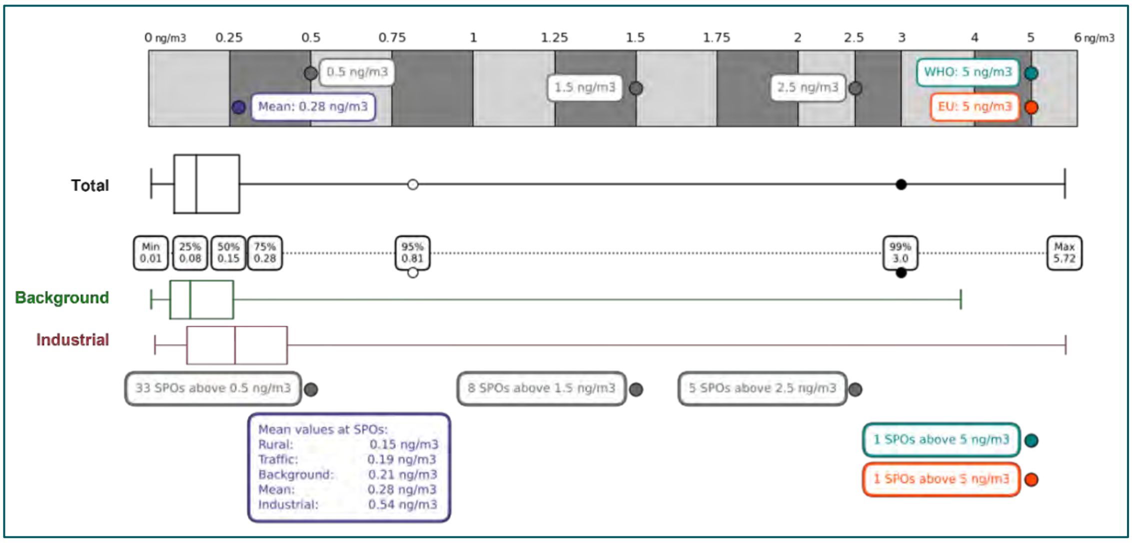


Cadmium

Figure A-71 shows that:

- 1 monitoring site out of those with over 85% data coverage does not meet the current EU standard for cadmium of 5 ng/m^3.
- 5 monitoring sites recorded concentrations above 2.5 ng/m^3.
- 8 monitoring sites recorded concentrations above 1.5 ng/m^3.
- 33 monitoring sites recorded concentrations above 0.5 ng/m^3.
- Monitoring sites in industrial areas show the highest cadmium concentrations with an average of 0.54 ng/m^3.
- The median, lower and upper quartiles, and maximum value are lower for background sites compared to industrial sites.

Figure A-71 - Distribution of cadmium concentrations in PM10 monitored at 367 stations in EEA reporting countries in 2019. Total (black), background (green), and industrial (brown). Monitoring sites are above 85% data coverage.

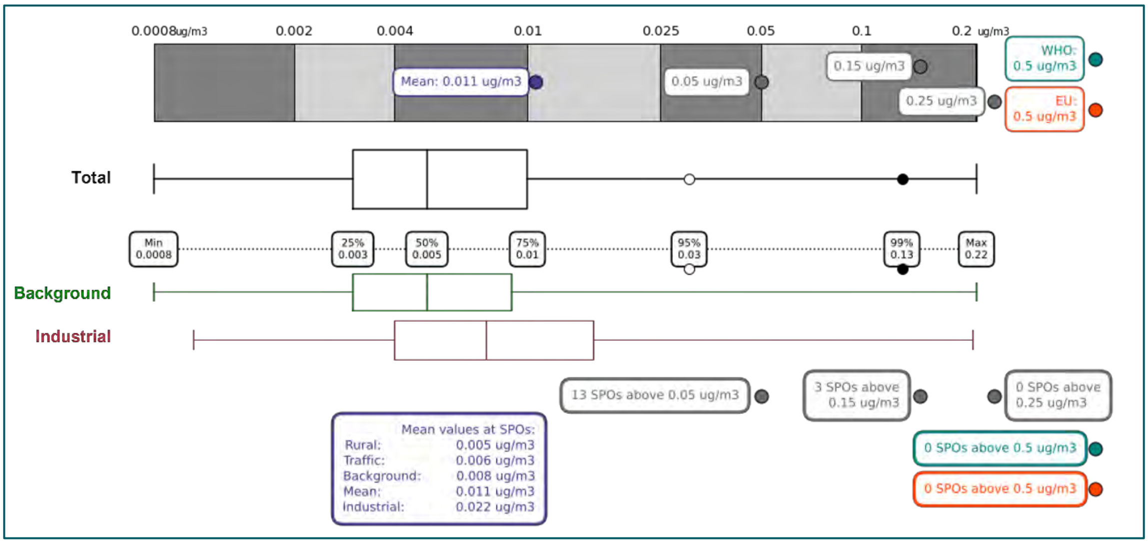


Lead

Figure A-72 shows that:

- All monitoring sites in 2019 with over 85% data coverage were in compliance with the EU standard for lead of 0.5 µg/m3.
- No monitoring sites recorded concentrations above 0.25 µg/m3.
- 3 monitoring sites recorded concentrations above 0.15 µg/m3.
- 13 monitoring sites recorded concentrations above 0.05 µg/m3.
- Monitoring sites in industrial areas show the highest lead concentrations with an average of 0.022 µg/m3.
- The median, lower and upper quartiles are lower, but the maximum value is higher for background sites compared to industrial sites.

Figure A-72: Distribution of lead concentrations in PM10 monitored at 375 stations in EEA reporting countries in 2019. Total (black), background (green), and industrial (brown). Monitoring sites are above 85% data coverage.

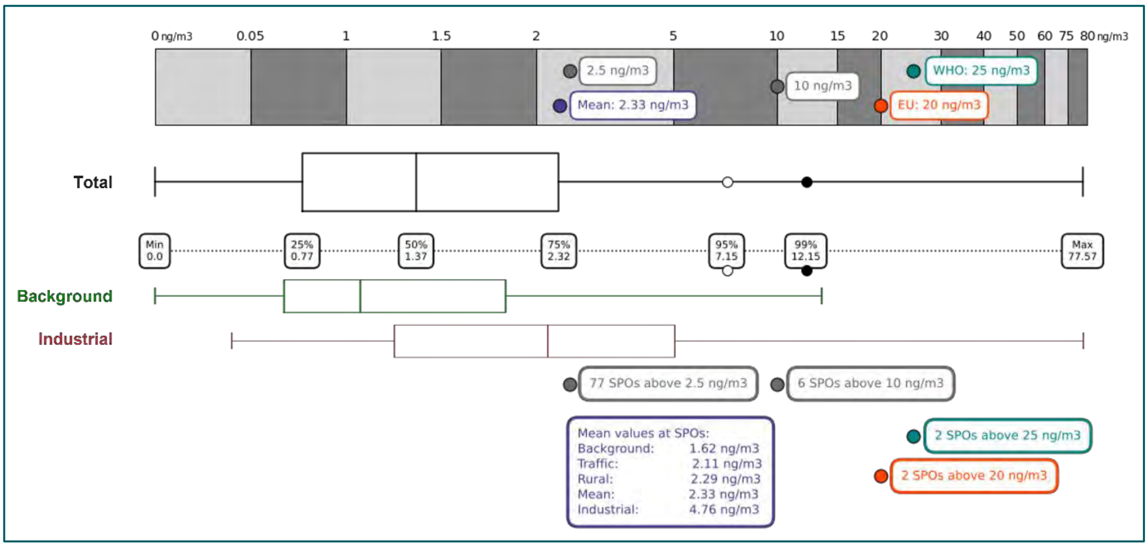


Nickel

Figure A-73 shows that:

- 2 monitoring sites out of those with over 85% data coverage do not meet the EU standard for nickel of 20 ng/m3.
- 6 monitoring sites recorded concentrations above 10 ng/m3.
- 77 monitoring sites recorded concentrations above 2.5 ng/m3.
- Monitoring sites in industrial areas show the highest nickel concentrations with an average of 4.76 ng/m3.
- The median, lower and upper quartiles, and maximum value are lower for background sites compared to industrial sites.

Figure A-73 - Distribution of nickel concentrations in PM10 monitored at 348 stations in EEA reporting countries in 2019. Total (black), background (green), and industrial (brown). Monitoring sites are above 85% data coverage.



The statistics from the boxplot distributions of the heavy metals are summarised in Table A-16, showing the mean, minimum, maximum, and total count for each pollutant under each monitoring station type. The number of monitoring sites above each threshold for each pollutant is presented, disaggregated by monitoring site type: background, industrial, and traffic. The thresholds refer to the proposed thresholds (Table A-17) and display the number of monitoring sites that would be impacted if the EU standards were to be updated to lower concentrations. The number of exceeding monitoring sites increases as the concentration threshold decreases for each heavy metal.

Table A-16: Summary statistics of the heavy metal concentrations in EEA reporting countries in 2019, split by station type. The counts above thresholds 3, 4, and 5 relate to the proposed thresholds. Monitoring sites refer to above 85% data coverage.

Pollutant	Nickel ng/m^3			Lead µg/m^3			Arsenic ng/m^3			Cadmium ng/m^3		
Site Type	Background	Industrial	Traffic	Background	Industrial	Traffic	Background	Industrial	Traffic	Background	Industrial	Traffic
Mean	1.62	4.76	2.11	0.0082	0.0221	0.0061	0.802	1.38	0.567	0.215	0.545	0.195
Minimum	0.00	0.40	0.077	0.0008	0.001	0.001	0.03	0.013	0.069	0.009	0.02	0.033
Maximum	13.5	77.6	9.85	0.221	0.215	0.029	16.2	21.3	1.73	3.80	5.72	0.946
Total count	219	70	59	237	74	64	227	69	58	229	76	62
Count above WHO guideline	0	2	0	0	0	0	2	2	0	0	1	0
Count above EU standard	0	2	0	0	0	0	2	3	0	0	1	0
Count above threshold 3	3	3	0	0	0	0	6	5	0	2	3	0
Count above threshold 4	32	30	15	1	2	0	14	7	0	2	6	0
Count above threshold 5	-	-	-	4	9	0	76	35	19	12	17	4

Table A-17 below illustrates the significant rise in potential exceedance situations with increased ambition in targets for heavy metals. For Nickel, 2 stations are in exceedance for the current limit value, but where this is substantially reduced to 2.5 ng/m^3 the number of stations in exceedance rises to 77. A similar scale of challenge is seen for arsenic, where 5 monitoring stations are in exceedance but under the most stringent proposed limit value change the number of stations rises to 130. Lower challenges are seen for both lead and cadmium, where under the most stringent proposed limit value change the number of exceedance situations changes from 0 to 13 (Pb) and 1 to 33 (Cd).

Table A-17 - Summary table of the number of monitoring sites that are in exceedance of the proposed concentration thresholds for nickel, lead, arsenic, and cadmium. For the concentration thresholds, WHO guideline levels or 1/100,000 lifetime risk levels are presented in bold font. Existing EC standards are shown in blue font. 1/1,000,000 lifetime risk levels are shown in *italic font*.

Thresholds considered	Nickel		Lead		Arsenic		Cadmium	
	Concentration (ng/m3)	Count above threshold	Concentration (µg/m3)	Count above threshold	Concentration (ng/m3)	Count above threshold	Concentration (ng/m3)	Count above threshold
Threshold 1: WHO guideline	**25**	2	**0.5**	0	**6.6**	4	**5**	1
Threshold 2: EU standard	20	2	0.5	0	6	5	5	1
Threshold 3: Low	10	6	0.25	0	4	11	2.5	5
Threshold 4: Mid	*2.5*	77	0.15	3	2	21	1.5	8
Threshold 5: High	-	-	0.05	13	*0.66*	130	*0.5*	33

Heavy Metal Exceedances

Measured concentrations at 11 monitoring sites across the EEA reporting countries were not in compliance with the existing EU standards in 2019 for arsenic, cadmium, and nickel, as set out in Table A-18. The highest number of sites exceeding the EU standard was for arsenic. No monitoring sites in EEA reporting countries exceeded the EU standard for lead in 2019.

These 11 monitoring stations may be representative of the situations giving rise to exceedances that could also occur at other locations across the European Union, where no air quality monitoring is currently carried out. Further investigation into these 11 locations was carried out to identify the potential causes of these exceedances. Similar conclusions could potentially be drawn at other comparable locations across the EU.

Table A-18 - Number of sites that are not in compliance with the EU concentration standards for arsenic, lead, cadmium, and nickel in 2019 across EEA reporting countries.

Data Coverage	Arsenic	Lead	Cadmium	Nickel
Above 85%	5	0	1	2
Below 85%	2	0	0	1

The monitoring sites that were found to exceed the existing EU standards are mostly industrial suburban monitoring sites, and are located in Belgium, France, Norway, Finland, Poland and Italy. Analysis of the presence of E-PRTR industrial sites in the vicinity of each of these monitoring stations indicated that the key sources of metals giving rise to the measured exceedances are likely to be industrial metal production facilities (Table A-19

Table A-19). The distances between the exceeding monitoring site and potential E-PRTR source range from 0.5 km to 3.6 km.

Table A-19: Description of monitoring sites that exceeded the current EU standards for heavy metals in 2019 across EEA reporting countries, and potential sources of metals pollution.

Heavy metal	Location	Site type	Concentration / ng/m³	Exceedance of EU standard	Data coverage	Potential E-PRTR source	Distance and direction from potential source
Arsenic	Priolo, Italy	Background urban	41.4	590%	49%	Thermal power station	3.4 km NNW
	Antwerpen, Belgium	Industrial suburban	21.3	255%	99%	Precious metals production	0.6 km SW
	Antwerpen, Belgium	Background urban	16.2	170%	99%	Precious metals production	0.8 km SW
	Głogów, Poland	Background urban	11.8	97%	98%	No apparent source within 10 km	-
	Harjavalta, Finland	Industrial suburban	10.9	82%	14%	Copper production	1.9 km NW
	Antwerpen, Belgium	Industrial suburban	7.63	27%	98%	Precious metals production	1.5 km SW
	Bagneaux-sur-Loing, France	Industrial suburban	6.37	6%	100%	Flat glass manufacturer	0.5 km SSE
Cadmium	Antwerpen, Belgium	Industrial suburban	5.72	14%	99%	Precious metals production	0.6 km SW
Nickel	Isbergues, France	Industrial rural	77.6	288%	100%	No apparent source within 10 km	-
	Harjavalta, Finland	Industrial suburban	37.7	89%	14%	Non-ferrous crude metals production	3.6 km NW
	Kristiansand, Norway	Industrial suburban	28.0	40%	100%	No apparent source within 10 km	-

Three monitoring sites were found to exceed EU standards in Antwerpen (Belgium), three counts for arsenic and one count for cadmium. These sites are located in the vicinity of a single E-PRTR industrial site, at which precious metals are produced. The remaining exceedances were all related to different E-PRTR industrial sites.

Three monitoring sites which exceed EU standards did not have a reported pollutant release within a 10 km radius in 2019: Głogów (Poland), Isbergues (France) and Kristiansand (Norway). This was found to be consistent with the 2018 and 2020 E-PRTR data. This could be due to one or more factors:

- Concentrations at the monitoring sites could be affected by an E-PRTR site outside of a 10 km radius.
- Local E-PRTR industrial sites may not have reported pollutant releases.

- Smaller-scale industrial sites below E-PRTR reporting thresholds may have contributed to the measured levels of heavy metals.
- Some countries outside of the EU were not covered by the E-PRTR database during these years – this is relevant to the measured levels of nickel at the Kristiansand site in Norway.
- Concentrations could be impacted by sources other than stack emissions, such as background concentrations, non-industrial emission sources such as traffic or domestic coal use, resuspension, or fugitive emissions.

Table A-20 provides a summary of the percentage of monitoring sites for nickel, lead, arsenic, and cadmium that were located within a 2 km and a 10 km radius of one or more E-PRTR sites. This shows the percentages of monitoring sites at which one or more nearby E-PRTR sites reported an associated pollutant release; monitoring sites at which a E-PRTR site of any kind is located in the vicinity; and monitoring sites with no E-PRTR sites in the vicinity.

Table A-20 - Percentage of monitoring sites related to each reported pollutant releases from E-PRTR industrial sites across EEA reporting countries in 2019. Monitoring sites include both above and below 85% data coverage.

Heavy metal	Total number of monitoring sites	Monitoring sites with emitting E-PRTR site within radius (%)		Monitoring sites with any E-PRTR site within radius (%)		Monitoring sites with no E-PRTR site within radius (%)	
		2 km	10 km	2 km	10 km	2 km	10 km
Nickel	731	1.1%	9.3%	46%	92%	54%	7.8%
Lead	745	1.5%	6.3%	46%	91%	54%	8.7%
Arsenic	723	1.2%	6.0%	46%	91%	54%	9.0%
Cadmium	751	1.5%	7.6%	46%	91%	54%	8.9%

In summary, 75% of the reported exceedances for the assessed heavy metals in 2019 could potentially be explained by a reported pollutant release from an E-PRTR industrial site within a 10 km radius of the monitoring station. These industrial sites are a mix of thermal power stations, precious metals producers, copper manufacturers, flat glass manufacturers, and non-ferrous crude metals producers, and are located between 0.5 km and 3.6 km away from the monitoring sites exceeding EU standards.

Summary

Compliance with EU standards for heavy metals (target values for all except lead) is not a major issue across Europe, with only exceptional exceedances being observed. These can potentially be attributed to nearby industrial plant operations.

Should the EU standards be tightened to lower values, however, we expect significantly more cases of non-compliance, depending on the ambition level of the new standard, and assuming that emission levels do not change. For monitoring sites with over 85% data coverage, , there are 2 stations are in exceedance for the current nickel standard, but where this is substantially reduced to 2.5 ng/m^3 the number of stations in exceedance rises to 77. A similar scale of challenge is seen for arsenic, where 5 monitoring stations are in exceedance in 2019 but under the most stringent standard change considered in this analysis the number of stations rises to 130. Lower challenges are seen for both lead and cadmium, where under the most stringent potential standard considered the number of exceedance situations changes from 0 to 13 (Pb) and 1 to 33 (Cd).

This analysis is inherently uncertain due to the limitations and completeness of the data within E-PRTR. Although we observe the potential scale of the challenge to attain more stringent standards for heavy metals, more evidence is required to bring more confidence. It is recommended that dispersion modelling of the reported emissions from E-PRTR registered facilities, potentially supplemented by national databases, would improve the robustness of these conclusions and allow further assessment of population exposure to heavy metal pollution. If air quality standards are tightened, exceedances would be recorded at many more monitoring stations – assuming that emissions stay constant, including from E-PRTR registered facilities. A systematic investigation of the causes of these exceedances would become still more important. More comprehensive and systematically reported data from industrial sites and air quality monitoring sites would provide wider evidence to support the evaluation of potential future changes to the EU air quality standards for heavy metals.

Appendix 5 - Health impact modelling

General methodology

Tiered approach

We have developed a tiered approach to quantify the health impacts related to air pollution. The first Tier quantifies the premature mortality caused by the long-term exposure to particulate matter and nitrogen dioxide pollution, and the premature mortality caused by the peak exposure to ozone pollution,using the concentration response functions (CRF) recommended by the WHO (Chen & Hoek, 2020; Huangfu & Atkinson, 2020) for all the pollutants. The second Tier focuses on health outcomes caused by long-term and short-term exposure based on the HRAPIE recommendations (WHO, 2013) from 2013 (chronic bronchitis in adults, bronchitis symptoms in children, cardiovascular hospital admissions, respiratory hospital admissions, infant mortality, restricted activity days and lost working-days). We consider these outcomes as the second Tier of the approach, as they have been put forward by the WHO, and have undergone the largest degree of review. Acknowledging that there have been developments in the underlying evidence base since HRAPIE, but that the WHO has not yet undertaken a comprehensive, recent review of morbidity pathways, we have added a Third Tier, which focuses on the morbidity effects beyond HRAPIE. This third Tier is thus included to incorporate new insights that became apparent after the HRAPIE study in 2013, and to provide a more complete overview of the health impact due to air pollution. We have undertaken our own targeted review of literature to explore whether there are other pathways for which evidence is convincing to be included in the morbidity impact study and included three additional health outcomes in the primary analysis (asthma in children, lung cancer, stroke (CVA)), and three additional health effects in a sensitivity study (COPD, Diabetes Mellitus Type 2 and myocardial infarction). The three Tiers are described in more detail in the next section.

Counterfactual concentration

For the main analysis, quantification of health impacts for comparing the benefits of different policy options is limited to the impact of air pollution concentrations in excess of the revised WHO Air Quality Guidelines (from 2021). Health effects below these concentrations are not considered, and all results (maps, bar graphs and numbers) thus refer to the health impact *above* these cut-off values. Specifically, for particulate matter, the health impact is limited to the impact above 5 µg/m^3, while for nitrogen dioxide the impact is limited to the impact above 10 µg/m^3. This approach has been adopted given that:

- The guideline exposure levels have been subject to extensive review work from WHO and represent an up to date overview of scientific knowledge on the subject, including on levels above which the health impacts are well documented
- There is added uncertainty in the applicability of concentration response functions below the guideline exposure levels suggested by the WHO (also note that below these levels the contribution of natural sources of air pollution becomes more significant).

It is acknowledged, however, that this approach likely underestimates the total impact of air pollution on health (and thus also the likely benefits of action to improve air quality). For this reason, further quantification will be carried out to inform sensitivity runs, in which it is assumed that health impacts also occur below the WHO Air Quality Guidelines. These sensitivity tests are further outlined in the section on the detailed description of the methodology.

Alignment with previous work

The methodology is aligned as much as feasible with previous air pollution cost-benefit analyses funded by the EU, and with the assessment reports provided by the European Environmental Agency (EEA). For the first Tier (chronic mortality), the input for the historic baseline year (2015) is as much as feasible consistent with the input used by the EEA in its yearly assessment of the impact of air pollution on health (EEA, 2017). Additional sensitivity tests have focused on the comparison of the chronic mortality results for the historic year with the results provided by the EEA in its yearly assessment report. The methodology and input datasets for the second Tier (morbidity according to HRAPIE) is based on the approach applied in the First and Second Clean Air Outlook.

Detailed description

Tier 1: Chronic mortality

The first Tier quantifies the premature mortality caused by the long-term exposure to particulate matter and nitrogen dioxide pollution, and the premature mortality caused by the peak exposure to ozone pollution,using the concentration response functions (CRF) recommended by the WHO. The WHO updated its air quality guidelines last year (2021). In the process of the update, also the systematic reviews on the current scientific knowledge concerning the mortality related to exposure to air pollution have been updated, leading in turn to updated concentration response functions[6]. These latest WHO exposure response functions will be deployed in this analysis (see Table A-21 for details). The premature mortality will also be estimated per one year age group. We combine these estimates with the life expectancy of EuroStat, which allows the assessment of the number of years of life lost (YLL), which in turn can be used in the economic assessment. The assessment provides mortality statistics on a 1kmx1km grid, which are further aggregated per NUTS2, NUTS1 and NUTS0 region. The final results of Indicator #2 will thus include premature mortality and years of life lost provided for each NUTS2 (or coarser) region in the EU27.

Table A-21: Overview of the pollutants considered in Tier 1, along with the concentration response functions (CRFs) and health data considered for each pollutant.

Pollutant	Relative Risk with 95% uncertainty per 10 µg/m3	Population	Type of exposure	Underlying Metareview for the CRF
Particulate matter	1.08 (1.06; 1.09)	30-…	Long-term	(Huangfu & Atkinson, 2020)
Nitrogen dioxide	1.02 (1.01; 1.04)	30-…	Long-term	(Chen & Hoek, 2020)
Ozone	1.01 (1.00; 1.02)	All ages	Peak	(Chen & Hoek, 2020)

For the main scenario analysis, quantification of health impacts for comparing the benefits of different policy options is limited to the impact of air pollution concentrations in excess of the revised WHO Air Quality Guidelines. It is acknowledged, however, that this approach likely underestimates the total

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[6] The relative risk for exposure to particulate matter has been increased from 1.062 per 10 ug/m^3 to 1.08 per 10 ug/m^3, while the relative risk for exposure to nitrogen dioxide has been decreased from 1.055 per 10 ug/m^3 to 1.02 per 10 ug/m^3. The relative risk for ozone has been updated from 1.0029 per 10 ug/m^3 to 1.01 per 10 ug/m^3, while is has also been acknowledged that the uncertainty on the relative risk for ozone was underestimated in the HRAPIE results. According to the updated WHO functions, the relationship between long-term exposure to ozone pollution and premature mortality is only borderline causal.

attributable mortality. For this reason, further quantification has been carried out to inform sensitivity runs, in which it is assumed that mortality impacts also occur below the WHO Air Quality Guidelines. In detail, the following two sensitivity tests will be applied:

- Sensitivity runs that assume mortality impacts also below WHO Air Quality Guideline levels (and as low as 0 µg/m3 for all relevant pollutants, including air pollution from all natural and anthropogenic sources).
- Sensitivity runs that assume mortality impacts also below WHO Air Quality Guideline levels (and as low as 0 µg/m3 for all relevant pollutants, including air pollution from anthropogenic sources only).
- Sensitivity runs that assume different concentration response functions (i.e. with a more pronounced health impact assumed already at lower levels of air pollution, as suggested by more recent studies).

The exposure response functions recommended by the WHO in its 2021 assessment use updated relative risks that differ significantly from the relative risks applied in preceding impact studies (e.g. Clean Air Outlook I and II) and assessment reports of the EEA. To facilitate a comparison of the results of the current project with those of these earlier assessment reports, a second set of sensitivity tests focuses on the application of the relative risks used in the preceding studies, which are based on the HRAPIE CRFs (WHO, 2013). In addition, for NO_2, we also use the CRFs put forward in the reports of the Committee on the Medical Effects of Air Pollutants (COMEAP, 2015), as several national and regional administrations have relied on these CRFs to assess the health impact of air pollution. An overview of all the relative risks, cut-off values and concentrations considered is provided in this Appendix in the sections concerning the sensitivity tests.

The air quality data used for the health impact assessment depends on the pollutant: the premature mortality caused by exposure to NO_2 and PM is based on the annual mean pollutant concentrations modeled by uEMEP, whereas the mortality caused by ozone uses the SOMO35 indicator, which is defined as the yearly sum of the daily maximum of 8-hour running average over 35 ppb, as modeled by EMEP. The main analysis is based on the standard modelling results, hence omitting the bias correction. A sensitivity test focuses on the impact of this assumption on the mortality and the benefits of action to improve air quality. Additionally, the sensitivity test compares the chronic mortality impact based on the EMEP / uEMEP data with the impact based on the air quality maps of the European Topic Centre on Air pollution and Climate change mitigation (ETC-ACM) for the historical year (Horálek et al., 2018).

Apart from the air quality input, the input for the baseline year (2015) is as much as feasible consistent with the input used by the EEA in its yearly assessment of the impact of air pollution on health. The baseline mortality and life expectancy data will therefore be aligned with the data used by the EEA. The following input data is thereby used:

- Gridded population data (1km by 1km) for 2018 from GeoStat as baseline population data used to distribute the mortality over 1km grid cells (Eurostat, 2018)
- EuroStat population on January 1st by age per country (Eurostat, 2022) to rescale the population data to the actual official population data, and to provide a population fraction per age group
- EuroStat cause of death by country and occurrence per 5 year age group (Eurostat, 2022) to extract the ratio between all natural deaths and all cause of deaths
- EuroStat deaths by age (1 year interval) per country (Eurostat, 2022) to estimate the number of natural deaths per age group, relying on the ratios deduced in the previous bullet point

- EuroStat Life Expectance by age (1 year interval) per country (Eurostat, 2022). The data is available from 0 to 85+ years old; to reflect all age groups available for mortality data (up to 95+), we extrapolate the life expectancy to ages above 85, using regression on the life expectance data for age groups 79 -85.
- Where necessary, gap filling has been applied to complement missing data (e.g. using data for the last available year).

For future years, we consider the baseline population scenario of EuroStat for all future scenarios. The same population data is thus used for all scenarios (irrespective of the underlying details of the scenario), which ensures a consistent methodology across assessment of different policy options. More in detail, the following datasets are used:

- EuroStat projected number of deaths per age group per year (Eurostat, 2021) to estimate the change in the baseline mortality rates between the future year and 2019, which are thereafter combined with the mortality figures for 2018 (coming from the fourth bullet point above).
- EuroStat projected life expectancy per age group for future years (Eurostat, 2021) to estimate the future life expectancy.

Tier 2: Morbidity according to HRAPIE

Tier 2 quantifies the morbidity impact considered in the HRAPIE recommendations from 2013. The approach in the study at hand is based on the approach applied in the second Clean Air Outlook (Amann et al., 2020b, 2020a), but only focusing on the morbidity endpoints associated with (long-term and short-term) exposure to $PM_{2.5}$. These endpoints include chronic bronchitis in adults, bronchitis symptoms in children (both caused by long-term exposure) and cardiovascular hospital admissions, respiratory hospital admissions, infant mortality, restricted activity days and lost working-days (caused by short-term exposure). The exposure response functions and underlying studies are provided in Table A-22. The exact details on the exposure response functions and the incidence data is provided in the guiding document on the implementation of the HRAPIE recommendations for EU air pollution cost-benefit analyses (Holland, 2014). We deviate from this methodology for the baseline mortality data concerning infant mortality, for which we rely on EuroStat datasets. To obtain the yearly number of deaths of infants between 1 month and 1 year, we the dataset of the number of deaths per country in the age group below one year[7] with the dataset of the ratio (per country) between the number of deaths below 28 days and the total number of deaths below one year (Eurostat, 2022)[8].

For future years, we used the same baseline incidence rate as for the historical year and applied these rates to the future population projections of EuroStat to compute the incidence estimates for the future years. The only exception concerns the infant mortality, for which more detailed future projections on the incidence rates are available in the EuroStat projections. We therefore use the actual EuroStat projections of the number of deaths in the age group from 0 to 1 year for 2030 and 2050.

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[7] Based on EuroStat deaths by age (1 year interval) per country (Eurostat, 2022)

[8] Data on this ratio is missing for recent years for some European countries. We have used the EU27 average values for these countries.

Table A-22: Overview of the health effects considered in Tier 2, along with the concentration response functions (CRFs) and health data considered for each health effect.

Health outcome	Relative Risk with 95% uncertainty per 10 µg/m³	Population	Type of exposure	Underlying Metareview for the CRF
Chronic bronchitis in adults	1.117 (1.040; 1.189)	18-…	Long-term	(Abbey et al., 1995) (Schindler et al., 2012)
Bronchitis symptoms in children	1.08 (0.98; 1.19)	6-12	Long-term	(Hoek et al., 2012)
Cardiovascular hospital admissions	1.0091 (1.0017; 1.0166)	All ages	Short-term	APED studies, 2000-2009
Respiratory hospital admissions	1.019 (0.9982; 1.0402)	All ages	Short-term	APED studies, 2000-2009
Restricted activity days	1.047 (1.042; 1.053)	All ages	Short-term	(Ostro, 1987)
Work-days lost	1.046 (1.039; 1.053)	20 - 65	Short-term	(Ostro, 1987)
Infant mortality	1.04 (1.02; 1.07)	1 month – 1 year	Long-term	(Woodruff et al., 1997)

Tier 3: Morbidity beyond HRAPIE

Rationale

Acknowledging that there have been developments in the underlying evidence base since HRAPIE, but that the WHO has not undertaken a comprehensive, recent review of morbidity pathways, we have added a Third Tier of health pathways, which focus on the morbidity effects beyond HRAPIE. We have undertaken our own targeted review of literature to explore whether there are other pathways for which evidence is convincing to be included in the morbidity impact study. This third Tier is thus included to incorporate new insights that became apparent after the HRAPIE study in 2013, and to provide a more complete overview of the health impact due to air pollution. The results furthermore substantiate the health impact observed in Tier 1 and 2, as the mortality and lost-working days / restricted activity days due to exposure to air pollution are partially linked to the health effects considered in this tier. The analysis will only consider morbidity pathways associated with exposure to $PM_{2.5}$. Because a similar exercise on the quantification of the morbidity beyond HRAPIE has been started by the EEA (for its yearly assessment reports) and is of interest for all cost-benefit analyses in Europe, the development of this Tier has been done in discussion with the team of the Clean Air Outlook II and the EEA.

Selection of health outcomes

We considered families of health effects that have not been considered in detail in HRAPIE, but which the US EPA classifies in the highest two levels ("causal" or "likely to be causal") of its causality determination in its Integrated Science Assessment for Particulate Matter (U.S. EPA., 2019). These include respiratory effects, cardiovascular effects and cancer. In addition, we also consider metabolic diseases (listed as "suggestive causal relationship, but not sufficient evidence to infer"), due to its importance for society. For each of the families of health effects, we include at least one endpoint, arriving at a set of six health outcomes: Diabetes Mellitus Type 2, asthma in children, COPD, lung cancer, stroke (CVA) and myocardial infarction.

Because the scientific evidence concerning a causal relationship between the exposure to air pollution and the incidence of the health outcomes is different for these six health outcomes (as documented in detail in the next section), we have decided to classify them in two groups. The first group entails the health outcomes for which causality has been proven, and these will be included in the primary analysis. On the other hand, the second group entails the health outcomes for which causality is suggestive, but not proven, and these will be included in a sensitivity test. Hence, we finally arrive at three additional health outcomes for the primary analysis (asthma in children, lung cancer, stroke (CVA)), and three additional health effects in a sensitivity study (COPD, Diabetes Mellitus Type 2 and non-fatal myocardial infarction). Note that myocardial infarction and stroke have already been quantified in a supplementary analysis in CAO II, and that childhood asthma and diabetes have been listed as outcomes listed for “possible inclusion” in the CAO II study (Amann et al., 2020b).

The concentration response functions for all health outcomes are based on a literature review, focusing on systematic reviews and meta-analyses. Preference has been given to studies linked to (inter)national health networks (e.g. American Heart Association, American Thoracic Society, International Agency for Research on Cancer) and workshop reports of meetings of these networks. A list of the selected CRFs is provided in Figure A-74, while the next section documents the literature considered in the decision on the CRFs. Because the final CRFs have not undergone the detailed review process of the WHO, the uncertainty on these relations is larger than the uncertainty on the relations for mortality (Tier 1). In addition, recent studies focusing on regions with low (relatively, on a global scale) concentrations in Europe (Brunekreef & et al., 2021) suggest the concentration response functions from global meta-reviews might underestimate the effects in a European context. We therefore introduce an additional sensitivity analysis, in which we use the CRFs derived in the latest ELAPSE study as an alternative to the CRFs based on the literature review (Brunekreef & et al., 2021). The relative risks derived in this study have also been added to Figure A-74. In addition, the impact analysis relies on baseline health data (incidence per capita) for the diseases considered. For the reference year, incidence data for the diseases will be taken from available pan-European or international datasets, complemented with data of the Global Burden of Disease if specific data from the underlying health sector is unavailable. More details on these choices are discussed in the next section, and an overview (including the ICD-10 classification which were used) is provided in Figure A-74. We will moreover use the same baseline incidence rate for the future scenarios, and apply these rates to the future population projections of EuroStat to compute the incidence estimates for the future years.

Detailed description of the health outcomes

In this section, we provide an overview of the literature review concerning the concentration response functions and incidence rates that are applied in the third tier of the health impact assessment.

Stroke (cerebrovascular accident, CVA)

The relation between cardiovascular diseases and exposure to air pollution is considered to be “likely causal” according to the US EPA (U.S. EPA., 2019), and, specifically, the relationship between stroke and long-term exposure to particulate matter is “causal” according to the American Heart Association (Brook et al., 2010). Therefore, stroke is included as a health outcome in the primary analysis for Tier 3.

Several recent meta-reviews have focused on the quantification of the relationship between stroke and the long-term exposure to air particulate matter. A meta-analysis based on 20 underlying epidemiological studies derived a relative risk of 1.13 (1.04; 1.23) per 10 µg/m^3 (Scheers et al., 2015). A more recent systematic review found a similar concentration-response function for Europe (1.14 (1.10; 1.23) per 10 µg/m^3), based on 16 cohort studies (Yuan et al., 2019). Finally, a systematic review and meta-analysis of the American Heart Association, taking 20 studies on incident stroke into account, arrived at a relative risk of 1.13 (1.11; 1.15) per 10 µg/m^3 (Alexeeff et al., 2021). These three reviews hence arrived at similar values for the central estimates for the relative risks, but with somewhat deviating uncertainty intervals. We have opted to use the dose-response functions of Alexeeff et al., since this review is more recent.

Incidence data per country is taken from the 2017 dataset of the European Cardiovascular Disease Statistics from the European Heart Network (EHN, 2017).

Myocardial infarction

The relation between cardiovascular diseases and exposure to air pollution is considered to be “likely causal” according to the US EPA (U.S. EPA., 2019), and, specifically, the relationship between myocardial infarction and long-term exposure to particulate matter is “suggestive of a positive association but not conclusive” according to the American Heart Association (Alexeeff et al., 2021). Therefore, myocardial infarction is included as an additional health outcome in the sensitivity test concerning the third Tier of the health impact assessment.

A systematic review and meta-analysis of the American Heart Association (Alexeeff et al., 2021), taking 17 studies on incident myocardial infarction into account, arrived at a relative risk of 1.08 (0.99; 1.18) per 10 µg/m^3.

Incidence data per country is taken from the 2017 dataset of the European Cardiovascular Disease Statistics from the European Heart Network (EHN, 2017).

Lung Cancer

The relation between lung cancer and exposure to air pollution is considered to be “likely causal” according to the US EP (U.S. EPA., 2019), and air pollution has been designated as a Group I carcinogen by the International Agency for the Research on Cancer (IARC, 2013; Loomis et al., 2013). Therefore, lung cancer is included as a health outcome in the primary analysis for Tier 3.

Two recent systematic reviews have focused on a quantification of the dose-response relations. In the review of Hamra et al. 18 studies have been included, yielding to a meta relative risk of 1.09 (1.04; 1.14) per 10 µg/m^3 (Hamra et al., 2014). A more recent meta-analysis included 17 studies, and derived a meta relative risk of 1.08 (1.03; 1.12) per 10 µg/m^3 (Huang et al., 2017). Both reviews thus arrive at very similar results for the dose-response functions. We have opted to include the dose-response function of Hamra et al., because of the involvement of several international research networks (amongst other the IARC and the Health Effects Institute), whereas such institutes are not involved in the latter study.

Incidence data per country is taken from the 2020 dataset of the European Cancer Information System (ECIS) from the European Joint Research Center (JRC) (JRC, 2020). The incidence per capita for ICD-10 codes C33-34 for the population above 20 years has been considered.

Diabetes Mellitus type 2

The relation between metabolic diseases and exposure to air pollution is considered to be “suggestive but not sufficient to infer a causal link” according to the US EPA (U.S. EPA., 2019). Therefore, diabetes mellitus type 2 is included as an additional health outcome in the sensitivity test concerning the third Tier of the health impact assessment.

Two recent systematic reviews have focused on a quantification of the dose-response relations. (Eze et al., 2015) have analyzed the results of 13 studies and derived a relative risk of 1.10 (1.02,1.18) per 10 µg/m^3. (Yang et al., 2020) have analyzed the results of 86 studies and arrived at an increased risk of 1.10 (1.04,1.17) per 10 µg/m^3. Both reviews thus arrive at very similar results for the dose-response functions. We have opted to include the dose-response functions of Yang et al, since this review is more recent. Both reviews finally conclude that additional high-quality studies assessing dose-response functions are needed, highlighting the larger uncertainty and substantiating the inclusion of this health outcome in the sensitivity tests rather than in the primary analysis.

Incidence data per country is taken from the 2019 Global Burden of Disease (IHME, 2020). The incidence per capita for all ages has been considered.

Asthma in children

The relation between respiratory effects and exposure to air pollution is considered to be “likely causal” according to the US EPA (U.S. EPA., 2019), and, specifically the relation between the incidence of asthma in children and long-term exposure to particulate matter is “causal” according to the Epidemiology Group of the American Thoracic Society (Thurston et al., 2020). Therefore, the incidence of asthma in children is included as a health outcome in the primary analysis for Tier 3.

The relation between the incidence of asthma in children and the exposure to air pollution has been quantified in two recent studies. In the ESCAPE epidemiological study, an odds ratio of 1.04 (1.02 ; 1.07) per 1 ug/m^3 has been observed (Jacquemin et al., 2015). A systematic review focusing on 21 underlying studies, found a risk estimate of 1.03 (1.01; 1.05) per 1 ug/m^3 (Khreis et al., 2017), closely in line with the results of the ESCAPE study. We have opted to include the latter dose-response function, as this function is based on a meta-review.

Incidence data per country is taken from the 2019 Global Burden of Disease (IHME, 2020). The incidence per capita for all ages has been considered.

COPD (Chronic obstructive pulmonary disease)

The relation between respiratory effects and exposure to air pollution is considered to be “likely causal” according to the US EPA (U.S. EPA., 2019), but, according to the Epidemiology Group of the American Thoracic Society (Thurston et al., 2020), “although combined toxicological and epidemiological evidence supports the hypothesis that long-term air pollution is related to COPD onset, further investigations are needed to definitively conclude that there is a causal connection.” Therefore, COPD is included as an additional health outcome in the sensitivity test concerning the third Tier of the health impact assessment.

The relation between the incidence of COPD and the exposure to air pollution has been quantified in a single meta-analysis focusing on 7 underlying studies (Park et al., 2021). In the study, a health ratio of 1.18 (1.13; 1.23) per 10 ug/m^3 has been observed.

Incidence data per country is taken from the 2019 Global Burden of Disease (IHME, 2020). The incidence per capita for all ages has been considered.

Figure A-74: Overview of the health effects considered in Tier 3, along with the concentration response functions (CRFs) and health data considered for each health effect. The table furthermore summarizes additional CRFs from recent meta-reviews and results of the ELAPSE study.

Family of health outcome	Health outcome	Relative Risk with 95% uncertainty	Underlying reference for the CRF	Health metric	Source for health data	ICD10 code	Year for incidence data	Population	Type	Comparison: Alternative CRFs from recent meta-studies and reviews	Comparison: Results of ELAPSE (Brunekreef & et al., 2021)
Cardiovascular diseases	Stroke (CVA)	1.13 (1.11; 1.15) per 10 ug/m3	(Alexeeff et al., 2021)	Incidence of cases	EHN European Cardiovascular Disease Statistics	I60-69	2017	all ages	Primary analysis	Other meta-reviews have derived similar values for the central estimates, but with a somewhat larger uncertainty range (Scheers et al., 2015) RR: 1.13 (1.04;1.23) per 10 ug/m3 (Yuan et al., 2019) RR: 1.14 (1.10; 1.23) per 10 ug/m3	Higher impact in ELAPSE, HR: 1.21 (1.02 ; 1.46) per 10 ug/m3
	Myocardial infarction	1.08 (1.0; 1.18) per 10 ug/m3	(Alexeeff et al., 2021)	Incidence of cases	EHN European Cardiovascular Disease Statistics	I21	2017	all ages	Sensitivity study		Uncertainty intervals overlap HR: 1.04 (0.9 ; 1.21) per 10 ug/m3
Metabolic diseases	Diabetes Mellitus Type 2	1.10 (1.04,1.17) per 10 ug/m3	(Yang et al., 2020)	Incidence of cases	Global Burden of Disease	E11	2019	all ages	Sensitivity study	Other meta-reviews have derived similar CRFs (Eze et al., 2015) RR: 1.1 (1.02,1.18) per 10 ug/m3	
Cancer	Lung cancer	1.09 (1.04; 1.14) per 10 ug/m3	(Hamra et al., 2014)	Incidence of cases	European Cancer Information System (JRC)	C33-34	2020	20-…	Primary analysis	Other meta-reviews have derived similar CRFs (Huang et al., 2017) 1.08 (1.03; 1.12) per 10ug/m3	Higher impact in ELAPSE HR: 1.28 (1.10 ; 1.56) per 10 ug/m3
Respiratory diseases	Asthma (children)	1.03 (1.01; 1.05) per 1 ug/m3	(Khreis et al., 2017)	Incidence of cases	Global Burden of Disease	J45	2019	0-15	Primary analysis	Similar CRF from the ESCAPE cohort study (age group 7-15) (Jacquemin et al., 2015) RR: 1.04 (1.02 ; 1.07) per 1 ug/m3	
	COPD	1.18 (1.13; 1.23) per 10 ug/m3	(Park et al., 2021)	Incidence of cases	Global Burden of Disease	J41-J44	2019	20-…	Sensitivity study		Higher impact in ELAPSE HR: 1.36 (1.12; 1.66) per 10 µg/m3

Limitations

There are several limitations associated with to the health impact assessment.

For the first Tier (chronic mortality), the following limitations are observed:

- We only consider the mortality related to long-term exposure to PM, NO_2 and O_3. Other pollutants and mortality due to short-term exposure are not considered.
- We do not correct the results for an overlap in the premature deaths between the different pollutants (although a consideration for overlaps is taken into account in the valuation step – see Appendix 6). As an indicative estimate for the order of magnitude of the overlap, HRAPIE (WHO, 2013) suggests an overlap of 33%. This number is, however, associated with a large uncertainty.
- Since the meteorological data is the same for each year under consideration, the impact of climate change is not considered.
- The uncertainty on the results is larger for the results per country, in comparison with the totals for the EU-27.
- The approach is based on the WHO exposure response functions and the cut-off values are set at the WHO air quality guidelines. This approach likely underestimates the total impact of air pollution on health (and thus also the likely benefits of action to improve air quality).

For the second and the third Tier, the following limitations are observed:

- We only consider the morbidity related to exposure to particulate matter. Other pollutants are not considered.
- Future projections for the baseline incidence are unavailable for most health outcomes. We therefore use the morbidity rates for the most recent year for the future baseline morbidity. Impacts due to improvements in health care, more / less healthy lifestyle etc. are hence not considered.
- Since the meteorological data is the same for each year under consideration, the impact of climate change is not considered.
- The uncertainty on the results is larger for the results per country, in comparison with the totals for the EU-27.
- The uncertainty on the results of the Second and Third Tier is larger than the uncertainty on the First Tier, mostly due to very large uncertainties in the input datasets (concentration response functions, baseline morbidity). When interpreting the results, the focus should lie on relative differences, while absolute values should only be interpreted when one also refers to the uncertainty intervals.

Health impacts - Detailed results

This appendix provides the detailed results for the health impact indicator. The following results are provided:

- Tables with absolute mortality per country for the baseline and the MTFR scenarios
- Tables with total morbidity in the EU-27 for the all scenarios for 2030 and 2050
- Barplots of the mortality per 100,000 inhabitants per country for all pollutants and all scenarios
- Maps with the mortality per 100,000 inhabitants per NUTS1 region for all pollutants and scenarios. The colour scales have been fixed per year.

Full results (NUTS2 level for mortality and country level for morbidity) could be added as GIS data files.

Tables per country with mortality for baseline and MTFR

Table A-23: Premature deaths caused by exposure to $PM_{2.5}$ pollution per country in the EU27 under the baseline and MTFR scenario. Countries with fewer than 1 attributable deaths per year have been labeled as "<1", while countries for which none of the populated grid cells have concentrations above the WHO guidelines have been labeled as "nihil".

	2015	2020	2030		2050	
NUTS code	Base	Base	Base	MTFR	Base	MTFR
AT	2774 (2110 ; 3100)	1652 (1254 ; 1847)	619 (469 ; 692)	125 (95 ; 140)	188 (142 ; 210)	7 (6 ; 8)
BE	5254 (4001 ; 5867)	3579 (2720 ; 4000)	1804 (1368 ; 2018)	674 (510 ; 754)	630 (477 ; 705)	46 (35 ; 52)
BG	5373 (4094 ; 5997)	3978 (3026 ; 4444)	2018 (1531 ; 2257)	760 (576 ; 851)	909 (689 ; 1018)	265 (201 ; 297)
CY	349 (266 ; 389)	321 (245 ; 358)	354 (269 ; 395)	338 (257 ; 378)	439 (334 ; 491)	418 (318 ; 467)
CZ	5558 (4234 ; 6206)	3387 (2573 ; 3786)	988 (749 ; 1106)	116 (88 ; 130)	82 (62 ; 92)	nihil
DE	32772 (24911 ; 36625)	19097 (14488 ; 21363)	5393 (4085 ; 6038)	569 (430 ; 637)	746 (565 ; 835)	23 (17 ; 25)
DK	757 (573 ; 847)	455 (344 ; 509)	25 (19 ; 28)	nihil	nihil	nihil
EE	41 (31 ; 45)	34 (26 ; 38)	< 1	nihil	nihil	nihil
EL	7039 (5369 ; 7852)	5019 (3821 ; 5605)	3684 (2801 ; 4117)	2931 (2227 ; 3276)	3318 (2522 ; 3709)	2769 (2103 ; 3095)
ES	21930 (16747 ; 24453)	11281 (8593 ; 12594)	6996 (5314 ; 7822)	2666 (2021 ; 2983)	5661 (4296 ; 6332)	2273 (1723 ; 2544)
FI	218 (165 ; 244)	287 (218 ; 321)	55 (41 ; 61)	21 (16 ; 23)	21 (16 ; 23)	7 (5 ; 8)
FR	13459 (10220 ; 15049)	5680 (4307 ; 6355)	1793 (1358 ; 2007)	361 (273 ; 405)	386 (292 ; 432)	5 (4 ; 6)
HR	3946 (3020 ; 4395)	1992 (1517 ; 2224)	71 (54 ; 80)	28 (21 ; 31)	18 (13 ; 20)	15 (11 ; 16)
HU	8991 (6865 ; 10027)	5212 (3964 ; 5823)	2628 (1993 ; 2939)	509 (385 ; 570)	401 (304 ; 450)	33 (25 ; 37)
IE	82 (62 ; 91)	6 (5 ; 7)	nihil	nihil	nihil	nihil
IT	52831 (40496 ; 58800)	29201 (22268 ; 32583)	15384 (11689 ; 17197)	9982 (7577 ; 11164)	9341 (7091 ; 10446)	6116 (4643 ; 6839)
LT	823 (624 ; 920)	620 (470 ; 694)	161 (122 ; 180)	23 (17 ; 25)	3 (2 ; 3)	nihil
LU	116 (88 ; 129)	47 (36 ; 53)	< 1	nihil	nihil	nihil
LV	703 (535 ; 786)	543 (412 ; 607)	152 (115 ; 170)	8 (6 ; 9)	3 (3 ; 4)	nihil
MT	264 (202 ; 295)	232 (177 ; 259)	311 (237 ; 347)	290 (221 ; 323)	411 (313 ; 458)	383 (292 ; 428)
NL	6524 (4964 ; 7287)	4495 (3413 ; 5025)	2797 (2120 ; 3130)	1331 (1008 ; 1490)	911 (689 ; 1020)	91 (69 ; 102)
PL	22785 (17380 ; 25420)	17354 (13208 ; 19383)	4968 (3765 ; 5560)	1297 (982 ; 1453)	1181 (894 ; 1322)	58 (44 ; 65)
PT	3949 (3005 ; 4410)	1877 (1425 ; 2099)	744 (563 ; 833)	108 (82 ; 121)	522 (396 ; 585)	98 (74 ; 110)
RO	13356 (10181 ; 14906)	9753 (7420 ; 10894)	3893 (2953 ; 4356)	1727 (1308 ; 1933)	2057 (1559 ; 2302)	877 (664 ; 982)
SE	247 (187 ; 276)	328 (249 ; 367)	214 (163 ; 239)	188 (143 ; 210)	177 (134 ; 198)	158 (120 ; 176)
SI	1440 (1102 ; 1604)	748 (570 ; 835)	580 (441 ; 648)	102 (78 ; 114)	88 (67 ; 99)	6 (4 ; 6)
SK	2353 (1791 ; 2628)	1360 (1033 ; 1521)	479 (363 ; 537)	44 (33 ; 49)	77 (58 ; 86)	3 (2 ; 3)

Table A-24: Premature deaths caused by exposure to NO_2 pollution per country in the EU27 under the baseline and MTFR scenario. Countries with fewer than 1 attributable deaths per year have been labeled as "<1", while countries for which none of the populated grid cells have concentrations above the WHO guidelines have been labeled as "nihil".

	2015	2020	2030		2050	
NUTS code	Base	Base	Base	MTFR	Base	MTFR
AT	853 (431 ; 1670)	432 (218 ; 850)	9 (5 ; 18)	4 (2 ; 9)	nihil	nihil
BE	2041 (1033 ; 3987)	1044 (527 ; 2050)	171 (86 ; 337)	107 (54 ; 212)	2 (1 ; 3)	nihil
BG	496 (251 ; 974)	398 (201 ; 781)	96 (48 ; 189)	79 (40 ; 156)	nihil	nihil
CY	8 (4 ; 16)	< 1	nihil	nihil	nihil	nihil
CZ	410 (206 ; 806)	178 (89 ; 350)	5 (3 ; 10)	2 (1 ; 5)	nihil	nihil
DE	8358 (4221 ; 16392)	4295 (2166 ; 8450)	203 (102 ; 402)	61 (31 ; 121)	nihil	nihil
DK	102 (51 ; 201)	23 (12 ; 46)	nihil	nihil	nihil	nihil
EE	125 (63 ; 244)	79 (40 ; 154)	26 (13 ; 51)	24 (12 ; 48)	nihil	nihil
EL	2486 (1267 ; 4795)	1540 (781 ; 2994)	689 (348 ; 1351)	590 (298 ; 1158)	87 (44 ; 171)	63 (32 ; 125)
ES	5451 (2760 ; 10640)	2703 (1365 ; 5303)	798 (402 ; 1573)	530 (267 ; 1045)	243 (122 ; 477)	184 (93 ; 362)
FI	134 (67 ; 262)	55 (28 ; 109)	nihil	nihil	nihil	nihil
FR	6866 (3482 ; 13351)	3715 (1879 ; 7259)	685 (345 ; 1350)	484 (243 ; 954)	2 (1 ; 4)	< 1
HR	120 (60 ; 236)	14 (7 ; 29)	nihil	nihil	nihil	nihil
HU	407 (205 ; 802)	198 (100 ; 391)	11 (6 ; 22)	nihil	nihil	nihil
IE	79 (40 ; 155)	43 (22 ; 85)	nihil	nihil	nihil	nihil
IT	8255 (4178 ; 16119)	3215 (1623 ; 6308)	591 (299 ; 1156)	507 (257 ; 992)	321 (162 ; 628)	306 (155 ; 598)
LT	64 (32 ; 126)	71 (36 ; 139)	10 (5 ; 19)	9 (4 ; 18)	nihil	nihil
LU	18 (9 ; 35)	6 (3 ; 11)	nihil	nihil	nihil	nihil
LV	105 (53 ; 206)	78 (39 ; 153)	< 1	nihil	nihil	nihil
MT	5 (3 ; 10)	nihil	nihil	nihil	2 (1 ; 3)	2 (1 ; 3)
NL	2783 (1407 ; 5444)	1693 (854 ; 3326)	451 (227 ; 890)	244 (123 ; 481)	nihil	nihil
PL	1044 (526 ; 2057)	457 (230 ; 903)	12 (6 ; 24)	2 (1 ; 3)	nihil	nihil
PT	330 (166 ; 651)	86 (43 ; 169)	12 (6 ; 24)	7 (4 ; 15)	7 (4 ; 15)	6 (3 ; 11)
RO	912 (461 ; 1790)	588 (297 ; 1157)	213 (107 ; 420)	149 (75 ; 295)	7 (3 ; 13)	nihil
SE	279 (141 ; 547)	150 (76 ; 295)	nihil	nihil	nihil	nihil
SI	205 (104 ; 398)	125 (63 ; 244)	53 (27 ; 104)	50 (25 ; 98)	< 1	< 1
SK	174 (88 ; 340)	58 (29 ; 114)	10 (5 ; 20)	5 (3 ; 10)	nihil	nihil

Table A-25: Premature deaths caused by exposure to O_3 pollution per country in the EU27 under the baseline and MTFR scenario. Countries with fewer than 1 attributable deaths per year have been labeled as "<1", while countries for which none of the populated grid cells have concentrations above the WHO guidelines have been labeled as "nihil".

	2015	2020	2030		2050	
NUTS code	Base	Base	Base	MTFR	Base	MTFR
AT	1332 (0 ; 2630)	1329 (0 ; 2624)	1246 (0 ; 2463)	1114 (0 ; 2204)	1265 (0 ; 2504)	1096 (0 ; 2169)
BE	668 (0 ; 1325)	1212 (0 ; 2398)	1310 (0 ; 2592)	1244 (0 ; 2463)	1454 (0 ; 2878)	1332 (0 ; 2637)
BG	1904 (0 ; 3756)	1616 (0 ; 3193)	1369 (0 ; 2706)	1279 (0 ; 2529)	1082 (0 ; 2140)	1007 (0 ; 1993)
CY	127 (0 ; 249)	117 (0 ; 231)	155 (0 ; 305)	150 (0 ; 295)	208 (0 ; 408)	201 (0 ; 396)
CZ	1682 (0 ; 3323)	1779 (0 ; 3512)	1658 (0 ; 3278)	1484 (0 ; 2936)	1443 (0 ; 2855)	1241 (0 ; 2458)
DE	10541 (0 ; 20852)	13528 (0 ; 26730)	12729 (0 ; 25175)	11760 (0 ; 23271)	11447 (0 ; 22661)	10178 (0 ; 20162)
DK	363 (0 ; 719)	477 (0 ; 946)	534 (0 ; 1058)	510 (0 ; 1012)	528 (0 ; 1046)	496 (0 ; 984)
EE	65 (0 ; 129)	81 (0 ; 161)	83 (0 ; 166)	80 (0 ; 158)	92 (0 ; 182)	87 (0 ; 173)
EL	1844 (0 ; 3637)	1732 (0 ; 3419)	1847 (0 ; 3648)	1723 (0 ; 3405)	2083 (0 ; 4111)	1945 (0 ; 3840)
ES	6085 (0 ; 12010)	5876 (0 ; 11607)	6349 (0 ; 12546)	5887 (0 ; 11640)	7849 (0 ; 15513)	7092 (0 ; 14027)
FI	202 (0 ; 400)	295 (0 ; 586)	328 (0 ; 652)	315 (0 ; 625)	335 (0 ; 665)	318 (0 ; 631)
FR	5916 (0 ; 11702)	7353 (0 ; 14536)	7328 (0 ; 14500)	6895 (0 ; 13648)	7911 (0 ; 15661)	7210 (0 ; 14280)
HR	925 (0 ; 1826)	822 (0 ; 1623)	239 (0 ; 473)	220 (0 ; 434)	211 (0 ; 416)	191 (0 ; 378)
HU	2241 (0 ; 4422)	2042 (0 ; 4033)	1726 (0 ; 3411)	1548 (0 ; 3063)	1427 (0 ; 2824)	1247 (0 ; 2470)
IE	178 (0 ; 354)	207 (0 ; 410)	282 (0 ; 559)	279 (0 ; 554)	387 (0 ; 768)	381 (0 ; 755)
IT	13763 (0 ; 27089)	13363 (0 ; 26300)	12373 (0 ; 24392)	11261 (0 ; 22221)	12443 (0 ; 24560)	10988 (0 ; 21709)
LT	322 (0 ; 638)	305 (0 ; 605)	272 (0 ; 540)	258 (0 ; 512)	236 (0 ; 469)	222 (0 ; 440)
LU	42 (0 ; 83)	60 (0 ; 119)	63 (0 ; 124)	58 (0 ; 114)	76 (0 ; 151)	67 (0 ; 132)
LV	166 (0 ; 329)	187 (0 ; 372)	169 (0 ; 335)	160 (0 ; 318)	135 (0 ; 268)	127 (0 ; 253)
MT	61 (0 ; 120)	60 (0 ; 119)	76 (0 ; 150)	73 (0 ; 144)	101 (0 ; 198)	95 (0 ; 188)
NL	761 (0 ; 1511)	1297 (0 ; 2569)	1543 (0 ; 3059)	1487 (0 ; 2948)	1767 (0 ; 3503)	1614 (0 ; 3200)
PL	5170 (0 ; 10222)	5197 (0 ; 10279)	4705 (0 ; 9313)	4293 (0 ; 8503)	4354 (0 ; 8626)	3865 (0 ; 7661)
PT	1275 (0 ; 2521)	1466 (0 ; 2897)	1461 (0 ; 2889)	1324 (0 ; 2620)	1577 (0 ; 3119)	1402 (0 ; 2775)
RO	4327 (0 ; 8539)	3714 (0 ; 7339)	3166 (0 ; 6261)	2983 (0 ; 5901)	2710 (0 ; 5361)	2515 (0 ; 4977)
SE	503 (0 ; 999)	667 (0 ; 1323)	740 (0 ; 1468)	708 (0 ; 1404)	742 (0 ; 1472)	704 (0 ; 1397)
SI	304 (0 ; 600)	290 (0 ; 572)	264 (0 ; 523)	228 (0 ; 451)	251 (0 ; 497)	207 (0 ; 410)
SK	820 (0 ; 1619)	797 (0 ; 1575)	759 (0 ; 1501)	671 (0 ; 1327)	722 (0 ; 1428)	620 (0 ; 1228)

Tables on morbidity

Table A-26: Absolute morbidity caused by the exposure to PM$_{2.5}$ pollution in the EU27 under all scenario's for 2030.

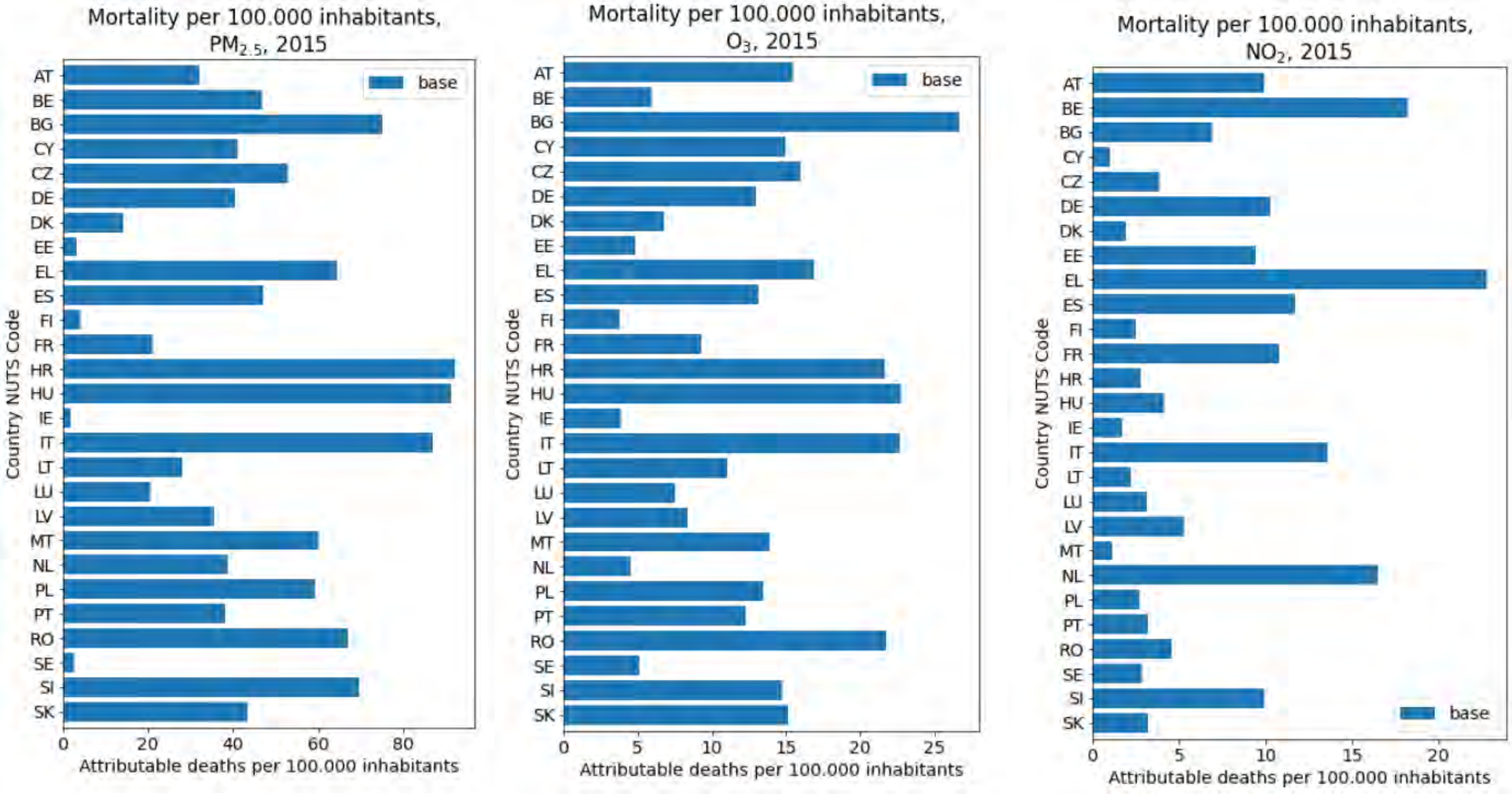
Health outcome	Unit	2030 baseline	2030 MTFR	2030 OPT 05 µg/m^3	2030 OPT 10 µg/m^3	2030 OPT 15 µg/m^3	2030 OPT 20 µg/m^3
Infant Mortality	Deaths per year	15 (7 ; 27)	6 (3 ; 11)	7 (3 ; 12)	7 (3 ; 13)	9 (4 ; 16)	13 (6 ; 23)
Bronchitis in Children (age 6 -12)	Cases per year	61000 (0 ; 136000)	25500 (0 ; 57100)	27900 (0 ; 62400)	30400 (0 ; 68200)	37600 (0 ; 84100)	52500 (0 ; 117000)
Chronic Bronchitis in adults	Incidence per year	24500 (8760 ; 38000)	10700 (3820 ; 16600)	11600 (4140 ; 18000)	12500 (4480 ; 19500)	15500 (5540 ; 24100)	20900 (7480 ; 32500)
Cardiovascular hospital admissions	Admissions per year	14100 (2650 ; 25600)	5540 (1040 ; 10100)	6120 (1150 ; 11100)	6680 (1250 ; 12100)	7980 (1500 ; 14500)	11900 (2240 ; 21600)
Respiratory hospital admissions	Admissions per year	14500 (0 ; 30100)	5670 (0 ; 11800)	6250 (0 ; 13000)	6810 (0 ; 14200)	8710 (0 ; 18100)	12500 (0 ; 26000)
Restricted activity days	Days per year	59500000 (53300000 ; 66900000)	25800000 (23100000 ; 29000000)	28000000 (25100000 ; 31500000)	30300000 (27200000 ; 34100000)	37500000 (33600000 ; 42100000)	50900000 (45600000 ; 57200000)
Lost working days	Days per year	21200000 (18000000 ; 24300000)	8390000 (7150000 ; 9630000)	9240000 (7860000 ; 10600000)	10200000 (8710000 ; 11700000)	12700000 (10800000 ; 14500000)	18100000 (15400000 ; 20800000)
Stroke (CVA)	Incidence per year	11500 (9800 ; 13100)	4830 (4130 ; 5520)	5290 (4530 ; 6040)	5640 (4820 ; 6440)	6650 (5690 ; 7590)	9710 (8300 ; 11100)
Lung cancer	Incidence per year	4260 (1950 ; 6440)	1830 (835 ; 2760)	1990 (909 ; 3010)	2160 (986 ; 3270)	2630 (1200 ; 3980)	3660 (1670 ; 5530)
Asthma in children (age < 16 years)	Incidence per year	23700 (8180 ; 38300)	9840 (3370 ; 15900)	10800 (3700 ; 17500)	11700 (4020 ; 19000)	14400 (4970 ; 23400)	20500 (7030 ; 33100)
Diabetes Mellitus Type2	Incidence per year	25700 (10700 ; 42000)	11100 (4580 ; 18100)	12000 (4980 ; 19700)	13000 (5380 ; 21300)	16100 (6680 ; 26400)	21800 (9040 ; 35700)
Non-fatal myocardial infarction	Incidence per year	33100 (0 ; 70400)	13600 (0 ; 29100)	15000 (0 ; 32000)	16100 (0 ; 34400)	19100 (0 ; 40600)	28000 (0 ; 59600)
COPD	Incidence per year	44900 (33300 ; 55800)	20100 (14900 ; 25100)	21700 (16100 ; 27000)	23700 (17600 ; 29500)	29500 (21900 ; 36700)	38600 (28700 ; 48100)

Table A-27: Morbidity caused by the exposure to PM$_{2.5}$ pollution in the EU27 under all scenario's for 2050. Values have been rounded to the nearest integer.

Health outcome	Unit	2050 baseline	2050 MTFR	2050 OPT 05 µg/m^3	2050 OPT 10 µg/m^3	2050 OPT 15 µg/m^3
Infant Mortality	Deaths per year	3 (1 ; 5)	1 (0 ; 2)	1 (0 ; 2)	1 (0 ; 3)	3 (1 ; 5)
Bronchitis in Children (age 6 -12)	Cases per year	24500 (0 ; 54900)	11600 (0 ; 25900)	12200 (0 ; 27200)	13000 (0 ; 29000)	22600 (0 ; 50600)
Chronic Bronchitis in adults	Incidence per year	10700 (3820 ; 16600)	5260 (1880 ; 8160)	5510 (1970 ; 8560)	5800 (2080 ; 9010)	9880 (3530 ; 15400)
Cardiovascular hospital admissions	Admissions per year	5370 (1010 ; 9740)	2430 (456 ; 4410)	2560 (480 ; 4650)	2710 (508 ; 4920)	4880 (915 ; 8860)
Respiratory hospital admissions	Admissions per year	5920 (0 ; 12300)	2680 (0 ; 5560)	2830 (0 ; 5880)	2990 (0 ; 6210)	5440 (0 ; 11300)
Restricted activity days	Days per year	25600000 (22900000 ; 28700000)	12500000 (11200000 ; 14100000)	13100000 (11800000 ; 14800000)	13800000 (12400000 ; 15600000)	23600000 (21200000 ; 26600000)
Lost working days	Days per year	8260000 (7030000 ; 9470000)	3790000 (3220000 ; 4340000)	3980000 (3390000 ; 4570000)	4250000 (3620000 ; 4880000)	7630000 (6490000 ; 8750000)
Stroke (CVA)	Incidence per year	4780 (4090 ; 5460)	2270 (1950 ; 2600)	2390 (2050 ; 2730)	2530 (2160 ; 2890)	4330 (3700 ; 4940)
Lung cancer	Incidence per year	1800 (823 ; 2720)	876 (401 ; 1320)	918 (420 ; 1390)	970 (444 ; 1470)	1660 (761 ; 2520)
Asthma in children (age < 16 years)	Incidence per year	9500 (3260 ; 15400)	4420 (1530 ; 7120)	4660 (1610 ; 7500)	4940 (1700 ; 7980)	8740 (3000 ; 14100)
Diabetes Mellitus Type2	Incidence per year	11100 (4580 ; 18100)	5500 (2280 ; 8980)	5760 (2390 ; 9400)	6020 (2500 ; 9840)	10300 (4250 ; 16800)
Non-fatal myocardial infarction	Incidence per year	13200 (0 ; 28100)	6210 (0 ; 13200)	6530 (0 ; 13900)	6900 (0 ; 14700)	12000 (0 ; 25600)
COPD	Incidence per year	20000 (14800 ; 24900)	9940 (7390 ; 12400)	10400 (7740 ; 13000)	11000 (8180 ; 13700)	18600 (13800 ; 23200)

Barplots for all scenarios

Figure A-75: Impact of all scenarios on the number of yearly premature deaths per country caused by the exposure to air pollution at levels above the WHO AQ guidelines for three pollutants ($PM_{2.5}$, left; O_3, middle; NO_2, right). Impacts for 2015 are considered.



Mortality per 100.000 inhabitants, $PM_{2.5}$, 2015

Mortality per 100.000 inhabitants, O_3, 2015

Mortality per 100.000 inhabitants, NO_2, 2015

Figure A-76: Yearly number of premature deaths per country caused by the exposure to air pollution at levels above the WHO AQ guidelines for three pollutants ($PM_{2.5}$, left; O_3, middle; NO_2, right). Impacts for 2030 are considered.

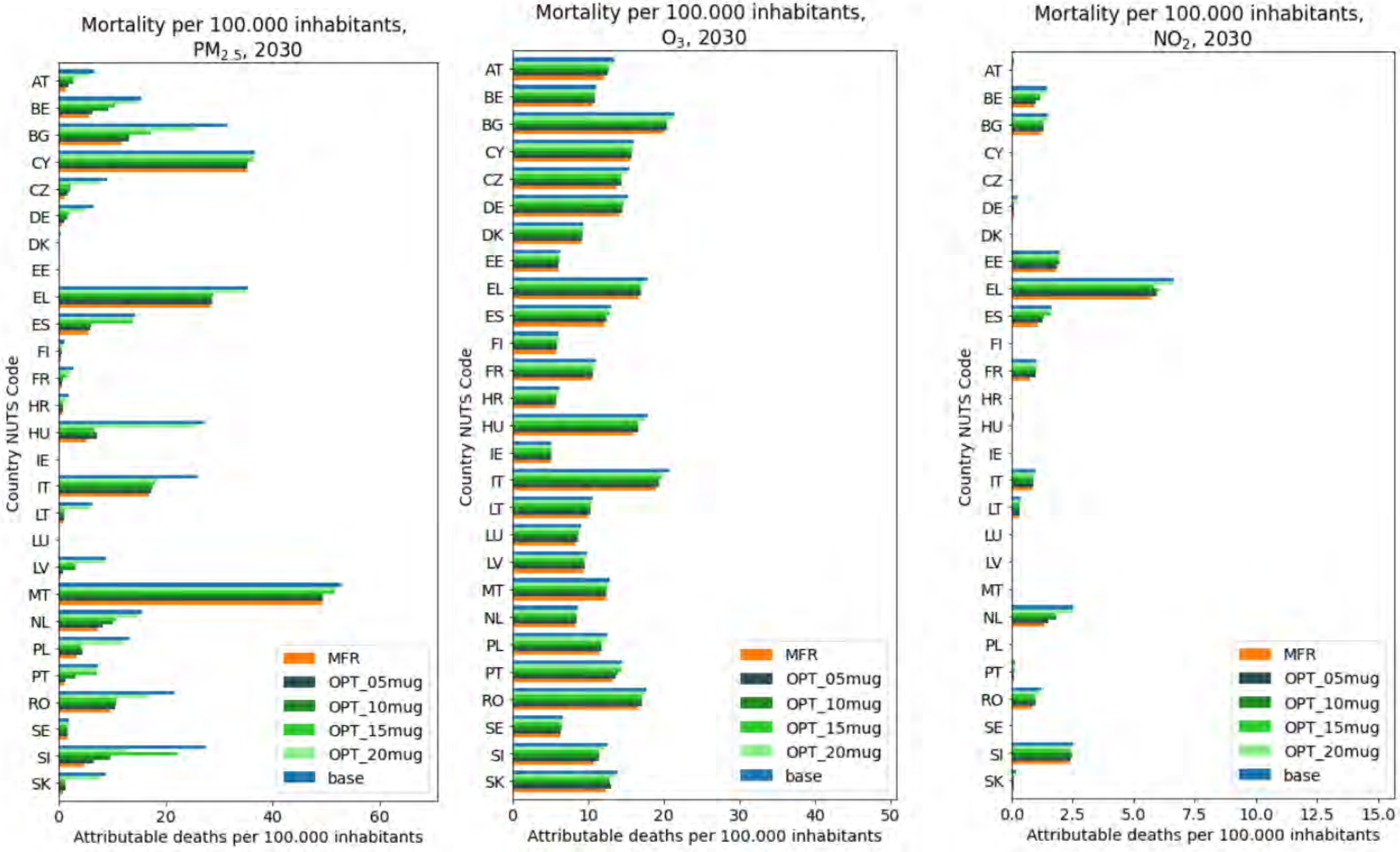
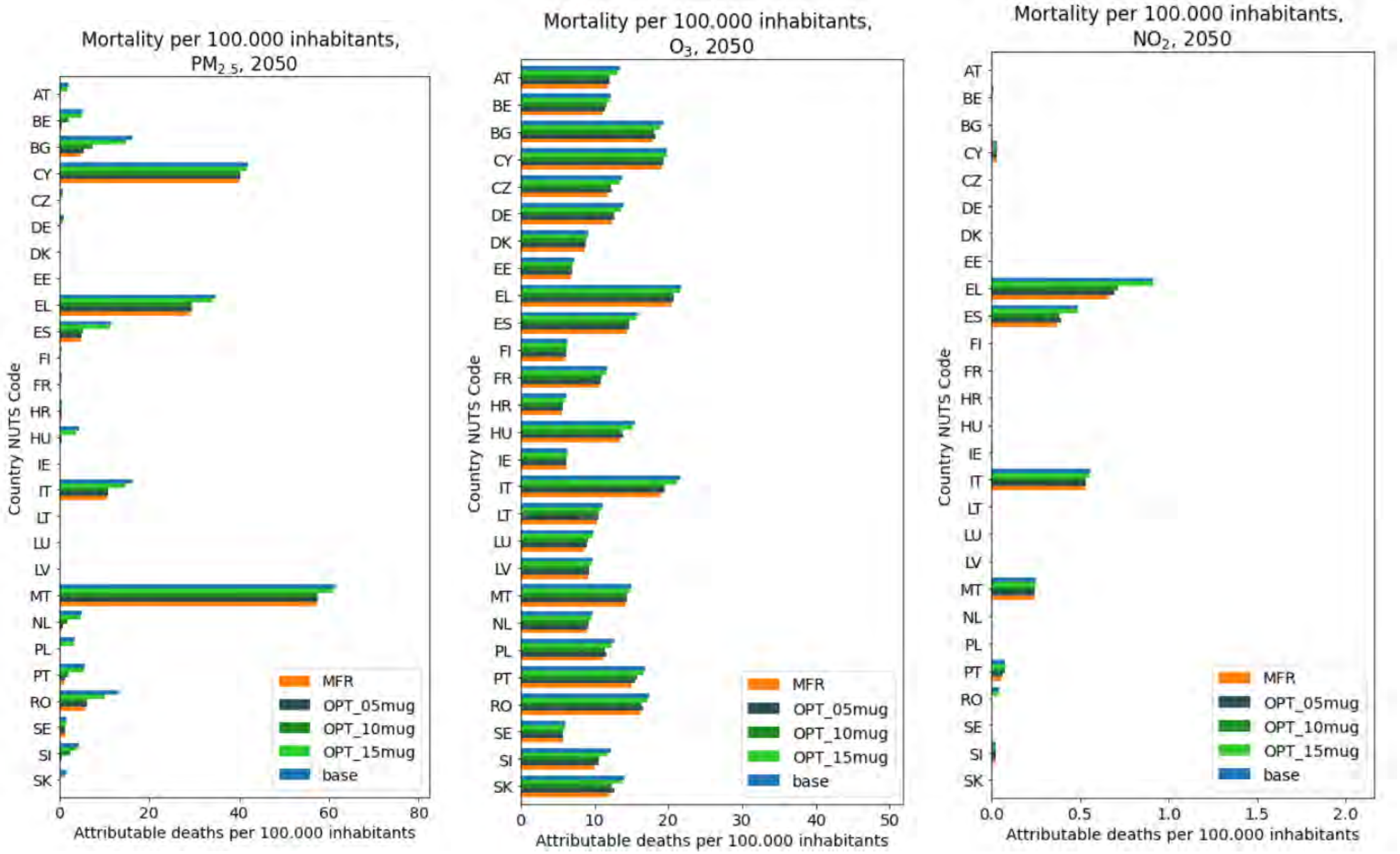


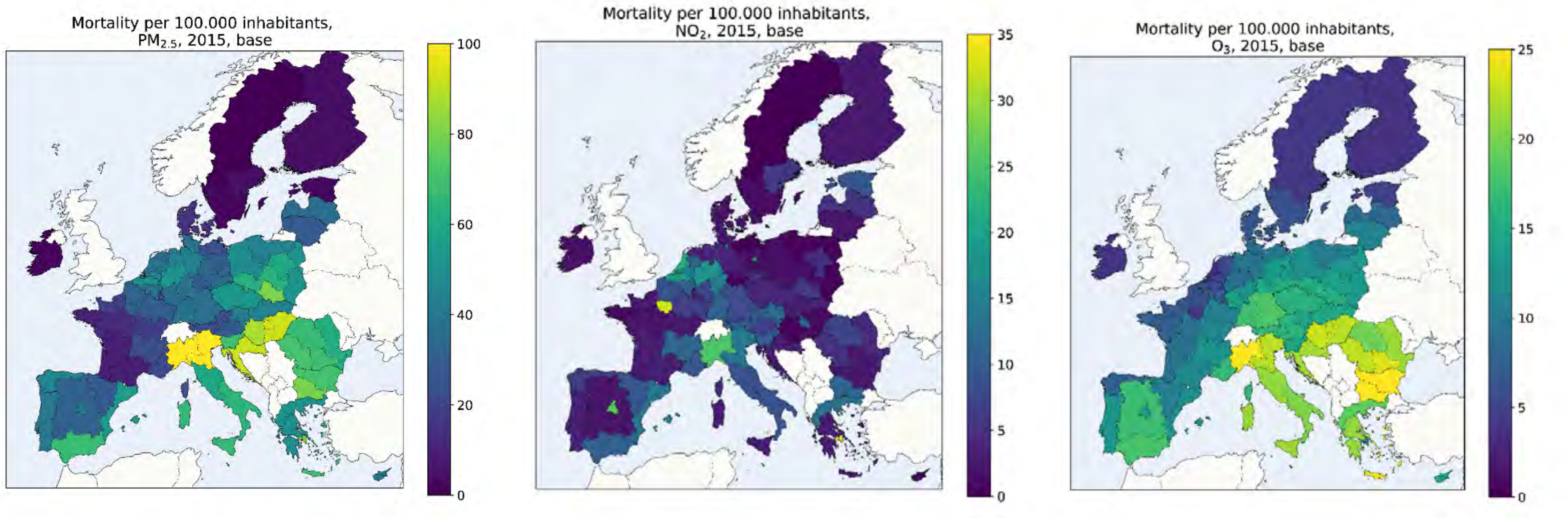
Figure A-77: Impact of all scenarios on the number of yearly premature deaths per country caused by the exposure to air pollution at levels above the WHO AQ guidelines for two pollutants ($PM_{2.5}$, left; O_3, middle; NO_2, right). Impacts for 2050.



Maps of chronic mortality per capita on NUTS1 level

2015

Figure A-78: Yearly number of premature deaths per 100.000 inhabitants caused by the exposure to air pollution at levels above the WHO AQ guidelines for three pollutants ($PM_{2.5}$, left; NO_2, middle; O_3, right). The maps show results for the baseline in 2015 per NUTS 1 region.



2030

Figure A-79: Yearly number of premature deaths per 100.000 inhabitants caused by the exposure to air pollution at levels above the WHO AQ guidelines for three pollutants ($PM_{2.5}$, left; NO_2, middle; O_3, right). The maps show results for the baseline in 2030 per NUTS 1 region.

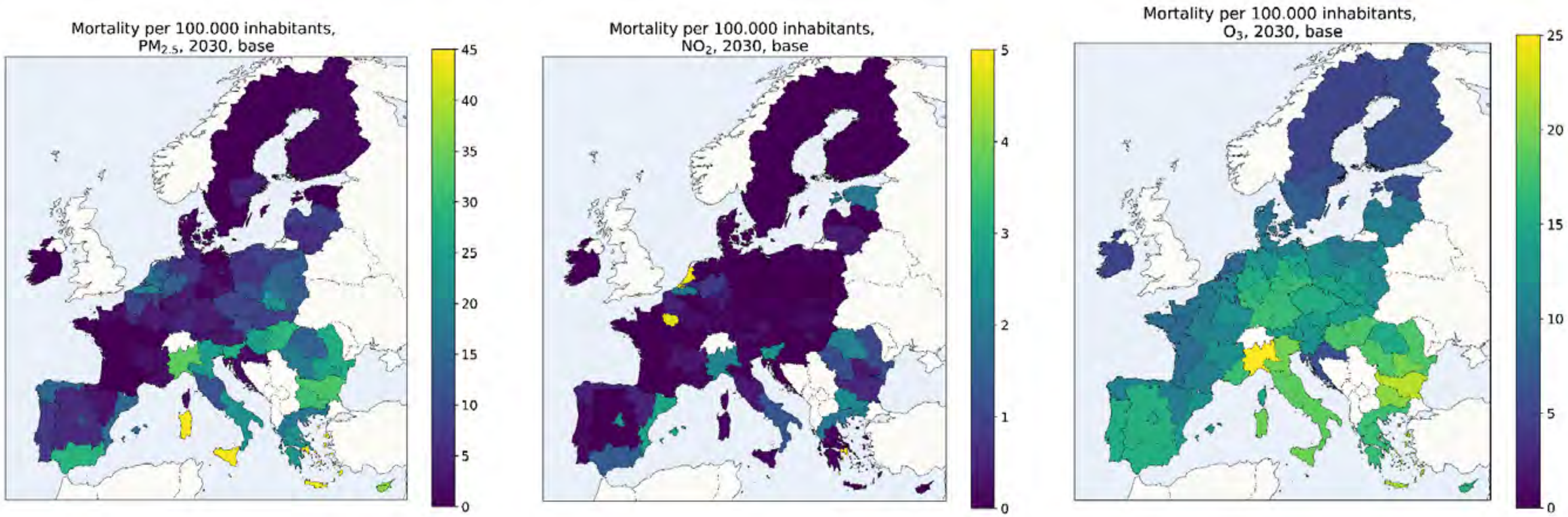


Figure A-80: Yearly number of premature deaths per 100.000 inhabitants caused by the exposure to $PM_{2.5}$ pollution at levels above the WHO AQ guidelines for three pollutants ($PM_{2.5}$, left; NO_2, middle; O_3, right). The maps show results for the MTFR scenario in 2030 per NUTS 1 region. The graphs use the same legend as the figure with the baseline results.

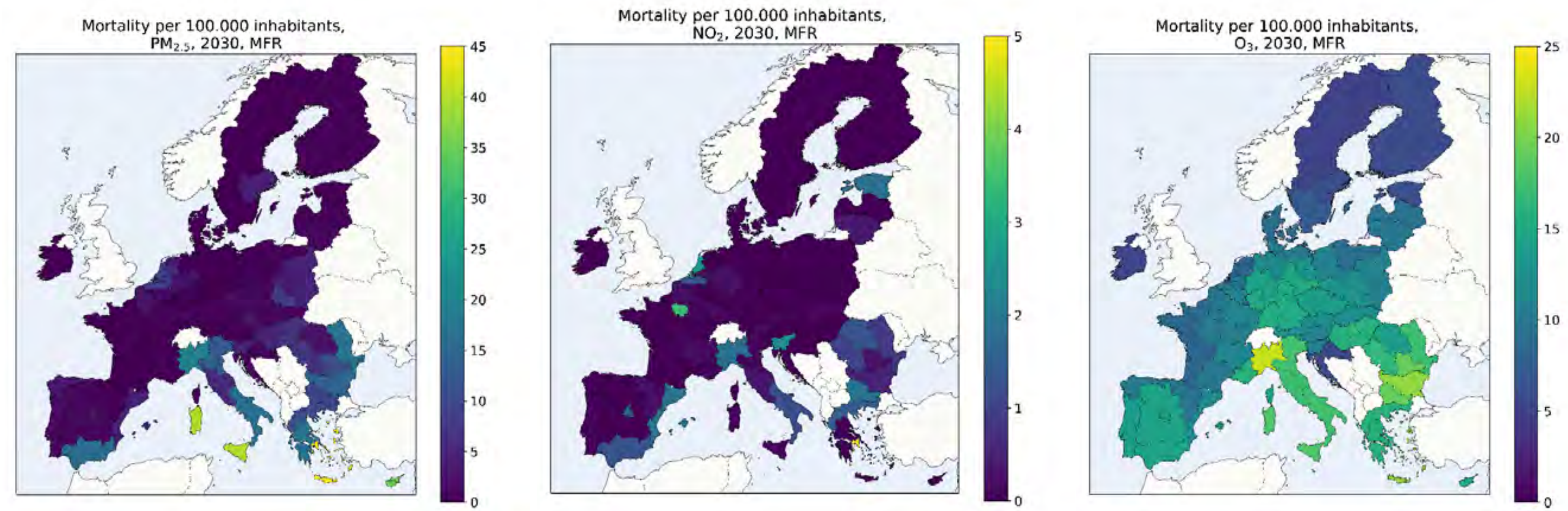


Figure A-81: Yearly number of premature deaths per 100.000 inhabitants caused by the exposure to PM$_{2.5}$ pollution at levels above the WHO AQ guidelines for three pollutants (PM$_{2.5}$, left; NO$_2$, middle; O$_3$, right). The maps show results for the OPT 05 µg/m^3 scenario in 2030 per NUTS 1 region. The graphs use the same legend as the figure with the baseline results

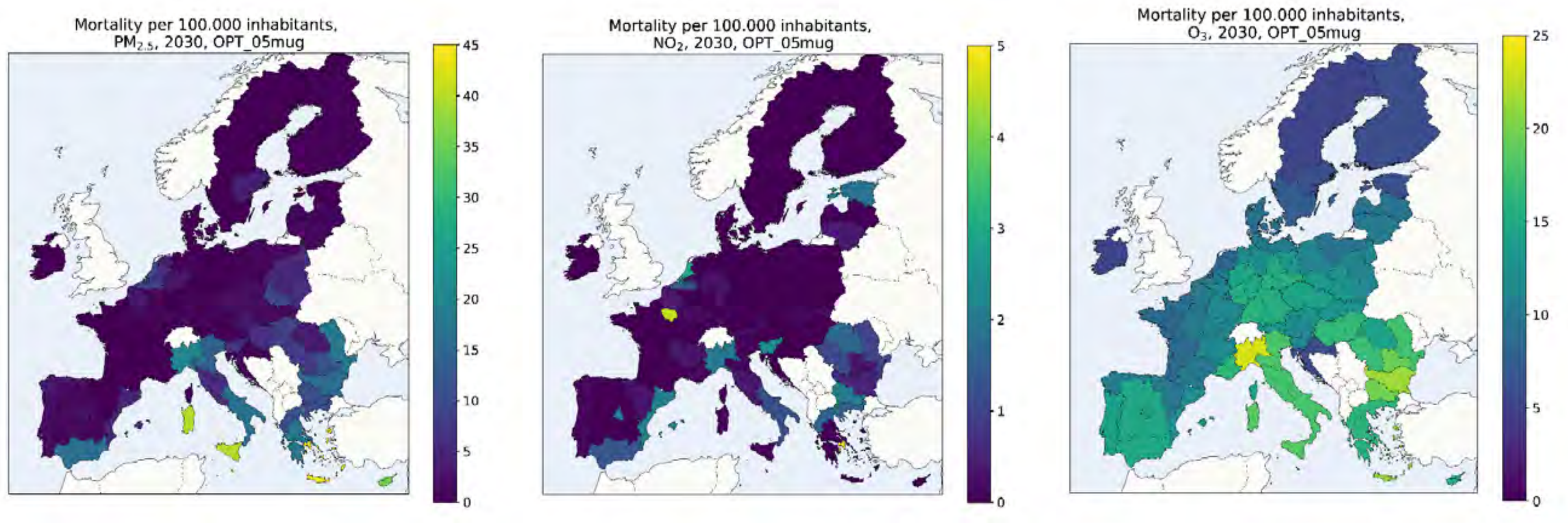


Figure A-82: Yearly number of premature deaths per 100.000 inhabitants caused by the exposure to $PM_{2.5}$ pollution at levels above the WHO AQ guidelines for three pollutants ($PM_{2.5}$, left; NO_2, middle; O_3, right). The maps show results for the OPT 10 µg/m³ scenario in 2030 per NUTS 1 region. The graphs use the same legend as the figure with the baseline results

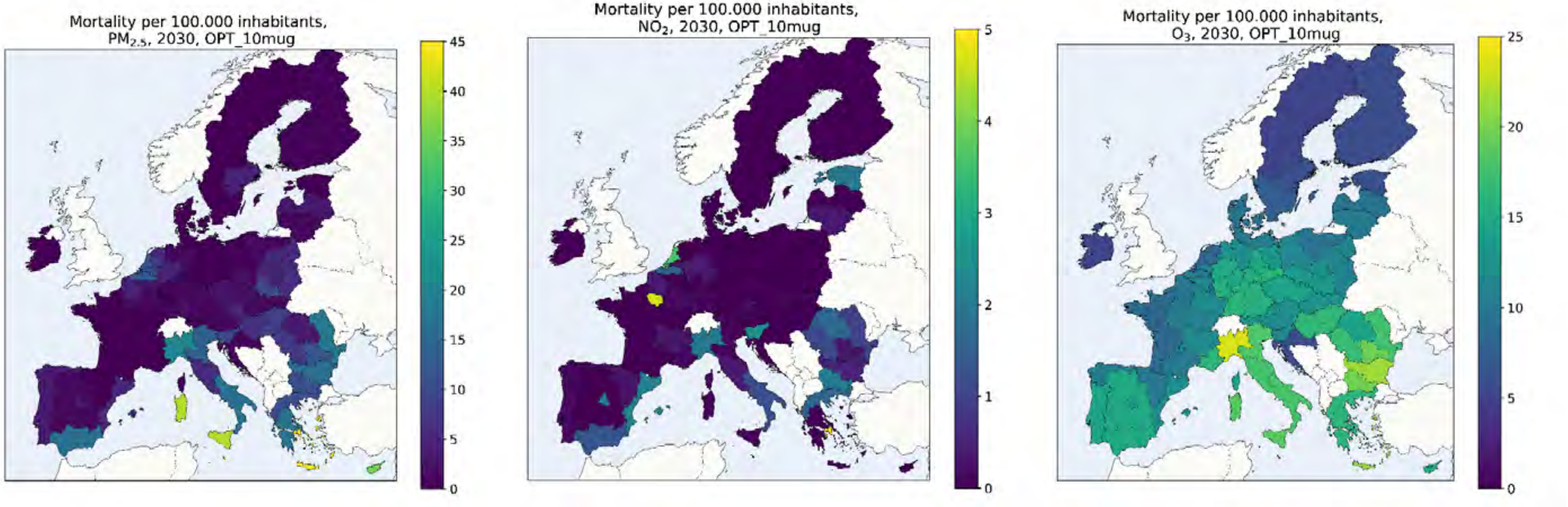


Figure A-83: Yearly number of premature deaths per 100.000 inhabitants caused by the exposure to $PM_{2.5}$ pollution at levels above the WHO AQ guidelines for three pollutants ($PM_{2.5}$, left; NO_2, middle; O_3, right). The maps show results for the OPT 15 µg/m^3 scenario in 2030 per NUTS 1 region. The graphs use the same legend as the figure with the baseline results

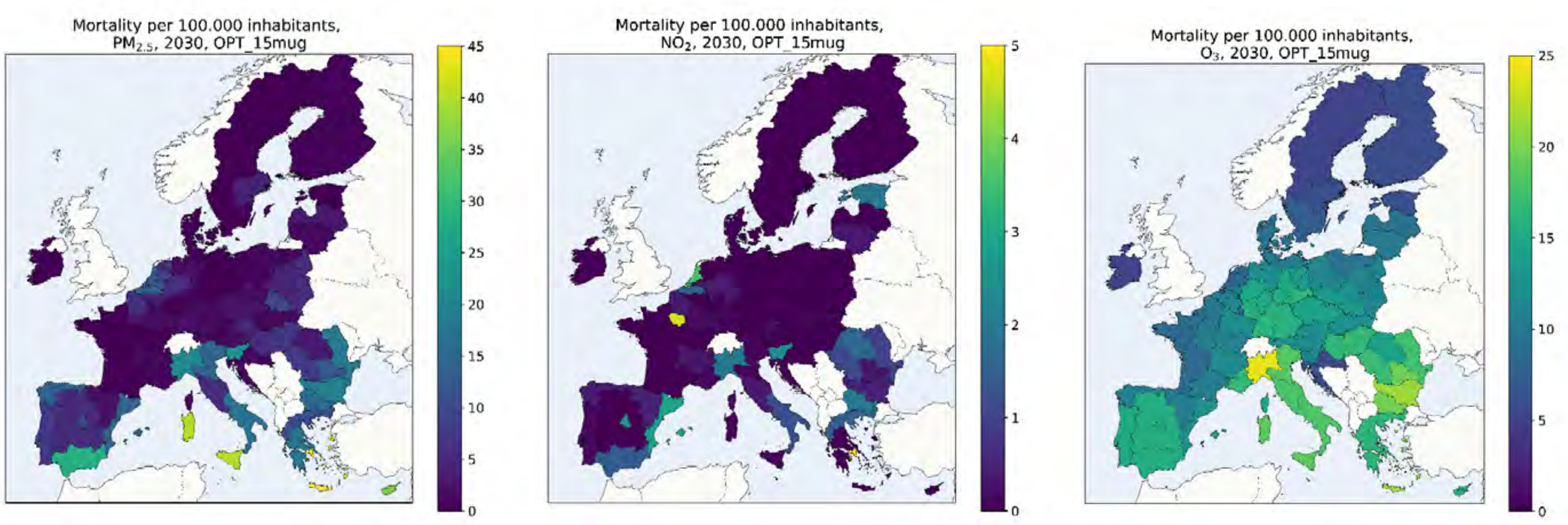
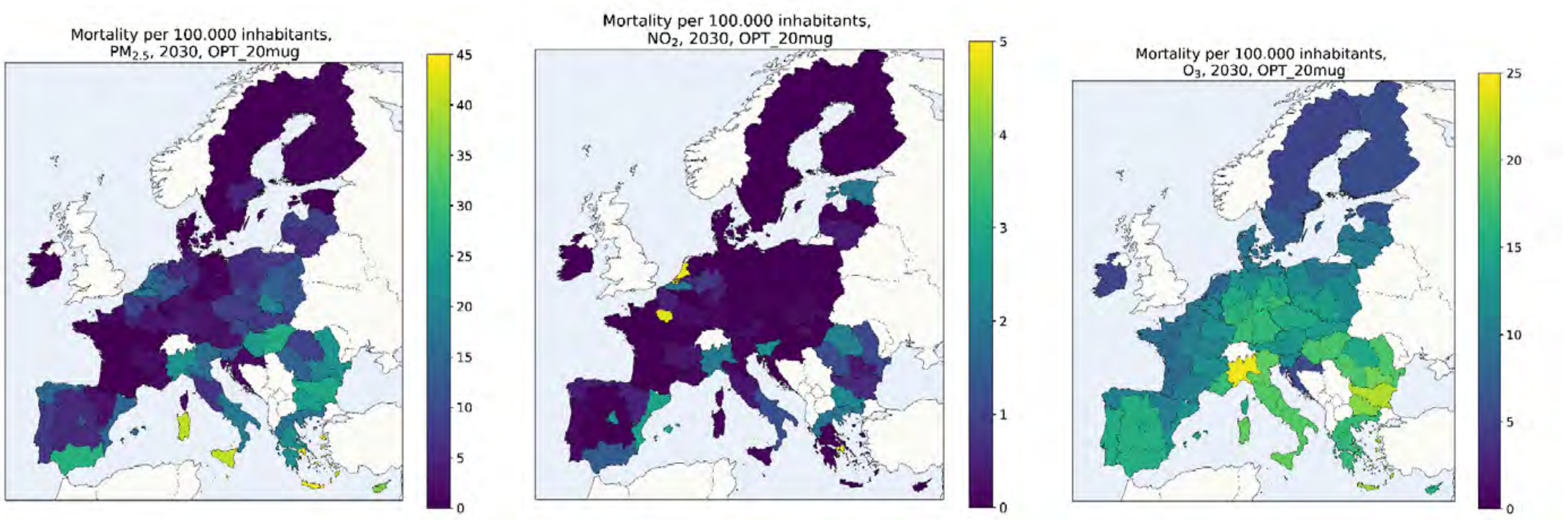


Figure A-84: Yearly number of premature deaths per 100.000 inhabitants caused by the exposure to $PM_{2.5}$ pollution at levels above the WHO AQ guidelines for three pollutants ($PM_{2.5}$, left; NO_2, middle; O_3, right). The maps show results for the OPT 20 µg/m^3 scenario in 2030 per NUTS 1 region. The graphs use the same legend as the figure with the baseline results



2050

Figure A-85: Yearly number of premature deaths per 100.000 inhabitants caused by the exposure to air pollution at levels above the WHO AQ guidelines for three pollutants ($PM_{2.5}$, left; NO_2, middle; O_3, right). The maps show results for the baseline in 2050 per NUTS 1 region.

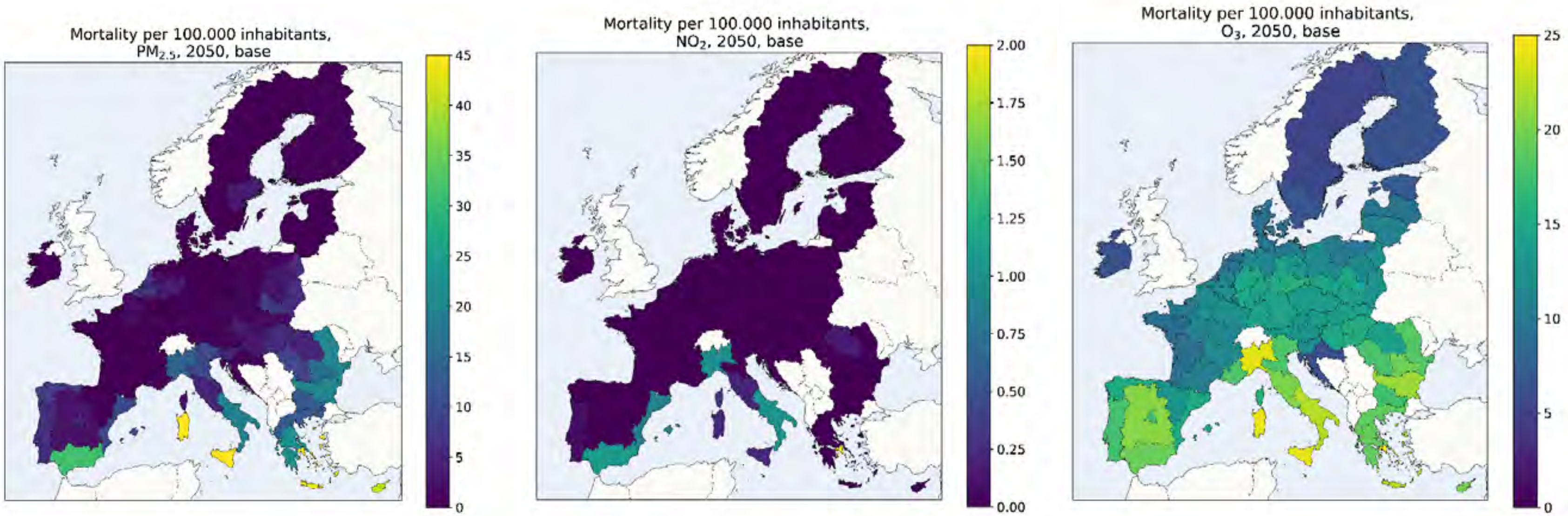


Figure A-86: Yearly number of premature deaths per 100.000 inhabitants caused by the exposure to air pollution at levels above the WHO AQ guidelines for three pollutants ($PM_{2.5}$, left; NO_2, middle; O_3, right). The maps show results for the MTFR scenario in 2050 per NUTS 1 region. The graphs use the same legend as the figure with the baseline results

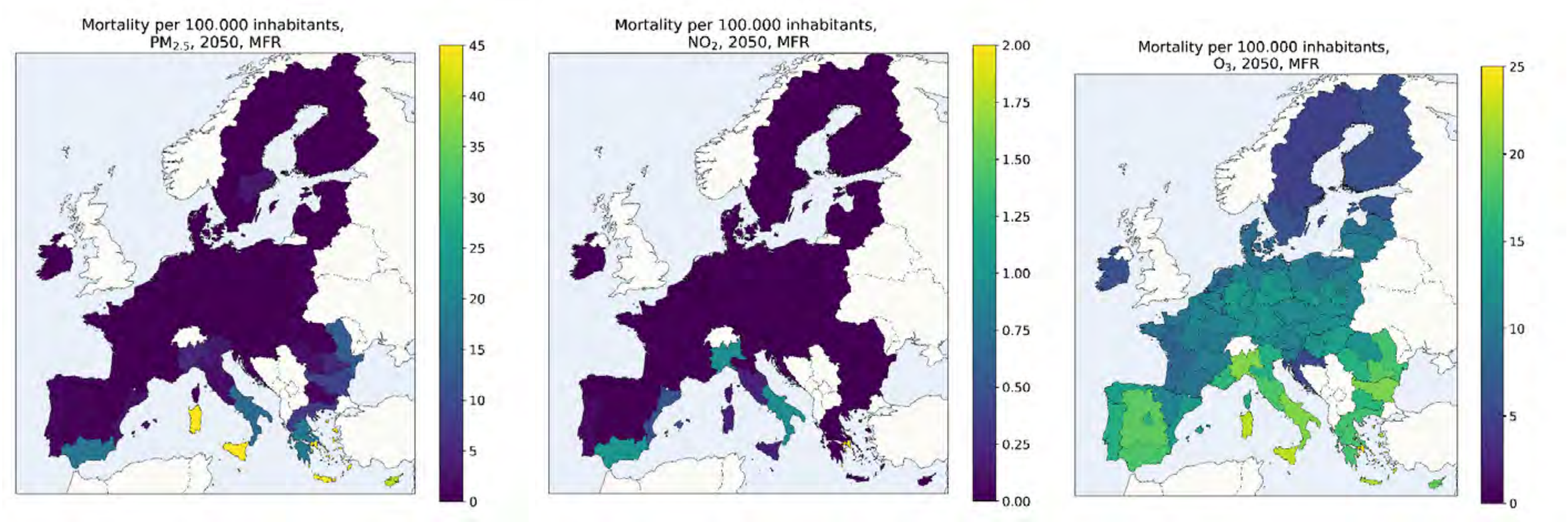


Figure A-87: Yearly number of premature deaths per 100.000 inhabitants caused by the exposure to air pollution at levels above the WHO AQ guidelines for three pollutants ($PM_{2.5}$, left; NO_2, middle; O_3, right). The maps show results for the OPT 05 µg/m^3 scenario in 2050 per NUTS 1 region. The graphs use the same legend as the figure with the baseline results

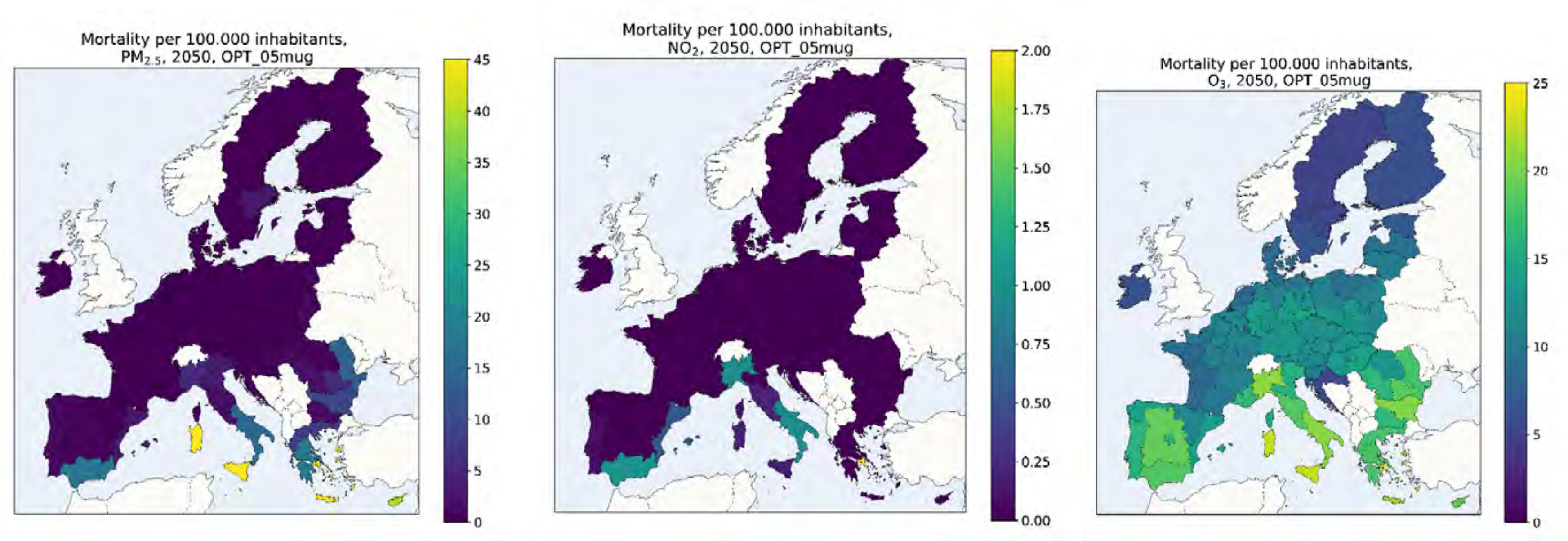


Figure A-88: Yearly number of premature deaths per 100.000 inhabitants caused by the exposure to air pollution at levels above the WHO AQ guidelines for three pollutants ($PM_{2.5}$, left; NO_2, middle; O_3, right). The maps show results for the OPT 10 µg/m^3 scenario in 2050 per NUTS 1 region. The graphs use the same legend as the figure with the baseline results

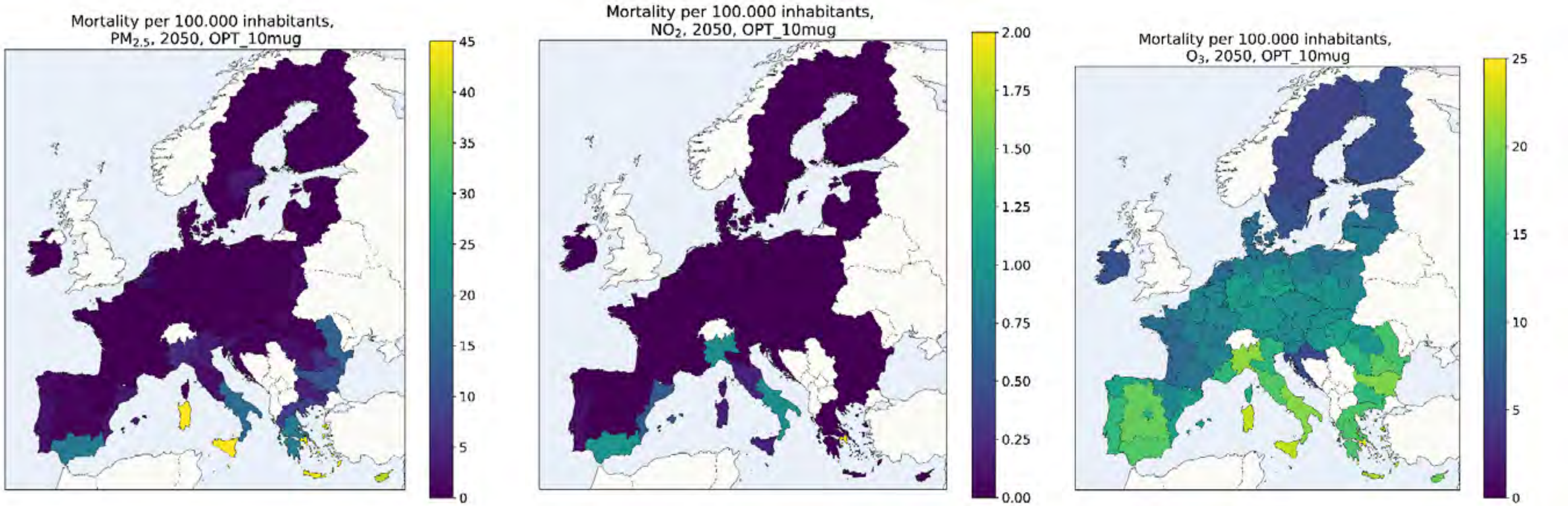
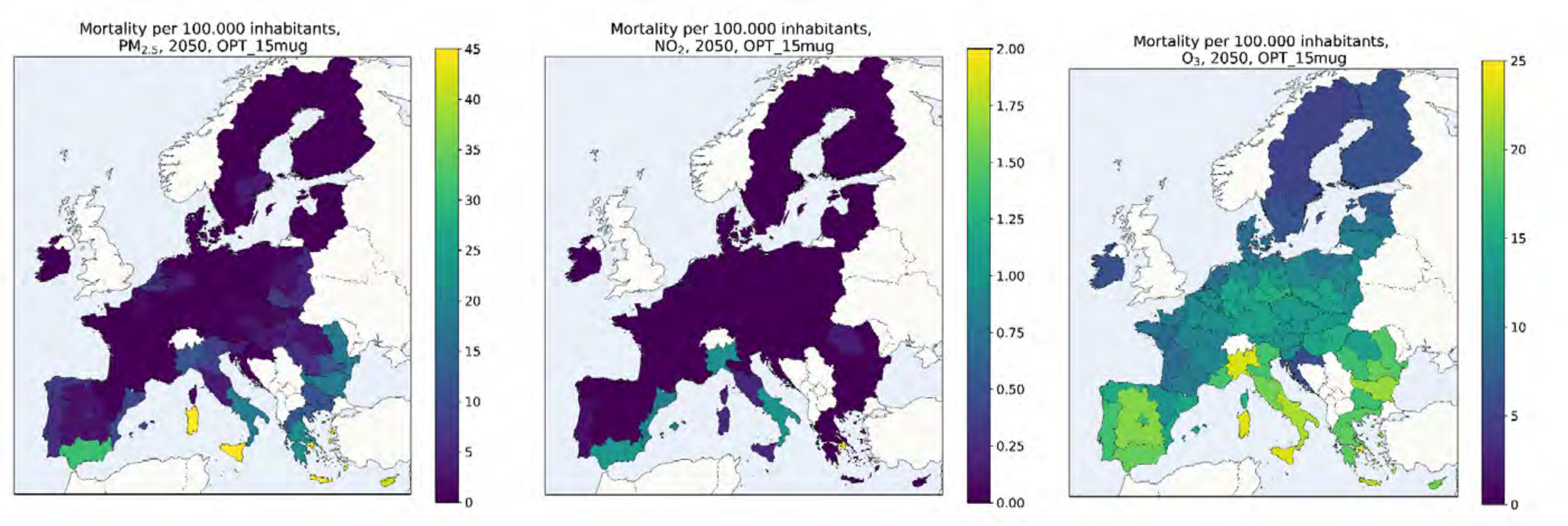


Figure A-89: Yearly number of premature deaths per 100.000 inhabitants caused by the exposure to air pollution at levels above the WHO AQ guidelines for three pollutants ($PM_{2.5}$, left; NO_2, middle; O_3, right). The maps show results for the OPT 15 µg/m^3 scenario in 2050 per NUTS 1 region. The graphs use the same legend as the figure with the baseline results



Appendix 6 - Valuation of health and non-health impacts of air pollution

Impacts on human health

Methodology

Tier 1&2 health impact pathways

Calculating the costs to society of air pollution is a means of monetising the effects of air pollution, such that they can be more readily compared to the costs of mitigation action. To estimate the costs to society, we have taken the health impacts calculated under Indicator #2 and have combined these with monetary impact values to capture the impact on: lost utility or welfare, lost labour (or productivity) and health care costs.

For human health impacts, for the relevant pathways covered under Tier 1 and 2 we have carried forward the monetary unit values applied in CAO2. As part of the CAO2 work, an extensive literature review of the latest valuation approaches (by organisations such as the OECD) was undertaken to arrive at the proposed values (European Commission, 2022). This work concluded in December 2020. No more up-to-date literature is known that would influence the approaches adopted to monetise impacts.

Table A-28 - Unit impact values applied in CAO2

Effect	2015 price year figures recommended for and used in CAO2	Main Source
Mortality – value of statistical life (VSL)	€3.6 million	Based on OECD (2012)
Mortality – value of a life year (VOLY)[9]	€94,660	Previous median estimate increased in proportion to the increase in mean VSL to reflect OECD (2012)
Infant Mortality (per death)	€5.5 million	Lower bound of OECD (2012) (factor 1.5 higher than average for adults)
Chronic Bronchitis in adults (per case)	€ 63,800	Maca (2011), Holland (2014) with concerns over severity of air pollution related bronchitis
Bronchitis in children (per event)	€358	Hunt et al (2016)
Respiratory Hospital Admissions (per case)	€4,800	Broadly mid-range from estimates and similar to DCE (2018)
Cardiac Hospital Admissions (per case)	€5,900	Broadly mid-range from estimates and similar to DCE (2018)
Restricted Activity Days (per day)	€131	Hunt et al (2016)
Work loss days (per day)	€155	Amann et al (2017)

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[9] To ensure consistency in the estimation of costs for countries with different life expectancies, we will assume the same life expectancy across Member State.

Tier 3 health impact pathways

The unit impact values were applied to the health effects assessed under Tier's 1 and 2, as defined in the preceding section. As noted, a number of additional effects were assessed under a Tier 3. These pathways went beyond those defined in WHO's HRAPIE. Although CAO2 considered and monetised some of these pathways, not all pathways were captured. As such, to inform the valuation in this impact assessment study, a targeted literature review was undertaken to support the selection of appropriate monetary impact values for these pathways.

COPD is also included as a pathway under Tier 3 of the health impact analysis. However, given the potential for overlap with chronic bronchitis, COPD is excluded from the valuation step of the analysis.

Cerebrovascular accident (CVA)

The health impact assessment has based its calculation on the incidence of health endpoints according to ICD10 codes I60-69. This includes a wide range of conditions with varying severity. The findings of this valuation review are presented in Table A-29 where values used and reviewed as part of CAO2, these are also included in the table below as a reminder.

Table A-29 - CVA valuation review (Highlighted row(s) shows values selected for analysis)

Source	Study Year	Description of method	Value	Prices
CAO2 (European Commission, 2022)	**2020**	**Average of Astrom and Ricardo**	**EUR 394,000**	**2005**
Studies reviewed as part of CAO2				
Van de Vel and Buekers	Ongoing	Per hospitalisation	EUR 33,904	
Astrom	PC		EUR 555,936 per case	2005
Ricardo	2020	QALY	£311,000 per case	2017
Other				
BenMAP (BenMAP, 2022)	2015	Direct medical costs incurred during initial hospitalisation and the 360 days following hospital discharge. The study identifies individuals experiencing a first-time stroke using ICD-9 codes 434 and 436. Estimated the average costs for nonfatal cases by weighting the costs for individuals discharged with disability and without disability by their prevalence (23 and 77 %, respectively).	USD 33,962	2015
PHE AQ tool (Public Health England, 2018)	2018	Based on prevalence Primary care, social care, medication, secondary care	£1,338 per case per year	Uncertain (likely 2015/16)
PHE ROI tool	2018	Annual social care costs Based on : Luengo-Fernandez et al., (2013)2	£7,477 per case per year	Uncertain (likely 2013)
(Saka, McGuire, & Wolfe, 2009)	2009	Captures direct, indirect health care, lost wages and benefits Also some impacts of mortality and benefit payments	~£96,000 per case per year [BACK-CALC]	2005
(Xu, et al., 2018)	2017	Ranging from £19,000 to £107,000 depending on range of factors including severity; Focuses on health and social care costs	£46,000 over five years	Uncertain
(Patel, et al., 2017)	2017	NHS medical cost, social care cost, ongoing unpaid care	£45,409 in 1st year after stroke and £24,778 in subsequent years.	2015
Rochmah et al	2021	Meta-analyses of US studies Cost of illness method – direct and indirect costs: (direct costs 86.2%, and indirect costs 13.8%). The criteria for inclusion were stroke patients, the economic burden of stroke disease based on cost of illness method	USD 1809.51-325,108.84	Uncertain (likely 2012)

Source	Study Year	Description of method	Value	Prices
(Nicholson et al., 2016)	2016	Medical costs only	$11,900 EU average;	2013
(European Heart Network, 2017)	2017	Direct health, productivity loss, informal care	EUR 10,587 per case per year	Uncertain (likely 2015)
(Ringborg, Yin, Martinell, Stålhammar, & Lindgren, 2009)	2009		Total cost EUR 19,500 (event and post event) - annual cost	2007
(Danese, et al., 2016)	2016		£4,000 short term, £700-100 longer term	2016

There is a wide range of valuation estimates in the literature. This in part reflects different methodological approaches to monetising the conditions (e.g. variance between studies considering only direct costs, versus those considering also indirect costs or adopting a QALY approach) as well as the wide range of conditions and severities captured by the pathway. It is also important to note that the studies monetise impacts based on prevalence and incidence. Those studies that only focus on direct health care costs only adopt the lowest monetary values. Those that capture wider costs, e.g. social care, lost wages, etc, tend to produce slightly higher monetary estimates. Thus, the highest estimates are those that present a more comprehensive valuation (i.e. QALY approach).

As noted, both the CRF and health impact analysis seem to consider a range of possible endpoints under this condition with a varying degree of severity. The monetary value adopted for CAO2 is at the top of the range of valuations discovered in this literature review. Although this in part reflects methodology (i.e. CAO2 captures effects other than direct costs), the CAO2 value might also be conflated with the most severe effects. Unpicking the CAO2 estimate, this is based on an average of values adopted in Ricardo and Astrom studies. Ricardo calculates its effect over 15 years, which is different to many of the other studies reviewed, which consider effects over 5 years (over 5 years, the Ricardo estimate is less than some of the other studies). Hence the CAO2 estimate is being inflated by the influence of the value used by Astrom.

Value selected: The valuation used in CAO2 appears at the top end of the range. This study has selected the valuation range proposed by Xu et al (as highlighted in the table above), and has adopted the central value. By selecting a value towards the lower end of the overall range, this seeks to balance that the pathway: covers a wide range of effects with different severities, understanding that the more severe effects are less common.

Diabetes

The following table presents the outputs of the focused literature review for diabetes.

Table A-30 – Valuation of diabetes (Highlighted row(s) shows values selected for analysis)

Source	Study Year	Description of method	Value	Prices
CAO2 (European Commission, 2022)	**2020**	**No valuation**		
Studies reviewed as part of CAO2				
Van de Vel and Buekers	Ongoing	Per incidence	EUR 13,257	2019
Ricardo	2020	Per incidence 9 year span	£183,000	2017
Other				
(PSSRU, 2021)	2022	Include some costs for diabetes, but only related to co-morbidity with depression (£858 for 6 months care) and last year of life (£15,000 hospital and social care, vs £12,150 for all people)	£858 (6 months collaborative care) + £2,900 (last year)	Uncertain (likely 2021)
(Hex, Bartlett, Wright, Taylor, & Varley, 2012)	2012	50:50 direct and indirect (sickness, presenteeism, informal care)	~£5,000 per case per year (estimated)	2010/11
(Stedman et al., 2020)	2020	Focus on medical costs, but net of ordinary person	£1,120 per case per annum	Uncertain
(Feher et al., 2016)	2016	WTP study among diabetes sufferers. Done at a symptom level, but interesting that values are fairly low: e.g. $100 for a % point reduction in mmol/mil		2014
(NHS England, 2016)	2016	Seems to use a QALY score + valuation of around £3,000 per case per year	£3,000 per case per year (estimated)	Uncertain (likely 2016)

As for CVA above, the underlying epidemiological study appears to adopt quite a wide definition of the health condition (e.g. considering diabetes and a range of pre-diagnosis effects). As such again this could signal a wide range of severities. From the literature, the range of valuation appears smaller than that of CVA (with the exception of Ricardo). The Ricardo study seems very large in comparison, although this assessed the impacts over a 9 year period.

Value selected: The estimate contained in Van del Vel seems at the low end of the valuation range. Combining the direct cost from Stedman (£1,120 pa) with the indirect cost from Hex et al (£2,500) over a 9 year duration produces a higher bound estimate of £32,600. Given the pathway is likely to represent a range of conditions with different severities, and assuming that less severe conditions are likely to be more frequent than more severe, to avoid over-estimation, we have selected a point in between (slightly negatively skewed) Van del Vel and the derived estimate.

Lung cancer

Table presents the outputs of the focused literature review for lung cancer. Given the nature of the condition, it is assumed that there is less capacity for variation in severity between pathways relative to other pathways (e.g. CVA or diabetes).

Table A-31 - Valuation of lung cancer (Highlighted row(s) shows values selected for analysis)

Source	Study Year	Description of method	Value	Prices
CAO2 (European Commission, 2022)	**2020**	**Average of DCE (2018) and Ricardo (2019)**	**EUR 24,473**	**2005**
Studies reviewed as part of CAO2				
DCE			~EUR 21,000 (DKK 163,000)	
Van de Vel and Buekers	Ongoing	Per incidence	EUR 66,609	2019
Ricardo	2020	Per incidence 1.8 year span	£49,000	2017
Other				
BenMAP	2015	Based on cost of treatment over 5 years; assume no lost earnings;	USD 33,000 / case	2015
PHE AQ tool (Public Health England, 2018)	2018	Based on prevalence Primary care, social care, medication, secondary care	£642 per case per year	Uncertain (likely 2015/16)
(Luengo-Fernandez, Leal, Gray, & Sullivan, 2013)	2013	Health care, lost working days, and informal care Study also looked at productivity losses due to mortality but excluded	All cancers £34,000 per diagnosis per year (estimated)	Uncertain
(Cancer Research UK, 2012)	2012	Medical costs	£9,071 per annum	Uncertain
(British Lung Foundation, 2017)	2017	Indirect / direct cost ratio of 12%		
(Laudicella, Walsh, Burns, & Smith, 2016)	2016	Total cost of treatment over 9 years	£25,847	2010

The studies focusing only on direct medical costs generally producer lower valuation estimates (E.g. Laudicella £25,000). Those capturing additional non-direct costs produce higher valuations, e.g. Leal et al - £68,000 over two years.

Value selected: the estimate defined in CAO2 sits within the range produced by the literature review, although towards the lower end. As such this has been carried forward for this assessment.

Myocardial infarction

Table presents the outputs of the focused literature review for myocardial infarction.

Table A-32 - Valuation of myocardial infarction (Highlighted row(s) shows values selected for analysis)

Source	Study Year	Description of method	Value	Prices
CAO2 (European Commission, 2022)	**2020**	**Average of Astrom and US EPA**	**EUR 47,000**	**2005**
Studies reviewed as part of CAO2				
Van de Vel and Buekers	Ongoing	Per incidence	EUR 17,275	2019
Astrom	PC*		EUR 27,530 per case	2005
US EPA	2011		USD 84,171	2017
Other				
BenMAP	2015	Varies depending on age and gender Comprised of medical cost (fixed across wage, ~$48k; and opportunity cost (lost earnings) $0 for those <24 rising to $113k for 55-65	USD 47,000 to 162,000 / case	2015
US EPA Cobra Tool (US EPA, 2021)	Ongoing		USD 162,169 / case	Uncertain
PHE AQ tool (Public Health England, 2018)	2018	Based on prevalence Primary care, social care, medication, secondary care	£8,275 - cost first year £2,158 - cost subsequent years	Uncertain (likely 2015/16)
(Nicholson et al., 2016)	2016	Meta-analysis; direct medical costs only	$11,664 acute MI; $5,966 average for Europe	2013
(European Heart Network, 2017)	2017	Direct health, productivity loss, informal care; outpatient and inpatient visits For angina and first acute myocardial infarction	EUR 3,450 per IHD case (estimated)	Uncertain (likely 2015)
(Tiemann, 2008)	2008	Meta-review of AMI medical costs across Europe EUR 400 in Hungary to EUR 7,500 in Italy: average EUR 3800	EUR 3,800 average	Uncertain
(Hakkinen et al., 2012)	2012	Meta-review of AMI medical costs across Europe	EUR 4,400 – 6,400	Uncertain
(Ringborg, Yin, Martinell, Stålhammar, & Lindgren, 2009)	2009	Inpatient and non-inpatient costs	EUR 10,035	2007
(Bishu et al., 2020)	2020	Additional medical $7,000 Reduction in annual wage $10,200 US study	USD 17,200	2016
(Danese, et al., 2016)	2016	Medical costs	£4300 short term, £900 - 1400 longer term	2016

*Personal communication

The majority of the studies reviewed identified focus only on direct medical costs. Medical costs in the EU appear somewhat lower than in the US (e.g. comparing the study by Bishu to that of the US EPA). Indeed the medical costs of BenMap seem a lot higher than all other studies. It is noted that the values used in CAO2 were an average of Astrom and the US EPA.

Value selected: Based on the review, it appears that valuation in the EU is lower than that in the US. CAO2 adopted an average of Astrom and US EPA. To mitigate the risk that using the US EPA study could inflate costs in Europe, we opt to revert to using the values from Astrom directly.

Asthma children

Table A-33 presents the outputs of the focused literature review for asthma in children.

Table A-33 - Valuation of asthma in children (Highlighted row(s) shows values selected for analysis)

Source	Study Year	Description of method	Value	Prices
CAO2 (European Commission, 2022)	**2020**		**EUR 4 per bronchillator use** **EUR 42 per symptom day**	**2005**
Studies reviewed as part of CAO2				
Hunt et al	2016		EUR 464	2010
DG MOVE			Bronchodilator use EUR1 / day Lower respiratory symptoms (adults and children) / cough days / lower respiratory symptoms excl. cough EUR38 / day	Uncertain (likely 2007)
Van de Vel and Buekers	Ongoing		Asthma incidence (0-19) EUR 2,768 Days with asthma symptoms EUR 52	2019
DCE			Bronchodilator use DKK 167 /case Cough DKK 316 / day Lower resp. symptoms DKK 91 / day	
Ricardo	2020		£499,000 per incidence	2017
Health Canada			Asthma symptom days 9.8 - 168 CAN$	
US EPA	2011		$369 - emergency room visit for asthma $54 asthma exacerbation	2017
Other				
BenMAP	2015		$17,232 - new asthma onset 0-17 age $219 - cough / day 0-17 age use of inhaler $0.35	2015
US COBRA tool	Ongoing		Lower resp. symptoms $27 Emergency room visit asthma $562 Asthma exacerbation $74	Uncertain
(Mussio, Brandt, & Hanemann, 2021)	2007		WTP for a device that reduces a child's asthma symptoms by 50% is $125/month (s.d. $20).	Uncertain (likely 2007)
(Brandt, Lavin, & Hanemann, 2012)	2012		Mean household WTP for a 50% reduction in symptom-days (and accompanying reductions in psychosocial stress) at $56.48 to $64.84 per month	Uncertain (likely 2012)
(Hanemann & Brandt, 2006)	2006	The mean WTP in the traditional parametric model is $68.50/month. By extending the spike model of Kriström (1997) to the one-and one-half bounded case we get a mean WTP of $63/month. Using two alternative hypothetical drugs to treat symptoms, O'Conor & Blomquist estimate a willingness to pay of approximately $1,300 to $4,900 a year for a 100% reduction in symptoms.	The lower-bound mean WTP for a 50% reduction in symptoms using the Turnbull estimator is $66.73/month, or a conservative estimate of $696/year, for a mean reduction of 96 days and 30 nights a year.	Uncertain
(Mukherjee et al., 2016)	2016	Medical costs per annum	£185 / case (estimated)	Uncertain
(Perry et al., 2019)	2019	Medical costs	USD total direct costs $3,100 - 13,600 average annual	2013
(AAFA, 2015)	Website		Total direct cost $3,260 per year per person	2009

The literature contains valuations for a range of different conditions – the health impact assessment has focused on incidence, rather than say symptom days, so those studies considering incidence are most relevant. Those studies valuing a change in incidence produce a wide range, from the low bound estimate of Van del Vel (EUR 2,800) to the very high estimate by Ricardo £499,000. The valuation studies concerning incidence also vary in their specification – e.g. some look at WTP to avoid a month of symptoms. The WTP valuations (once normalised in terms of duration) appear at the higher end of the range, and based on the valuation and described symptoms, could be conflated with more serious conditions.

Value selected: The pathway again is likely to reflect a wide range of conditions with varying severity, making valuation challenging. Van de Vel is at the lower end of the valuation range, and hence is likely to represent those suffering a short illness or only mild symptoms. The valuation assumed in BenMap is higher, and more towards the middle of the valuation range (hence potentially conflating with a moderate illness). Assuming that less severe conditions are likely to be more frequent than more severe, to avoid over-estimation, we have selected a value within the range of Van del Vel to BenMap (with a slight negative skew).

Results

The following tables present the results of the valuation of the human health impact pathways.

Table A-34 -Value of health impacts per annum- Baseline scenario (all values €m 2015 prices, EU27)

Health outcome	Pollutant	2020	2030	2050
Mortality (VOLY)	$PM_{2.5}$	462,741	202,004	99,252
Mortality (VOLY)	NO_2	76,483	14,570	2,423
Mortality (VOLY)	O_3	237,127	225,991	226,205
Mortality (VSL)	$PM_{2.5}$	140,228	58,418	25,257
Mortality (VSL)	NO_2	23,037	4,294	603
Mortality (VSL)	O_3	71,686	65,605	58,113
Infant Mortality	$PM_{2.5}$	336	83	17
Bronchitis Children	$PM_{2.5}$	59	22	9
Bronchitis Adults	$PM_{2.5}$	3,662	1,563	683
Cardiovascular Hospital Admissions	$PM_{2.5}$	216	83	32
Respiratory Hospital Admissions	$PM_{2.5}$	175	70	28
Restricted Activity Days	$PM_{2.5}$	18,733	7,795	3,354
Work Days Lost	$PM_{2.5}$	8,386	3,286	1,280
CVA	$PM_{2.5}$	2,767	1,128	469
Diabetes Mellitus Type2	$PM_{2.5}$	1,316	545	235
Lung cancer	$PM_{2.5}$	301	127	54
Asthma Children	$PM_{2.5}$	441	164	66
Myocardial Infarction	$PM_{2.5}$	2,802	1,111	443
COPD	$PM_{2.5}$	-	-	-
TOTALS				
Total (mortality valued using VSL)		739,061	443,971	332,125
Total (mortality valued using VOLY)		251,107	139,999	90,039

Note: Totals include $PM_{2.5}$ and O_3 mortality pathways, and all morbidity pathways (Tier 2 and 3); NO_2 excluded due to potential overlaps with $PM_{2.5}$

Table A-35 – Value of health impacts per annum – OPT20 (all values €m 2015 prices, EU27)

Health outcome	Pollutant	2020	2030	2050
Mortality (VOLY)	$PM_{2.5}$	-	171,955	-
Mortality (VOLY)	NO_2	-	14,288	-
Mortality (VOLY)	O_3	-	222,554	-
Mortality (VSL)	$PM_{2.5}$	-	49,887	-
Mortality (VSL)	NO_2	-	4,216	-
Mortality (VSL)	O_3	-	64,631	-
Infant Mortality	$PM_{2.5}$	-	72	-
Bronchitis Children	$PM_{2.5}$	-	19	-
Bronchitis Adults	$PM_{2.5}$	-	1,333	-
Cardiovascular Hospital Admissions	$PM_{2.5}$	-	70	-
Respiratory Hospital Admissions	$PM_{2.5}$	-	60	-
Restricted Activity Days	$PM_{2.5}$	-	6,668	-
Work Days Lost	$PM_{2.5}$	-	2,806	-
CVA	$PM_{2.5}$	-	953	-
Diabetes Mellitus Type2	$PM_{2.5}$	-	462	-
Lung cancer	$PM_{2.5}$	-	109	-
Asthma Children	$PM_{2.5}$	-	142	-
Myocardial Infarction	$PM_{2.5}$	-	940	-
COPD	$PM_{2.5}$	-	-	-
TOTALS				
Total (mortality valued using VSL)		-	408,142	-
Total (mortality valued using VOLY)		-	128,151	-

Note: Totals include $PM_{2.5}$ and O_3 mortality pathways, and all morbidity pathways (Tier 2 and 3); NO_2 excluded due to potential overlaps with $PM_{2.5}$; '-' denotes not modelled

Table A-36 – Value of health impacts per annum – OPT15 (all values €m 2015 prices, EU27)

Health outcome	Pollutant	2020	2030	2050
Mortality (VOLY)	$PM_{2.5}$	-	124,646	91,679
Mortality (VOLY)	NO_2	-	12,780	2,409
Mortality (VOLY)	O_3	-	217,652	222,681
Mortality (VSL)	$PM_{2.5}$	-	35,653	23,267
Mortality (VSL)	NO_2	-	3,777	599
Mortality (VSL)	O_3	-	63,187	57,207
Infant Mortality	$PM_{2.5}$	-	50	17
Bronchitis Children	$PM_{2.5}$	-	13	8
Bronchitis Adults	$PM_{2.5}$	-	989	630
Cardiovascular Hospital Admissions	$PM_{2.5}$	-	47	29
Respiratory Hospital Admissions	$PM_{2.5}$	-	42	26
Restricted Activity Days	$PM_{2.5}$	-	4,913	3,092
Work Days Lost	$PM_{2.5}$	-	1,969	1,183
CVA	$PM_{2.5}$	-	652	425
Diabetes Mellitus Type2	$PM_{2.5}$	-	341	218
Lung cancer	$PM_{2.5}$	-	78	50
Asthma Children	$PM_{2.5}$	-	100	61
Myocardial Infarction	$PM_{2.5}$	-	641	403
COPD	$PM_{2.5}$	-	-	-
TOTALS				
Total (mortality valued using VSL)		-	352,133	320,500
Total (mortality valued using VOLY)		-	108,675	86,614

Note: Totals include $PM_{2.5}$ and O_3 mortality pathways, and all morbidity pathways (Tier 2 and 3); NO_2 excluded due to potential overlaps with $PM_{2.5}$; '-' denotes not modelled

Table A-37 – Value of health impacts per annum – OPT10 (all values €m 2015 prices, EU27)

Health outcome	Pollutant	2020	2030	2050
Mortality (VOLY)	$PM_{2.5}$	-	102,201	54,078
Mortality (VOLY)	NO_2	-	12,201	2,083
Mortality (VOLY)	O_3	-	215,277	208,184
Mortality (VSL)	$PM_{2.5}$	-	29,124	13,596
Mortality (VSL)	NO_2	-	3,604	515
Mortality (VSL)	O_3	-	62,506	53,487
Infant Mortality	$PM_{2.5}$	-	39	6
Bronchitis Children	$PM_{2.5}$	-	11	5
Bronchitis Adults	$PM_{2.5}$	-	798	370
Cardiovascular Hospital Admissions	$PM_{2.5}$	-	39	16
Respiratory Hospital Admissions	$PM_{2.5}$	-	33	14
Restricted Activity Days	$PM_{2.5}$	-	3,969	1,808
Work Days Lost	$PM_{2.5}$	-	1,581	659
CVA	$PM_{2.5}$	-	553	248
Diabetes Mellitus Type2	$PM_{2.5}$	-	276	128
Lung cancer	$PM_{2.5}$	-	64	29
Asthma Children	$PM_{2.5}$	-	81	34
Myocardial Infarction	$PM_{2.5}$	-	540	232
COPD	$PM_{2.5}$	-	-	-
TOTALS				
Total (mortality valued using VSL)		-	325,462	265,810
Total (mortality valued using VOLY)		-	99,613	70,631

Note: Totals include $PM_{2.5}$ and O_3 mortality pathways, and all morbidity pathways (Tier 2 and 3); NO_2 excluded due to potential overlaps with $PM_{2.5}$; '-' denotes not modelled

Table A-38 – Value of health impacts per annum – OPT5 (all values €m 2015 prices, EU27)

Health outcome	Pollutant	2020	2030	2050
Mortality (VOLY)	$PM_{2.5}$	-	94,745	51,499
Mortality (VOLY)	NO_2	-	11,687	2,085
Mortality (VOLY)	O_3	-	214,487	208,154
Mortality (VSL)	$PM_{2.5}$	-	27,006	12,938
Mortality (VSL)	NO_2	-	3,455	515
Mortality (VSL)	O_3	-	62,283	53,497
Infant Mortality	$PM_{2.5}$	-	39	6
Bronchitis Children	$PM_{2.5}$	-	10	4
Bronchitis Adults	$PM_{2.5}$	-	740	352
Cardiovascular Hospital Admissions	$PM_{2.5}$	-	36	15
Respiratory Hospital Admissions	$PM_{2.5}$	-	30	14
Restricted Activity Days	$PM_{2.5}$	-	3,668	1,716
Work Days Lost	$PM_{2.5}$	-	1,432	617
CVA	$PM_{2.5}$	-	519	234
Diabetes Mellitus Type2	$PM_{2.5}$	-	254	122
Lung cancer	$PM_{2.5}$	-	59	27
Asthma Children	$PM_{2.5}$	-	75	32
Myocardial Infarction	$PM_{2.5}$	-	503	219
COPD	$PM_{2.5}$	-	-	-
TOTALS				
Total (mortality valued using VSL)		-	316,597	263,012
Total (mortality valued using VOLY)		-	96,655	69,794

Note: Totals include $PM_{2.5}$ and O_3 mortality pathways, and all morbidity pathways (Tier 2 and 3); NO_2 excluded due to potential overlaps with $PM_{2.5}$; '-' denotes not modelled

Table A-39 - Value of health impacts per annum - MTFR scenario (all values €m 2015 prices, EU27)

Health outcome	Pollutant	2020	2030	2050
Mortality (VOLY)	$PM_{2.5}$	-	87,116	49,145
Mortality (VOLY)	NO_2	-	10,284	2,031
Mortality (VOLY)	O_3	-	208,772	203,203
Mortality (VSL)	$PM_{2.5}$	-	24,747	12,332
Mortality (VSL)	NO_2	-	3,026	502
Mortality (VSL)	O_3	-	60,617	52,217
Infant Mortality	$PM_{2.5}$	-	33	6
Bronchitis Children	$PM_{2.5}$	-	9	4
Bronchitis Adults	$PM_{2.5}$	-	683	336
Cardiovascular Hospital Admissions	$PM_{2.5}$	-	33	14
Respiratory Hospital Admissions	$PM_{2.5}$	-	27	13
Restricted Activity Days	$PM_{2.5}$	-	3,380	1,638
Work Days Lost	$PM_{2.5}$	-	1,300	587
CVA	$PM_{2.5}$	-	474	223
Diabetes Mellitus Type2	$PM_{2.5}$	-	235	117
Lung cancer	$PM_{2.5}$	-	55	26
Asthma Children	$PM_{2.5}$	-	68	31
Myocardial Infarction	$PM_{2.5}$	-	456	208
COPD	$PM_{2.5}$	-	-	-
TOTALS				
Total (mortality valued using VSL)		-	302,641	255,550
Total (mortality valued using VOLY)		-	92,117	67,751

Note: Totals include $PM_{2.5}$ and O_3 mortality pathways, and all morbidity pathways (Tier 2 and 3); NO_2 excluded due to potential overlaps with $PM_{2.5}$; '-' denotes not modelled

Impacts on materials and the environment

As for human health, detrimental impacts of exposure to air pollution on the environment carries with it a societal cost. Methods have been developed over many years to monetise these impacts, such that they can be compared (alongside the human health effects) to the costs of mitigation. The approaches to monetise these impacts in this study are the same as those deployed under CAO2.

Damage to building materials was extensively researched in the 1980s and 1990s. Although research in the area continues, it is less active now than previously. Damage values per unit emission for SO_2 and NOx have been taken from the CASES study (University of Stuttgart, 2008).

The analysis of pollution and ***damage to crops*** considers all agricultural crop production in the EU, focussing on the effects of ozone. Methods are taken from the ECLAIRE study (Holland et al, 2015), drawing particularly on evidence generated through the Working Group on Effects under the Convention on Long Range Transboundary Air Pollution. The tool developed in ECLAIRE was updated for the CAO2 analysis, using agricultural production in 2018 for the baseline. The base year for production is held constant through the period of assessment, though it is acknowledged that production patterns across Europe may change in the period to 2050 as a consequence of climate change and other changes. No account is taken of impacts that may affect production of animals and associated products (milk, eggs, honey, wool).

The analysis of ***forest damage*** takes account of ozone impacts leading to reduced productivity of wood for sale and of reduced carbon sequestration. Methods are again taken from the ECLAIRE study (Holland et al, 2015). Changes in productivity are valued against market data. Changes in carbon sequestration are valued using recommendations from the Handbook on the External Cost of Transport (EC, 2019). These recommendations are to apply marginal carbon mitigation costs of €100/t CO2 up to 2030 and €269/tonne thereafter (2016 prices). Low and high variants were applied in the quantification of forest damage, with the Low estimate based on the application of carbon mitigation costs of €100/t CO2 throughout, and the High estimate applying carbon mitigation costs of €269/t CO2 from 2030 onwards.

Economic analysis of ***ecosystem damage*** is also based on the ECLAIRE study. It assesses impacts related to terrestrial ecosystems only. ECLAIRE used three methods to estimate damage costs for ecosystems, a willingness to pay (WTP) approach based on the results of research by Christie et al (2006, 2011, 2012), a repair cost approach described by Ott et al (Ott et al, 2006) and a 'regulatory revealed preference' approach (developed in the ECLAIRE study). The focus of analysis is on exceedance of the critical load or nitrogen in Natura 2000 sites, with valuation applied to the area subject to critical loads exceedance. No account was taken of exceedance of the critical load for acidification because the area concerned is far less than that affected by eutrophication and there is potential for double counting if results for both effects are combined. The WTP based approach is adopted here as the preferred option because it is consistent with that used for other impacts assessed in this report. Uncertainties in the methods used in ECLAIRE led to the use of a factor 3 variation between low and high estimates of damage.

Appendix 7 - Societal impacts and impacts on vulnerable groups

Distribution of costs

Overview

The costs of pollution to society are of two kinds: the costs which arise if no action is taken to address pollution, and the costs which arise if action is taken. The former relate to impacts resulting from the detrimental effects of pollution on human health and the environment. The latter relate to efforts made to reduce or eliminate the pollution source and/or mitigate its effects. The magnitude or impact of both these benefits and costs varies, affecting different groups, sectors and countries differently, according to a series of parameters or indicators. Impacts could vary at the:

- Member State level: EU countries (with different GDPs, employment levels, sectors, etc.) could be affected differently by costs as they would have to implement different mitigation measures.
- Sectoral level: different commercial sectors (i.e. industry, agriculture) could be impacted differently by these costs, which may have an onward impact on employment levels and wages.
- Household and social level: households with different income and education levels and age profile (i.e. elderly people, children) could also be affected in different ways.

It is important to note that these societal impacts, particularly the mitigation costs borne by different sectors and members of society, will crucially depend on (and can be mitigated or even compensated to a certain extent by) the specific policies, regulations or incentives put in place to deliver the mitigation actions. ***Any distributional effects will depend both on the technical abatement measures, and the policies and funding mechanisms to deliver them***. Further to this, air pollution ***abatement measures would not only bring about certain costs, but also a number of benefits and opportunities to many sectors and vulnerable members of society***.

Member State level

Air quality plans are a principal tool used by authorities to improve air quality, reduce emissions of air pollutants, and deliver benefits to public health. However, the implementation of these plans and the mitigation measures they contain come at certain monetary costs.

The detailed modelling undertaken as part of this study (and presented elsewhere in this report in further detail) estimates that the overall EU27 costs of air pollution mitigation measures in the baseline to 2030 will be around 80 billion €/year in 2025 and 2030. These costs are expected to decline to about to 30 billion €/year in 2050.

More importantly for the present analysis, these costs are unevenly distributed across Member States. Germany, France, Italy, Spain, and Poland are estimated to be the top five Member States who are estimated to bear the highest costs (between around 7.0 to 12.8 bn euros per year in 2030); while Latvia, Estonia, Luxembourg, Cyprus and Malta would bear the lowest (between 60 and 230 mn euros per year in 2030).

Going into further details, Table A-40**Error! Reference source not found.** below provides an overview of how these costs could impact each Member State under the different modelled policy scenarios.

Table A-40 - Air pollution abatement measure costs in 2030 (€bn)

	OPT20	OPT15	OPT10	OPT5	MTFR
Austria	0.00	0.03	0.03	0.21	0.58
Belgium	0.00	0.03	0.03	0.21	0.43
Bulgaria	0.00	0.08	0.14	0.14	0.34
Croatia	0.00	0.04	0.13	0.11	0.26
Cyprus	0.00	0.00	0.01	0.01	0.04
Czech Rep.	0.00	0.11	0.16	0.23	0.88
Denmark	0.00	0.02	0.01	0.12	0.60
Estonia	0.00	0.01	0.00	0.03	0.09
Finland	0.00	0.02	0.02	0.10	0.78
France	0.00	0.03	0.86	1.01	3.78
Germany	0.00	0.36	0.42	1.06	4.09
Greece	0.00	0.19	0.16	0.17	0.73
Hungary	0.00	0.26	0.19	0.16	0.56
Ireland	0.00	0.00	0.00	0.02	0.34
Italy	0.45	0.55	1.02	0.91	2.04
Latvia	0.00	0.01	0.01	0.04	0.17
Lithuania	0.00	0.10	0.10	0.09	0.26
Luxembourg	0.00	0.00	0.00	0.00	0.05
Malta	0.00	0.00	0.00	0.00	0.01
Netherlands	0.00	0.02	0.02	0.17	0.75
Poland	0.00	0.97	0.90	0.71	2.31
Portugal	0.00	0.00	0.02	0.10	0.51
Romania	0.09	0.39	0.43	0.42	1.04
Slovakia	0.00	0.07	0.07	0.06	0.33
Slovenia	0.01	0.01	0.01	0.04	0.12
Spain	0.00	0.00	0.81	0.82	2.58
Sweden	0.00	0.01	0.00	0.08	0.39
EU-27	**0.56**	**3.28**	**5.58**	**7.02**	**24.06**

Again, as under the baseline, the costs of additional mitigation under the scenarios is estimated to vary by Member State. According to these estimates, under OPT20 and OPT15, costs would be relatively low for all Member States, with the exceptions being Poland, Romania, Italy, Germany and Hungary. Going into the most ambitions scenarios (OPT10 and OPT5), the countries most affected remain similar, with the addition of Spain and France. On the contrary, among those that could bear fewer costs are Cyprus, Estonia, Luxembourg, Malta, Slovakia, Slovenia, Sweden, Finland.

The distribution of costs will be dependent on a series of factors, including importantly the levels of pollution and type of contributing source. For example, for five EU countries, namely Austria, Denmark, Finland, the Netherlands, Portugal, road traffic was the only major source of exceedances reported. Consequently, for these countries abatement measure costs would focus mainly on this sector. Meanwhile, other countries would have to face further costs as part of the air pollution mitigation measures, since their exceedances also come from many different sources. For example, in Italy (particularly in the northern region) and some central and eastern European countries exceedances of the EU daily limit value for PM_{10}, and high concentrations of $PM_{2.5}$ are common. The use of solid fuels (for heating households and in some industrial facilities and power plants) is the main reason for the present situation together with an older vehicle fleet. In Slovenia 57% of exceedances were attributed to domestic heating; Slovakia attributed 50%, Bulgaria 45%, Poland 38% and Romania 36% (European Commission, 2022). Also, in southern Europe, countries such as Italy, France and Spain, reported exceedances in ozone related to transport in urban and rural areas (European Commission, 2022).

Sectoral level

Air pollution control costs are also likely to be unevenly distributed across economic sectors. According to the estimations made by the GAINS model, more than half of the control costs for emissions in the baseline emerge from the transport sector. Otherwise significant costs will also fall on the industry sector, followed less significantly by residential, power and agriculture sectors. Beyond the baseline, the additional costs per sector under the additional abatement scenarios also vary, and change between the scenarios. Under OPT20 to 2030 and OPT15 to 2050, additional costs are very small overall. For all other scenarios to 2030 and 2050, the modelling suggests the costs may be most substantial for the industry and agriculture sectors (and also the residential sector – see next section for further discussion).

Hence, it is highly likely that costs of mitigation action will be disproportionately distributed across sectors of the economy, with more polluting sectors potentially facing a greater proportion of the costs. Where certain sectors and businesses within these sectors face additional costs, this may have an impact on the viability of their businesses, on employment and workers, and also on their linked supply chains. As such, where mitigation action is put in place at Member State level, it will be crucial that attention is paid to the sectors affected, the risks to ongoing operations, employment and supply chains, and how best to mitigate such risks.

Where there is little opportunity to pass costs through (e.g. in very price sensitive sectors), there is a greater ***risk for the businesses directly affected and their employees***. Businesses across and within different sectors hold different tolerance to risk, depending on typical margins, leverage ratios, etc. In some cases, costs may be absorbed by profit margins. However, in other cases, businesses may need to adjust their operations or products to accommodate additional burden. This could be absorbed by co-benefits of the adjustments, such as energy efficiency gains. But if not, the adjustments needed could include potentially reducing operating or other costs in other areas to compensate for the additional burden. These cost reductions could include labour cost savings, which could be achieved by either reducing the number of employees or wages.

Where the additional risk placed on businesses feeds through to a change in employment, this could have important indirect distributional effects as the demographics of the labour force vary between different sectors of the economy. For example, in more energy intensive sectors – such as transport (particularly, of people and logistics), construction and power generation (European Commission, n.d.) – which will be more significantly affected, salaries tend to be lower on average than other sectors (e.g. relative to the services sector which is far less emissions intensive). For example in 2016, yearly salary per employee in manufacturing (EUR 19,977) and Transportation and Storage (EUR 21,347) were below the average for all Industry, construction and service sectors (EUR 21,449), and further below the average across only service sectors (EUR 23,335) (Eurostat, 2016). It is worth noting, however, that these grouping of sectors encompass big differences within each group: i.e. there will be employees in energy-intensive sectors with incomes above the averages for all sectors, and employees in non-energy intensive sectors (e.g. retail) with much lower incomes. In addition, in these sectors most affected, many workers tend to hold lower levels of education and qualifications, as these tend not to be required to perform some of their daily tasks. Hence some of the more vulnerable groups in society would face a disproportionately higher risk should costs be absorbed by the businesses directly facing additional burden. However, this highlights a potential general risk that some of the sectors most affected tend, on average, to employ a sample of relatively lower paid workers in the economy.

Where costs can wholly, or in part, be passed on by businesses directly facing additional burden, costs in one sector can also propagate to other sectors via ***linkages in the supply chain***, therefore spreading risks to other areas of the economy.

There is also a general risk that smaller (and sometimes this can extend to medium) enterprises may be more at risk than larger firms where they face additional costs. These enterprises typically have lower revenues, profits and cash reserves which can be used to absorb and cost increases. That said, additional mitigation action may create opportunities for SMEs, where support for energy efficiency and use of renewable energy help SMEs stay competitive in the mid- and long-term and improve resilience towards volatile fossil fuel prices. Additionally, the development of low-emission goods and services industries could become more competitive as governments promote these mitigation policies creating jobs and increasing wages.

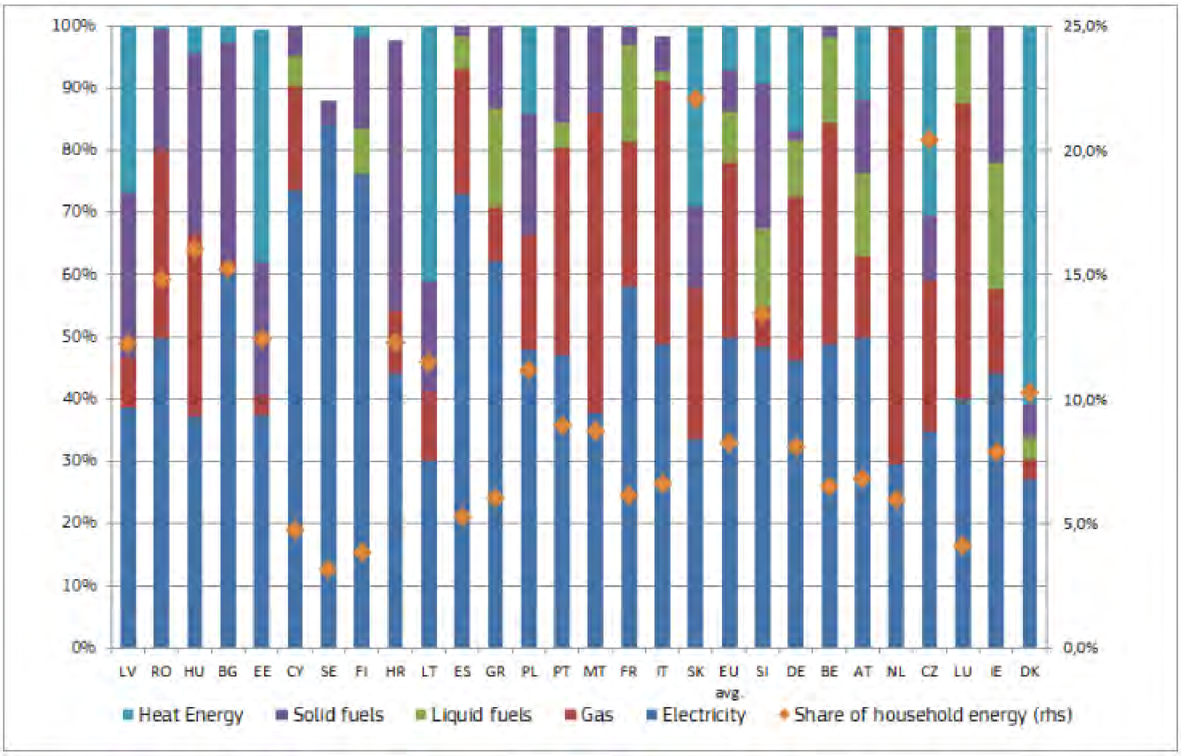
Finally, businesses may also ***pass through costs to consumers***. In this respect, all segments of society would be impacted to some extent by price increases. The nature of any disproportionate effect will depend on which products are affected, to what extent and variance in the patterns of consumptions between different groups in society. Richer segments of society generally tend to consume more goods and services overall (Eurostat, 2020), therefore they could probably bear a greater proportion of the overall costs of compliance. However, for some commodities, in particular fundamental goods and services such as energy and food, poorer households tend to spend a greater proportion of their disposable income on these products and services (European Commission, 2020). According to a report by the European Commission (European Commission, 2020), in the EU €945 was spent on energy on average by the poorest household, which represented 8.3% of their total consumption expenditure. Meanwhile, lower-middle income households spend an average 7.4%, and middle-income households around 6.3%. There are also significant differences across the EU on both absolute expenditures and the share of energy in the total household expenditure. Countries in Central and Eastern Europe, primarily owing to lower incomes compared Northern and Western Europe, spend significantly higher share on energy within their household expenditure. As an example, in Sweden the poorest households spent only 3.2% of their total expenditure on energy, whereas in Slovakia this share is higher than 22.1%. These differences by country are also seen in average household expenditure on food. According to Eurostat, for example, households in Romania spent around a fifth of total household consumption expenditure on food and non-alcoholic beverages (27.8%). The next highest shares were in Lithuania (20.9%) and Estonia (19.6%). Meanwhile, member States where the proportion of expenditure on food is the lowest are Ireland (8.7%), Luxembourg (9.1%) and Austria (9.7%).

Household and social level

Measures taken to abate air pollutant emissions will also fall directly on the household sector, which introduces a risk that the costs of mitigation measures are born differently by different groups. These costs are mostly focused on energy consumption in households (mainly for heating) and transportation.

Under the additional abatement scenarios, greater costs are likely to fall on those using more polluting solid fuels for heating. Actions to reduce energy use, change energy type, ban the use of solid fuels and/or improve combustion efficiency of solid household fuels are likely to be measures taken to reduce emissions. Such measures certainly imply a greater change, and potentially higher costs for the households affected. The disparity in costs bearing would not only be felt within each Member State, but also between Member States. Despite the fact that solid fuels only represent a small fraction in the total energy expenditure in the EU, in some Central and East European countries they comprise a measurable share (Figure A-90). As such, when implementing additional mitigation actions, Member States should be aware of the potential disproportionate burden placed on some households, and any potential correlation between the use of solid fuels and vulnerable characteristics.

Figure A-90. Share of expenditure on household energy products and share of energy in total expenditure for the poorest households by EU Member State **(European Commission, 2020)**



That said, some mitigation measures could present an opportunity for those most affected. Energy efficiency measures help mitigate air pollutant emissions through the reduction of total residential energy consumption, therefore also delivering energy bill savings to consumers. In the EU, energy efficiency measures are viewed as a way to guarantee sustainable energy supply, cut greenhouse gas emissions, improve security of supply and reduce import bills, and promote the EU's competitiveness. Energy efficiency is therefore a strategic priority for the Energy Union, and the EU promotes the principle of 'energy efficiency first'. In that sense, the EU has already adopted a series of policies for energy performance of buildings (Energy Performance of Buildings Directive (2010/31/EU)[10] and higher

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[10] https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1529483556082&uri=CELEX%3A32018L0844

standards for equipment and appliances (Energy Efficiency Directive ((EU) 2018/2002)[11]. However, according to the European Commission, in order to reach climate-neutrality by 2050, consumption in households must decrease further. Therefore, structural adaptation in buildings and houses measures, such as thermal insulation or the installation of green technologies to reduce energy use, could form part of the mitigation measures deployed. Hence where the risk associated with the upfront cost of such measures can be reduced or even mitigated (e.g. through Governments facing the costs of renovate or build new sustainable buildings and houses and offer them an affordable price for those more deprived sectors), the subsequent energy savings present an opportunity.

The other important cost burden for households will likely be through expenditure on transportation. Generally the share of transport fuels within the total expenditure increases with household income: The poorest households spend 3% on transport energy on EU average, while lower-middle income and middle-income households respectively spend 4% and 4.4% (European Commission, 2020). Higher income households rely more on private means of transportation, although lower income households, who do own private means of transportation, tend to use/drive older, more polluting vehicles, as in general, they have less disposable income to spend on upgrading them for newer, less polluting models. Poorer households tend to use public transport (Titheridge et al., 2014) to a greater extent, and as such may benefit most from improvements to service provision and networks but could also face additional costs associated with improvements, depending on how these are funded. However, this could be mitigated or even compensated by governmental policies, subsidises and incentives (European Commission, 2022). As an example, governments could subsidise or make public transport free for lower income segments of society; subsidise the upgrading of older vehicles or the acquisition on new ones, as well as the use of sustainable fuels; or deploy bikes and biking lanes for people to use at a low fee.

Summary

No definite conclusions can be made regarding any potential disproportionate societal impacts (and distribution of costs) across different societal groups. This is because the distribution of costs will ultimately be dependent on the policies and measures put in place by Member States to deliver the technical mitigation potential.

That said, this review of evidence has highlighted a number of risk factors and opportunities which, if not considered and addressed, could lead to disproportionate positive or negative effects for some vulnerable groups.

A number of risk factors and opportunities have been identified for lower income households. Meanwhile, there is no strong evidence to conclude that other social groups such as children, elderly households would have to bear higher costs than the rest.

Risk factors and opportunities have been identified by considering potential patterns of impacts on a Member State, sectoral and household level. In some cases costs will be placed directly on households, in others the potential impacts (and risks) will be indirect. For many of the risk factors, the true risk will depend on a number of variables (including and in addition to the policy delivery mechanism). This includes any complementary, risk mitigation that Member States may choose to implement either as part of (or alongside) the policy delivering the mitigation measures – where Member States identify and

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[11] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv%3AOJ.L_.2018.328.01.0210.01.ENG

recognise the potential for risks and opportunities, it may be that risks can be substantially, if not wholly mitigated, and opportunities partly or wholly seized. The below table sets out the risk factors and opportunities identified in this analysis.

Table A-41. Summary of societal impacts of air pollution and societal impacts of air pollution abatement measures, including resulting inequalities

Viewpoint	Risks	Opportunities
Sectoral (indirect impacts through businesses)	• Costs likely to be greater for certain (e.g. energy intensive) sectors of the economy. This could have an indirect effect on the viability of some businesses in these sectors, employment and linked supply chains. • Where costs feed through to impacts on employment, it is important to be mindful of potential variations in labour force demographics between affected sectors. • SMEs in affected sectors could be at greater risk as they have fewer resources and activities over which to spread additional costs • Costs could be passed through to consumers through higher prices, which could carry indirect disproportionate effects for different households.	• Productivity benefits from improved health of workforce are estimated in the modelling to outweigh the additional costs for all sectors (with the exception of agriculture) • Agriculture will also benefit from reduced crop losses, as shown by the GAINS models and efficiency gains from mitigation measures (e.g. precision farming) • The development of low-emission goods and services industries could become more competitive as governments promote these mitigation policies creating jobs and increasing wages • Abatement measures that support energy efficiency and use of renewable energy help SMEs stay competitive in the mid- and long-term and improve resilience towards volatile fossil fuel prices
Direct household impacts	• Households using solid or more emissions intensive fuels for heating (and cooking) will likely be more effective. As such, some Member States (where use of solid fuels is more prevalent) will be likely more affected, and Member States should also be mindful of potential demographic variance in the use of solid fuels when implementing additional abatement • Households will also face varying costs depending on their transport behaviour. Households with greater private transport use will face additional costs where these sources are targeted by Member States, and policy-makers should pay attention to how emissions are targeted and who may be most affected. Households may also face additional	• Some mitigation measures (e.g. energy efficiency) may lead to private benefits (e.g. energy bill reductions) • Poorer households tend to use public transport to a greater extent, and as such may benefit most from improvements to service provision and networks.

Viewpoint	Risks	Opportunities
	costs of using public transport, depending on how improvements are funded	

Distribution of benefits

Establishing an approach to the quantitative analysis

The aim of the quantitative analysis is to understand the impact of the proposed interventions on sensitive population groups across the EU. The literature review identified several papers produced by the European Environment Agency (EEA) which were used to inform the approach adopted for this study:

- ***The Eionet Report*** (Petchesi, 2019) provided an update on previous work undertaken by The Centre for Research on Environment Society and Health (CRESH) (CRESH, 2013) which investigated the links between levels of air pollution and socio-economic inequality.
- Most recently, ***the EEA Report*** (EEA, 2019) was produced in response to the EU's Seventh Environment Action Programme review which highlighted that '*European environmental policies need to focus particularly on areas where 'particularly sensitive or vulnerable groups of society … are exposed to high levels of pollutants'* (European Commission, 2013).

Both reports sought to draw links between levels of exposure to air pollution and citizens' socio-economic status across Europe. In line with the observations made by (WHO, 2021) the EEA analysis partially focused on the relationship between the concentration of air pollutant and areas with a low/high age demographic. WHO report that a body of scientific research has shown evidence of a correlation between these groups and hospital admissions for a diagnosed medical condition in areas with a higher concentration of an air pollutant.

Both reports also look at economic status as an indicator of a region's potential vulnerability to poor air quality as guided by (WHO, 2012). Reviewing the potential impacts on citizens who had poorer living conditions (e.g. those with less access to clean water, home heating), less opportunities to work in different areas of employment and poor access to health services are more likely to be at risk by adverse changes in the concentration of air pollutants.

To complete this assessment, both papers identified the '*Nomenclature of territorial units for statistics'* (NUTS) dataset (Eurostat, 2022) (available through the EU Eurostat web portal) and '*Local Administration Unit'* (Eurostat, 2022) data to understand the composition of demographics across Member States. The NUTS dataset provides information on a range of socio-economic factors (such as citizen's age, gender, level of education and unemployment) across three geographical boundary sizes (NUTS layers), which are determined by the human population density of each area.

Both papers identified limitations within the NUTS dataset for each spatial level of resolution:

- the dataset with the highest spatial resolution (UAC) (where the EU is divided into the smallest sized areas, and providing the best indicator for micro-changes) being restricted to data covering the major urban areas only;
- the next highest level of resolution (NUTS 3) only contains a dataset that can act as an indicator of the age of the population;

- The lowest resolution layer used (NUTS 2) included far more data which can be used as indicators for income and health inequality, but was limited by the low resolution, which in turn limits the granularity with which the relationship between air pollution exposure and demographic variables can be explored.

Table A-42 - Datasets used by the EEA papers reviewed

Spatial scale	Population Size	Indicators available
Urban Audit Cities (UAC)	Not set (confined to size of city administration boundary)	• Age • Unemployment • Level of education • Access to green space • Mortality rate due to given condition
NUTS 3	150k – 800k	• Per capita GDP
NUTS 2	800k - 3 m	• Per capita household income • Age • Long-term unemployment • Education

A review of available demographic datasets undertaken under this study determined that despite these limitations, the NUTS database represents the most complete dataset available and the assessment under this study has therefore also been conducted using this database. It was determined that the UAC datasets used in the EIONET papers were not appropriate for this analysis as they were limited to specific cities only, and hence was not repeated as part of this analysis.

From the range of indicators available, only certain variables were used as a tool for assessing the impacts of the scenarios modelled within this study, as defined in the following table.

Table A-43 Short list of datasets considered for the analysis

Spatial scale	Population Size	Indicators used
NUTS 3	150k - 800k	• Age (young and elderly groups)
NUTS 2	800k - 3 m	• Euros per inhabitant • Level of education • Long-term unemployment rates

The first step of the analysis was to calculate the population-weighted mean concentrations in each grid cell. This compares the modelled pollutant concentrations (taken from the detailed dispersion modelling undertaken in this study, see Appendix 3) to the size of the population exposed to this level of concentration of the pollutant concerned. This was undertaken by using GIS software to map the modelled concentrations (given in the form of a raster image) and the desired spatial resolution (Eurostat, 2022). The following formula details the technique used to calculate the population weighted exposure for each spatial level:

1) Identify the number of modelled pollutant points within each spatial boundary and average to provide the mean concentration value for each grid cell.
2) Multiply the population concentration of each LAU with its corresponding population
3) Sum up the total from each local administrative unit (LAU) calculated in step 1 which falls within the boundary of the desired spatial region

4) Divide the figure from step 3 by the total population of each spatial region.

The population weighting was undertaken on the basis of the grid in which the population data was provided (LAU). However, this grid is different to those on which the demographic data is available (NUTS). Hence the next step was to map across the population weighted concentrations from the LAU grid to the NUTS grid. One limitation in this step was that some spatial areas did not always fully align between the two grids, meaning some population (LAU) cells spread across two or more cells from the demographic (NUTS) datasets, and some spread across EU and non-EU cells. Hence some small proportion of a NUTS population may have been lost to a neighbour region. That said, our assessment of this issue estimated an error percentage of below 1%.

The demographic characteristics were defined in terms of quintiles – i.e. each spatial region was ranked by its demographic characteristic relative to each of the spatial regions considered within the analysis. This was undertaken by calculating the proportion of the number of citizens within each spatial region that met the criteria of an assessed indicator (e.g. the number of citizens under the age of 16) and used a percentile ranking to assign a quantile grouping in accordance to how the spatial region compared to all others modelled within the assessment.

The final step was then to overlay the population weighted average concentration for each spatial region with the quintile ranking of each demographic characteristic of each spatial region.

Statistical analysis was then conducted to understand any distribution patterns in the air quality impacts of the five modelled scenarios for the year 2030. The main output are boxplots which provide a clear picture as to how the range of population weighted concentration values changes with each option. The model outputs were disaggregated by quintile class so that it was clear to identify whether any sensitive group benefit less/more in comparison with regions of different proportional demographic sizes. The year 2030 was used for this analysis as modelled outputs. Outputs for years after 2030 are likely to be more uncertain due to the influence of unforeseen factors that could affect the prediction of the models, in addition to there being greater uncertainty about whether existing patterns of demographic characteristics will still hold in the future. An additional review of the changes of the mean modelled 2030 concentrations from the 2030 baseline model was also undertaken. The results from this analysis was provided in a bar chart where the bars were disaggregated by quintile grouping, the absolute level of reduction of each pollutant was provided on these figures for clarity.

A Spearman's rank correlation coefficient method was also used to further explore the relationship between the absolute concentration and the changes in concentration between the quantile rankings for each sensitive demographic. This approach provided an insight as to whether there was a strong correlation between low/high pollutant values and quintile class and therefore indicated if any region with a low/high of the sensitive demographic was disproportionally affected by the modelled scenario.

Understanding the impacts on sensitive groups

Following the methodology defined by the EEA, our analysis focuses on those vulnerable due to age (i.e. both young and elderly populations). Review of available demographics data identified that the NUTS 3 dataset provided the highest resolution of data for exploratory analysis. This dataset was found to have several limitations as estimates of the age of citizens within each zone was grouped in four-year periods (i.e. citizens aged between 5-9 totalled 81,144 in zone BE10). This meant that the use of this data placed a slight limitation on which age ranges could be reviewed. For instance, the upper age bound of a child, usually set at 16 years old, had to be lowered to 14 for the dataset to be used. For elderly citizens, we have used a lower age bound of 65 in line with normal retirement age; this lower age bound matches the groupings given in the NUTS 3 dataset. The ratio of each demographic to the total population size for each NUTS 3 region was calculated and a quintile group was assigned to each region based on the calculated ratio's ranking position relative to the total dataset.

The demographic data for each of these vulnerable groups at NUTS3 level is presented in Figure A-91 and Figure A-92.

Figure A-91 - Mapping of NUTS 3 children under 14 quintiles (quintile 5 representing areas of highest number of children)

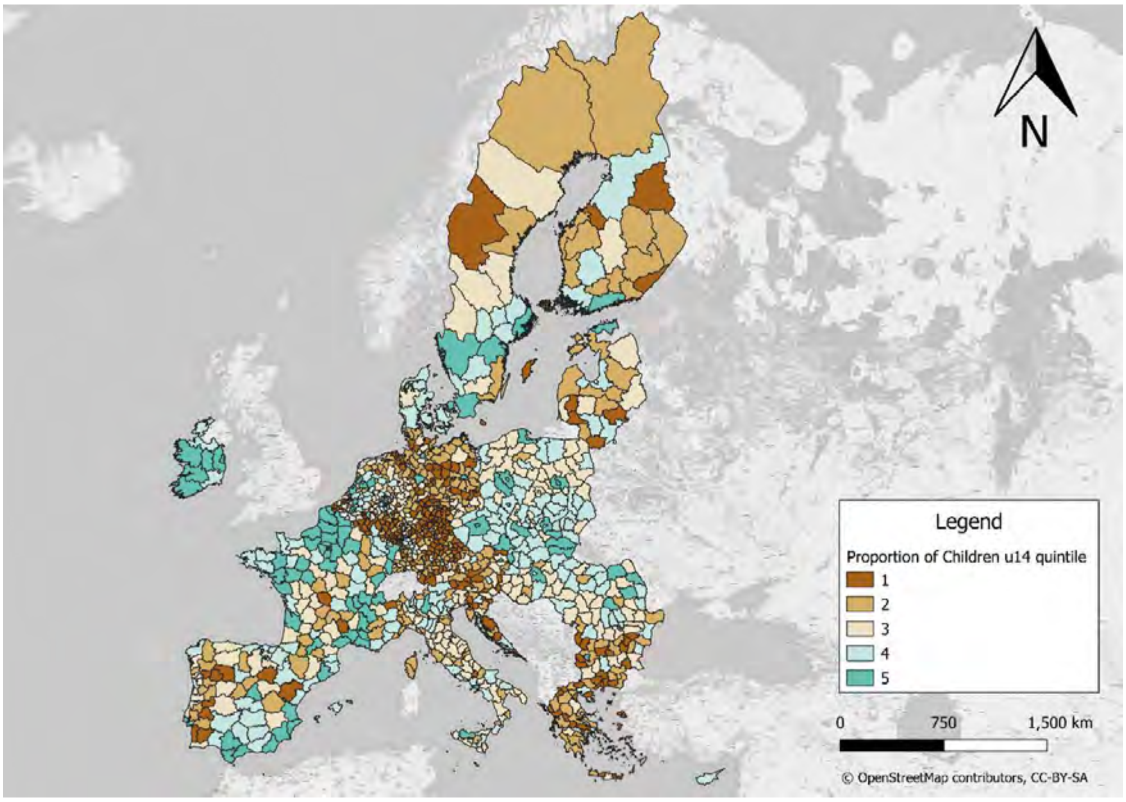
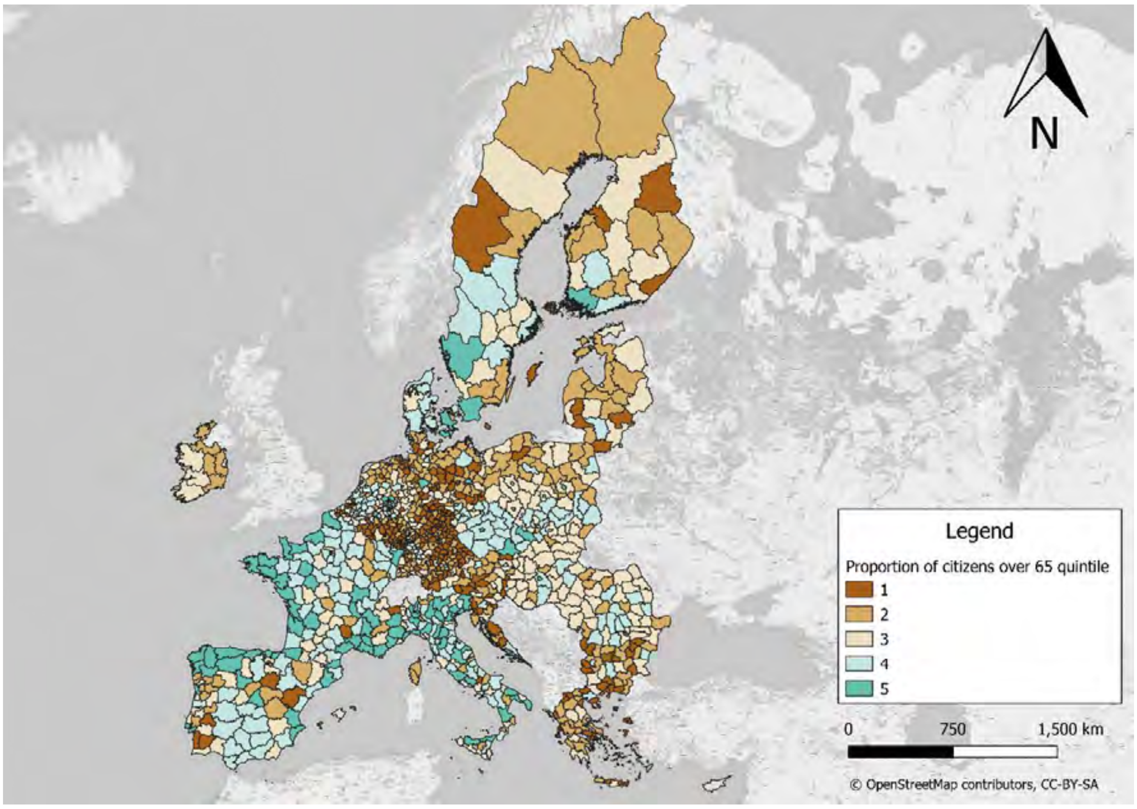


Figure A-92 Mapping of NUTS 3 adults aged over 65 quintiles (quintile 5 representing areas of highest number of elderly residents)



Understanding the impacts on societal indicative groups

Review of possible metrics available in the NUTS database found it was not possible to conduct an analysis on the impact of the modelled scenarios at the LAU or NUTS 3 spatial resolution as the required demographic characteristic data was not available at this resolution. Review of the possible metrics at the NUTS 2 spatial resolution found that that data was sufficient for the use of multiple indicators. Table A-44 shows the choice of indicators used for the assessment.

Table A-44: Indicators used to assess the impacts of the modelled changes on economically deprived social groups

Spatial scale	Population Size	Indicators used
NUTS 2	800k – 3 m	• Euros per inhabitant • Level of education • Long-term unemployment rates

For these datasets, no additional processing was required to calculate a ratio between grouping and total population for each spatial area as the data was provided in these formats already and a quintile classification was assigned based on the ranking position of each spatial region.

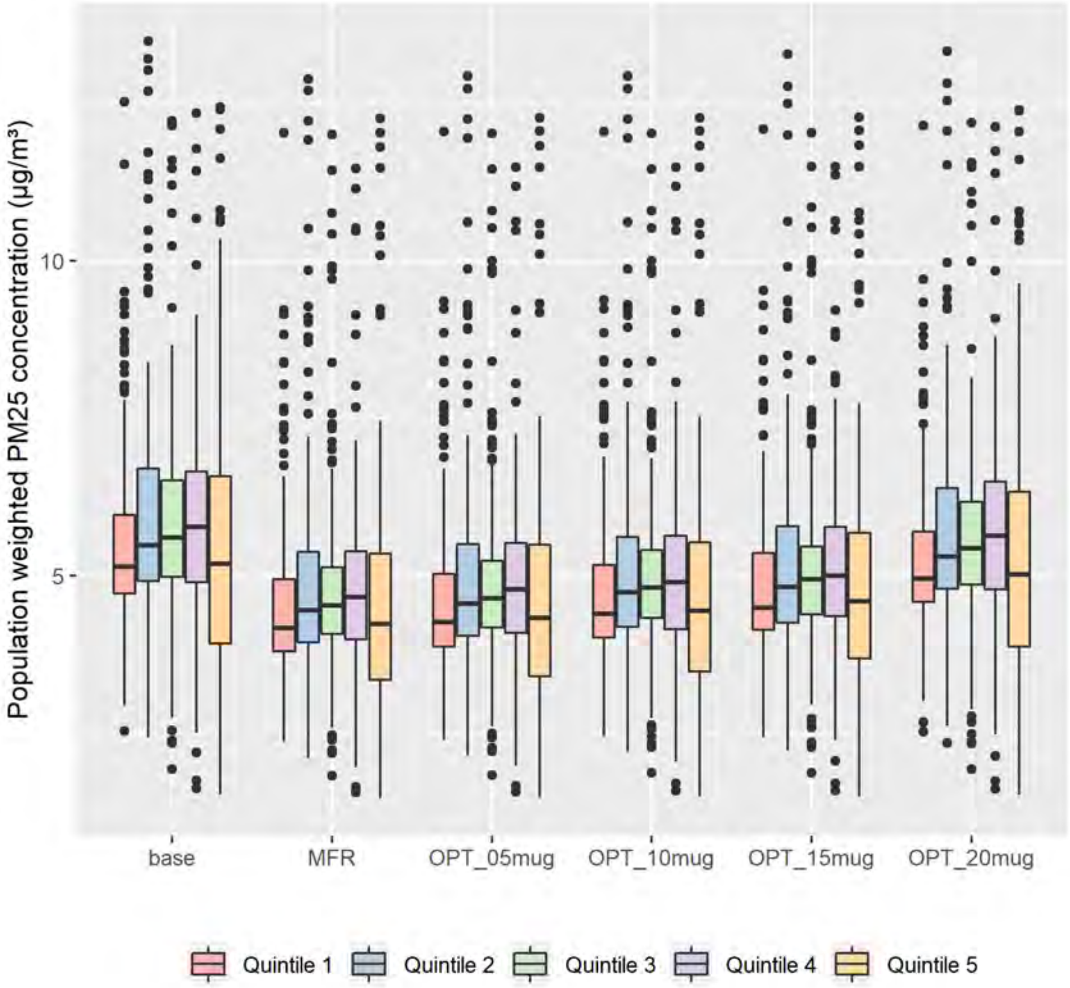
Effects of each scenario on vulnerable age groups - detailed results

The boxplot figures show statistical data, where the medium concentration value is represented by a horizontal line in the middle of the box shown for each scenario. The upper and lower ends of each box represent the first and third quartiles whilst the extended whiskers (vertical lines) represent the region which is 1.5x the value of the interquartile range (third quartile minus the first quartile). The plots also show dots which represent values that are greater than this range, these are outlier values. The highest dots represent the max averaged concentration for the spatial level (NUT 3) used in this analysis.

Analysis of the relationship between the changes in NO_2 caused by each scenario and sensitive age groups

Figure A-93 shows a boxplot displaying the relationship between the predicted changes in PM2.5 pollutant and areas with a low (quintile 1) to high (quintile 5) proportion of citizens under the age of 14 years old at the NUTS 3 spatial resolution.

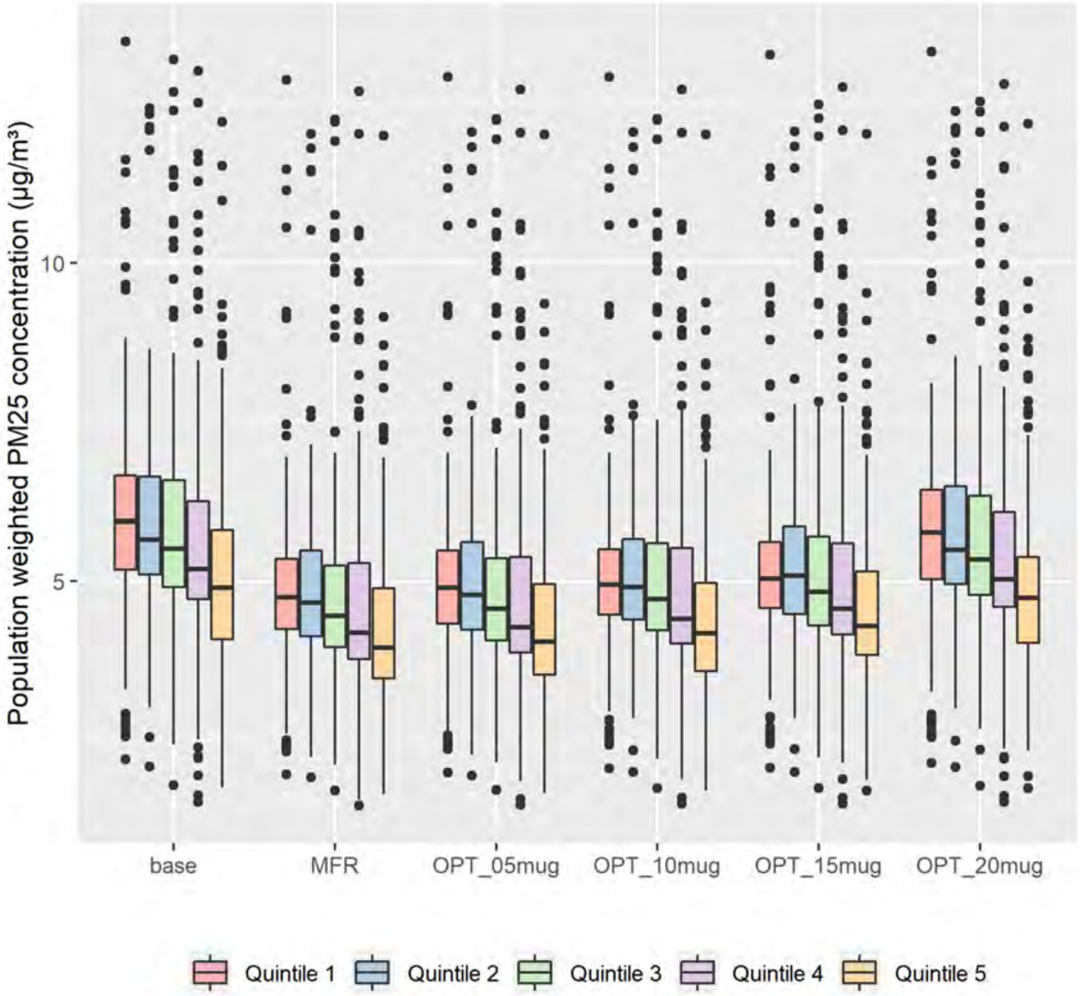
Figure A-93: 2030 population weighted exposure for $PM_{2.5}$ (µg/m^3) for the child quintile groupings at NUTS 3 spatial resolution



For the 2030 base year, the figure shows that the medium $PM_{2.5}$ concentration increases between quintile 1 and 4 before decreasing in areas with the highest proportion of children under the age of 14 years old (quintile 5). The figure shows that this relationship seen across the quintile classes is not impacted by any of the scenarios modelled.

Figure A-94 shows a boxplot displaying the relationship between the predicted changes in PM2.5 pollutant and areas with a low (quintile 1) to high (quintile 5) proportion of citizens over the age of 65 years old at the NUTS 3 spatial resolution.

Figure A-94: 2030 population weighted exposure for $PM_{2.5}$ ($\mu g/m^3$) for the citizens over the age of 65 quintile groupings at NUTS 3 spatial resolution

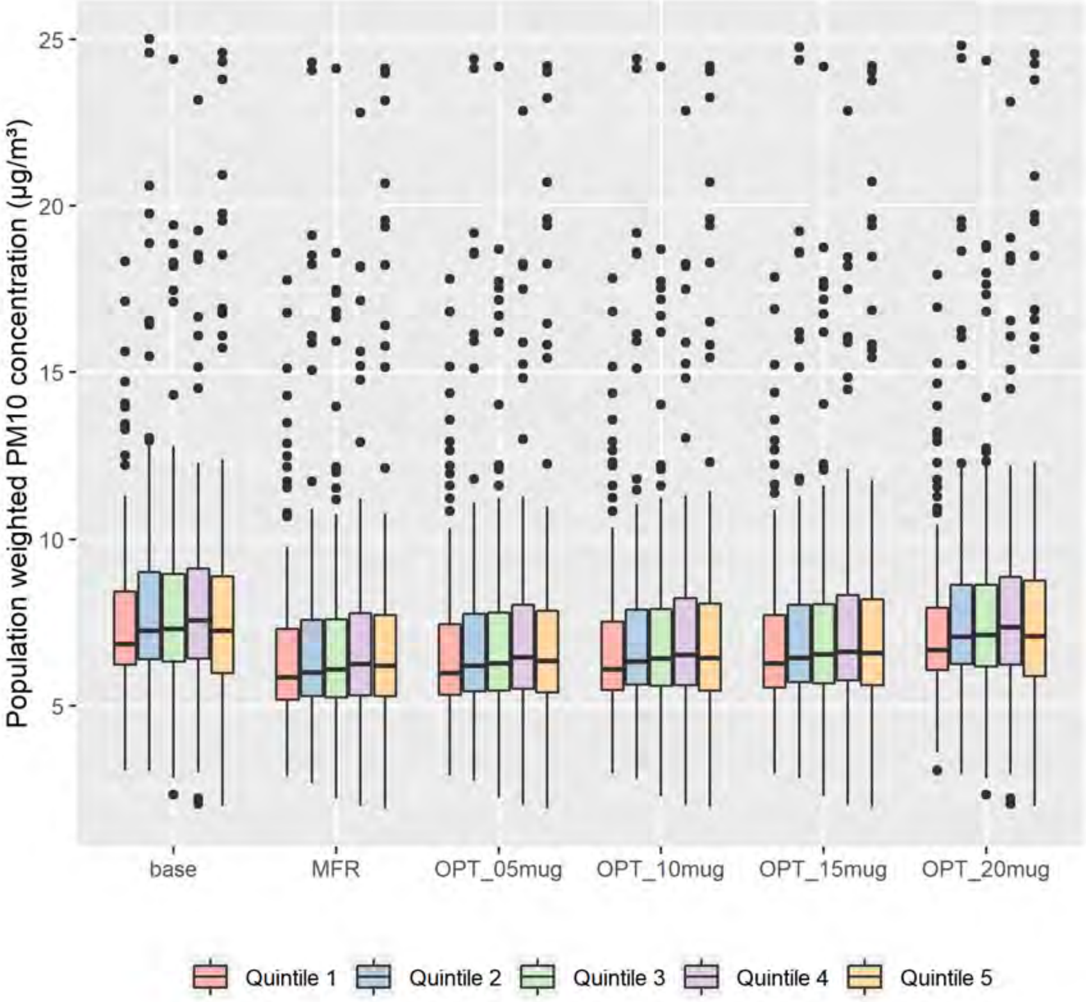


For the 2030 base year, the figure shows that the medium $PM_{2.5}$ concentration decreases with each increase in quintile class, and therefore lowest in areas with the highest proportion of citizens over the age of 65 years old. The figure shows that this relationship seen across the quintile classes is generally not impacted by any of the scenarios modelled, although the medium concentration values become closer across the quintile classes in the OPT_10mug scenario.

Analysis of the relationship between the changes in PM_{10} caused by each scenario and sensitive age groups

Figure A-95 shows a boxplot displaying the relationship between the predicted concentrations of PM10 pollutant and areas with a low (quintile 1) to high (quintile 5) proportion of citizens under the age of 14 years old at the NUTS 3 spatial resolution.

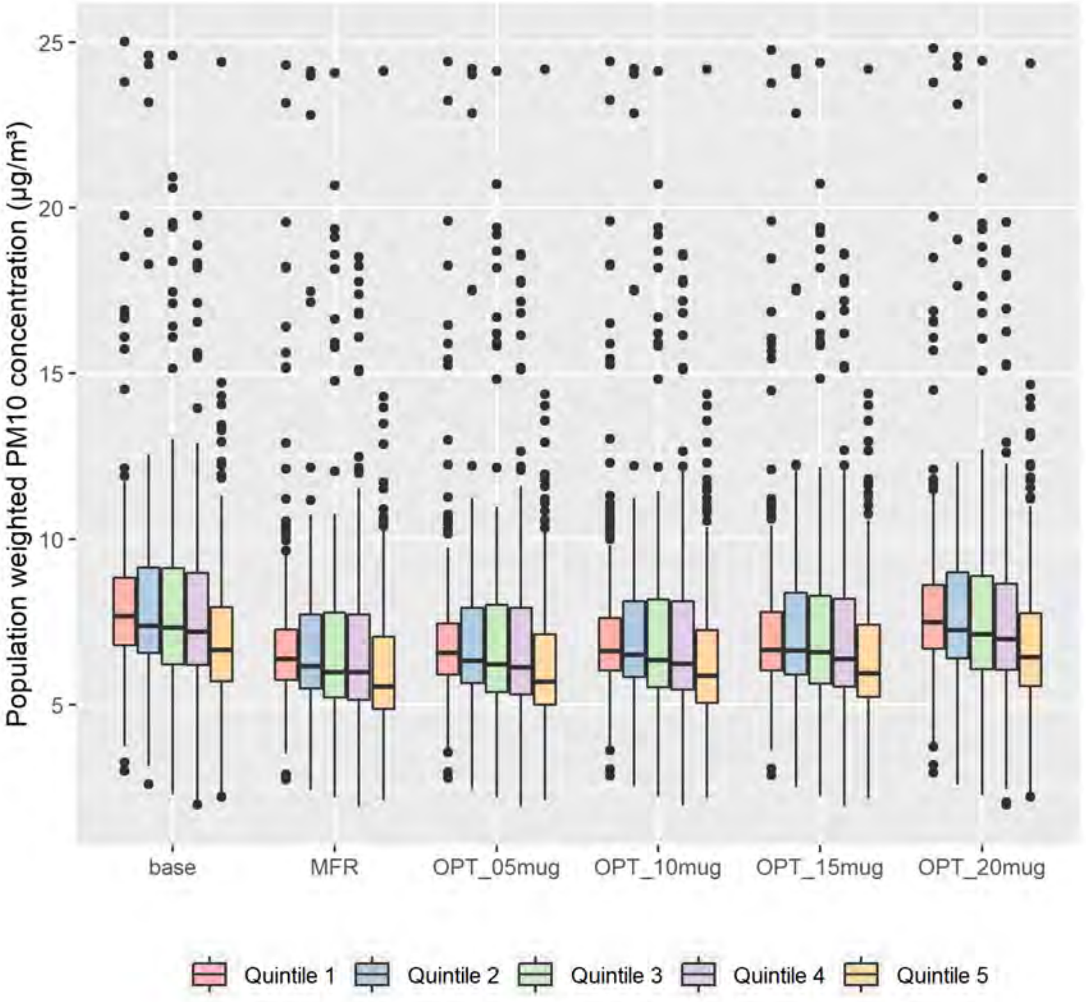
Figure A-95: 2030 population weighted exposure for PM_{10} (µg/m³) for the child quintile groupings at NUTS 3 spatial resolution



The figure shows that for the 2030 modelled base year, exposure to PM_{10} was reasonably similar across the quintile groups. The model suggests that the relationship between the quintile groups shown for the base year is likely to be retained through the implementation of the modelled scenarios.

Figure A-96 shows a boxplot displaying the relationship between the predicted changes in PM10 pollutant and areas with a low (quintile 1) to high (quintile 5) proportion of citizens over the age of 65 years old at the NUTS 3 spatial resolution.

Figure A-96: 2030 population weighted exposure for PM_{10} (µg/m^3) for the citizens over the age of 65 quintile groupings at NUTS 3 spatial resolution

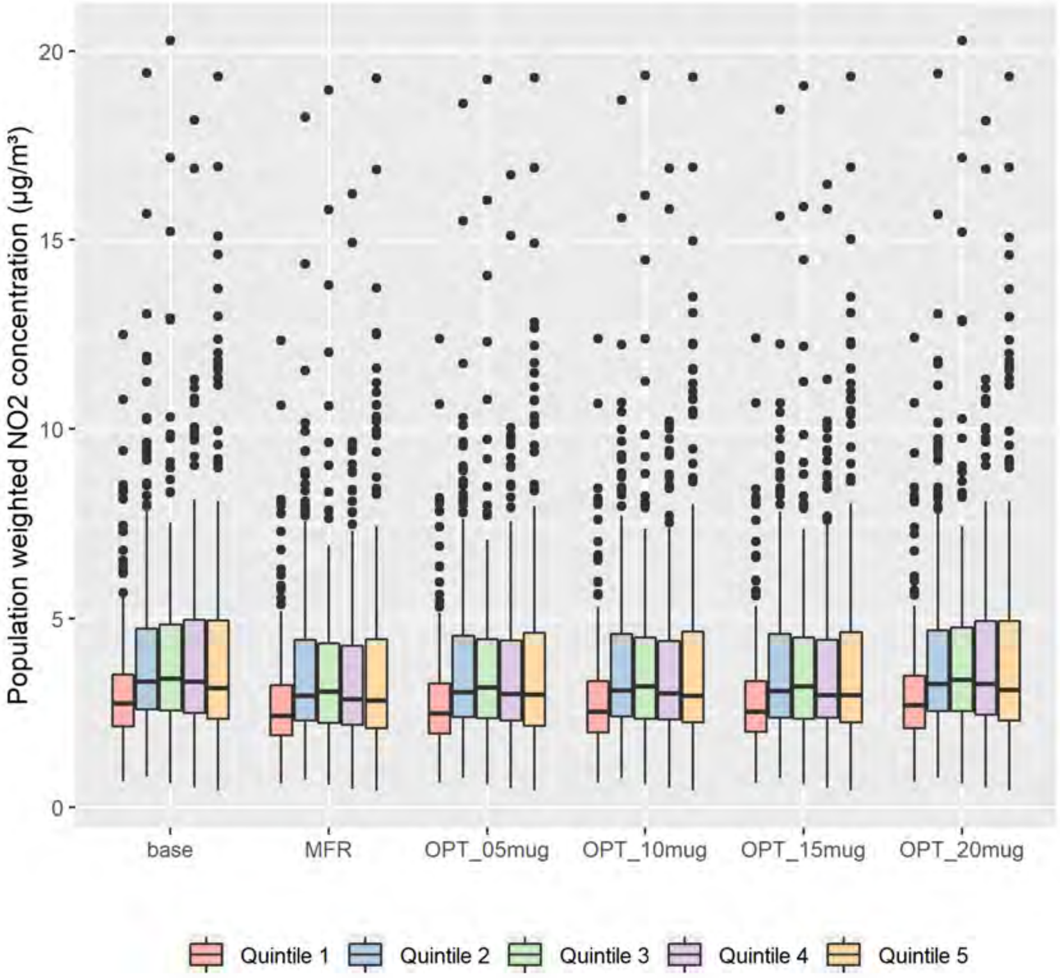


The figure shows that for the 2030 modelled base year, exposure to PM_{10} was lowest, on average, in areas with the highest proportion of citizens over the age of 65 years old (quintile 5), with the medium concentration value decreasing with the increase in quintile class number. The figure shows that this pattern changes with the implementation of any of the modelled scenarios.

Analysis of the relationship between the changes in NO_2 caused by each scenario and sensitive age groups

Figure A-97 shows a boxplot displaying the relationship between the predicted changes in NO2 pollutant and areas with a low (quintile 1) to high (quintile 5) proportion of citizens under the age of 14 years old at the NUTS 3 spatial resolution.

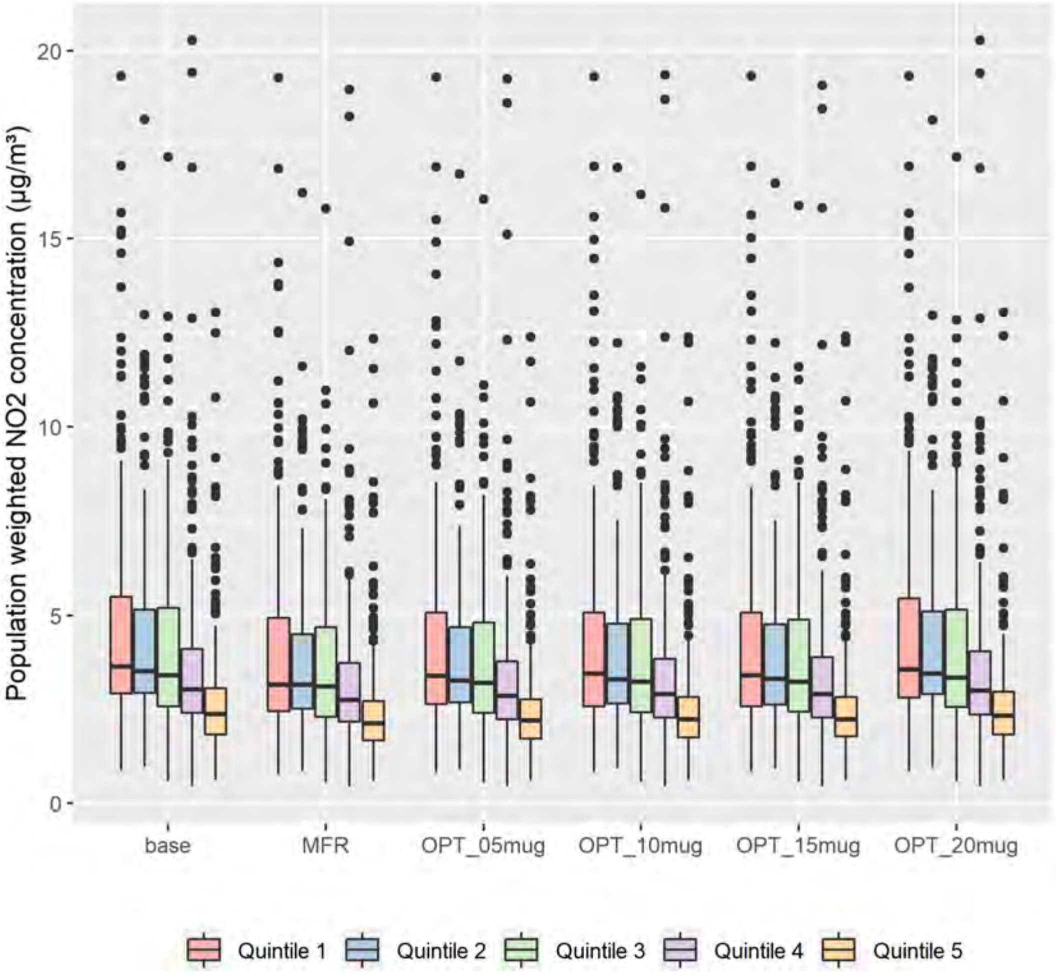
Figure A-97: 2030 population weighted exposure for NO_2 (µg/m^3) for the child quintile groupings at NUTS 3 spatial resolution



The figure shows that for the 2030 modelled base year, exposure to NO_2 was lowest, on average, in areas with the lowest proportion of children under the age of 14 years old (quintile 1) and that the average medium and upper quintile concentration value was similar across all other quintile groups. The figure shows that this pattern changes with the implementation of any of the modelled scenarios.

Figure A-98 shows a boxplot displaying the relationship between the predicted changes in NO_2 pollutant and areas with a low (quintile 1) to high (quintile 5) proportion of citizens over the age of 65 years old at the NUTS 3 spatial resolution.

Figure A-98 2030 population weighted exposure for NO_2 (µg/m^3) for the citizens over the age of 65 quintile groupings at NUTS 3 spatial resolution

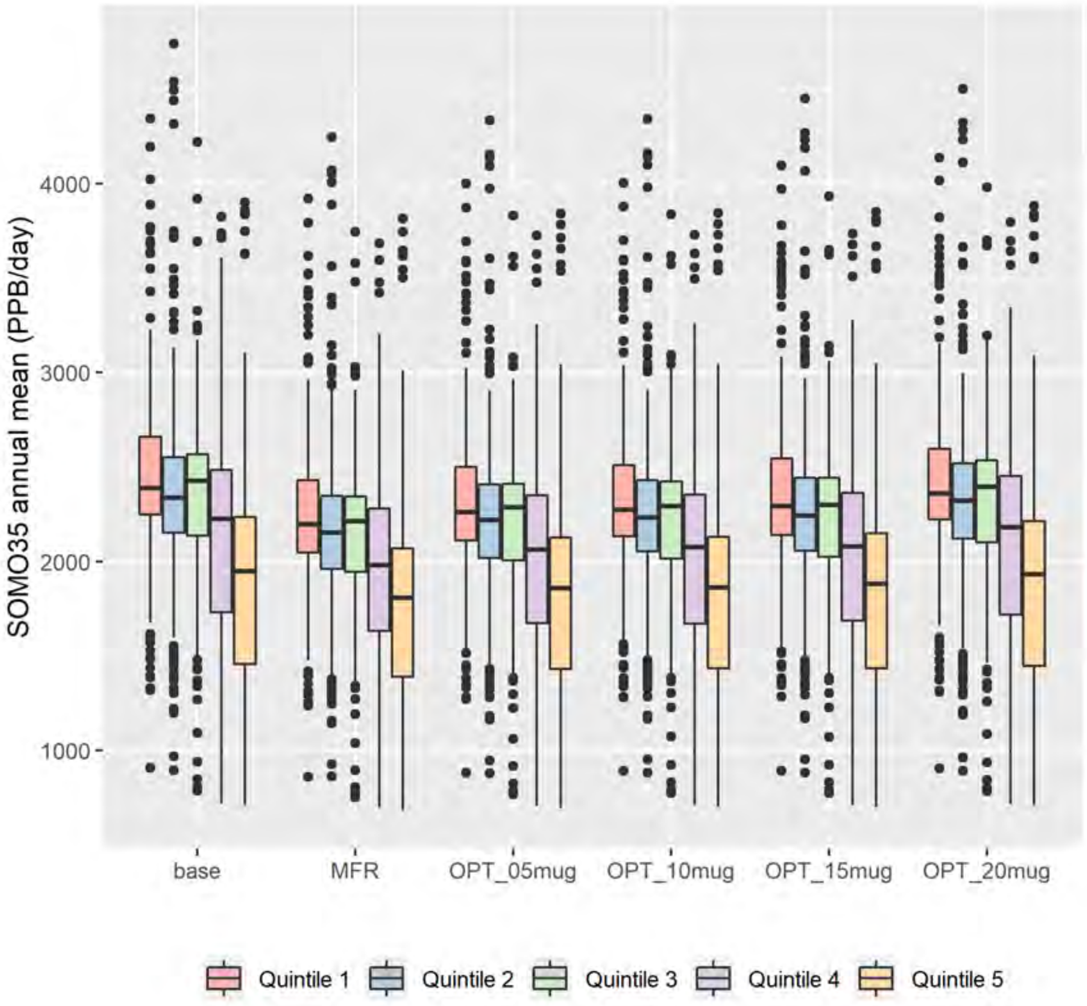


The figure shows that for the 2030 modelled base year, exposure to NO_2 was lowest, on average, in areas with the highest proportion of citizens over the age of 65 years old (quintile 5), with the medium concentration value decreasing with the increase in quintile class number. The figure shows that this pattern changes with the implementation of any of the modelled scenarios.

Analysis of the relationship between the changes in Ozone caused by each scenario and sensitive age groups

Figure A-99 shows a boxplot displaying the relationship between the predicted concentrations of Ozone pollutant in areas with a low (quintile 1) to high (quintile 5) proportion of citizens under the age of 14 years old at the NUTS 3 spatial resolution. Concentrations of Ozone have been measured differently to other pollutants which have been based on the average of the annual hourly mean. These Ozone measurements are aligned to the SOMO35 indicator. The SOMO35 value shown is the annual average of the daily total of the highest 8-hour rolling mean above 35 ppb.

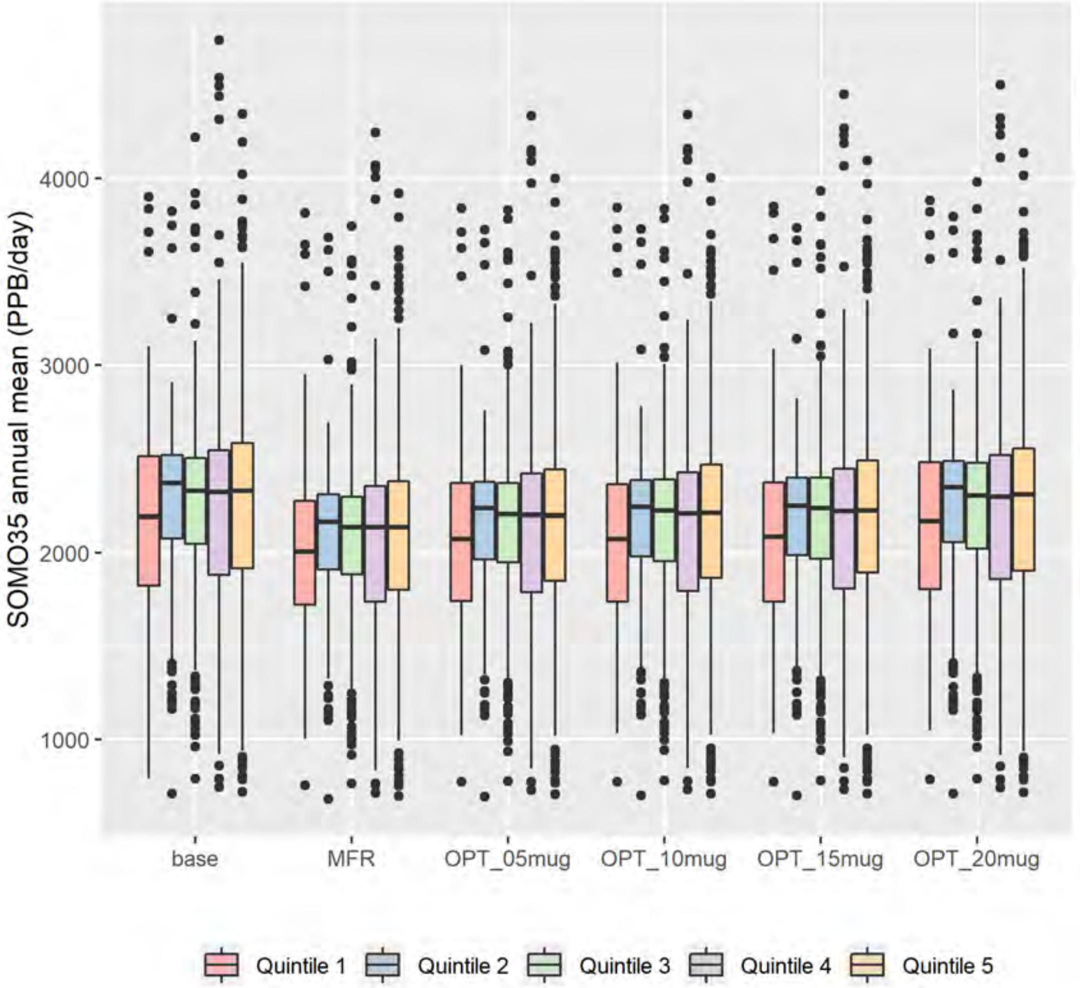
Figure A-99: 2030 exposure to Ozone (annual mean SOMO35) for the child quintile groupings at NUTS 3 spatial resolution



For the 2030 base year, the figure shows that the medium Ozone concentration are reasonably similar between quintiles 1 and 3, whilst also showing that citizens living in quintiles 4 and 5 areas are predicted to be exposed to lower concentrations. This suggests that areas that have a higher proportion of children are generally areas where Ozone concentrations are the lowest. The figure shows that this relationship between quintile groups remains unchanged by each of the modelled scenarios.

Error! Reference source not found. Figure A-100 shows a boxplot displaying the relationship between the predicted changes in Ozone pollutant and areas with a low (quintile 1) to high (quintile 5) proportion of citizens over the age of 65 years old at the NUTS 3 spatial resolution.

Figure A-100: 2030 exposure to Ozone (annual mean SOMO35) for the citizens over the age of 65 quintile groupings at NUTS 3 spatial resolution



For the 2030 base year, the figure shows that the medium Ozone concentration for each quintile are relatively similar, with only areas with the lowest proportion of citizens over the age of 65 years old (quintile 1) experiencing lower daily 8-hour averages than the other quintiles. The figure shows that this relationship seen across the quintile classes is generally not impacted by any of the scenarios modelled.

Key results of analysis of exposure of sensitive groups to air pollution

The following tables present the mean statistics underpinning the box plots above.

Table A-45 Summary results of analysis for $PM_{2.5}$ exposure for children

	Scenarios	Quintile				
		1	2	3	4	5
2030 Baseline population-weighted mean concentration	Baseline	5.49	5.98	5.85	5.79	5.43
Average change in population-weighted mean concentration (relative to 2030 baseline	OPT20	-0.25	-0.25	-0.18	-0.15	-0.11
	OPT15	-0.62	-0.76	-0.7	-0.64	-0.5
	OPT10	-0.76	-0.87	-0.81	-0.8	-0.66
	OPT5	-0.86	-0.99	-0.93	-0.91	-0.76
Average % change in population-weighted mean concentration (relative to 2030 baseline	OPT20	-4.08	-3.77	-2.93	-2.51	-1.9
	OPT15	-11.06	-12.44	-11.82	-10.66	-8.77
	OPT10	-13.97	-14.43	-13.74	-13.59	-11.74
	OPT5	-15.89	-16.77	-16	-15.53	-13.74

Table A-46 Summary results of analysis for $PM_{2.5}$ exposure for elderly

	Scenarios	Quintile				
		1	2	3	4	5
2030 Baseline population-weighted mean concentration	Baseline	6	6.05	5.89	5.62	5.11
Average change in population-weighted mean concentration (relative to 2030 baseline	OPT20	-0.16	-0.16	-0.19	-0.21	-0.22
	OPT15	-0.73	-0.7	-0.67	-0.62	-0.54
	OPT10	-0.85	-0.84	-0.8	-0.74	-0.69
	OPT5	-0.94	-0.98	-0.95	-0.86	-0.77
Average % change in population-weighted mean concentration (relative to 2030 baseline	OPT20	-2.55	-2.67	-3.09	-3.34	-3.68
	OPT15	-11.93	-11.58	-11.24	-10.69	-9.86
	OPT10	-13.92	-13.89	-13.55	-13.17	-13.32
	OPT5	-15.59	-16.32	-16.22	-15.32	-14.88

Table A-47 Summary results of analysis for PM_{10} exposure for children

	Scenarios	Quintile				
		1	2	3	4	5
2030 Baseline population-weighted mean concentration	Baseline	7.5	8.03	7.97	7.95	7.91
Average change in population-weighted mean concentration (relative to 2030 baseline	OPT20	-0.26	-0.27	-0.19	-0.16	-0.12
	OPT15	-0.64	-0.79	-0.74	-0.67	-0.52
	OPT10	-0.8	-0.91	-0.84	-0.84	-0.69
	OPT5	-0.91	-1.04	-0.97	-0.96	-0.8
Average % change in population-weighted mean concentration (relative to 2030 baseline	OPT20	-3.34	-3.17	-2.46	-2.11	-1.52
	OPT15	-8.84	-10.02	-9.48	-8.57	-6.79
	OPT10	-11.02	-11.54	-10.91	-10.75	-8.89
	OPT5	-12.52	-13.36	-12.71	-12.26	-10.34

Table A-48 Summary results of analysis for PM_{10} exposure for elderly

	Scenarios	Quintile				
		1	2	3	4	5
2030 Baseline population-weighted mean concentration	Baseline	8.34	8.19	8.09	7.77	7.07
Average change in population-weighted mean concentration (relative to 2030 baseline	OPT20	-0.17	-0.18	-0.21	-0.23	-0.23
	OPT15	-0.76	-0.74	-0.7	-0.65	-0.56
	OPT10	-0.89	-0.88	-0.84	-0.78	-0.73
	OPT5	-0.99	-1.03	-0.99	-0.9	-0.8
Average % change in population-weighted mean concentration (relative to 2030 baseline	OPT20	-2.15	-2.25	-2.56	-2.74	-3.01
	OPT15	-9.71	-9.35	-8.95	-8.39	-7.81
	OPT10	-11.1	-11.1	-10.74	-10.24	-10.33
	OPT5	-12.36	-13.03	-12.81	-11.89	-11.52

Table A-49 Summary results of analysis for NO_2 exposure for children

	Scenarios	Quintile				
		1	2	3	4	5
2030 Baseline population-weighted mean concentration	Baseline	3.09	4.09	4.04	4.13	4.24
Average change in population-weighted mean concentration (relative to 2030 baseline	OPT20	-0.06	-0.06	-0.05	-0.05	-0.02
	OPT15	-0.18	-0.28	-0.29	-0.3	-0.21
	OPT10	-0.2	-0.29	-0.28	-0.32	-0.22
	OPT5	-0.24	-0.34	-0.33	-0.37	-0.29
Average % change in population-weighted mean concentration (relative to 2030 baseline	OPT20	-1.91	-1.48	-1.17	-1.35	-0.67
	OPT15	-5.74	-6.67	-6.62	-7.07	-4.64
	OPT10	-6.39	-6.71	-6.63	-7.38	-4.8
	OPT5	-7.74	-7.87	-7.61	-8.21	-6.01

Table A-50 Summary results of analysis for NO_2 exposure for elderly

	Scenarios	Quintile				
		1	2	3	4	5
2030 Baseline population-weighted mean concentration	Baseline	4.78	4.42	4.13	3.66	2.72
Average change in population-weighted mean concentration (relative to 2030 baseline	OPT20	-0.06	-0.04	-0.05	-0.05	-0.05
	OPT15	-0.34	-0.32	-0.28	-0.22	-0.14
	OPT10	-0.34	-0.33	-0.28	-0.23	-0.15
	OPT5	-0.37	-0.4	-0.35	-0.29	-0.19
Average % change in population-weighted mean concentration (relative to 2030 baseline	OPT20	-1.49	-1.1	-1.24	-1.31	-1.54
	OPT15	-7.88	-7.03	-6.13	-5.5	-4.71
	OPT10	-7.78	-7.28	-6.14	-5.85	-5.34
	OPT5	-8.06	-8.39	-7.62	-7.26	-6.53

Table A-51 Summary results of analysis for Ozone exposure for children

	Scenarios	Quintile 1	2	3	4	5
2030 Baseline population-weighted mean concentration	Baseline	2452.31	2368.68	2332.33	2140.08	1905.62
Average change in population-weighted mean concentration (relative to 2030 baseline	OPT20	-43.5	-38.91	-30.38	-26.49	-16.33
	OPT15	-104.22	-104.64	-101.27	-82.45	-51.56
	OPT10	-129.59	-121.21	-115.56	-97.3	-64.15
	OPT5	-144.29	-132.95	-126.73	-105.34	-70.69
Average % change in population-weighted mean concentration (relative to 2030 baseline	OPT20	-1.61	-1.46	-1.24	-1.18	-0.82
	OPT15	-4.14	-4.24	-4.23	-3.71	-2.55
	OPT10	-5.14	-4.87	-4.81	-4.37	-3.14
	OPT5	-5.76	-5.37	-5.29	-4.73	-3.47

Table A-52 Summary results of analysis for Ozone exposure for elderly

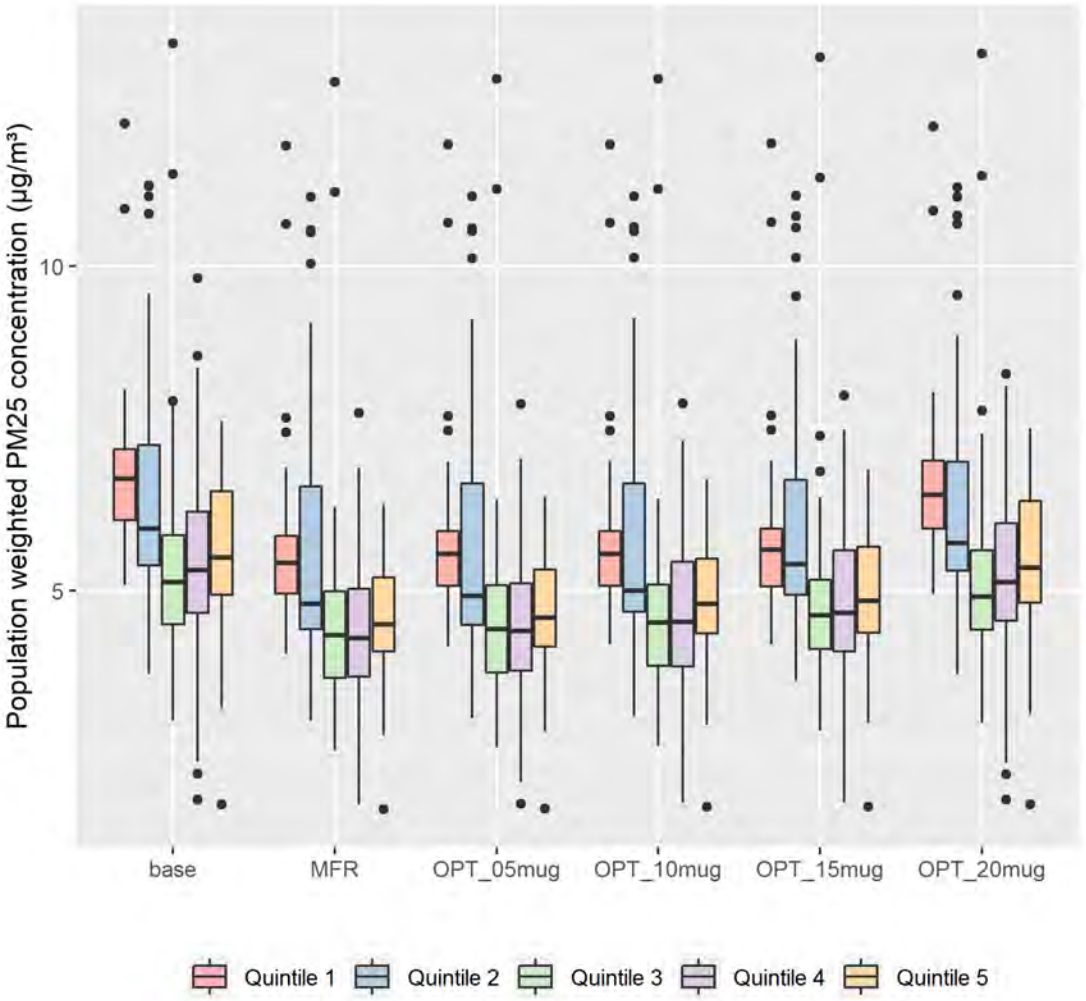
	Scenarios	Quintile 1	2	3	4	5
2030 Baseline population-weighted mean concentration	Baseline	2157.83	2267.55	2249.55	2267.15	2313.45
Average change in population-weighted mean concentration (relative to 2030 baseline	OPT20	-24.58	-27.53	-29.57	-35.67	-39.87
	OPT15	-87.7	-94.75	-87.48	-89.41	-91.75
	OPT10	-99.84	-107.62	-102.6	-107.96	-116.6
	OPT5	-105.04	-117.1	-114.98	-119.83	-129.94
Average % change in population-weighted mean concentration (relative to 2030 baseline	OPT20	-1.12	-1.19	-1.23	-1.36	-1.49
	OPT15	-3.96	-4.05	-3.74	-3.69	-3.69
	OPT10	-4.45	-4.59	-4.37	-4.42	-4.72
	OPT5	-4.66	-4.99	-4.92	-4.95	-5.33

Effects of each scenario on economically deprived social groups

Analysis of the relationship between the predicted concentration of $PM_{2.5}$ from each scenario and economically deprived groups

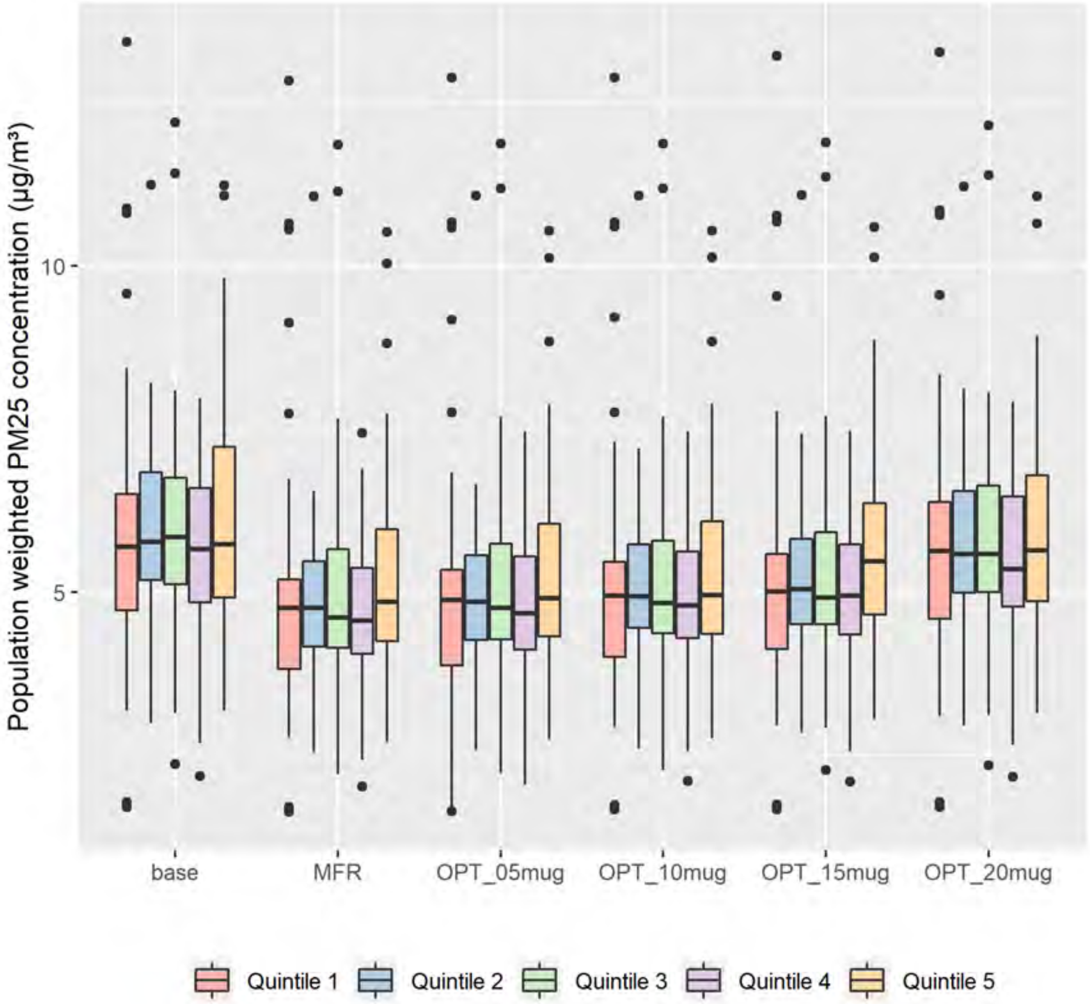
Figure A-101 shows a boxplot displaying the relationship between the predicted changes in $PM_{2.5}$ pollutant and areas with a low (quintile 1) to high (quintile 5) share of euro's per inhabitant at the NUTS 2 spatial resolution.

Figure A-101 2030 population weighted exposure for $PM_{2.5}$ (µg/m^3) for the euros per inhabitant quintile groupings at NUTS 2 spatial resolution



The figure shows that for the 2030 modelled base year, there is no clear relationship between areas with a low/high share of euro per inhabitant and exposure to $PM_{2.5}$. The figure shows that relative to all other quintile classes, no quintile class is going to experience a larger benefit than any other in each modelled scenario compared to the baseline prediction. Figure A-102 shows a boxplot displaying the relationship between the predicted concentration of $PM_{2.5}$ pollutant and areas with a low (quintile 1) to high (quintile 5) rate of unemployment at the NUTS 2 spatial resolution.

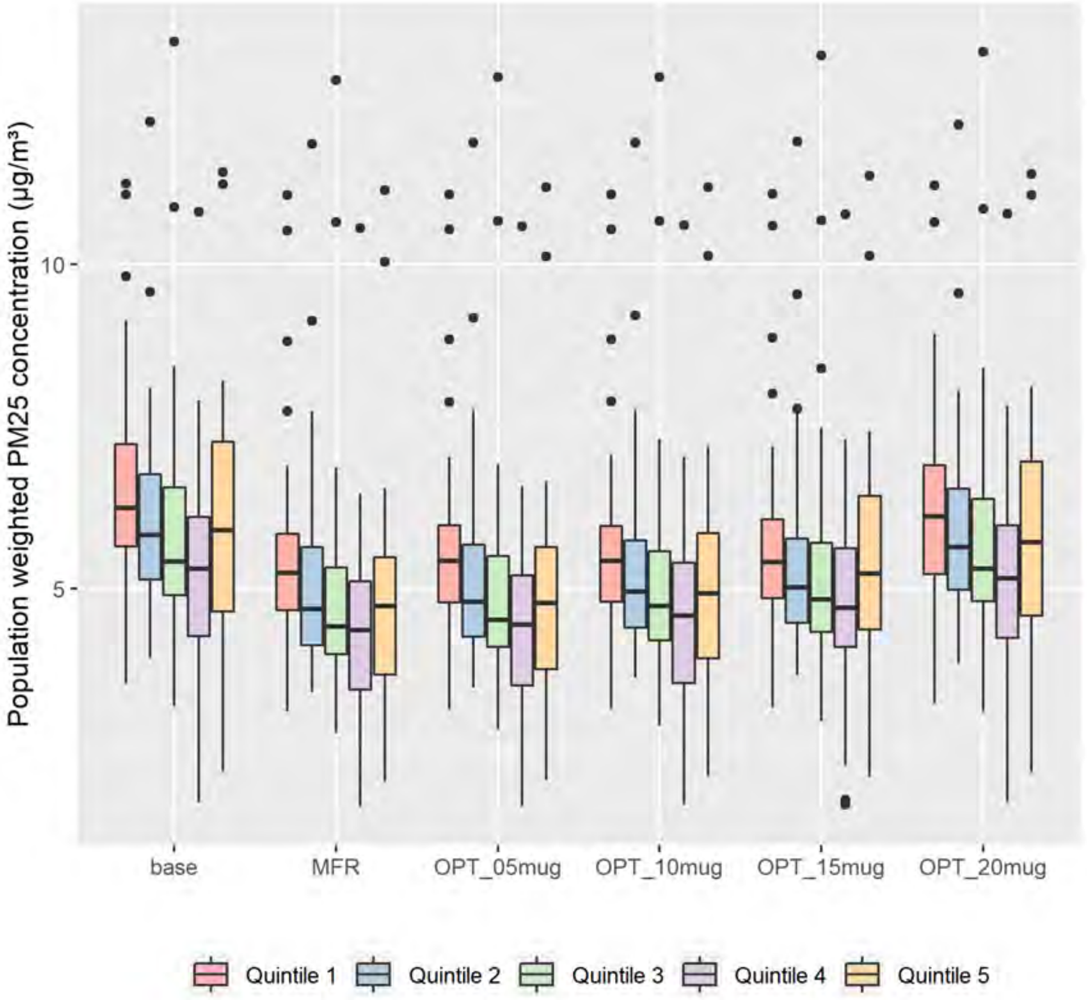
Figure A-102 : 2030 population weighted exposure for $PM_{2.5}$ (µg/m^3) with comparison to areas with a low/high rate of unemployment at NUTS 2 spatial resolution



The figure shows that for the 2030 modelled base year, the medium line for each quintile class is predicted to be relatively similar. The figure shows that this relationship is not predicted to be changed by the changes caused by the introduction of the five scenarios.

Figure A-103 shows a boxplot displaying the relationship between the predicted concentrations of PM2.5 pollutant and areas with a low (quintile 1) to high (quintile 5) of inhabitants educated at tertiary education facilities (levels 5 – 8) at NUTS 2 spatial resolution.

Figure A-103: 2030 population weighted exposure for $PM_{2.5}$ (µg/m^3) with comparison to areas with a low/high percentage of inhabitants educated at levels 5 to 8 at NUTS 2 spatial resolution

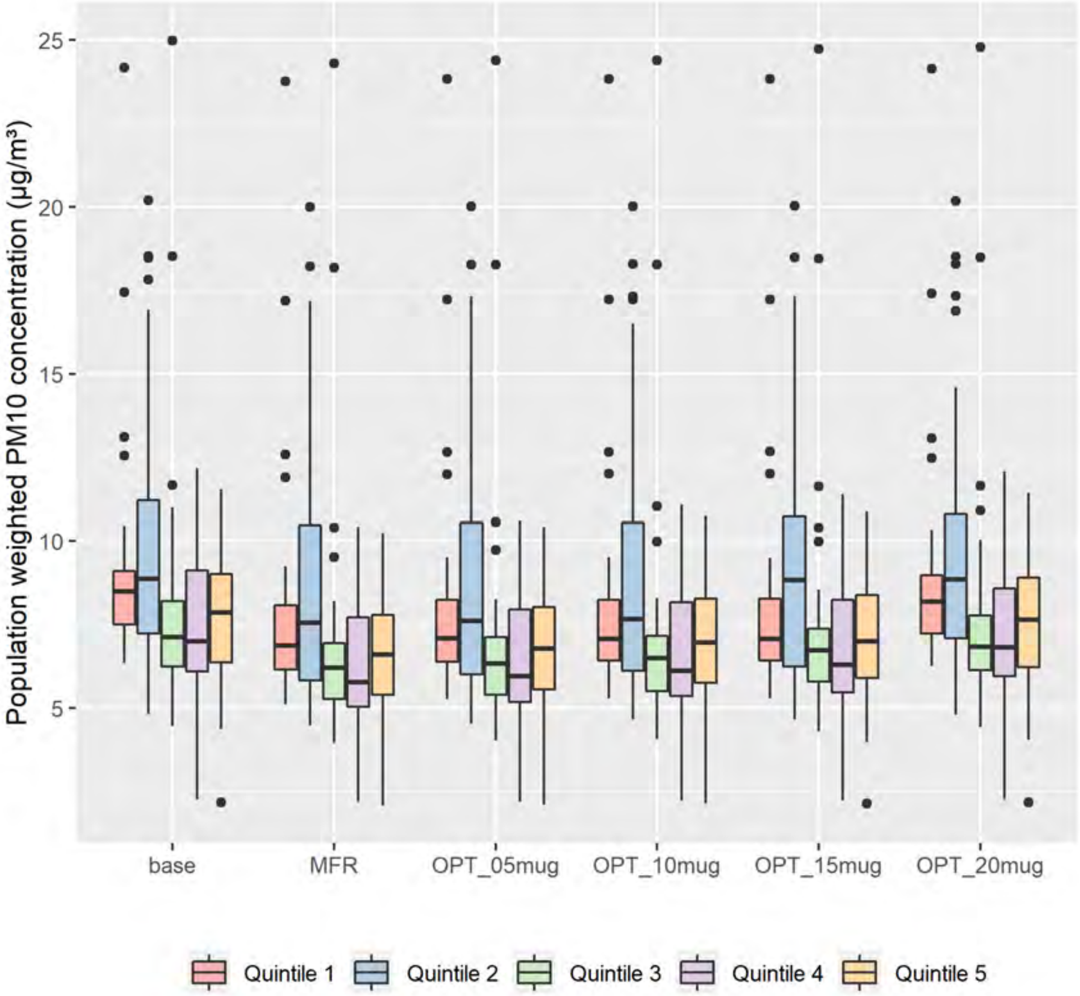


For the 2030 base year, the figure shows that the medium $PM_{2.5}$ concentration decreases between quintile 1 and 4 before increasing in areas with the highest proportion of levels 5-8 educated inhabitants (quintile 5). The figure shows that this relationship seen across the quintile classes is not impacted by any of the scenarios modelled.

Analysis of the relationship between the predicted concentration of PM_{10} from scenario and economically deprived groups

Figure A-104 shows a boxplot displaying the relationship between the predicted concentration of PM10 pollutant and areas with a low (quintile 1) to high (quintile 5) share of euro's per inhabitant at the NUTS 2 spatial resolution.

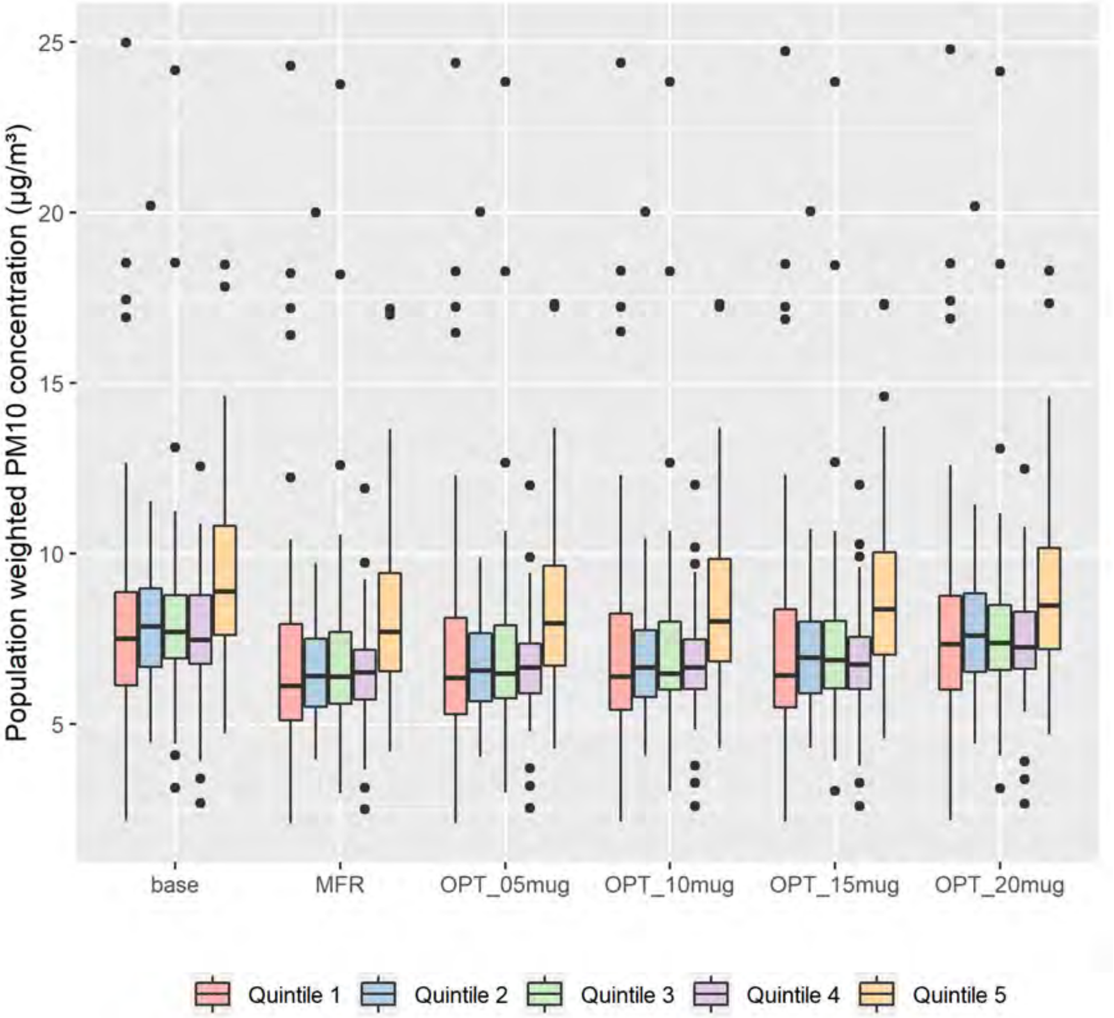
Figure A-104: 2030 population weighted exposure for PM_{10} (µg/m³) for the euros per inhabitant quintile groupings at NUTS 2 spatial resolution



The figure shows that for the 2030 modelled base year, there is no clear relationship between areas with a low/high share of euro per inhabitant and exposure to PM_{10}. The figure shows that relative to all other quintile classes, no quintile class is going to experience a larger benefit than any other in each modelled scenario compared to the baseline prediction.

Figure A-105 shows a boxplot displaying the relationship between the predicted concentration of PM10 pollutant and areas with a low (quintile 1) to high (quintile 5) rate of unemployment at the NUTS 2 spatial resolution.

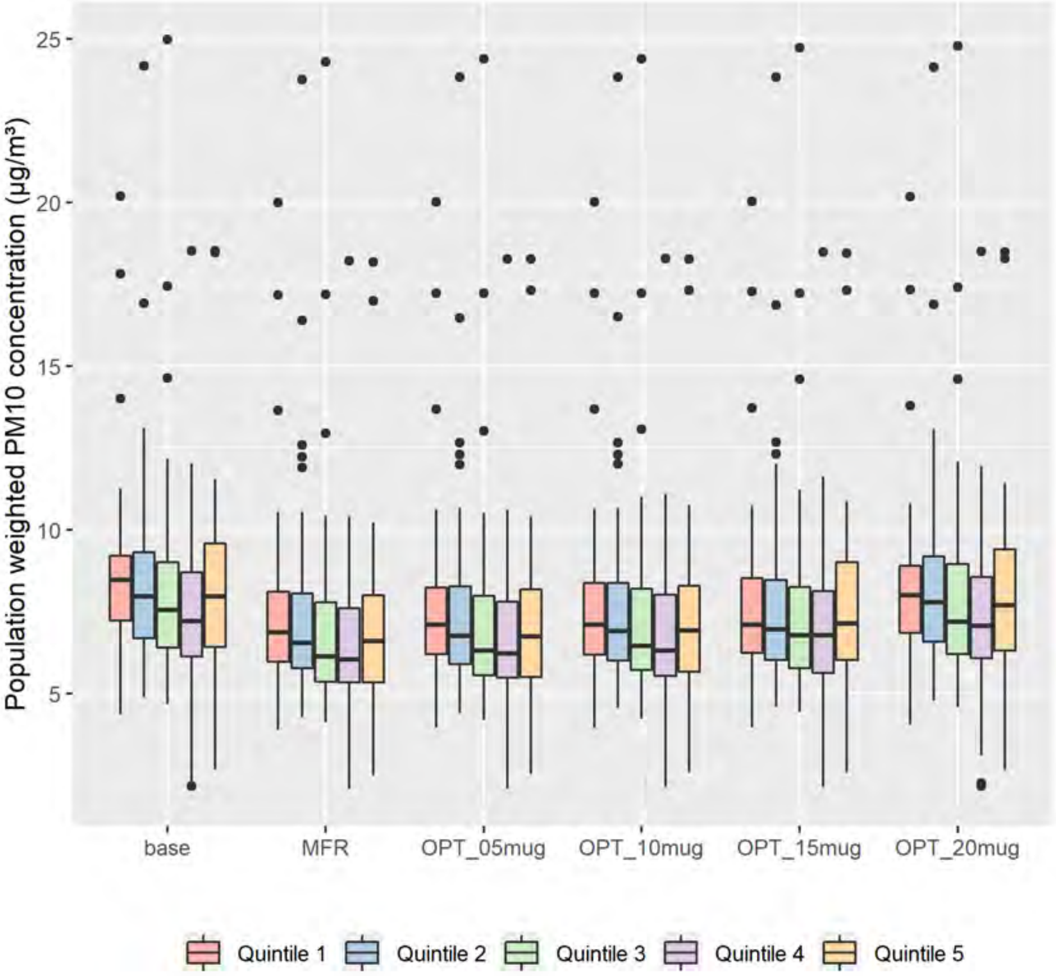
Figure A-105: 2030 population weighted exposure for PM$_{10}$ (µg/m^3) with comparison to areas with a low/high rate of unemployment at NUTS 2 spatial resolution



The figure shows that the model predicts that areas with the highest rate of unemployment (quintile 5) is likely to have the highest average concentration of PM$_{10}$ with the medium value fairly consistent in the other quintile classes. The figure suggests that although the medium value for the quintile 1 class falls in comparison to the relative position of the medium line in other quintiles in the baseline prediction in the MTFR, 05,10 and 15mug scenarios, the implementation of any of the modelled scenarios will otherwise have little impact on the relationship between quintile classes.

Figure A-106 shows a boxplot displaying the relationship between the predicted concentration of PM10 pollutant and areas with a low (quintile 1) to high (quintile 5) of inhabitants educated at tertiary education facilities (levels 5 – 8) at NUTS 2 spatial resolution.

Figure A-106: 2030 population weighted exposure for PM_{10} (µg/m^3) with comparison to areas with a low/high percentage of inhabitants educated at levels 5 to 8 at NUTS 2 spatial resolution

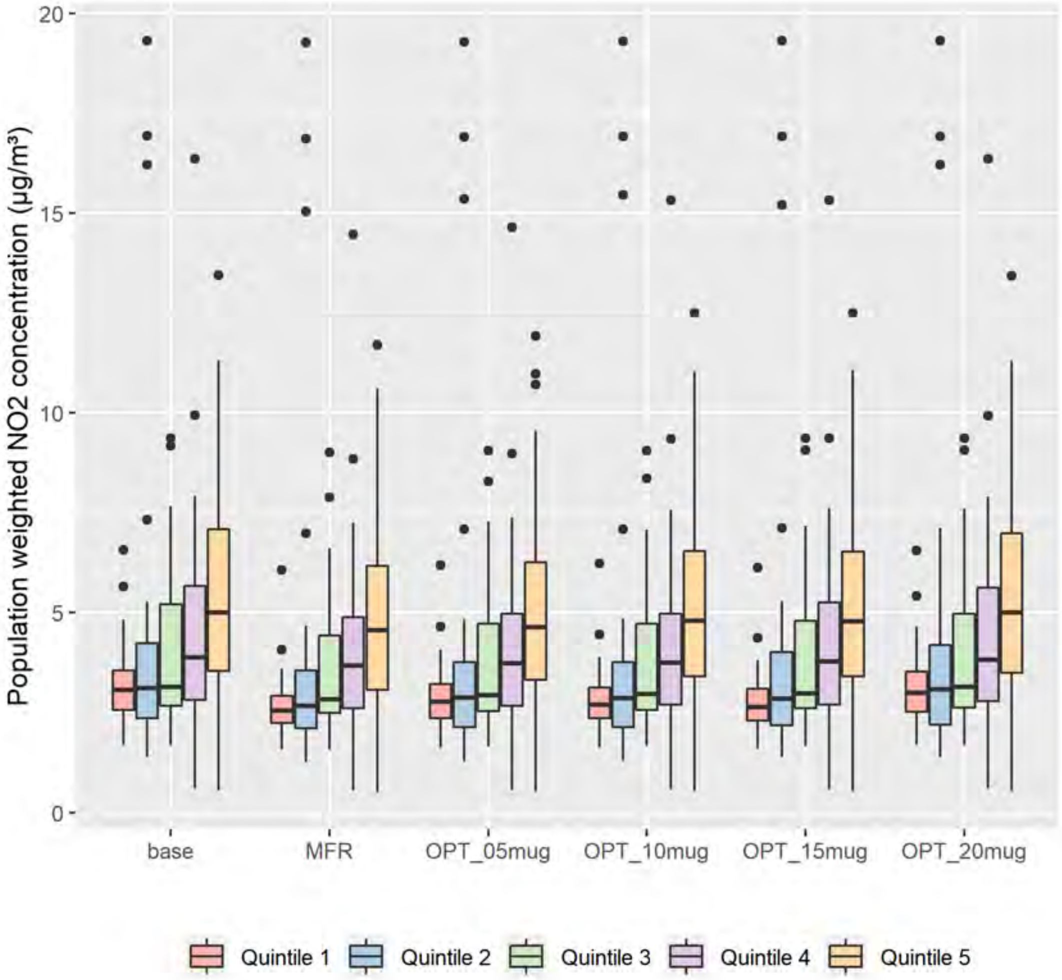


For the 2030 base year, the figure shows that the medium PM_{10} concentration decreases between quintile 1 and 4 before increasing in areas with the highest proportion of levels 5-8 educated inhabitants (quintile 5). The figure shows that this relationship seen across the quintile classes is not impacted by any of the scenarios modelled.

Analysis of the relationship between the predicted concentration of NO_2 from scenario and economically deprived groups

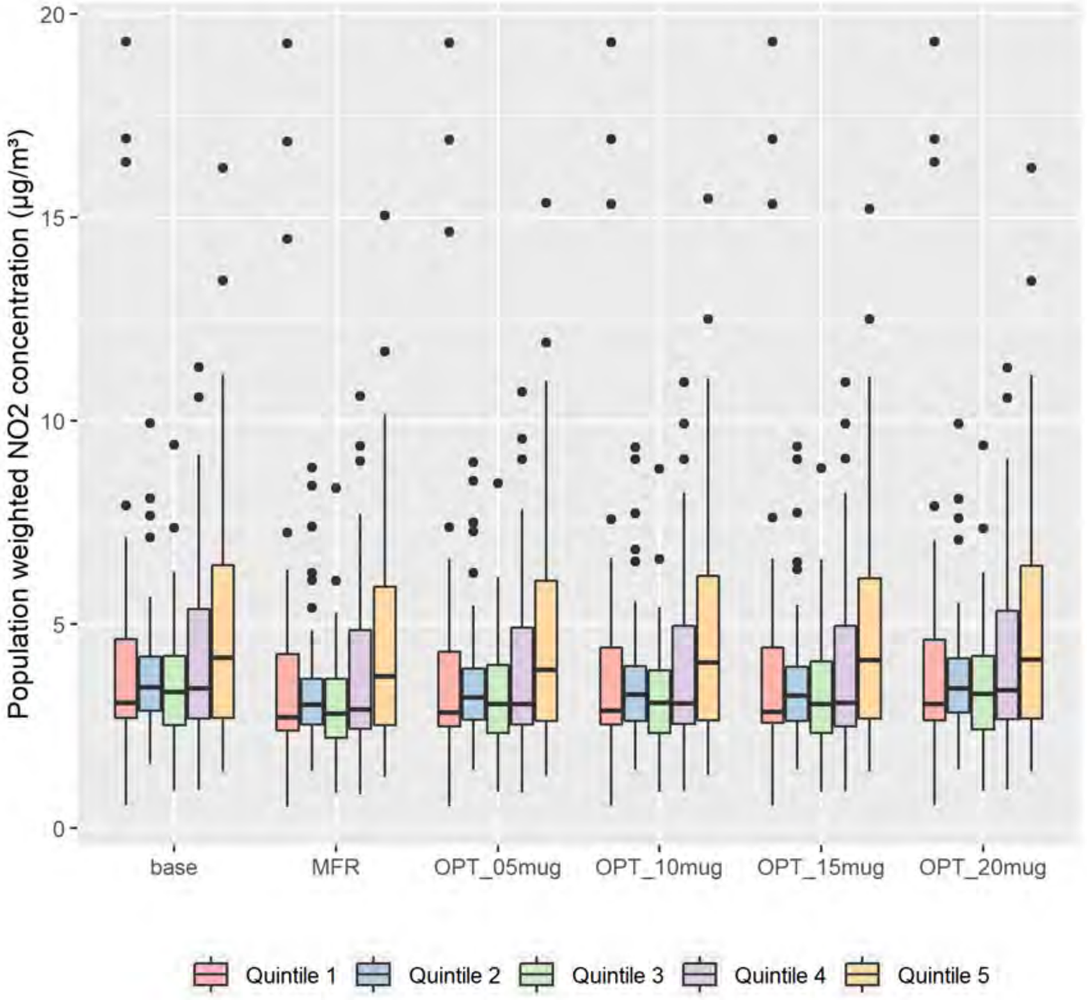
Figure A-107 shows a boxplot displaying the relationship between the predicted changes in NO_2 pollutant and areas with a low (quintile 1) to high (quintile 5) share of euro's per inhabitant at the NUTS 2 spatial resolution.

Figure A-107: 2030 population weighted exposure for NO_2 ($\mu g/m^3$) for the euros per inhabitant quintile groupings at NUTS 2 spatial resolution



The figure shows that for the 2030 modelled base year, exposure to NO_2 was lowest, on average, in areas with the lowest share of euros (quintile 1), with the medium concentration value increasing with the increase in quintile class number. The figure shows that this pattern changes with the implementation of any of the modelled scenarios. Figure A-108 shows a boxplot displaying the relationship between the predicted changes in NO_2 pollutant and areas with a low (quintile 1) to high (quintile 5) rate of unemployment at the NUTS 2 spatial resolution.

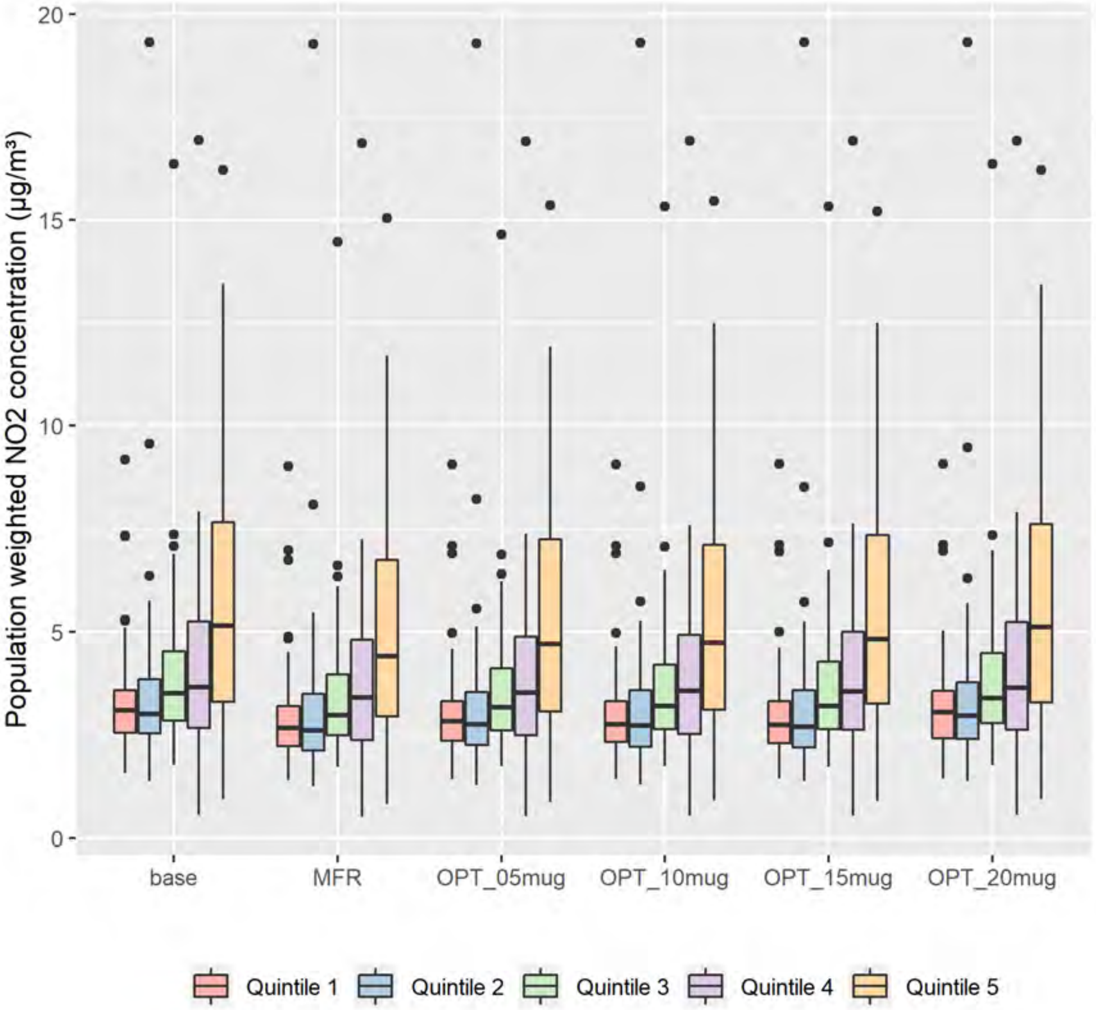
Figure A-108: 2030 population weighted exposure for NO_2 (µg/m^3) with comparison to areas with a low/high rate of unemployment at NUTS 2 spatial resolution



The figure shows that the model predicts that areas with the highest rate of unemployment (quintile 5) is likely to have the highest average concentration of NO_2 with the medium value fairly consistent in the other quintile classes. The figure suggests that this relationship is not likely to change due to the implementation of any of the modelled scenarios.

Figure A-109 shows a boxplot displaying the relationship between the predicted changes in NO2 pollutant and areas with a low (quintile 1) to high (quintile 5) of inhabitants educated at tertiary education facilities (levels 5 – 8) at NUTS 2 spatial resolution.

Figure A-109: 2030 population weighted exposure for NO_2 (µg/m^3) with comparison to areas with a low/high percentage of inhabitants educated at levels 5 to 8 at NUTS 2 spatial resolution

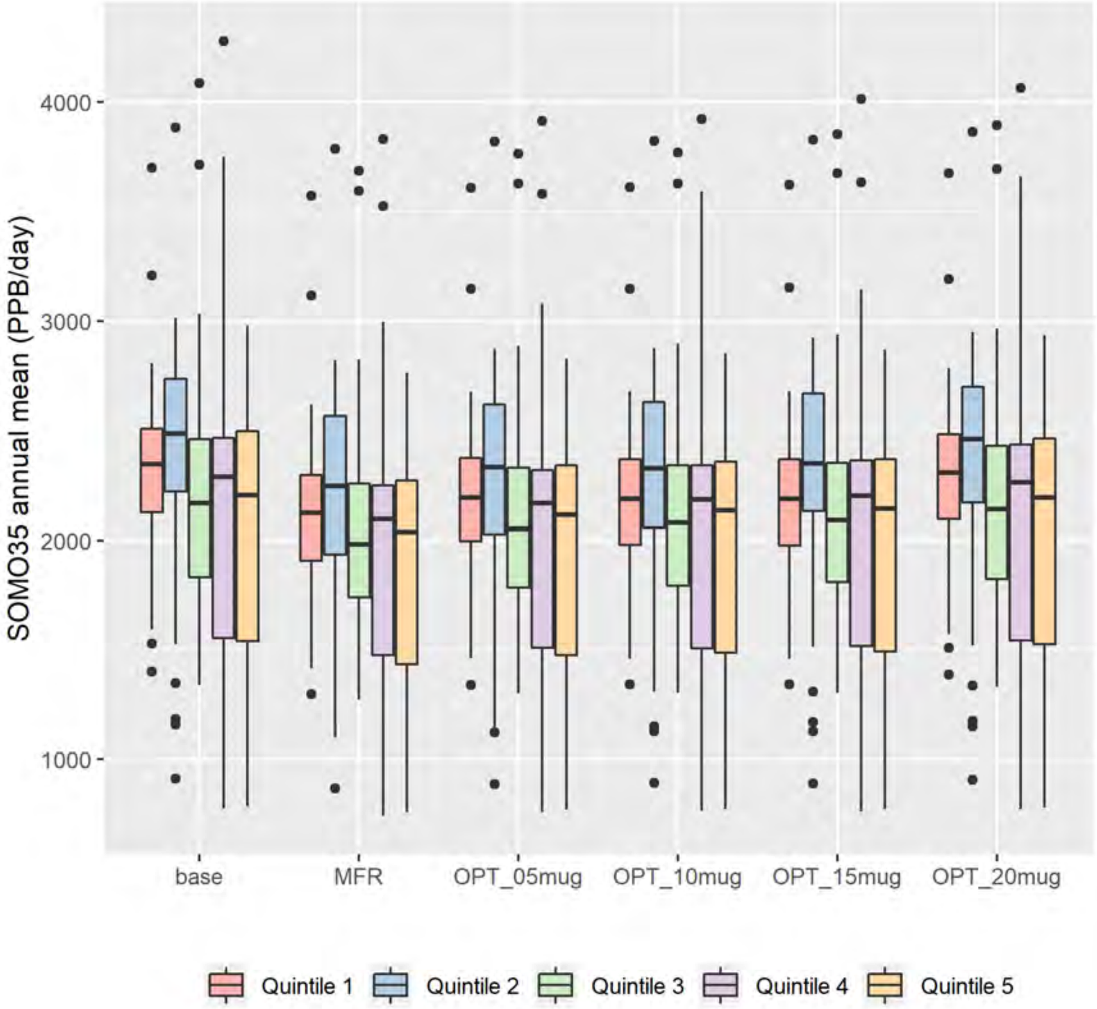


The figure shows that the model predicts that areas with the highest proportion of inhabitants educated at levels 5-8 institutions (quintile 5) are likely to be exposed to the highest average concentration of NO_2 with the medium value fairly consistent in the other quintile classes. The figure suggests that this relationship is not likely to change due to the implementation of any of the modelled scenarios.

Analysis of the relationship between the predicted concentration of Ozone from each scenario and economically deprived groups

Figure A-110 shows a boxplot displaying the relationship between the predicted concentration of Ozone pollutant and areas with a low (quintile 1) to high (quintile 5) share of euro's per inhabitant at the NUTS 2 spatial resolution.

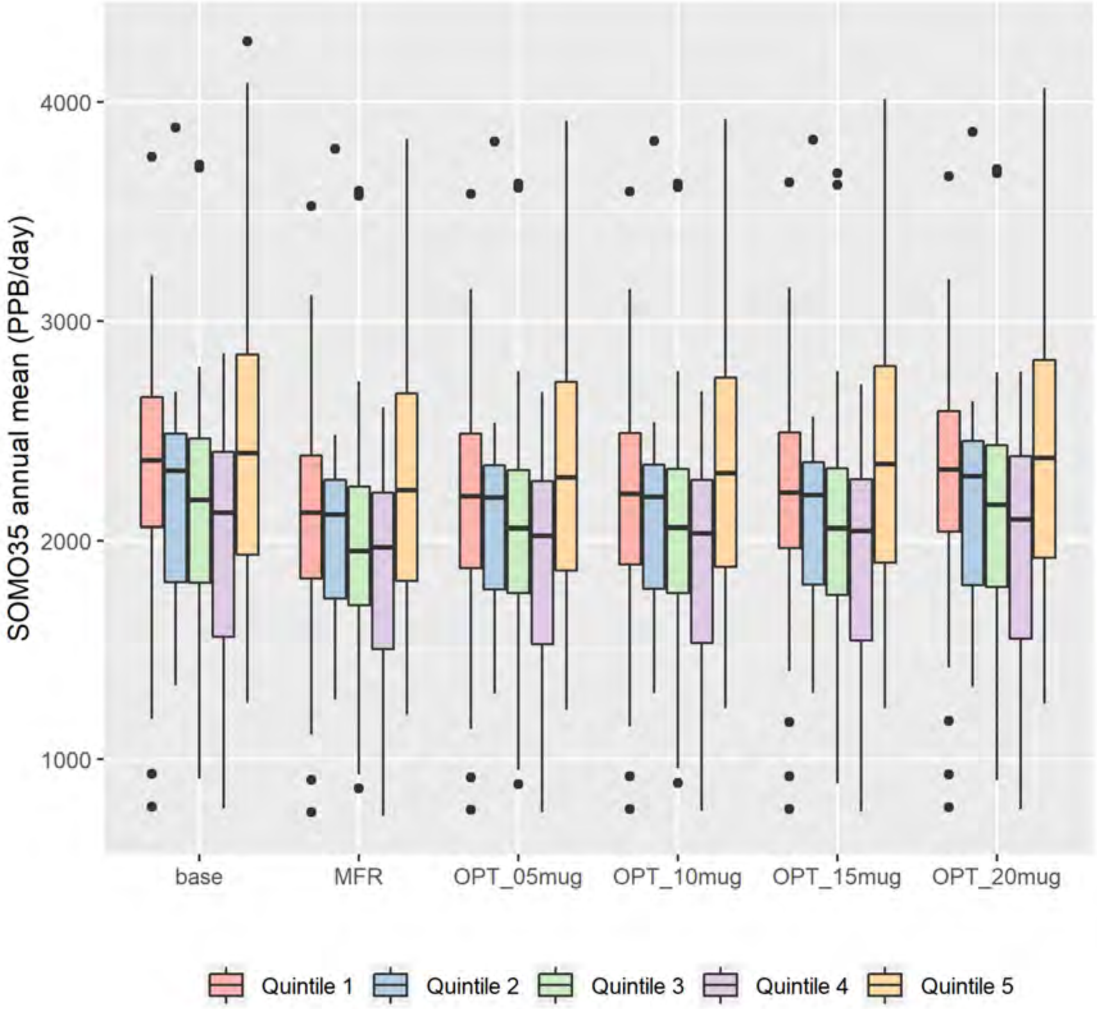
Figure A-110: 2030 exposure to Ozone (annual mean SOMO35) for the euros per inhabitant quintile groupings at NUTS 2 spatial resolution



The figure shows that for the 2030 modelled base year, there is no clear relationship between areas with a low/high share of euro per inhabitant and exposure to Ozone, with all medium concentration values within a similar range of values. The figure shows that relative to all other quintile classes, no quintile class is going to experience a larger benefit than any other in each modelled scenario compared to the baseline prediction.

Figure A-111 shows a boxplot displaying the relationship between the predicted concentration of Ozone pollutant and areas with a low (quintile 1) to high (quintile 5) rate of unemployment at the NUTS 2 spatial resolution.

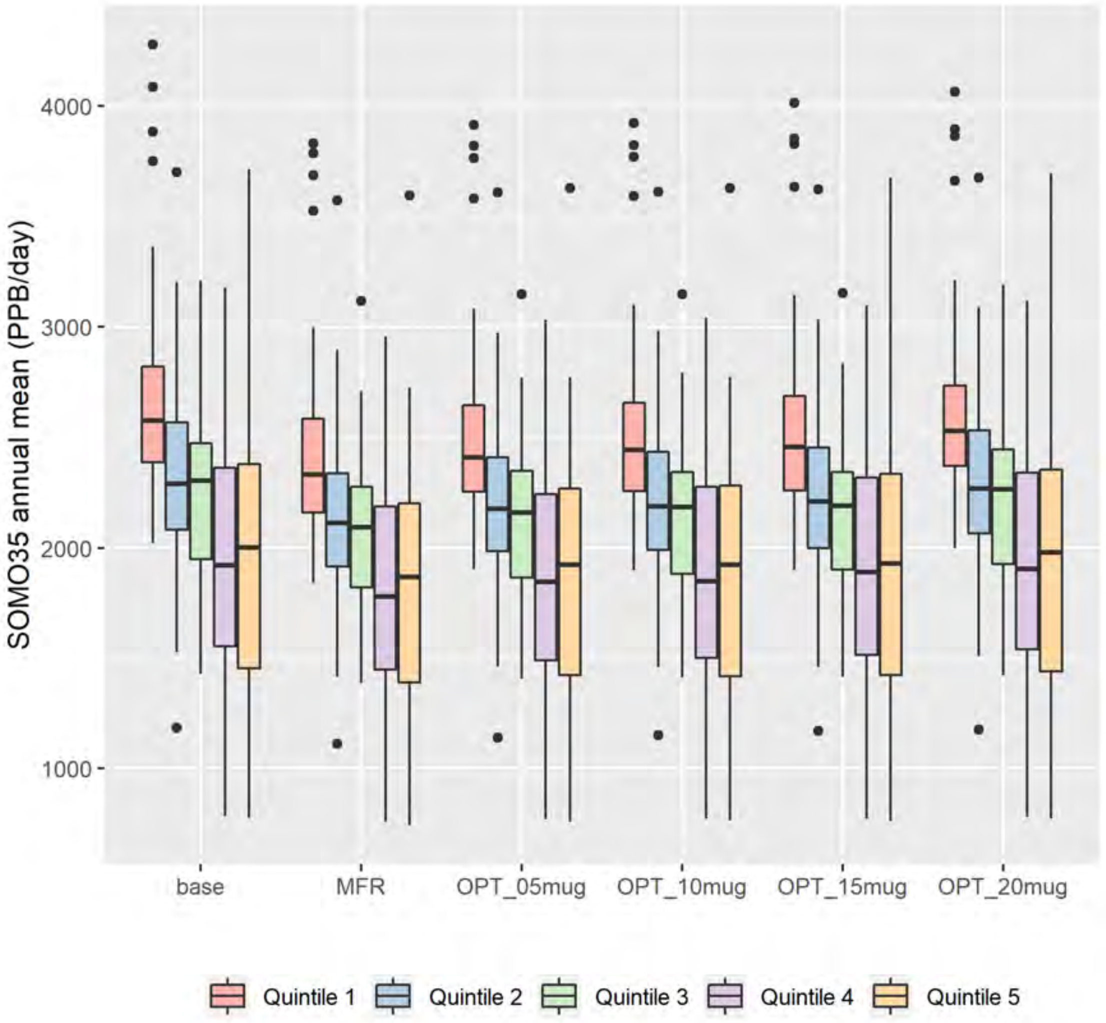
Figure A-111: 2030 exposure to Ozone (annual mean SOMO35) with comparison to areas with a low/high rate of unemployment at NUTS 2 spatial resolution



The figure shows that for the 2030 modelled base year, the medium line for each quintile class is predicted fall with each quintile class with the exception of the one representing areas with the highest rate of unemployment (quintile 5) where the medium concentration value is highest. The figure shows that this relationship is not predicted to be changed by the changes caused by the introduction of the five scenarios.

Figure A-112 shows a boxplot displaying the relationship between the predicted concentration of Ozone pollutant and areas with a low (quintile 1) to high (quintile 5) of inhabitants educated at tertiary education facilities (levels 5 – 8) at NUTS 2 spatial resolution.

Figure A-112: 2030 exposure to Ozone (annual mean SOMO35) with comparison to areas with a low/high percentage of inhabitants educated at levels 5 to 8 at NUTS 2 spatial resolution



For the 2030 base year, the figure shows a general relation between the quintile classes where the inter quartile range of concentration values decrease with each quintile class, showing that areas with the highest proportion of levels 5-8 educated inhabitants (quintile 5) are generally exposed to the lowest concentrations of Ozone pollutant. The figure shows that this relationship seen across the quintile classes is not impacted by any of the scenarios modelled.

Key results from the analysis on the impacts on air quality in areas with low/high proportion of economically deprived citizens

The following tables present the mean statistics underpinning the box plots above.

Table A-53 Summary results of analysis for $PM_{2.5}$ exposure for income per capita

	Scenarios	Quintile				
		1	2	3	4	5
2030 Baseline population-weighted mean concentration	Baseline	6.81	6.58	5.38	5.32	5.54
Average change in population-weighted mean concentration (relative to 2030 baseline	OPT20	-0.18	-0.14	-0.19	-0.22	-0.13
	OPT15	-1.02	-0.44	-0.51	-0.58	-0.6
	OPT10	-1.04	-0.77	-0.78	-0.73	-0.68
	OPT5	-1.04	-0.84	-0.88	-0.88	-0.89
Average % change in population-weighted mean concentration (relative to 2030 baseline	OPT20	-2.7	-2.09	-3.23	-3.6	-2.38
	OPT15	-15.46	-6.85	-9	-10.14	-10.44
	OPT10	-15.75	-12.6	-14.47	-12.82	-11.78
	OPT5	-15.82	-13.76	-16.25	-15.47	-15.43

Table A-54 Summary results of analysis for $PM_{2.5}$ exposure for employment

	Scenarios	Quintile				
		1	2	3	4	5
2030 Baseline population-weighted mean concentration	Baseline	5.91	6.04	5.85	5.63	6.14
Average change in population-weighted mean concentration (relative to 2030 baseline	OPT20	-0.13	-0.18	-0.18	-0.16	-0.23
	OPT15	-0.61	-0.77	-0.7	-0.65	-0.45
	OPT10	-0.71	-0.91	-0.8	-0.79	-0.79
	OPT5	-0.82	-1.04	-0.9	-0.91	-0.87
Average % change in population-weighted mean concentration (relative to 2030 baseline	OPT20	-2.45	-2.85	-2.91	-2.64	-3.18
	OPT15	-10.47	-12.66	-11.65	-10.82	-6.78
	OPT10	-12.26	-15.07	-13.63	-13.47	-13.07
	OPT5	-14.34	-17.25	-15.36	-15.65	-14.39

Table A-55 Summary results of analysis for $PM_{2.5}$ exposure for education

Scenarios		Quintile				
		1	2	3	4	5
2030 Baseline population-weighted mean concentration	Baseline	6.61	6.15	5.89	5.18	5.78
Average change in population-weighted mean concentration (relative to 2030 baseline	OPT20	-0.38	-0.15	-0.14	-0.08	-0.14
	OPT15	-0.89	-0.69	-0.63	-0.44	-0.55
	OPT10	-0.95	-0.8	-0.79	-0.64	-0.85
	OPT5	-0.97	-0.9	-0.91	-0.76	-1.01
Average % change in population-weighted mean concentration (relative to 2030 baseline	OPT20	-5.74	-2.46	-2.39	-1.54	-2.14
	OPT15	-13.52	-11.66	-10.84	-7.93	-8.72
	OPT10	-14.48	-13.54	-13.62	-12.24	-13.86
	OPT5	-14.91	-15.31	-15.84	-14.48	-16.64

Table A-56 Summary results of analysis for PM_{10} exposure for income per capita

Scenarios		Quintile				
		1	2	3	4	5
2030 Baseline population-weighted mean concentration	Baseline	9.01	9.93	7.9	7.23	7.74
Average change in population-weighted mean concentration (relative to 2030 baseline	OPT20	-0.19	-0.15	-0.21	-0.24	-0.15
	OPT15	-1.06	-0.46	-0.53	-0.61	-0.63
	OPT10	-1.08	-0.83	-0.83	-0.76	-0.71
	OPT5	-1.09	-0.9	-0.93	-0.92	-0.93
Average % change in population-weighted mean concentration (relative to 2030 baseline	OPT20	-2.31	-1.68	-2.64	-2.99	-1.95
	OPT15	-12.84	-5.54	-7.05	-7.98	-8.01
	OPT10	-13.07	-9.68	-11.09	-10.01	-9.01
	OPT5	-13.12	-10.6	-12.4	-12.04	-11.78

Table A-57 Summary results of analysis for PM_{10} exposure for employment

	Scenarios	Quintile				
		1	2	3	4	5
2030 Baseline population-weighted mean concentration	Baseline	8.36	8.09	8.24	7.66	9.23
Average change in population-weighted mean concentration (relative to 2030 baseline	OPT20	-0.14	-0.19	-0.19	-0.17	-0.25
	OPT15	-0.63	-0.8	-0.73	-0.68	-0.49
	OPT10	-0.74	-0.94	-0.84	-0.83	-0.86
	OPT5	-0.86	-1.08	-0.94	-0.96	-0.94
Average % change in population-weighted mean concentration (relative to 2030 baseline	OPT20	-1.99	-2.38	-2.45	-2.18	-2.6
	OPT15	-8.42	-10.23	-9.3	-8.6	-5.24
	OPT10	-9.75	-12.13	-10.84	-10.55	-9.66
	OPT5	-11.37	-13.83	-12.15	-12.21	-10.61

Table A-58 Summary results of analysis for PM_{10} exposure for education

	Scenarios	Quintile				
		1	2	3	4	5
2030 Baseline population-weighted mean concentration	Baseline	8.79	8.77	8.31	7.53	8.25
Average change in population-weighted mean concentration (relative to 2030 baseline	OPT20	-0.4	-0.16	-0.15	-0.09	-0.15
	OPT15	-0.93	-0.72	-0.66	-0.46	-0.56
	OPT10	-0.99	-0.84	-0.83	-0.67	-0.88
	OPT5	-1.02	-0.95	-0.95	-0.81	-1.05
Average % change in population-weighted mean concentration (relative to 2030 baseline	OPT20	-4.78	-2	-1.99	-1.22	-1.77
	OPT15	-11.31	-9.23	-8.6	-6.11	-6.66
	OPT10	-12.06	-10.59	-10.59	-9.17	-10.56
	OPT5	-12.41	-11.94	-12.28	-10.83	-12.64

Table A-59 Summary results of analysis for NO_2 exposure for income per capita

	Scenarios	Quintile				
		1	2	3	4	5
2030 Baseline population-weighted mean concentration	Baseline	3.16	4.22	3.94	4.34	5.53
Average change in population-weighted mean concentration (relative to 2030 baseline	OPT20	-0.06	-0.05	-0.04	-0.05	-0.03
	OPT15	-0.39	-0.18	-0.18	-0.22	-0.33
	OPT10	-0.36	-0.27	-0.22	-0.25	-0.33
	OPT5	-0.31	-0.3	-0.26	-0.34	-0.45
Average % change in population-weighted mean concentration (relative to 2030 baseline	OPT20	-1.68	-1.61	-1.16	-1.09	-0.7
	OPT15	-11.84	-4.84	-4.04	-4.76	-5.64
	OPT10	-10.74	-7.33	-5.19	-5.24	-5.52
	OPT5	-9.5	-8.32	-6.19	-6.95	-7.4

Table A-60 Summary results of analysis for NO_2 exposure for employment

	Scenarios	Quintile				
		1	2	3	4	5
2030 Baseline population-weighted mean concentration	Baseline	4.5	3.95	3.56	4.2	5.03
Average change in population-weighted mean concentration (relative to 2030 baseline	OPT20	-0.04	-0.04	-0.05	-0.04	-0.06
	OPT15	-0.26	-0.33	-0.29	-0.27	-0.17
	OPT10	-0.26	-0.31	-0.31	-0.29	-0.27
	OPT5	-0.3	-0.35	-0.34	-0.35	-0.33
Average % change in population-weighted mean concentration (relative to 2030 baseline	OPT20	-1.68	-1.61	-1.16	-1.09	-0.7
	OPT15	-11.84	-4.84	-4.04	-4.76	-5.64
	OPT10	-10.74	-7.33	-5.19	-5.24	-5.52
	OPT5	-9.5	-8.32	-6.19	-6.95	-7.4

Table A-61 Summary results of analysis for NO_2 exposure for education

	Scenarios	Quintile				
		1	2	3	4	5
2030 Baseline population-weighted mean concentration	Baseline	3.44	3.66	4.12	4.1	5.9
Average change in population-weighted mean concentration (relative to 2030 baseline	OPT20	-0.09	-0.04	-0.05	-0.03	-0.03
	OPT15	-0.27	-0.27	-0.28	-0.19	-0.31
	OPT10	-0.26	-0.26	-0.28	-0.22	-0.4
	OPT5	-0.25	-0.3	-0.33	-0.29	-0.5
Average % change in population-weighted mean concentration (relative to 2030 baseline	OPT20	-2.55	-1.23	-1.32	-0.67	-0.49
	OPT15	-7.89	-7.91	-6.73	-4.29	-4.57
	OPT10	-7.78	-7.71	-6.75	-5.34	-6.42
	OPT5	-7.54	-8.53	-7.63	-6.69	-7.91

Table A-62 Summary results of analysis for Ozone exposure for income per capita

	Scenarios	Quintile				
		1	2	3	4	5
2030 Baseline population-weighted mean concentration	Baseline	2318.15	2385.82	2203.52	2136.36	2056.77
Average change in population-weighted mean concentration (relative to 2030 baseline	OPT20	-26.82	-28.31	-33.65	-37.23	-23.71
	OPT15	-124.17	-80.7	-70.47	-78.61	-73.71
	OPT10	-123.59	-112.33	-101.12	-98.32	-82.35
	OPT5	-119.87	-123.5	-113.54	-109.94	-93.95
Average % change in population-weighted mean concentration (relative to 2030 baseline	OPT20	-1.18	-1.13	-1.35	-1.42	-1.06
	OPT15	-5.43	-3.31	-3	-3.26	-3.24
	OPT10	-5.39	-4.57	-4.38	-4.04	-3.63
	OPT5	-5.22	-5.07	-4.97	-4.57	-4.15

Table A-63 Summary results of analysis for Ozone exposure for education

	Scenarios	Quintile				
		1	2	3	4	5
2030 Baseline population-weighted mean concentration	Baseline	2700.45	2319.01	2235.32	1946.92	1898.59
Average change in population-weighted mean concentration (relative to 2030 baseline	OPT20	-58.88	-28.5	-26.66	-18.47	-18.43
	OPT15	-138.23	-98.16	-89.61	-52.74	-52.05
	OPT10	-158.19	-111.35	-102.11	-78.76	-68.12
	OPT5	-161.37	-121.09	-112.66	-89.69	-76.19
Average % change in population-weighted mean concentration (relative to 2030 baseline	OPT20	-2.04	-1.19	-1.18	-0.87	-0.89
	OPT15	-5.19	-4.19	-3.93	-2.57	-2.48
	OPT10	-5.85	-4.76	-4.45	-3.76	-3.22
	OPT5	-5.95	-5.18	-4.89	-4.3	-3.64

Table A-64 Summary results of analysis for Ozone exposure for employment

	Scenarios	Quintile				
		1	2	3	4	5
2030 Baseline population-weighted mean concentration	Baseline	2274.57	2215.07	2116.49	2027.56	2433.79
Average change in population-weighted mean concentration (relative to 2030 baseline	OPT20	-32.98	-27.16	-27.12	-24.13	-37.56
	OPT15	-97.87	-96.62	-91.27	-76.49	-66.06
	OPT10	-112.44	-106.97	-95.57	-88.79	-111.42
	OPT5	-121.78	-115.67	-101.24	-96.1	-123.17
Average % change in population-weighted mean concentration (relative to 2030 baseline	OPT20	-1.35	-1.2	-1.21	-1.07	-1.3
	OPT15	-4.06	-4.23	-4.13	-3.48	-2.4
	OPT10	-4.7	-4.72	-4.32	-4.02	-4.21
	OPT5	-5.1	-5.1	-4.6	-4.39	-4.72

Appendix 8 - Administrative burdens

Methodology

Compliance with the policy options could create a range of costs for a number of different actors. One such cost are administrative burdens. This is particularly the case for policy options in Policy Areas 2 and 3 for which changes in administrative burdens are anticipated to be the key impact. These impacts are relevant for public authorities (EC, national, regional, local authorities) and businesses.

To assess the potential administrative burden placed on different actors, we followed the EU's Better Regulation Toolbox Standard Cost Model (SCM) (European Commission, n.d.) . To estimate administrative costs, the SCM follows a simple equation, combining: number of activities required, with the time required per activity and the cost per unit of time spent. An important component is to determine what actions and activities would be part of the baseline (i.e. in the absence of new policy options) and which actions and activities are additional, or would be reduced, as a result of a new policy option. Separating the costs of the existing AAQ Directives (the baseline scenario), from the estimated additional costs or cost reductions of new policy options was critical to determine the incremental costs arising as a result of the implementation of new options.

This section provides a brief overview and analysis of the administrative burden each of the policy options under the three intervention areas would imply for relevant stakeholders, namely the European Commission and the Member States. No significant additional administrative burdens are anticipated as a consequence of the interventions is expected for other actors – i.e. industry and citizens.

The assessment of these costs was formed considering several relevant sources, including: the data and evidence collected through the Fitness Check, the analysis of targeted survey responses (focusing on the open question responses and considering the different viewpoints that stakeholders from different backgrounds (industry, NGOs, academy, national/regional authorities) expressed) and the parallel 'Strengthening of air quality monitoring, modelling and plans under the Ambient Air Quality Directives' study.

As gaps were identified, experts were consulted to fill in those missing pieces of information and to complement the existing data. Based on the latest scientific knowledge, expert judgement was also essential for sense-checking and adjusting estimations made in previous assessments and reports.

On this basis, an illustrative quantitative estimate of costs was developed for many of the policy interventions, both in terms of one-off costs and/or annual recurring costs.

Where a quantitative cost was not developed, a qualitative assessment was performed. Interventions were assigned a qualitative rating based on cost ranges from low (< EUR 100k) to high (>EUR 1m). This section also takes into account potential cost savings, which similarly range from low (< 100k) to high (>1m). The 'key table' below presents the assessment criteria which is reflected throughout each of the interventions. These ranges apply to operational costs per annum, and annualised capital costs.

Table A-65 Administrative burden Key

Impact	Range (EUR)
High Saving	> 1m
Mid Saving	1m – 100k
Low Saving	< 100k
Very low saving	(+)
Very low cost	(-)
Low Cost	< 100k
Mid Cost	1m – 100k
High Cost	> 1m

It is important to caveat that the illustrative quantitative estimates in some cases are based on very limited, if any, underpinning evidence and data. As such, some estimates rely more so on expert judgement. As such, the costs in practice could vary relative to the ranges presented here. In addition, alongside the cost per action, assumptions have been made around the quantity of 'actions' that are required – e.g. the number of plans to be made or revised, the number of new monitoring sites required, etc. Again the quantity of 'actions' could vary in practice, and as such the costs may scale up or indeed down where more or fewer of such actions are required in practice.

Costs of air quality plans

On Policy Area 1, all the interventions consider the revision or introduction of different EU air quality standards. In addition, several of the interventions under Policy Areas 2 and 3 would also entail the revision, extension or update to air quality plans. The revision of air pollutant standards will generate administrative burdens where ambition is increased and new points come into exceedance. As a consequence, competent authorities will need to introduce new (or revise existing) AQ Plans. Hence the cost per developing and/or revising air quality plans is a key assumption in the administrative burden analysis.

The Fitness Check provides a detailed overview of the development of air quality plans, as well as the costs associated with it, considering several case studies. Local plans are needed where measures taken at other levels have not delivered compliance with the limit values defined for air quality. Based on this, there are significant differences in costs across different plans, varying also between Member States. This variation reflect the size of the problem, and the type and mix of sources driving the exceedances at a local level. Measures are put in place in key sectors associated with exceedance of limit values (i.e. transport and domestic heating). For some countries, there are also a significant number of measures relating to information provision.

Information gathered for the Fitness Check, highlights that Member States incur in high administrative cost and burden information for the development of air quality plans. A number of activities must be carried out to set these plans up and keep them running. These account for one-off and recurring costs of over 1 million euros for Member States. As an example, these activities include monitoring and assessment (EUR 12.7 million, according to Poland), reporting and assessment regime change costs (EUR 150,000 per year, according to The Netherlands), supporting activities, such as data reporting, accreditation, modelling, database maintenance, intercomparisons, QA/QC (EUR 800,000, according to Denmark), reporting costs (EUR 301,268, according to Croatia). As a summary, France provides an estimate of EUR 65.6 million as costs on an aggregated level for the total activities of France's Authorized Air Quality Monitoring Associations (AASQAs) including activities outside the scope of monitoring including public information provision and assessing impacts of Air Quality Plans. It is noted that these cost estimates are likely to cover the development and management of multiple plans, rather than the development of a single plan for a given exceedance.

Revisions and updates of different EU air quality standards ($PM_{2.5}$, PM_{10}, ozone, pollutants of emerging concern, etc.) would result in the need to update Member States air quality plans to comply with the new regulations. Hence, expert judgement suggests that costs for all Policy Area 1 interventions can be summarised within the costs of developing an air quality plan and would overall imply an increase in the competent authorities' administrative burden. The degree to which this would affect each Member State would vary, provided that some would be closer to meeting those new revised standards, while other would be further away from them. For those standards which could drive a large number of new exceedances with even a small change (e.g. $PM_{2.5}$, PM_{10}, NO_2 and ozone), administrative costs are likely to be high. Where there is broad compliance with existing and proposed standards (e.g. SO_2, CO, benzene, etc), it could be assumed that administrative costs would at most still be low.

As a final remark, it is worth noting that some of the costs for developing an air quality plan, are also related and sometimes accounted for in other interventions under Policy Area 2 - such as B2 'Establish short-term EU air quality standards (daily or hourly) for additional air pollutants that currently only have annual or seasonal standards e.g. $PM_{2.5}$.', B3 'Expand the application of the exposure reduction targets (relative reduction in exposure).' - and Policy Area 3 - such as N1 'Refine the minimum information to be included in an air quality plan'. These were carefully considered to avoid double counting these costs.

For the analysis, we assume a cost range for air quality plans of EUR 100,000 to EUR 250,000 per plan. The same values are assumed for the development of new, and revision of existing plans.

The following tables present the illustrative estimates and underpinning assumptions for the upfront and ongoing administrative burdens associated with the interventions across Policy Areas.

Table A-66 Upfront administrative burden - evidence and assessment

Code	Intervention description	Target Group	Total initial - Low	Total initial - Central	Total initial - High	Total annualised one-off cost	Comments / assumptions
A1	Introduce a mechanism for adjusting EU air quality standards upon publication of new scientific advice (including, but not limited to, the publication of new WHO guidelines).	EC				Low	A low one-off cost is expected to be incurred by the European Commission to develop the mechanism and process by which to conduct the review.
A2	Introduce a mechanism for adjusting EU air quality standards based on technical progress in air pollution reduction.					Very Low	Negligible cost
A3	Introduce a provision to allow for EU Member States to adopt more stringent standards in light of the new technical and scientific progress coupled with an obligation to notify the European Commission.					Very Low	Negligible cost
A4	Keep and periodically update a list of priority air pollutants to ensure air pollutants of emerging concern are monitored.	EC				Low	A low one-off cost is expected to be incurred by the European Commission related to the compilation of a list of priority pollutants of emerging concern. This compilation would entail engagement with the scientific and health community.
B1	Establish short-term EU air quality standards (daily or hourly) for additional air pollutants that currently only have annual or seasonal standards e.g. PM2.5.	EC				Low	A low one-off cost is expected to be incurred by the European Commission related to legal review (expert judgement). Administrative burdens associated with exceedances of standards are included in other interventions (e.g. O2)
B2	Define alert thresholds and information thresholds for all air pollutants as triggers for alerting the public and taking short-term action.	EC				Low	A low one-off cost is expected to be incurred by the European Commission to provide guidance to Member States authorities related to the response required for the alert thresholds and information thresholds.
B3	Expand the application of the exposure reduction targets (relative reduction in exposure).	EC/MS Cas				Low	A low one-off cost is expected to be incurred by the European Commission to review the list of pollutants and measurement basis for the targets decide whether other pollutants should be included. Member States are expected to face high one-off cost to review the assessment and respond should they breach exposures targets, implement the new reporting requirements for new targets, and implementing new systems of calculating exposure. Moreover, high-one off costs are expected to be incurred by Member States to set up the systems and equipment required, although this depends on which pollutants any new target is set for. High costs have been assigned to both actions based on expert judgement and understanding of the processes required. Although annualised over 20 years, these costs are also considered low

Code	Intervention description	Target Group	Total initial - Low	Total initial - Central	Total initial - High	Total annualised one-off cost	Comments / assumptions
B4	Provide guidance on the provisions concerning types of EU air quality standards and on the action to be taken in case of exceedance of different types of standards	EC				Low	A medium one-off cost is expected to be incurred by the European Commission to develop the guidance interpreting all standards. Further to this, the European Commission would have to develop 'best practices' for Member States describing the measures needed to address exceedances of specific pollutants. Both these actions were assigned medium costs though expert judgement. A medium one-off cost is expected to be incurred by the European Commission to develop the guidance interpreting all standards. Further to this, the European Commission would have to develop 'best practices' for Member States describing the measures needed to address exceedances of specific pollutants. Both these actions were assigned medium costs though expert judgement. Annualised over 20 years, these are considered low
B5	Establish limit values for additional air pollutants (i.e. for air pollutants currently subject to target values).	EC				Low	A low one-off cost is expected to be incurred by the European Commission to establish limit values for additional air pollutants. This intervention is linked to Policy Area 1. Expert judgment suggests that main cost would be associated with data collection which is covered in other interventions. Further indirect costs (not captured by this intervention), could arise depending on where the limit vales are set at. Costs associated with exceedances of new standards are captured under other interventions (e.g. R1, R2)
C1	Further specify the obligation to take measures to keep exceedance periods as short as possible.	EC/MS Cas	6,800,000	11,900,000	17,000,000	596,876.03	A low one-off cost is expected to be incurred by the European Commission to update the existing list of obligations. Member State competent authorities should already be aware of mitigation measures available to reduce emissions. CAs required to assess the impact of specified measures in their AQ Plan. CAs required to undertake further assessment of measures to demonstrate all specified measures have been fully assessed. Includes running models and producing a new version of AQ Plan. Quantitative assumption: Applies to MSs with AQ plans that have not adequately assessed the impact of specified measures. Assume this applies to max 68 exceeding zones (2020) Cost of new AQ Plan €100k-250k
C2	Reformulate the term "as short as possible" with a defined time period.	MS Cas	6,800,000	11,900,000	17,000,000	596,876.03	No costs are expected to be incurred by the European Commission as a result of this intervention. Some Member States may incur further mitigation costs to achieve compliance earlier to meet the new specified time. However this only applies to those in exceedance. CAs required to bring forward measures to achieve compliance. Assessment of further measures to achieve compliance (not including mitigation costs) and new version of AQ Plan. Quantitative assumption: Applies to MSs exceeding LVs and remain likely to over the medium term. Assume this applies to maximum 68 exceeding zones (2020). Cost of new AQ Plan €100k-250k
C3	Require a clearer coordination between short-term action plans (STAP) and air quality plans.	MS Cas	337,500	590,625	843,750	29,624.36	CAs to update their AQ Plans/STAPs to better co-ordinate/amalgamate both plans. Update to existing plans. Not likely to require further impact assessment but would require a new version of the AQ Plans. Quantitative assessment: Applies to MSs likely to exceed alert/information thresholds. Assume 25% MSs at risk of exceedance and 50% of these require better co-ordination = 3 MSs. Cost of new STAP €100k-250k.
C4	Introduce an obligation for effective short-term action plans for each pollutant to prevent / tackle air pollution events.	MS Cas	405,000	1,046,250	1,687,500	52,477.44	The magnitude of the costs is difficult to estimate and would depend on each Member State considering the number of plans being developed and what the threshold will be set at for needing to develop one. This intervention builds on existing requirements but implies adding additional pollutants. Also, should action plans be enacted during an episodic event, mitigation costs could be high for the duration of the event. CAs to prepare STAPs for new alert thresholds e.g. for PM10. Assessment of measures to reduce episodic events and preparation of STAP. Quantitative assessment: Applies to MSs likely to exceed any new alert/information thresholds. Assume this is 15-25% of MSs. Cost for one new STAP €100k-250k
C5	Mandate regular updates of air quality plans.					Very Low	Negligible cost

Code	Intervention description	Target Group	Total initial - Low	Total initial - Central	Total initial - High	Total annualised one-off cost	Comments / assumptions
D1	Establish a requirement for Member States to involve specific actors in air quality plan development and to specify coordination arrangements for the development and implementation of air quality plans.	MS Cas	6,439,754	6,439,754	6,439,754	323,002.94	The costs of this intervention would be applicable only to Member States which need to develop a plan, i.e. based on exceedances. Each Member State will have several plans but not all of their regions will likely need to have one. Expert judgement suggests the costs associated with this measure would be high as for each plan, it would imply consulting and engaging with several stakeholder groups. CAs required to consult the public and stakeholders at stages during the preparation of their AQ Plan. Preparing, managing and analysing stakeholder events and public consultations to support AQ plan development. Quantitative assessment: 2 FTEs for 1 year per exceeding zone (max 68 in 2020).
D2	Introduce a requirement for Member States harmonise air quality plans and air quality zones (and require a ‘one zone, one plan’ approach).	MS Cas	6,800,000	11,900,000	17,000,000	596,876.03	"A cost is expected to be incurred by Member States to harmonise current and future air quality plans with air quality zones, as there are generally a large number of both of them. A medium cost has been assigned to this intervention based on expert judgement and stakeholder feedback which informed of the potential burden related to the revision of existing plans. CAs to prepare AQ Plan for each zone in exceedance.
M1	Require the use of an agreed methodology when assessing transboundary air pollution/contributions to local/regional air pollution	MS Cas	6,800,000	11,900,000	17,000,000	596,876.03	One-off costs associated to this intervention would range from no costs to medium costs depending on each member State’s situation. Expert judgement suggests that a medium one-off cost is expected to be incurred by those Member who do not have the adequate competency to measure and model transboundary pollution in place, while no costs would be incurred by those where these competencies already exist. CAs to revise their modelling methods to adopt new approach. Used in source apportionment to support AQ plans. Re-running AQ models to assess future compliance and impact of mitigation measures. May require an updated AQ Plan. Quantitative assessment: Applies to all MSs for maximum 68 zones (exceeding zones in 2020) Assume €100k- 250k for updated AQ Plan
M2	Require transboundary cooperation and joint action on air quality if assessments of transboundary air pollution/contributions above certain thresholds (to be defined)	MS Cas				Low	A one-off cost associated to this intervention would be incurred by competent authorities in those bordering Member States were transboundary pollution is an issue. Expert judgement suggests that costs would stem from having to mobilise resources to design joint air quality plans, carry out regional scale modelling and assess the impact of transboundary mitigation measures. Annualised over 20 years, these are anticipated to be low
E1	Introduce minimum levels for financial penalties.	EC/MS Cas				Low	Based on expert judgement, a low one-off cost is expected to be incurred by the European Commission associated with setting the new minimum levels for those financial penalties (unless there was significant consultation on how to set the levels). A low one-off cost is potentially expected to be incurred by the Member States related to setting the financial penalties if the Commission only sets the criteria for this to be done.
E2	Introduce specific provisions that guarantee a right to compensation for damage to health.					Very Low	Negligible cost
E3	Set up a fund to be fed by the payment of penalties and which can be used to compensate material damage or finance air quality measures.	EC/MS Cas				Low	Overall, one-off and recurring costs of this intervention are estimated by expert judgement to be low, associated mainly with the fund set-up and consequent management and administration of the payments. These costs would fall to either the European Commission or the Member States depending on how the fund regulation is set up.
E4	Introduce an explicit ‘access to justice’ clause in the Ambient Air Quality Directives.					Very Low	Negligible cost

Code	Intervention description	Target Group	Total initial - Low	Total initial - Central	Total initial - High	Total annualised one-off cost	Comments / assumptions
F1	Introduce more specific requirements to ensure regular reporting of up–to–date data / information (instead of allowing Member States to report data as available).	MS Cas	2,025,000	2,700,000	3,375,000	135,425.65	CAs to publish monitoring data in real time. Requires data management and release of data via website. Quantitative assessment: Apples to all MSs but assume 25% not already providing real time data access. Assume system to be set up (€300k – 500k per MS) and 2 FTEs to oversee publication.
F2	Require Member States to provide specific health / and health protection information to public as soon as exceedances occur.	MS CAs	20,250	20,250	20,250	1,015.69	Small one-off costs are expected to be incurred by the Member States as a result of this intervention depending on the health data required. Systems will have to be established to collect and produce this data.
F3	Mandate specific communication channels with citizens, including user-friendly tools for public access to air quality and health risks information and monitoring to use (for example, smartphone apps and/or social media dedicated pages).	EC/MS Cas	1,269,000	1,269,000	1,269,000	63,650.06	A low one-off cost is expected to be incurred by the European Commission to check if Member States are complying with the measure (expert judgement). A low one-off cost is expected to be incurred by those Member States who do not have such channels in place, and/or existing channels which are different or require alignment with the prescribed channels (expert judgement). CAs to publish air quality alerts via media channels. Marketing and comms of air quality alerts. Assumes air quality forecasting systems are in place. Quantitative assessment: 1FTE marketing/comms to work with AQ technical experts for each of the 27 Member States.
F4	Require Member States to use harmonised air quality index bands.	MS Cas	135,000	202,500	270,000	10,156.92	A low one-off cost is expected to be incurred by Member States as they would have to adapt their indices. CAs to publish alerts according to the EU index. Establish an alert system according to the EU Index. Quantitative assessment: Assume all MS have an air quality forecasting system in place. Requires setting up an alternative index and daily publication. Assume applies to 50% of MSs at estimated cost of €10,000 - 20,000 each
G1	Allow / continue to allow the use of indicative monitoring to substitute fixed monitoring as part of air quality assessment.	MS Cas	8,550,000	21,375,000	34,200,000	1,072,119.76	Cas to deploy more indicative monitors. Assumes the purchase of low cost sensors, data management and reporting. Quantitative assessment: Sensors €500 – 5,000 per pollutant and €1000 commissioning costs. Assume high uptake of low cost sensors for NO_2 and PM_{10}. (3,000 NO_2 samplers and 2700 PM_{10} samplers)
G2	Make the use of air quality modelling mandatory as part of air quality assessment (in some circumstances).	MS Cas	3,196,202	6,392,403	9,588,605	320,627.92	CAs to establish modelling assessments. Expertise to set up and run models at a national level. Quantitative assessment: Assume 50% of MS already have modelling systems in place. Require 5 - 15 FTEs modelling expertise per MS
G3	Require a regular review of the assessment regime following clear criteria defined in the Directive.	MS Cas				Low	Costs have been based on the estimated calculated in the SR9 report. The requirements of the intervention are similar to those under Solution 9: 'Guidance for the calculation of exposure and exceedance situation indicators'. The costs have been confirmed by expert judgment for this intervention.
H1	Change the minimum number of sampling points that are required per air quality zone.	MS Cas	7,210,000	10,815,000	14,420,000	542,454.98	A high one-off cost would be incurred by Member States as it will require the instrumentation and installation of further monitoring sampling points per air quality zone. CAs to establish additional reference sampling points to meet minimum requirements. Set up and manage new sampling locations for at least 2 pollutants. Quantitative assessment: Assume 2%-4% increase in sampling points for NO2, PM10, PM2.5 and Ozone. Assume current total are 4,000 NO2; 2,700 PM10, 1,350 PM2.5 and 1,960 for O3. Assume €80k for new sampling location for one pollutant and €15k for each additional pollutant per site.
H2	The minimum number of sampling points for measuring PM10 and PM2.5 will be considered independently from each other.	MS Cas	843,750	4,640,625	8,437,500	232,762.84	A high one-off cost would be incurred by Member States as it will require the instrumentation and installation of further monitoring sampling points for measuring PM10 and PM2.5 independently from each other. CAs to adhere to new PM2.5 minimum number of sampling points requirement. For some MSs installation of new PM2.5 monitors. Quantitative assessment: Assume 25% of MSs will need an additional 5-50 PM2.5 sampling points. Assume €25k per analyser

Code	Intervention description	Target Group	Total initial - Low	Total initial - Central	Total initial - High	Total annualised one-off cost	Comments / assumptions
H3	Simplify the definitions of types of monitoring station and/or sampling point locations - and only differentiate for them to distinguish between hotspots or background concentrations.	MS Cas	2,700,000	4,050,000	5,400,000	203,138.48	As this intervention implies a simplification of definitions, expert judgement suggests both a low one-off cost in terms of the revising the station classification procedure. Reclassifying sampling location types. Desk based task but may require collection of additional site meta data. Quantitative assessment: Assume mostly desk based and meta data can be collected during routine site visits. Applies to all MSs
I1	Specify that sampling points with exceedances of limit values for any of the pollutants measured under the Ambient Air Quality Directives should be maintained for a defined number of years.					Very Low	Negligible cost
I2	Include the requirement to monitor long-term trends if fixed monitoring stations are discontinued (by assessing air quality via indicative measurements or air quality modelling).	MS Cas	120,000	180,000	240,000	9,028.38	Additional costs would be very low if fixed reference samplers are replaced with indicative monitors. There would be an initial decommissioning and commissioning of the samplers. The cost of new low cost Sensors €2,000 – 5,000 per pollutant and €1000 commissioning costs. However, assume likely to apply to very few sampler locations 1%
I3	Establish a protocol to follow should a sampling point have to be re-located due to, for example, infrastructure development or changes in the assessment regimes.	EC/MS Cas	600,000	900,000	1,200,000	45,141.88	A low one-off cost could be incurred by the European Commission associated with drafting the protocol/guidance. Expert judgement suggests that Member States would likely incur a low one-off cost related to the modifications in current sites where sampling points need to be relocated, and further low recurring maintenance related to running the new devices which might be needed (i.e. data management costs). Relocation of sampling points when current location no longer applicable. Setting up a new monitoring location. Assume current equipment will be relocated. Quantitative assessment: Assume 1% of samplers would be re-located each year (40) at cost of €15k – 30k each. Assume all current equipment will be relocated e.g. analysers and monitoring enclosure. No additional recurring costs as monitoring was already in place.
J1	Further clarify (and reduce flexibilities related to) the macro-siting criteria for sampling points.	EC/MS Cas	1,200,000	3,000,000	4,800,000	150,472.95	A potential low one-off cost could be incurred by the European Commission should it be necessary for them to check that the reported new sites are compliant. Expert judgement suggests there could be some low one-off costs due to the need to review the analysis of the criteria. Further costs could be incurred by Member States should they need to relocate or replace some stations that no longer meet the criteria do not meet the criteria which would be high. Similarly, there could be some additional costs associated to finding a new site to relocation stations. Change in monitoring locations. Relocation of sampling points to adhere to new siting criteria. Quantitative assessment: Assume 2-4% of sampling locations (assume of 4,000 across EU27) requires re-location at cost of €15k – 30k each. Assume all current equipment will be relocated e.g. analysers and monitoring enclosure. No additional recurring costs as monitoring was already in place.
J2	Further clarify (and reduce flexibilities related to) the micro-siting criteria for sampling points.	EC/MS Cas	1,200,000	3,000,000	4,800,000	150,472.95	A potential low one-off cost could be incurred by the European Commission should it be necessary for them to check that the reported new sites are compliant. Expert judgement suggests there could be some low one-off costs due to the need to review the analysis of the criteria. Further costs could be incurred by Member States should they need to relocate or replace some stations that no longer meet the criteria do not meet the criteria which would be high. Similarly, there could be some additional costs associated to finding a new site to relocation stations. Change in monitoring locations. Relocation of sampling points to adhere to new siting criteria. Quantitative assessment: Assume 2-4% of sampling locations (assume of 4,000 across EU27) requires re-location at cost of €15k – 30k each. Assume all current equipment will be relocated e.g. analysers and monitoring enclosure. No additional recurring costs as monitoring was already in place.

Code	Intervention description	Target Group	Total initial - Low	Total initial - Central	Total initial - High	Total annualised one-off cost	Comments / assumptions
J3	Introduce the concept of a spatial representative area which should be estimated (and reported) for each sampling point (irrespective of exceedances being measured or not).	MS Cas	3,871,202	7,404,903	10,938,605	371,412.54	Expert judgement suggests a low one-off for this intervention to be incurred by Member States for training/adoption of new guidance. Recurring costs linked to the establishment of a methodology and then re-running the scripts, would also be low. Assess SR of monitoring sites. Expertise to set up and run models at a national level. Quantitative assessment: Assume 50% of MS already have modelling systems in place and costs for this group would be €50k - 100k. For other 50% of MS (if G2 not taken up) require modelling capacity building to support this task
K1	Further define the data quality requirements for sampling points / measurements used for air quality assessments.		1,300,000	1,950,000	2,600,000	97,807.42	Monitoring data management changes. Desk based minor changes to data management techniques. Quantitative assessment: Assume applies to all MSs and all samplers (up to 4,000 locations for all pollutants). Assume changes can readily be made to code and not apply retrospectively.
K2	Make it mandatory to provide up-to-date information on the pollutant concentration for certain air pollutants for a minimum number of sampling points per air quality zone.	MS Cas	2,025,000	2,700,000	3,375,000	135,425.65	Member States are already providing up-to-date information. However, this is done to varying degrees. The overall one-off costs of this intervention would depend on number of Member States which will have high implantation costs (namely Italy). Expert judgement suggests theses costs could be medium given that some Member States already have the required infrastructure in place while other do not. CAs to prepare monitoring data in real time for publication. Requires data management for release of data via website. Quantitative assessment: Apples to all MSs but assume 25% not already providing real time data access. Assume system to be set up (€300k – 500k per MS) and 2 FTEs to prepare data ready for publication.
K3	Introduce a standardized ‘modelling quality objective’ as a quality control mechanism to assess whether a modelling based assessment is fit-for-purpose.	MS Cas	135,000	405,000	675,000	20,313.85	Assuming modelling systems are already in place, aggregated medium one-off costs are expected to be incurred by Member States to update them, as there are already many systems running. Establishment of specific modelling quality checks. Desk based modelling tasks. Quantitative assessment: Assume 50% MSs undertake modelling and already use MQO, Other 50% carry out some level of QA. Additional QA assume cost of €10k - 50k per annum per MS
K4	Modify the definition of measurement uncertainty by defining it in absolute values and not in percentage values (or a combination of both).	MS Cas	1,300,000	1,950,000	2,600,000	97,807.42	Monitoring data management changes. Desk based minor changes to data management techniques. Quantitative assessment: Assume applies to all MSs and all samplers (up to 4,000 locations for all pollutants). Assume changes can readily be made to code and not apply retrospectively.
L1	Require monitoring stations that measure continuously certain emerging air pollutants (e.g. called “supersites” across the Member States).	MS Cas	10,800,000	21,600,000	32,400,000	1,083,405.23	High one-off costs are expected to be incurred by those Member States that do not have ‘supersites’ already in place. Expert judgement suggests costs of acquisition, and installation of these monitoring stations would be high. Monitoring would increase with additional pollutants at Supersites. Quantitative assessment: Assume 2-6 new supersites per MS. Each capital cost is €200k
L2	Require monitoring of additional air pollutants at a minimum number of sampling points and with relevant data quality requirements.	MS Cas	25,000,000	87,500,000	150,000,000	4,388,794.34	As in S10 in SR9, expert judgement confirms that a high one-off cost is expected to be incurred for Member States to set up new samplers for additional pollutants. For recurring costs, this is expected to be medium to low depending on the number of additional monitoring stations that are required within each Member State. Monitoring increase. Quantitative assessment for additional pollutants to monitor: Assume €25k capital cost and €15k running costs per pollutant per site. Assume applies to all MS and range from 1-3 pollutants and 1000-2000 sites in EU27. Assume use existing monitoring locations
L3	Expand the list of required and/or recommended volatile organic compounds (VOCs) to measure.	MS Cas	13,500,000	33,750,000	54,000,000	1,692,820.67	A medium one-off cost is expected to be incurred by Member States related to the acquisition of additional VOCs samplers. Further to this Member States would also face medium recurring costs, dependant on the number of samplers they have. Additional monitoring requirements. Further VOCs to be measured at existing sites. Quantitative assessment: Assume applies to all MSs but monitoring equipment will be replaced at capital cost of €100k . Assume 5-20 sites per MS

Code	Intervention description	Target Group	Total initial - Low	Total initial - Central	Total initial - High	Total annualised one-off cost	Comments / assumptions
N1	Refine the minimum information to be included in an air quality plan.	MS Cas	6,800,000	11,900,000	17,000,000	596,876.03	As in S32 in SR9, a high one-off cost is expected to be incurred by Member States as it would involve the process of setting up the air quality plan, including costly and time-consuming activities, namely, stakeholder engagement, health impact assessment, proposing and evaluation measures, etc. CAs required to prepare further information to support their AQ Plan. CAs to update their AQ Plan. Quantitative assessment: Applies to MSs with AQ plans that not adequately reported minimum requirements (Assume maximum 68 zones in exceedance in 2020). Cost of new AQ Plan €100k-250k
O1	Revise standards for annual PM2.5	MS Cas	200,000	4,025,000	137,000,000	201,884.54	# sites remain in exceedance in 2030 multiplied by cost of plan
O2	Introduce standards for daily PM2.5	MS Cas	200,000	4,025,000	137,000,000	201,884.54	Same as O1 - short-term set in line with annual average so in isolation, same # exceedances
O3	Revise average exposure standards for PM2.5	MS Cas	2,700,000	4,725,000	6,750,000	236,994.89	Assume all MS have to revise national plan
P1	Revise standards for annual PM10	MS Cas	400,000	4,025,000	15,250,000	201,884.54	# sites remain in exceedance in 2030 multiplied by cost of plan
P2	Revise standards for daily PM10	MS Cas	400,000	4,025,000	15,250,000	201,884.54	Same as P1 - short-term set in line with annual average so in isolation, same # exceedances
P3	Introduce average exposure standards for PM10	MS Cas	2,700,000	4,725,000	6,750,000	236,994.89	Assume all MS need to put in place new national plan
Q1	Revise standards for annual NO2	MS Cas	900,000	1,575,000	110,500,000	78,998.30	# sites remain in exceedance in 2030 multiplied by cost of plan
Q2	Revise/introduce standards for hourly/daily NO2	MS Cas	900,000	1,575,000	110,500,000	78,998.30	Same as Q1 - short-term set in line with annual average so in isolation, same # exceedances
Q3	Introduce average exposure standards for NO2	MS Cas	2,700,000	4,725,000	6,750,000	236,994.89	Assume all MS need to put in place new national plan
R1	Introduce standards for peak-season O3	MS Cas		-		Very Low	Central option assumes no change
R2	Revise standards for 8-hour O3	MS Cas	-	-	114,250,000	Very Low	# sites remain in exceedance in 2030 multiplied by cost of plan
R3	Introduce average exposure standards for O3	MS Cas	2,700,000	4,725,000	6,750,000	236,994.89	Assume all MS need to put in place new national plan
S1	Revise standards for annual SO2	MS Cas		-		Very Low	Central option assumes no standard
S2	Revise standards for daily/hourly SO2	MS Cas		-		Very Low	All options consistent with WHO AQG, which can be achieved with limited additional effort
T1	Revise standards for daily/8-hour CO	MS Cas		-		Very Low	All options consistent with WHO AQG, which can be achieved with limited additional effort
U1	Revise standards for annual benzene	MS Cas		-		Very Low	All options consistent with WHO AQG, which can be achieved with limited additional effort
V1	Revise standards for annual benzo(a)pyrene	MS Cas	7,700,000	24,062,500	66,750,000	1,206,918.44	# sites remain in exceedance in 2030 multiplied by cost of plan
W1	Revise standards for annual lead	MS Cas		-		Very Low	All options consistent with WHO AQG, which can be achieved with limited additional effort
X1	Revise standards for annual arsenic	MS Cas		-		Very Low	All options consistent with WHO AQG, some exceedances remain in 2019, but does not reflect further progress to 2030. Assume no extra effort
Y1	Revise standards for annual cadmium	MS Cas		-		Very Low	All options consistent with WHO AQG, some exceedances remain in 2019, but does not reflect further progress to 2030. Assume no extra effort
Z1	Revise standards for annual nickel	MS Cas		-		Very Low	All options consistent with WHO AQG, some exceedances remain in 2019, but does not reflect further progress to 2030. Assume no extra effort

Code	Intervention description	Target Group	Total initial - Low	Total initial - Central	Total initial - High	Total annualised one-off cost	Comments / assumptions
Ø1	Introduce standards for additional air pollutants	MS Cas				High	The administrative burden is dependent on the number of additional areas of exceedance that require air quality plans as a result of the average exposure indicator – noting though that the scope of pollutants for this intervention are not currently regulated under the AAQ Directives and thus the administrative burden will be greater than if it was building on existing provisions.

Table A-67 - Ongoing (recurring) Administrative burden - evidence and assessment

Code	Intervention description	Target group	Illustrative quantitative administrative cost - low	Illustrative quantitative administrative cost – central	Illustrative quantitative administrative cost - High	Total administrative burden - central	Comments
A1	Introduce a mechanism for adjusting EU air quality standards upon publication of new scientific advice (including, but not limited to, the publication of new WHO guidelines).	EC				Low	a low recurrent cost will be incurred to conduct the required reviews upon the publication of new scientific evidence. A low cost has been assigned to both actions based on expert judgement and understanding of the processes required. The frequency of the reviews, and therefore the total cost, is uncertain as it will be dependent on the publication of future reports.
A2	Introduce a mechanism for adjusting EU air quality standards based on technical progress in air pollution reduction.	EC				Low	A low primarily ongoing cost is expected to be incurred by the European Commission to review and acknowledge the technical progress in air pollution reduction. Expert judgement suggests that the set-up costs for the review mechanism in the Directive are negligible
A3	Introduce a provision to allow for EU Member States to adopt more stringent standards in light of the new technical and scientific progress coupled with an obligation to notify the European Commission.	EC/MS CAs				Low	Costs for reviewing the notifications sent by Member States to the European Commission are negligible, as they already have mechanisms in place to undertake such activity (expert judgement).
A4	Keep and periodically update a list of priority air pollutants to ensure air pollutants of emerging concern are monitored.	EC				Low	"The review and update of priority air pollutants is expected to imply low recurring costs for the European Commission. Expert judgement suggests these costs would mostly be linked to independent expert review of the air pollutant list based on the latest scientific findings.
B1	Establish short-term EU air quality standards (daily or hourly) for additional air pollutants that currently only have annual or seasonal standards e.g. PM2.5.					Very Low	Negligible cost

Code	Intervention description	Target group	Illustrative quantitative administrative cost - low	Illustrative quantitative administrative cost – central	Illustrative quantitative administrative cost - High	Total administrative burden - central	Comments
B2	Define alert thresholds and information thresholds for all air pollutants as triggers for alerting the public and taking short-term action.	MS CAs				Low	A low ongoing cost is expected to be incurred by Member States to communicate with the public when pollutants exceed the established thresholds. Based on expert judgement, this intervention would imply extending the alerts required hence cost are associated with the inclusion of additional pollutants as triggers for alerting the public. As the systems required to do so are assumed to already be in place there would be no one-off costs
B3	Expand the application of the exposure reduction targets (relative reduction in exposure).	MS CAs				Low	small recurring costs are likely to be incurred by Member States linked to the reporting and reviewing requirements of the set new targets
B4	Provide guidance on the provisions concerning types of EU air quality standards and on the action to be taken in case of exceedance of different types of standards					Very Low	Negligible cost
B5	Establish limit values for additional air pollutants (i.e. for air pollutants currently subject to target values).					Very Low	Negligible cost
C1	Further specify the obligation to take measures to keep exceedance periods as short as possible.					Very Low	Negligible cost
C2	Reformulate the term “as short as possible” with a defined time period.					Very Low	Negligible cost
C3	Require a clearer coordination between short-term action plans and air quality plans.					Very Low	Negligible cost
C4	Introduce an obligation for effective short-term action plans for each pollutant to prevent / tackle air pollution events.					Very Low	Negligible cost
C5	Mandate regular updates of air quality plans.	MS CAs	1,360,000	2,380,000	3,400,000	2,380,000	Costs would be associated with the number of plans (likely to be high) and the work needed to update them. Expert judgement suggests a high recurring cost as this is likely to be needed approximately periodically. CAs required to update their AQ Plan (possibly every 5 years). Assessment of further measures to achieve compliance (not including mitigation costs) and new version of AQ Plan. Quantitative assessment: Applies to maximum 68 zones. Cost of new AQ Plan €100k-250k
D1	Establish a requirement for Member States to involve specific actors in air quality plan development and to					Very Low	Negligible cost

Code	Intervention description	Target group	Illustrative quantitative administrative cost - low	Illustrative quantitative administrative cost – central	Illustrative quantitative administrative cost - High	Total administrative burden - central	Comments
	specify coordination arrangements for the development and implementation of air quality plans.						
D2	Introduce a requirement for Member States harmonise air quality plans and air quality zones (and require a ‘one zone, one plan’ approach).					Very Low	Negligible cost
M1	Require the use of an agreed methodology when assessing transboundary air pollution/contributions to local/regional air pollution					Very Low	Negligible
M2	Require transboundary cooperation and joint action on air quality if assessments of transboundary air pollution/contributions above certain thresholds (to be defined)					Very Low	Negligible cost
E1	Introduce minimum levels for financial penalties.					Very Low	Negligible cost
E2	Introduce specific provisions that guarantee a right to compensation for damage to health.	MS CAs				Very Low	Negligible cost as measure helps enforce compliance with existing directive. In practice, high recurring costs could arise in Member States as the number of claims for health damage increases due to this intervention. This is based on expert judgement suggestions stating that legal proceedings are expensive.
E3	Set up a fund to be fed by the payment of penalties and which can be used to compensate material damage or finance air quality measures.	EC/MS CAs				Low	Overall, one-off and recurring costs of this intervention are estimated by expert judgement to be low, associated mainly with the fund set-up and consequent management and administration of the payments. These costs would fall to either the European Commission or the Member States depending on how the fund regulation is set up.
E4	Introduce an explicit ‘access to justice’ clause in the Ambient Air Quality Directives.	MS CAs				Very Low	Negligible cost as measure helps enforce compliance with existing directive. In practice, high recurring costs could arise in Member States as the number of claims for health damage increases due to this intervention. This is based on expert judgement suggestions stating that legal proceedings are expensive.

Code	Intervention description	Target group	Illustrative quantitative administrative cost - low	Illustrative quantitative administrative cost – central	Illustrative quantitative administrative cost - High	Total administrative burden - central	Comments
F1	Introduce more specific requirements to ensure regular reporting of up–to–date data / information (instead of allowing Member States to report data as available).	MS CAs	639,240	639,240	639,240	638,388	Low recurring costs are expected to be incurred by the European Commission to check if Member States are complying with the measure. Recurring costs incurred by Member States would likely rise as reporting requirements increases. However, expert judgement suggests these would be low given that technology to report real-time is already available and many countries already publish (nearly) real-time data. Further costs could potentially arise from having to turn data and information into a language that layman understand. CAs to publish monitoring data in real time. Requires data management and release of data via website. Quantitative assessment: Apples to all MSs but assume 25% not already providing real time data access. Assume system to be set up (€300k – 500k per MS) and 2 FTEs to oversee publication.
F2	Require Member States to provide specific health / and health protection information to public as soon as exceedances occur.	EC/MS CAs	20,250	20,250	20,250	20,016	On the basis that the information is required annually there will be a small recurring cost . Low recurring costs are expected to be incurred by the European Commission to check if Member States are reporting as soon as exceedances happen (expert judgement). Member States to provide information to the public as soon as exceedances of alert thresholds occur. Publication (on regular comms channels) of health protection information when alert threshold exceeded. Quantitative assessment: Assume 25% of MS regularly breach alert thresholds and do not currently provide health protection information. Assume Alert thresholds are breached 10+ times each year
F3	Mandate specific communication channels with citizens, including user-friendly tools for public access to air quality and health risks information and monitoring to use (for example, smartphone apps and/or social media dedicated pages).	MS CAs	1,269,000	1,269,000	1,269,000	1,276,776	CAs to publish air quality alerts via media channels. Marketing and comms of air quality alerts. Assumes air quality forecasting systems are in place. Quantitative assessment: 1FTE marketing/comms to work with AQ technical exerts for each of the 27 Member State.
F4	Require Member States to use harmonised air quality index bands.					Very Low	Negligible cost
G1	Allow / continue to allow the use of indicative monitoring to substitute fixed monitoring as part of air quality assessment.					Very Low	Negligible cost
G2	Make the use of air quality modelling mandatory as part of air quality assessment (in some circumstances).	MS CAs	1,278,481	2,237,341	3,196,202	2,234,358	CAs to establish modelling assessments. Expertise to set up and run models at a national level. Quantitative assessment: Assume 50% of MS already have modelling systems in place. Require 2 - 5 FTEs modelling expertise per MS

Code	Intervention description	Target group	Illustrative quantitative administrative cost - low	Illustrative quantitative administrative cost – central	Illustrative quantitative administrative cost - High	Total administrative burden - central	Comments
G3	Require a regular review of the assessment regime following clear criteria defined in the Directive.	MS CAs				Low	Costs have been based on the estimated calculated in the SR9 report. The requirements of the intervention are similar to those under Solution 9: 'Guidance for the calculation of exposure and exceedance situation indicators'. The costs have been confirmed by expert judgment for this intervention.
H1	Change the minimum number of sampling points that are required per air quality zone.	MS CAs	1,200,000	2,200,000	3,200,000	2,100,000	Regarding the recurring costs, expert judgement has suggested that these would be medium where the minimum number increase is significant to low where the minimum number increase is less demanding . CAs to establish additional reference sampling points to meet minimum requirements. Set up and manage new sampling locations for at least 2 pollutants. Quantitative assessment: Assume 2%-4% increase in sampling points for NO2, PM10, PM2.5 and Ozone. Assume current total are 4,000 NO2; 2,700 PM10, 1,350 PM2.5 and 1,960 for O3. Recurring costs €15-20k per annum per site.
H2	The minimum number of sampling points for measuring PM10 and PM2.5 will be considered independently from each other.	MS CAs	506,250	2,784,375	5,062,500	2,784,375	Regarding the recurring costs, expert judgement has suggested that these would be medium where the minimum number increase is significant to low where the minimum number increase is less demanding. CAs to adhere to new PM2.5 minimum number of sampling points requirement. For some MSs installation of new PM2.5 monitors. Quantitative assessment: Assume 25% of MSs will need an additional 5-50 PM2.5 sampling points. Assume €15k recurring costs
H3	Simplify the definitions of types of monitoring station and/or sampling point locations - and only differentiate for them to distinguish between hotspots or background concentrations.					Very Low	Negligible cost
I1	Specify that sampling points with exceedances of limit values for any of the pollutants measured under the Ambient Air Quality Directives should be maintained for a defined number of years.	MS CAs				Very Low	Negligible cost - Assuming the sampling points are already installed, there would be no further one-off costs to be incurred by Member States.
I2	Include the requirement to monitor long-term trends if fixed monitoring stations are discontinued (by assessing air quality via indicative measurements or air quality modelling).	MS CAs				Very Low	Negligible recurring costs are expected as monitoring is continued which are likely to be very similar to previous costs without the intervention
I3	Establish a protocol to follow should a sampling point have to be re-located due to, for example,	MS CAs				Very Low	Negligible cost - Assuming the sampling points are already installed, there would be no further one-off costs to be incurred by Member States.

Code	Intervention description	Target group	Illustrative quantitative administrative cost - low	Illustrative quantitative administrative cost – central	Illustrative quantitative administrative cost - High	Total administrative burden - central	Comments
	infrastructure development or changes in the assessment regimes.						
J1	Further clarify (and reduce flexibilities related to) the macro-siting criteria for sampling points.					Very Low	Negligible cost
J2	Further clarify (and reduce flexibilities related to) the micro-siting criteria for sampling points.					Very Low	Negligible cost
J3	Introduce the concept of a spatial representative area which should be estimated (and reported) for each sampling point (irrespective of exceedances being measured or not).	MS CAs	1,278,481	2,237,341	3,196,202	2,234,358	Expert judgement suggests a low one-off for this intervention to be incurred by Member States for training/adoption of new guidance. Recurring costs linked to the establishment of a methodology and then re-running the scripts, would also be low. Assess SR of monitoring sites. Expertise to set up and run models at a national level. Quantitative assessment: Assume 50% of MS already have modelling systems in place. Require 2 - 5 FTEs modelling expertise per MS
K1	Further define the data quality requirements for sampling points / measurements used for air quality assessments.					Very Low	Negligible cost
K2	Make it mandatory to provide up-to-date information on the pollutant concentration for certain air pollutants for a minimum number of sampling points per air quality zone.	MS CAs	639,240	639,240	639,240	638,388	Member States are already providing up-to-date information. However, this is done to varying degrees. The overall one-off costs of this intervention would depend on number of Member States which will have high implantation costs (namely Italy). Expert judgement suggests theses costs could be medium given that some Member States already have the required infrastructure in place while other do not. Additionally, there are expected to be low recurring IT systems maintenance costs. CAs to prepare monitoring data in real time for publication. Requires data management for release of data via website. Quantitative assessment: Apples to all MSs but assume 25% not already providing real time data access. Assume system to be set up (€300k – 500k per MS) and 2 FTEs to prepare data ready for publication.
K3	Introduce a standardized 'modelling quality objective' as a quality control mechanism to assess whether a modelling based assessment is fit-for-purpose.	MS CAs	135,000	405,000	675,000	405,000	Assuming modelling systems are already in place, aggregated medium one-off costs are expected to be incurred by Member States to update them, as there are already many systems running. Further to this, Member States would incur in low recurring costs to ensure continuous checks that objectives are still being met. Establishment of specific modelling quality checks. Desk based modelling tasks. Quantitative assessment: Assume all MSs undertake modelling, and 50% already use MQO, Other 50% carry out some level of QA. Additional QA assume cost of €10k - 50k per annum per MS
K4	Modify the definition of measurement uncertainty by defining it in absolute values and not in					Very Low	Negligible cost

Code	Intervention description	Target group	Illustrative quantitative administrative cost - low	Illustrative quantitative administrative cost – central	Illustrative quantitative administrative cost - High	Total administrative burden - central	Comments
	percentage values (or a combination of both).						
L1	Require monitoring stations that measure continuously certain emerging air pollutants (e.g. called “supersites” across the Member States).	MS CAs	2,700,000	5,400,000	8,100,000	5,400,000	High one-off costs are expected to be incurred by those Member States that do not have ‘supersites’ already in place. Expert judgement suggests costs of acquisition, and installation of these monitoring stations would be high. Further to this, Member States would also incur in medium recurring costs for running the sites. Monitoring increase. Additional pollutants at Supersites. Quantitative assessment: Assume 2-6 new supersites per MS and running cost is €50k
L2	Require monitoring of additional air pollutants at a minimum number of sampling points and with relevant data quality requirements.	MS CAs	15,000,000	52,500,000	90,000,000	45,000,000	As in S10 in SR9, expert judgement confirms that a high one-off cost is expected to be incurred for Member States. setting up new samplers for additional pollutants. For recurring costs, this is expected to be medium to low depending on the number of additional monitoring stations that are required within each Member State. Monitoring increase. Additional pollutants to monitor. Quantitative assessment: Assume €25k capital cost and €15k per pollutant per site. Assume applies to all MS and range from 1-3 pollutants and 1000-2000 sites in EU27. Assume use existing monitoring locations
L3	Expand the list of required and/or recommended volatile organic compounds (VOCs) to measure.	MS CAs	10,125,000	25,312,500	40,500,000	25,312,500	A medium one-off cost is expected to be incurred by Member States related to the acquisition of additional VOCs samplers. Further to this Member States would also face medium recurring costs, dependant on the number of samplers they have. Additional monitoring requirements. Further VOCs to be measured at existing sites. Quantitative assessment: Assume applies to all MSs but monitoring equipment will be replaced at capital cost of €100k and recurring cost of €75k. Assume 5-20 sites per MS
N1	Refine the minimum information to be included in an air quality plan.					Very Low	Negligible cost
O1	Revise standards for annual PM2.5					Very Low	Negligible cost
O2	Introduce standards for daily PM2.5					Very Low	Negligible cost
O3	Revise average exposure standards for PM2.5					Very Low	Negligible cost
P1	Revise standards for annual PM10					Very Low	Negligible cost
P2	Revise standards for daily PM10					Very Low	Negligible cost
P3	Introduce average exposure standards for PM10					Very Low	Negligible cost
Q1	Revise standards for annual NO2					Very Low	Negligible cost
Q2	Revise/introduce standards for hourly/daily NO2					Very Low	Negligible cost

Code	Intervention description	Target group	Illustrative quantitative administrative cost - low	Illustrative quantitative administrative cost – central	Illustrative quantitative administrative cost - High	Total administrative burden - central	Comments
Q3	Introduce average exposure standards for NO2					Very Low	Negligible cost
R1	Introduce standards for peak-season O3					Very Low	Negligible cost
R2	Revise standards for 8-hour O3					Very Low	Negligible cost
R3	Introduce average exposure standards for O3					Very Low	Negligible cost
S1	Revise standards for annual SO2					Very Low	Negligible cost
S2	Revise standards for daily/hourly SO2					Very Low	Negligible cost
T1	Revise standards for daily/8-hour CO					Very Low	Negligible cost
U1	Revise standards for annual benzene					Very Low	Negligible cost
V1	Revise standards for annual benzo(a)pyrene					Very Low	Negligible cost
W1	Revise standards for annual lead					Very Low	Negligible cost
X1	Revise standards for annual arsenic					Very Low	Negligible cost
Y1	Revise standards for annual cadmium					Very Low	Negligible cost
Z1	Revise standards for annual nickel					Very Low	Negligible cost
Ø1	Introduce standards for additional air pollutants	EC				Very Low	Negligible cost

Appendix 9 – Sensitivity analysis

This study has developed several strands of analysis, including detailed quantitative modelling deploying an integrated modelling approach, to inform the impact assessment around the proposed revisions to the AAQ Directives. There is inherent uncertainty around all analysis, and this is also true for the analysis performed under this study. Where analysis is undertaken and used as a basis for decision making, it is important to explore uncertainty in any analysis (including in its underpinning methodology, assumptions and data inputs), in order to identify which elements are most uncertain and the impact that changes to the inputs, assumptions or approach could have on the results of the analysis and the conclusions drawn from this.

We have undertaken sensitivity analysis around the core assessment to explore the uncertainties. The analysis has focused on three sensitivity tests:

- ***Border grid sensitivity case***: air-pollution modelling is undertaken on a gridded basis – i.e. where maps are divided into square cells as a basis for the assessment. The analysis and the modelling process might be sensitive to the choices made in how spatial parameters are separated into grids. In this case, as the map is divided into grids, some areas of the EU that border non-EU states may be allocated to a grid square that includes both EU and non-EU territory. This sensitivity tests whether the inclusion of non-EU territory in the central analysis could have an impact on the results.
- ***Health impact computation:*** Improvement in human health is a key aim and benefit of the proposed revisions to the AAQ Directives. The central analysis includes detailed quantification of the potential effects. These calculations are based on the latest available evidence consolidated in the 2021 WHO Air Quality Guidelines and their underpinning scientific reviews. Since their publication, however, additional epidemiological studies have been published, which point to the possibility of using slight adjustments to the parameters in the calculation of human health impacts. This sensitivity tests the calculation of human health impacts under different input assumptions.
- ***Assumptions around IED in the baseline***: This support study to the Impact Assessment of the revision of the AAQDs commenced in April 2021. In parallel, revisions were also being considered to the Industrial Emissions Directive (IED). Over the course of this study, the proposed revisions to the IED were published, alongside a supporting impact assessment (IA) . However, the integrated impact modelling under this study was too advanced at that point to allow reflection and incorporation of the proposed IED updates into the modelling for the present study. Also, the assessment of policy options in the IED IA was done predominantly in a qualitative manner, hence not yielding elements that could be directly implemented in the present study. As such, the central baseline presented in the main report does not capture any potential effect of revisions to the IED proposed in 2022. This sensitivity tests what impact including a more up-to-date impression of the possible impacts of the IED, in the baseline, might have.

Overall, the sensitivity tests show that the central results are robust to these uncertainties: Under all sensitivity tests, the ranking of the net benefits or benefit-cost ratios between the scenarios does not change. In addition, the border grid sensitivity case suggests that the central analysis may somewhat overstate the mitigation costs associated with particular scenarios due to this uncertainty, and the health impact computation sensitivity suggests that the health benefits may be somewhat understated in the central analysis, in comparison to an appraisal methodology which reflects more recent evidence around the effects.

Sensitivity: Border grid sensitivity case

Box – Sensitivity of the assessment to the allocation of grid cells

The scenarios are assessed on the basis of a modelling approach which 'optimises' the selection of mitigation options in order to meet a given air pollutant concentration – i.e. mitigation options are selected to achieve emission reductions of a certain pollutant in ascending cost order, until sufficient abatement has been selected to meet the necessary air pollutant concentration limit. This optimisation occurs for each 'grid cell' (i.e. the spatial disaggregation of the model) individually and uses the highest concentration increment attained anywhere within the respective 28km grid cell as a constraint. In some cases however, additional analysis showed that the highest concentrations in some grid cells containing both EU and non-EU population (i.e. those cells on the EU border) are in fact driven by concentrations outside the EU border, typically due to border cities in the neighbouring country. In these cases, it is the higher concentrations beyond the EU border which is driving the measures taken by the model. Such situations were found along the Eastern and South-eastern EU border to Belarus, Ukraine, Serbia, Bosnia-Herzegovina, and Turkey. As a sensitivity case, the optimization for attaining different ambient $PM_{2.5}$ concentration levels was repeated but now excluding grid cells with cities close to the border but outside the EU. A total of 13 grid cells were excluded from the analysis as a result.

The sensitivity test concluded that although some specific impacts change under particular scenarios change, the overall pattern of net benefits and BCR remains the same as the central analysis – i.e. under all sensitivity tests, the ranking of the net benefits or benefit-cost ratios between the scenarios does not change. Excluding these grid cells excluded several cells that had relatively high concentrations in the baseline. Hence under the scenarios, mitigation action was no longer required in these cells to achieve the air pollution standards. In turn, the emissions reduction and also the costs associated with mitigation was lower under the sensitivity analysis – hence the central analysis somewhat overstates mitigation costs for some scenarios (the following table presents the mitigation costs under the sensitivity and a comparison to the central analysis). The sensitivity case has a stronger impact on some scenarios in some years, relative to others. Namely, emission reductions under OPT15 in 2030, and OPT10 in 2050 are significantly reduced, with a smaller reduction of for OPT10 in 2030, and all other scenarios are broadly the same. This is driven by the baseline concentrations in both the EU and non-EU areas of the border cells, and how they compare to the different standards.

Table: Variance in mitigation costs between central and sensitivity analysis

	2030				2050		
	OPT20	OPT15	OPT10	OPT5	OPT15	OPT10	OPT5
Central	-560	-3,280	-5,580	-7,020	-50	-4,670	-6,080
Sensitivity	-560	-992	-5,107	-7,020	-50	-3,704	-6,080
Difference	*0*	*-2,288*	*-473*	*0*	*0*	*-966*	*0*

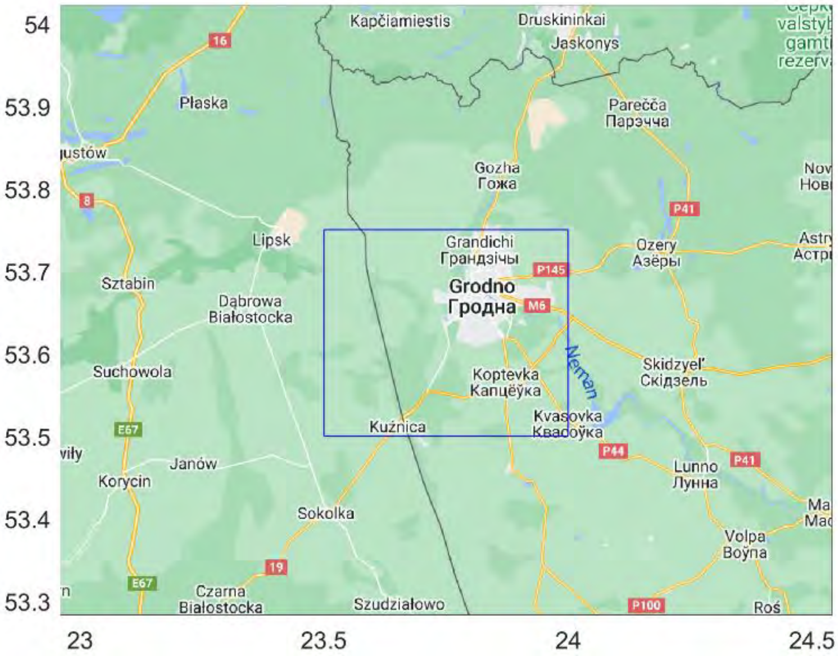
Rationale/background

The optimization in GAINS relies on atmospheric transfer coefficients calculated from sensitivity simulations of the EMEP CTM at roughly 28km resolution, in combination with a downscaling to ~7km resolution based on the CHIMERE model such that each 28km grid cell contains 16 sub-grids (Kiesewetter et al. 2015). This downscaling captures local $PM_{2.5}$ concentration increments due to low-level (residential combustion and traffic) sources of PPM (primary particulate matter). When generating cost-optimal scenarios for certain grid concentration targets, in order to keep the dimensions of the problem manageable, the optimization does not consider each 7km sub-grid cell individually but rather uses the highest concentration increment attained anywhere within the respective 28km grid cell as a constraint. In the analysis only those 28km grid cells are taken into account that include EU territory; in practice this means that only 28km grid cells were included in which at least some EU citizens live, according to the population map. It also means that in grid cells covering the EU outer border, there are living both EU and non-EU citizens, see Figure A-113.

Additional analysis showed, however, that the highest concentrations attained in some border grid cells containing both EU and non-EU population are caused by local increments outside the EU border, typically due to border cities in the neighbouring country. Since the optimization is formulated as a linear problem, the highest concentrations seen anywhere within a respective grid cell (which may extend beyond EU borders) actually drive the measures taken by the model. In such cases, where (non-EU) border towns cause the highest concentrations, the model requires neighbouring EU Member States (since no further mitigation beyond Baseline is assumed in non-EU countries) to take additional measures (often relatively strict) in order to reduce their contributions to these grid cells and achieve the concentration target level everywhere within a given grid cell.

Such situations were found along the Eastern and South-eastern EU border to Belarus, Ukraine, Serbia, Bosnia-Herzegovina, and Turkey. An example of one such situation is shown in the figure below.

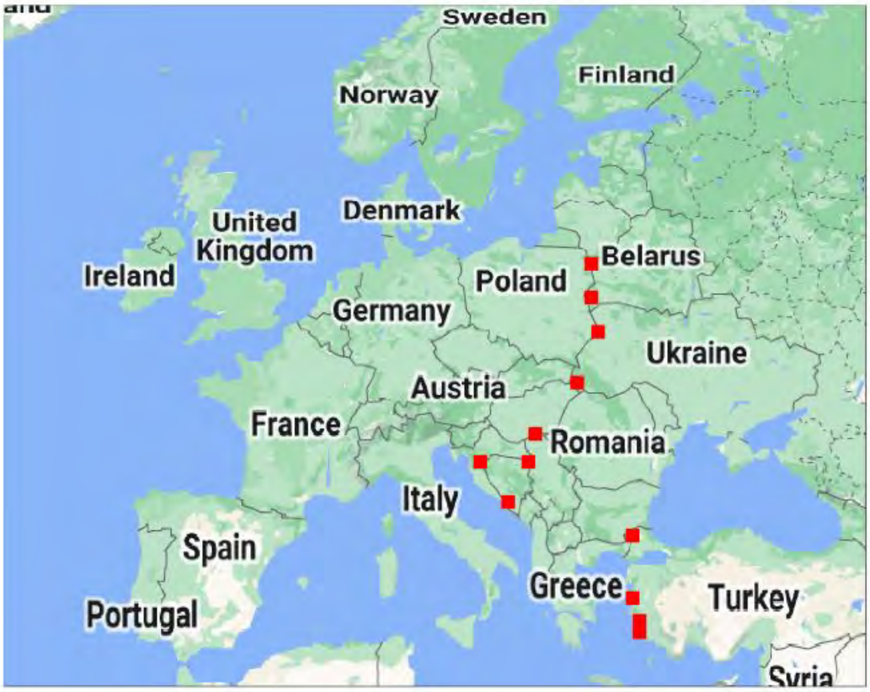
Figure A-113 A border grid cell (grid cell boundaries in blue) between Poland and Belarus with highest sub-grid PM$_{2.5}$ concentrations >15µg/m^3 in the Baseline due to a local PM$_{2.5}$ increment in the city of Grodno, Belarus. Map data © Google.



Scenario setup and results

For the central assessment of this report all border grid cells were included in the analysis to ensure complete territorial coverage. While the analysis was carried out, however, it was discovered that the particular circumstances in some bordering grid cells can drive the entire cost-effectiveness analysis for the whole EU (see above). Thus as a sensitivity case, the GAINS cost optimization for attaining different ambient PM2.5 concentration levels as presented in chapters 7 and 8 of the main report was repeated, but now excluding grid cells with cities close to the border but outside the EU. A total of 13 grid cells were excluded from the analysis as a result (see figure below). Typically, an excluded grid cell covers one Member state and one non-Member state (e.g. Poland/Belarus, Hungary/Belarus, etc.) but there is also a case where one Member state and two non-Member states are covered (Croatia/Serbia/Bosnia Herzegovina).

Figure A-114 Grid cells (red) excluded from the sensitivity analysis. Map data © Google.

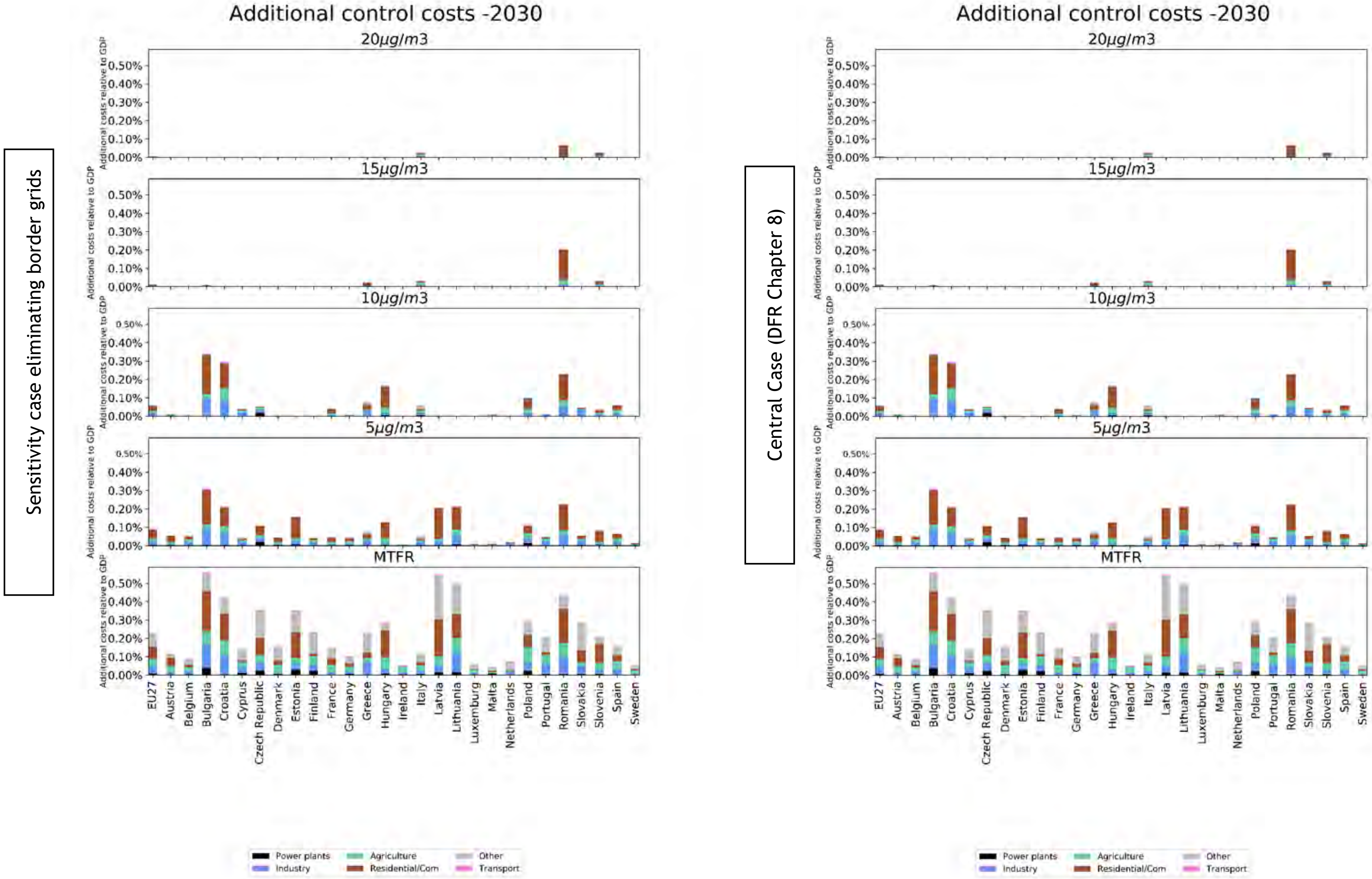


Exclusion of the selected grid cells leads to easier attainment of the prescribed standards/targets, particularly for the 15µg/m^3 case in 2030 and thus reduced costs in several EU countries (Figure A-115).

For the 10µg/m^3 target, the results are similar to the standard analysis presented in the main report (Figure 3). This is because at this more ambitious level, typically there is a need for concentration reductions to achieve this level also in grid cells that lie entirely within the Member State. Thus, neither in the standard analysis, nor in the sensitivity analysis the solution is driven by the border grid cell and so the solutions are very similar. For the 5ug/m^3 target, results are essentially identical to the standard analysis.

The emission reductions for achieving the different targets in this sensitivity case are shown in the tables and Figures below for 2030 and 2050.

Figure A-115 Additional control costs beyond baseline for achieving concentrations below certain target levels, comparison of the standard calculation as in Chapter 8 (left) versus the sensitivity case eliminating 13 border grid cells (right).



Emission results for 2030

The following tables present the outturn emission results under the border case sensitivity run, and a comparison to the core modelling result, for 2030s.

Table A-068. SO_2 emissions [kt SO_2] in the cost-optimal solutions for different $PM_{2.5}$ target levels for the border grid sensitivity case in 2030 (results of central analysis presented in Table 29 of main report), and difference to central analysis (+ve values where sensitivity emissions are higher than central case)

	Sensitivity case results						*Difference to central results*					
Member State	Baseline	Target 20ug/m^3	Target 15ug/m^3	Target 10ug/m^3	Target 5ug/m^3	MTFR	*Baseline*	*Target 20ug/m^3*	*Target 15ug/m^3*	*Target 10ug/m^3*	*Target 5ug/m^3*	*MTFR*
Austria	8	8	8	7	7	7	*0*	*0*	*0*	*-1*	*0*	*0*
Belgium	31	31	31	17	15	15	*0*	*0*	*14*	*0*	*0*	*0*
Bulgaria	41	41	33	19	19	19	*0*	*0*	*14*	*0*	*0*	*0*
Croatia	6	6	4	3	3	3	*0*	*0*	*1*	*0*	*0*	*0*
Cyprus	2	2	2	0	0	0	*0*	*0*	*0*	*0*	*0*	*0*
Czech Rep.	27	27	27	14	14	14	*0*	*0*	*11*	*0*	*0*	*0*
Denmark	9	9	9	9	7	7	*0*	*0*	*1*	*1*	*0*	*0*
Estonia	5	5	5	5	2	2	*0*	*0*	*3*	*3*	*0*	*0*
Finland	21	21	21	21	12	11	*0*	*0*	*8*	*7*	*0*	*0*
France	76	76	74	54	54	54	*0*	*0*	*10*	*0*	*0*	*0*
Germany	139	121	118	80	77	76	*0*	*0*	*29*	*0*	*0*	*0*
Greece	24	24	22	10	10	10	*0*	*0*	*12*	*0*	*0*	*0*
Hungary	7	7	7	5	5	5	*0*	*0*	*2*	*0*	*0*	*0*
Ireland	6	6	6	4	2	2	*0*	*0*	*0*	*-1*	*0*	*0*
Italy	66	36	33	33	33	33	*0*	*0*	*0*	*0*	*0*	*0*
Latvia	3	3	3	3	2	2	*0*	*0*	*0*	*0*	*0*	*0*
Lithuania	10	10	10	10	5	5	*0*	*0*	*5*	*5*	*0*	*0*
Luxembourg	1	1	1	1	1	0	*0*	*0*	*0*	*0*	*0*	*0*
Malta	1	1	1	1	1	1	*0*	*0*	*0*	*0*	*0*	*0*
Netherlands	15	15	15	12	11	11	*0*	*0*	*3*	*0*	*0*	*0*
Poland	137	137	137	82	77	77	*0*	*0*	*60*	*5*	*0*	*0*
Portugal	20	20	20	10	9	9	*0*	*0*	*0*	*0*	*0*	*0*
Romania	35	34	16	12	12	12	*0*	*0*	*4*	*0*	*0*	*0*
Slovakia	11	11	11	5	5	5	*0*	*0*	*6*	*0*	*0*	*0*
Slovenia	3	3	2	2	2	2	*0*	*0*	*0*	*0*	*0*	*0*
Spain	82	82	81	33	33	33	*0*	*0*	*-1*	*0*	*0*	*0*
Sweden	13	13	13	13	13	13	*0*	*0*	*0*	*0*	*0*	*0*
EU-27	**799**	**748**	**710**	**464**	**431**	**427**	***0***	***0***	***184***	***20***	***0***	***0***

Table A-69. NOx emissions [kt NO_2] in the cost-optimal solutions for different $PM_{2.5}$ target levels for the border grid sensitivity case in 2030 (results of central analysis presented in Table 30 of main report), and difference to central analysis (+ve values where sensitivity emissions are higher than central case).

	Sensitivity case results						*Difference to central results*					
Member State	Baseline	Target 20ug/m^3	Target 15ug/m^3	Target 10ug/m^3	Target 5ug/m^3	MTFR	*Baseline*	*Target 20ug/m^3*	*Target 15ug/m^3*	*Target 10ug/m^3*	*Target 5ug/m^3*	*MTFR*
Austria	62	60	59	54	51	48	*0*	*0*	*5*	*-1*	*0*	*0*
Belgium	92	92	92	87	78	76	*0*	*0*	*8*	*3*	*0*	*0*
Bulgaria	67	66	62	55	55	52	*0*	*0*	*7*	*0*	*0*	*0*
Croatia	26	25	24	16	18	16	*0*	*0*	*4*	*-3*	*0*	*0*
Cyprus	6	6	6	4	4	4	*0*	*0*	*0*	*0*	*0*	*0*
Czech Rep.	97	95	95	78	73	64	*0*	*0*	*22*	*4*	*0*	*0*
Denmark	63	63	63	63	55	52	*0*	*0*	*5*	*5*	*0*	*0*
Estonia	13	13	13	13	12	10	*0*	*0*	*0*	*0*	*0*	*0*
Finland	73	72	72	72	62	52	*0*	*0*	*6*	*4*	*0*	*0*
France	379	375	375	358	346	331	*0*	*0*	*5*	*0*	*0*	*0*
Germany	473	454	452	430	396	383	*0*	*0*	*47*	*22*	*0*	*0*
Greece	89	89	88	77	76	73	*0*	*0*	*14*	*0*	*0*	*0*
Hungary	66	65	65	53	57	50	*0*	*0*	*14*	*0*	*0*	*0*
Ireland	58	58	58	58	52	48	*0*	*0*	*0*	*0*	*0*	*0*
Italy	290	248	244	241	241	236	*0*	*0*	*-3*	*0*	*0*	*0*
Latvia	25	25	25	25	21	20	*0*	*0*	*1*	*1*	*0*	*0*
Lithuania	32	32	32	32	26	25	*0*	*0*	*6*	*6*	*0*	*0*
Luxembourg	8	8	8	8	7	5	*0*	*0*	*0*	*0*	*-1*	*0*
Malta	2	2	2	2	2	2	*0*	*0*	*0*	*0*	*0*	*0*
Netherlands	116	116	116	115	94	90	*0*	*0*	*13*	*12*	*-1*	*0*
Poland	303	289	289	276	244	209	*0*	*0*	*64*	*44*	*0*	*0*
Portugal	75	74	75	72	59	52	*0*	*-1*	*0*	*0*	*0*	*0*
Romania	127	125	118	102	102	93	*0*	*0*	*16*	*0*	*0*	*0*
Slovakia	38	38	38	29	29	23	*0*	*0*	*12*	*3*	*0*	*0*
Slovenia	17	15	15	15	15	14	*0*	*0*	*0*	*-1*	*0*	*0*
Spain	327	326	324	265	260	238	*0*	*0*	*-2*	*0*	*0*	*0*
Sweden	53	53	53	53	47	43	*0*	*0*	*4*	*4*	*0*	*0*
EU-27	**2978**	**2886**	**2864**	**2654**	**2484**	**2309**	***0***	***0***	***248***	***105***	***-1***	***0***

Table A-070. NH_3 emissions [kt NH_3] in the cost-optimal solutions for different $PM_{2.5}$ target levels for the border grid sensitivity case in 2030 (results of central analysis presented in Table 31 of main report), and difference to central analysis (+ve values where sensitivity emissions are higher than central case).

	Sensitivity case results						*Difference to central results*					
Member State	Baseline	Target 20ug/m^3	Target 15ug/m^3	Target 10ug/m^3	Target 5ug/m^3	MTFR	*Baseline*	*Target 20ug/m^3*	*Target 15ug/m^3*	*Target 10ug/m^3*	*Target 5ug/m^3*	*MTFR*
Austria	65	61	57	48	41	39	*0*	*0*	*6*	*-3*	*0*	*0*
Belgium	69	69	69	61	51	51	*0*	*0*	*0*	*0*	*0*	*0*
Bulgaria	44	42	41	32	32	30	*0*	*0*	*8*	*0*	*0*	*0*
Croatia	37	37	37	19	21	19	*0*	*0*	*14*	*0*	*0*	*0*
Cyprus	8	8	8	6	6	6	*0*	*0*	*0*	*0*	*0*	*0*
Czech Rep.	94	90	90	68	68	66	*0*	*0*	*22*	*0*	*0*	*0*
Denmark	67	67	67	67	55	52	*0*	*0*	*5*	*5*	*0*	*0*
Estonia	12	12	12	12	9	9	*0*	*0*	*0*	*0*	*0*	*0*
Finland	31	31	31	31	23	22	*0*	*0*	*0*	*0*	*0*	*0*
France	577	576	576	453	431	411	*0*	*0*	*17*	*-10*	*0*	*0*
Germany	550	533	531	432	339	331	*0*	*0*	*133*	*15*	*0*	*0*
Greece	56	54	50	44	44	43	*0*	*0*	*7*	*0*	*0*	*0*
Hungary	74	73	71	48	48	47	*0*	*0*	*24*	*0*	*0*	*0*
Ireland	124	124	124	123	115	97	*0*	*0*	*0*	*0*	*0*	*0*
Italy	336	254	251	249	251	244	*0*	*0*	*-2*	*0*	*0*	*0*
Latvia	17	17	17	17	14	13	*0*	*0*	*0*	*0*	*0*	*0*
Lithuania	44	41	41	41	31	29	*0*	*0*	*12*	*12*	*0*	*0*
Luxembourg	6	6	6	6	4	4	*0*	*0*	*0*	*0*	*0*	*0*
Malta	1	1	1	1	1	1	*0*	*0*	*0*	*0*	*0*	*0*
Netherlands	123	122	122	120	117	117	*0*	*0*	*2*	*1*	*0*	*0*
Poland	287	281	270	187	172	165	*0*	*0*	*104*	*21*	*0*	*0*
Portugal	51	50	50	50	36	33	*0*	*0*	*0*	*0*	*0*	*0*
Romania	166	159	130	111	113	108	*0*	*0*	*12*	*0*	*0*	*0*
Slovakia	25	23	23	15	15	15	*0*	*0*	*8*	*0*	*0*	*0*
Slovenia	17	14	13	13	12	11	*0*	*0*	*0*	*-2*	*0*	*0*
Spain	461	447	445	293	282	252	*0*	*0*	*-2*	*3*	*0*	*0*
Sweden	50	50	50	50	38	36	*0*	*0*	*0*	*0*	*0*	*0*
EU-27	**3392**	**3239**	**3178**	**2596**	**2369**	**2252**	***0***	***0***	***367***	***42***	***0***	***0***

Table A-71. VOC emissions [kt VOC] in the cost-optimal solutions for different $PM_{2.5}$ target levels for the border grid sensitivity case in 2030 (results of central analysis presented in Table 32 of main report), and difference to central analysis (+ve values where sensitivity emissions are higher than central case).

	Sensitivity case results						*Difference to central results*					
Member State	Baseline	Target 20ug/m^3	Target 15ug/m^3	Target 10ug/m^3	Target 5ug/m^3	MTFR	*Baseline*	*Target 20ug/m^3*	*Target 15ug/m^3*	*Target 10ug/m^3*	*Target 5ug/m^3*	*MTFR*
Austria	56	54	54	49	46	39	*0*	*0*	*2*	*0*	*0*	*0*
Belgium	75	74	74	71	67	60	*0*	*0*	*0*	*-1*	*0*	*0*
Bulgaria	50	43	42	38	38	31	*0*	*0*	*1*	*-1*	*0*	*0*
Croatia	37	32	32	18	18	17	*0*	*0*	*4*	*0*	*0*	*0*
Cyprus	6	5	5	5	5	4	*0*	*0*	*0*	*0*	*0*	*0*
Czech Rep.	117	111	109	94	92	75	*0*	*0*	*5*	*0*	*0*	*0*
Denmark	53	52	52	52	50	34	*0*	*0*	*0*	*0*	*0*	*0*
Estonia	12	11	11	11	11	8	*0*	*0*	*0*	*0*	*0*	*0*
Finland	44	42	42	42	39	31	*0*	*0*	*1*	*1*	*0*	*0*
France	496	489	486	439	448	382	*0*	*0*	*0*	*0*	*0*	*0*
Germany	687	661	652	568	564	445	*0*	*0*	*48*	*0*	*0*	*0*
Greece	96	95	87	72	72	65	*0*	*0*	*12*	*0*	*0*	*0*
Hungary	65	64	64	42	45	35	*0*	*0*	*22*	*-2*	*0*	*0*
Ireland	49	47	47	47	47	33	*0*	*0*	*0*	*0*	*0*	*0*
Italy	613	529	518	467	474	456	*0*	*0*	*0*	*0*	*0*	*0*
Latvia	22	21	21	21	18	11	*0*	*0*	*2*	*2*	*0*	*0*
Lithuania	25	23	23	23	20	14	*0*	*0*	*3*	*3*	*0*	*0*
Luxembourg	7	7	7	7	7	5	*0*	*0*	*0*	*0*	*0*	*0*
Malta	2	2	2	2	2	2	*0*	*0*	*0*	*0*	*0*	*0*
Netherlands	139	138	138	137	129	108	*0*	*0*	*1*	*0*	*0*	*0*
Poland	362	336	335	308	303	257	*0*	*0*	*18*	*5*	*0*	*0*
Portugal	89	85	85	81	78	65	*0*	*0*	*0*	*0*	*0*	*0*
Romania	119	99	97	92	94	76	*0*	*0*	*5*	*-2*	*0*	*0*
Slovakia	69	66	66	60	59	43	*0*	*0*	*6*	*0*	*0*	*0*
Slovenia	23	17	17	17	16	13	*0*	*0*	*-4*	*0*	*0*	*0*
Spain	425	418	402	328	342	295	*0*	*0*	*-16*	*0*	*0*	*0*
Sweden	84	82	82	82	76	68	*0*	*0*	*0*	*0*	*0*	*0*
EU-27	**3822**	**3602**	**3548**	**3172**	**3161**	**2670**	***0***	***0***	***108***	***6***	***0***	***0***

Table A-72. PM$_{2.5}$ emissions [kt PM2.5] in the cost-optimal solutions for different PM$_{2.5}$ target levels for the border grid sensitivity case in 2030 (results of central analysis presented in Table 33 of main report), and difference to central analysis (+ve values where sensitivity emissions are higher than central case).

	Sensitivity case results						*Difference to central results*					
Member State	Baseline	Target 20ug/m^3	Target 15ug/m^3	Target 10ug/m^3	Target 5ug/m^3	MTFR	*Baseline*	*Target 20ug/m^3*	*Target 15ug/m^3*	*Target 10ug/m^3*	*Target 5ug/m^3*	*MTFR*
Austria	10	10	10	8	7	6	*0*	*0*	*2*	*0*	*0*	*0*
Belgium	13	13	13	12	10	10	*0*	*0*	*0*	*0*	*0*	*0*
Bulgaria	18	12	12	8	8	8	*0*	*0*	*0*	*-1*	*0*	*0*
Croatia	10	10	10	4	4	4	*0*	*0*	*4*	*0*	*-1*	*0*
Cyprus	1	1	1	1	1	0	*0*	*0*	*0*	*0*	*0*	*0*
Czech Rep.	16	15	15	14	13	12	*0*	*0*	*1*	*0*	*0*	*0*
Denmark	11	11	11	11	8	8	*0*	*0*	*1*	*1*	*0*	*0*
Estonia	2	2	2	2	2	1	*0*	*0*	*0*	*0*	*0*	*0*
Finland	12	11	11	11	10	9	*0*	*0*	*0*	*0*	*0*	*0*
France	99	97	97	72	72	69	*0*	*0*	*5*	*0*	*0*	*0*
Germany	69	68	68	64	60	58	*0*	*0*	*4*	*0*	*0*	*0*
Greece	22	22	16	15	15	15	*0*	*0*	*1*	*0*	*0*	*0*
Hungary	30	30	30	12	13	12	*0*	*0*	*18*	*-1*	*0*	*0*
Ireland	6	6	6	6	6	5	*0*	*0*	*0*	*0*	*0*	*0*
Italy	73	58	56	56	56	55	*0*	*0*	*0*	*0*	*0*	*0*
Latvia	7	7	7	7	4	3	*0*	*0*	*2*	*2*	*0*	*0*
Lithuania	7	7	7	7	4	4	*0*	*0*	*3*	*3*	*0*	*0*
Luxembourg	1	1	1	1	1	1	*0*	*0*	*0*	*0*	*0*	*0*
Malta	0	0	0	0	0	0	*0*	*0*	*0*	*0*	*0*	*0*
Netherlands	14	13	13	13	12	12	*0*	*0*	*0*	*0*	*0*	*0*
Poland	75	70	70	50	52	49	*0*	*0*	*19*	*-1*	*0*	*0*
Portugal	26	26	26	18	12	11	*0*	*0*	*0*	*0*	*0*	*0*
Romania	43	27	23	24	24	22	*0*	*0*	*0*	*0*	*0*	*0*
Slovakia	9	9	9	6	5	5	*0*	*0*	*3*	*0*	*0*	*0*
Slovenia	9	5	5	5	4	3	*0*	*0*	*-4*	*0*	*0*	*0*
Spain	87	87	74	40	40	39	*0*	*0*	*-13*	*0*	*0*	*0*
Sweden	15	14	14	14	13	13	*0*	*0*	*0*	*0*	*0*	*0*
EU-27	**686**	**634**	**608**	**482**	**455**	**435**	***0***	***0***	***47***	***4***	***0***	***0***

Figure A-116 Relative SO_2 emission reductions beyond baseline for achieving concentrations below certain target levels, comparison of the standard calculation as in Chapter 8 (left) versus the sensitivity case eliminating 13 border grid cells (right).

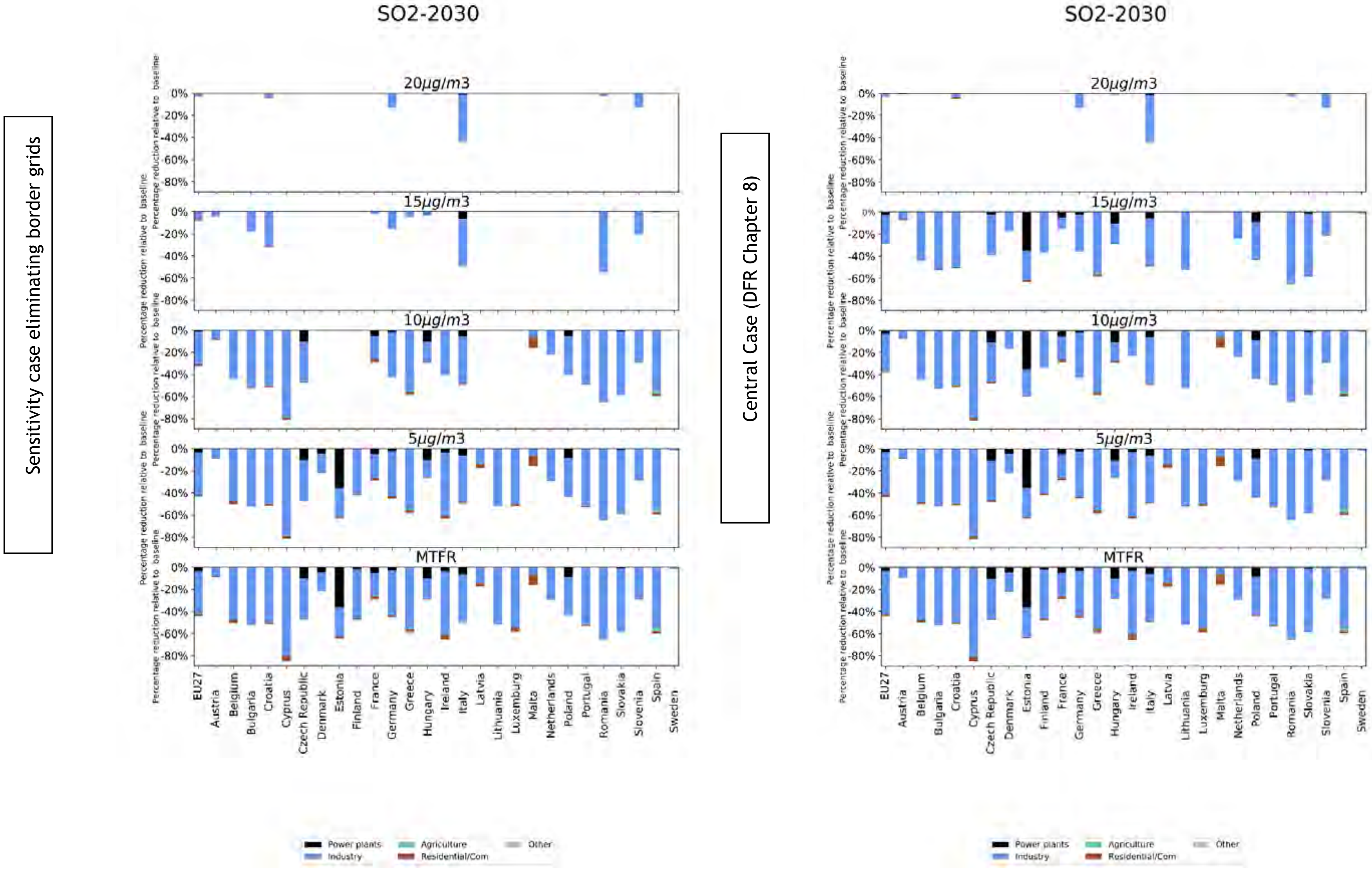


Figure A-117 Relative NOx emission reductions beyond baseline for achieving concentrations below certain target levels, comparison of the standard calculation as in Chapter 8 (left) versus the sensitivity case eliminating 13 border grid cells (right).

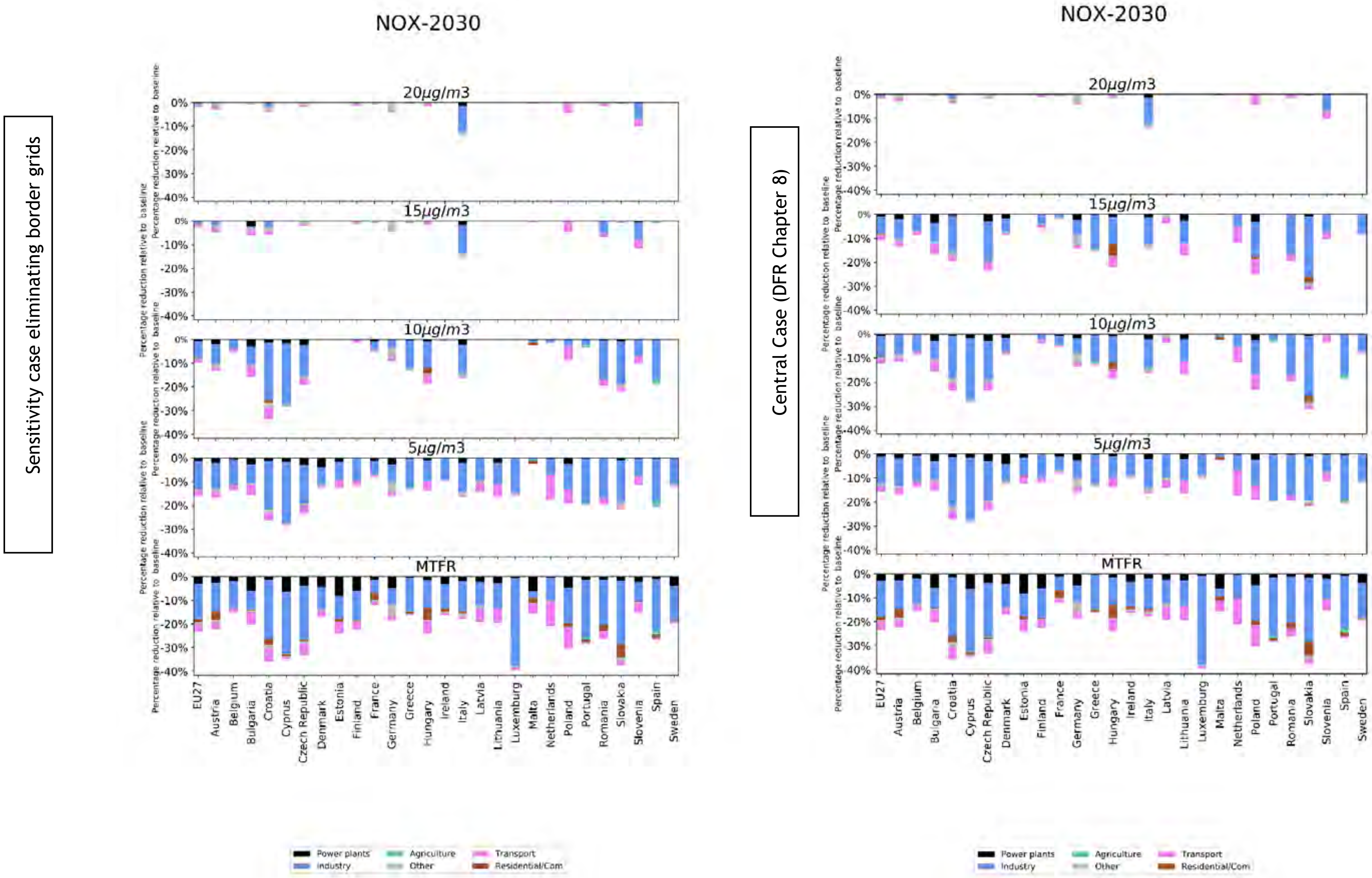


Figure A-118 Relative NH_3 emission reductions beyond baseline for achieving concentrations below certain target levels, comparison of the standard calculation as in Chapter 8 (left) versus the sensitivity case eliminating 13 border grid cells (right).

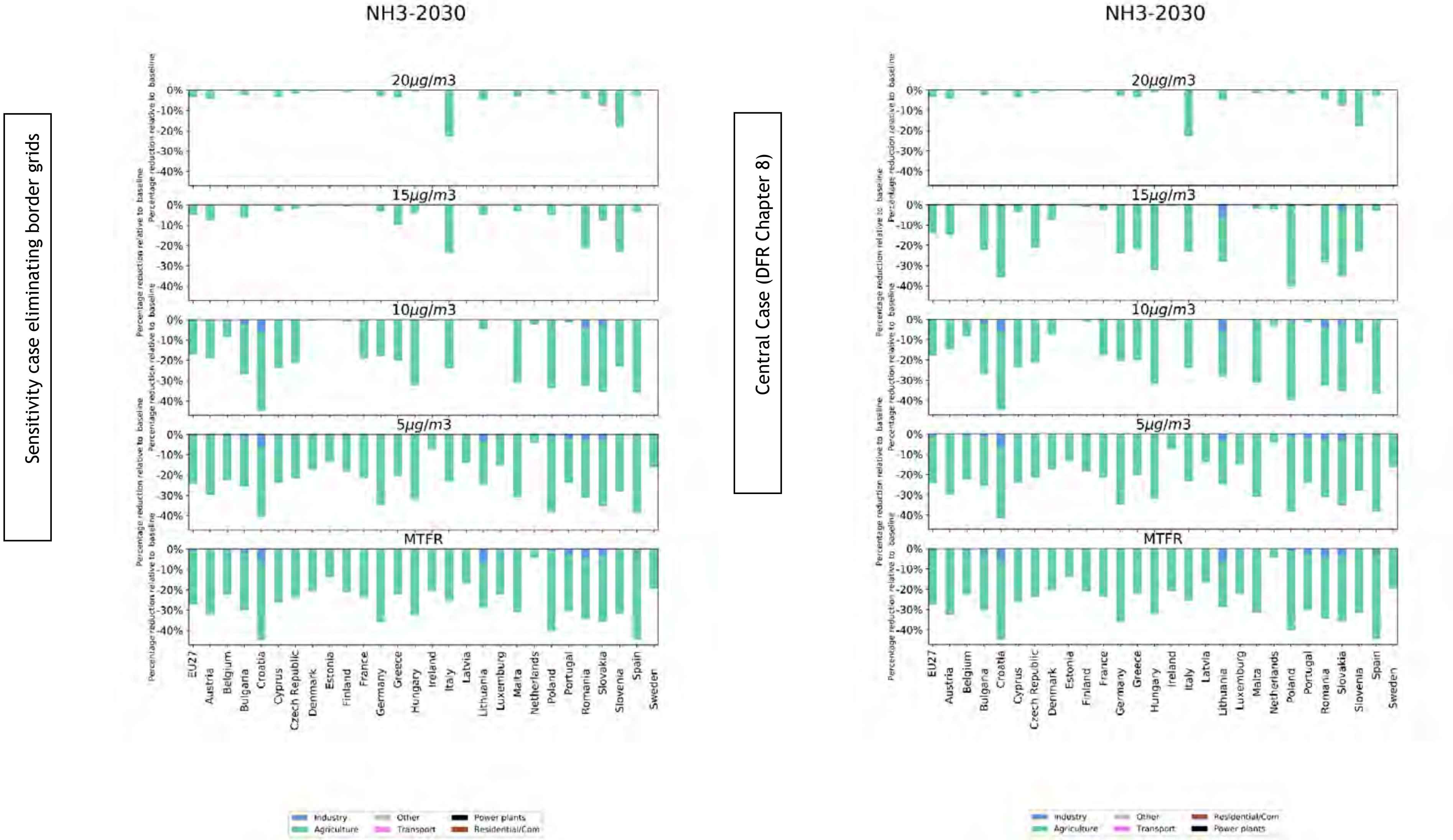


Figure A-119 Relative VOC emission reductions beyond baseline for achieving concentrations below certain target levels, comparison of the standard calculation as in Chapter 8 (left) versus the sensitivity case eliminating 13 border grid cells (right).

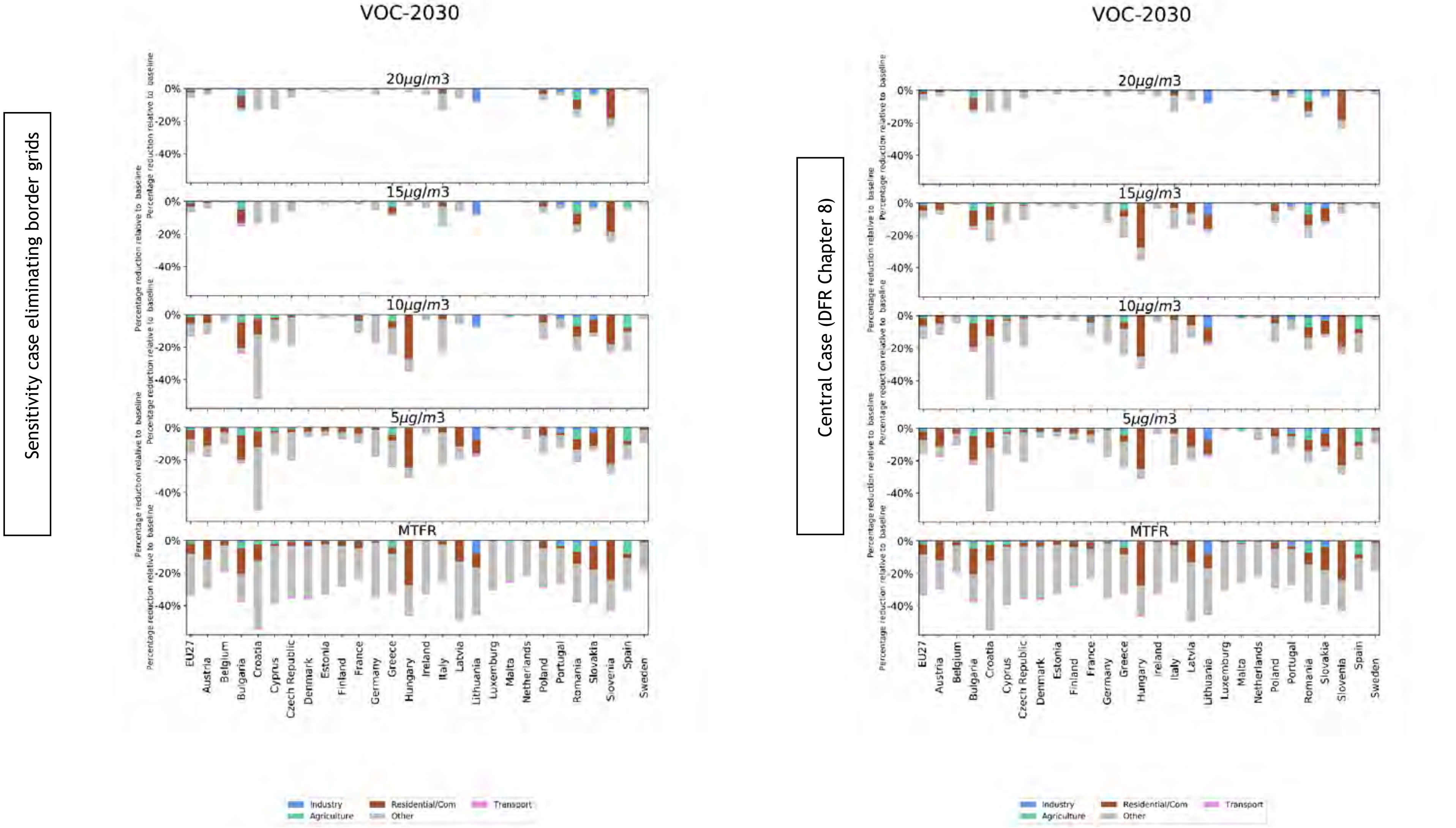
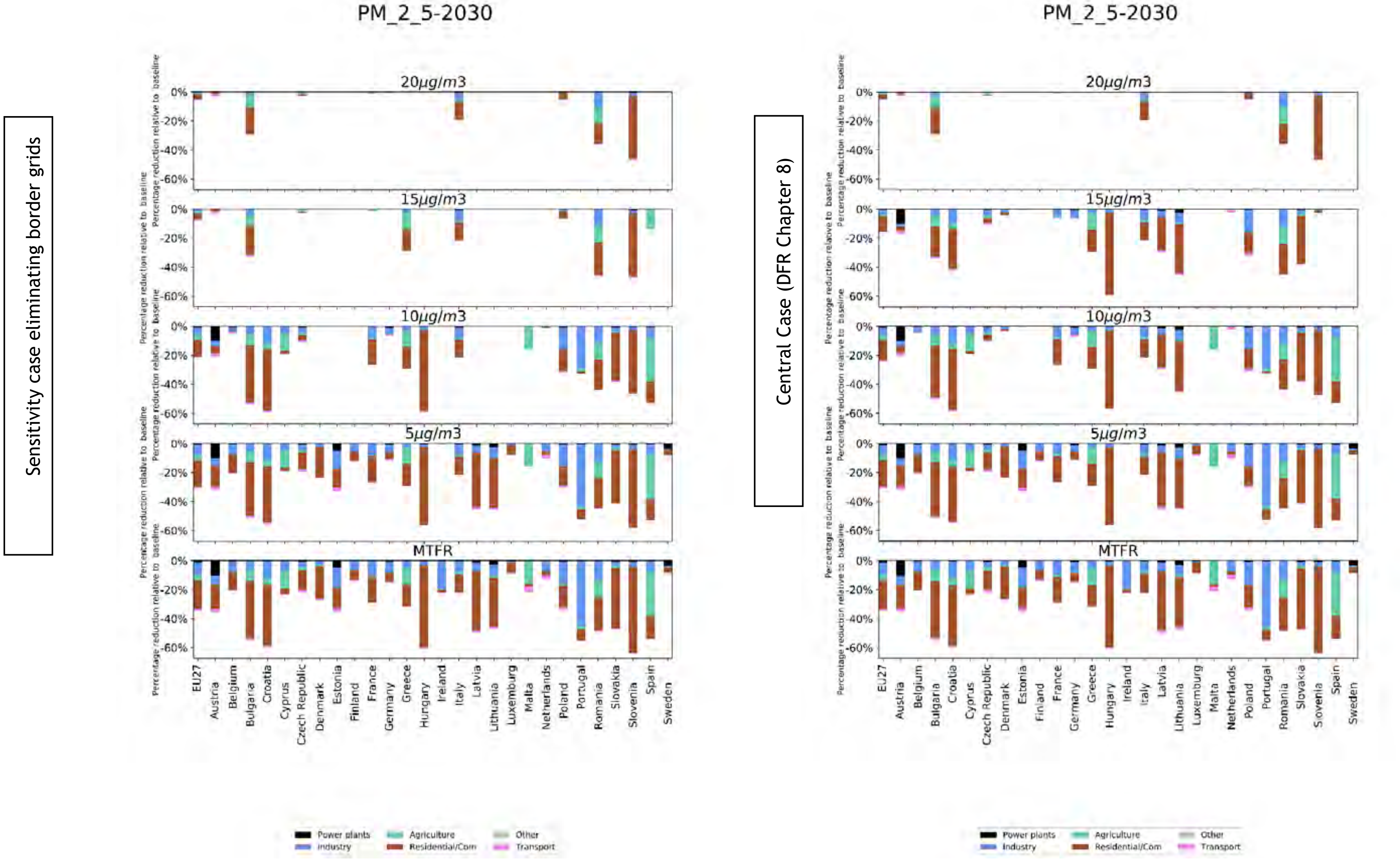


Figure A-120 Relative $PM_{2.5}$ emission reductions beyond baseline for achieving concentrations below certain target levels, comparison of the standard calculation as in Chapter 8 (left) versus the sensitivity case eliminating 13 border grid cells (right).



Emission results for 2050

The following tables present the outturn emission results under the border case sensitivity run, and a comparison to the core modelling result, for 2030s.

Table A-73. SO$_2$ emissions [kt SO$_2$] in the cost-optimal solutions for different PM$_{2.5}$ target levels for the border grid sensitivity case in 2050 (results of central analysis presented in Table 34 of main report), and difference to central analysis (+ve values where sensitivity emissions are higher than central case).

	Sensitivity case results					Difference to central results				
Member State	Baseline	Target 15ug/m^3	Target 10ug/m^3	Target 5ug/m^3	MTFR	*Baseline*	*Target 15ug/m^3*	*Target 10ug/m^3*	*Target 5ug/m^3*	*MTFR*
Austria	7	7	6	6	6	*0*	*0*	*0*	*0*	*0*
Belgium	29	29	19	14	14	*0*	*0*	*1*	*0*	*0*
Bulgaria	22	22	5	5	5	*0*	*0*	*0*	*0*	*0*
Croatia	4	4	2	2	2	*0*	*0*	*0*	*0*	*0*
Cyprus	2	2	0	1	0	*0*	*0*	*0*	*0*	*0*
Czech Rep.	15	15	8	8	8	*0*	*0*	*0*	*0*	*0*
Denmark	5	5	5	4	4	*0*	*0*	*0*	*0*	*0*
Estonia	2	2	2	1	1	*0*	*0*	*1*	*0*	*0*
Finland	16	16	16	9	8	*0*	*0*	*6*	*0*	*0*
France	58	58	37	37	37	*0*	*0*	*0*	*0*	*0*
Germany	109	109	63	63	63	*0*	*0*	*0*	*0*	*0*
Greece	18	18	6	6	6	*0*	*0*	*0*	*0*	*0*
Hungary	7	7	6	6	6	*0*	*0*	*0*	*0*	*0*
Ireland	6	6	6	3	2	*0*	*0*	*0*	*0*	*0*
Italy	58	57	38	38	38	*0*	*0*	*0*	*0*	*0*
Latvia	2	2	2	2	2	*0*	*0*	*0*	*0*	*0*
Lithuania	5	5	5	3	3	*0*	*0*	*2*	*0*	*0*
Luxembourg	1	1	1	1	0	*0*	*0*	*0*	*0*	*0*
Malta	1	1	0	0	0	*0*	*0*	*0*	*0*	*0*
Netherlands	13	13	13	10	10	*0*	*0*	*2*	*0*	*0*
Poland	72	72	29	29	29	*0*	*0*	*0*	*0*	*0*
Portugal	14	14	7	7	7	*0*	*0*	*0*	*0*	*0*
Romania	28	21	9	9	9	*0*	*0*	*0*	*0*	*0*
Slovakia	11	11	5	5	5	*0*	*0*	*0*	*0*	*0*
Slovenia	1	1	1	1	1	*0*	*0*	*0*	*0*	*0*
Spain	67	67	30	30	30	*0*	*0*	*0*	*0*	*0*
Sweden	11	11	11	10	10	*0*	*0*	*1*	*0*	*0*
EU-27	**584**	**576**	**336**	**311**	**309**	***0***	***0***	***14***	***0***	***0***

Table A-74. NOx emissions [kt NO_2] in the cost-optimal solutions for different $PM_{2.5}$ target levels for the border grid sensitivity case in 2050 (results of central analysis presented in Table 35 of main report), and difference to central analysis (+ve values where sensitivity emissions are higher than central case).

	Sensitivity case results					Difference to central results				
Member State	Baseline	Target 15ug/m^3	Target 10ug/m^3	Target 5ug/m^3	MTFR	*Baseline*	*Target 15ug/m^3*	*Target 10ug/m^3*	*Target 5ug/m^3*	*MTFR*
Austria	70	67	67	58	55	*0*	*0*	*9*	*0*	*0*
Belgium	89	89	89	68	68	*0*	*0*	*9*	*0*	*0*
Bulgaria	33	32	27	27	27	*0*	*0*	*0*	*0*	*0*
Croatia	17	16	9	11	9	*0*	*0*	*-3*	*0*	*0*
Cyprus	4	4	2	2	2	*0*	*0*	*0*	*0*	*0*
Czech Rep.	56	51	51	38	29	*0*	*0*	*17*	*0*	*0*
Denmark	35	35	35	29	28	*0*	*0*	*6*	*0*	*0*
Estonia	8	8	8	7	6	*0*	*0*	*0*	*0*	*0*
Finland	47	45	43	37	29	*0*	*0*	*3*	*0*	*0*
France	245	231	204	200	195	*0*	*0*	*4*	*0*	*0*
Germany	272	268	250	208	203	*0*	*0*	*29*	*0*	*0*
Greece	60	58	46	46	44	*0*	*0*	*-1*	*0*	*0*
Hungary	40	40	31	31	30	*0*	*0*	*1*	*0*	*0*
Ireland	44	43	43	38	36	*0*	*0*	*0*	*0*	*0*
Italy	193	184	134	134	133	*0*	*0*	*0*	*0*	*0*
Latvia	12	12	12	10	9	*0*	*0*	*1*	*0*	*0*
Lithuania	16	16	16	12	11	*0*	*0*	*5*	*0*	*0*
Luxembourg	5	5	5	3	2	*0*	*0*	*0*	*0*	*0*
Malta	1	1	1	1	1	*0*	*0*	*0*	*0*	*0*
Netherlands	71	71	71	58	55	*0*	*0*	*5*	*0*	*0*
Poland	172	160	160	126	107	*0*	*0*	*50*	*0*	*0*
Portugal	47	47	42	33	26	*0*	*0*	*0*	*0*	*0*
Romania	75	71	51	51	47	*0*	*0*	*2*	*0*	*0*
Slovakia	28	28	28	19	15	*0*	*0*	*12*	*0*	*0*
Slovenia	7	6	6	4	4	*0*	*0*	*0*	*0*	*0*
Spain	191	183	122	125	110	*0*	*0*	*4*	*0*	*0*
Sweden	34	34	34	29	26	*0*	*0*	*5*	*0*	*0*
EU-27	**1871**	**1805**	**1589**	**1407**	**1307**	***0***	***0***	***159***	***0***	***0***

Table A-75. NH_3 emissions [kt NH_3] in the cost-optimal solutions for different $PM_{2.5}$ target levels for the border grid sensitivity case in 2050 (results of central analysis presented in Table 36 of main report), and difference to central analysis (+ve values where sensitivity emissions are higher than central case).

	Sensitivity case results					Difference to central results				
Member State	Baseline	Target 15ug/m^3	Target 10ug/m^3	Target 5ug/m^3	MTFR	*Baseline*	*Target 15ug/m^3*	*Target 10ug/m^3*	*Target 5ug/m^3*	*MTFR*
Austria	65	62	48	42	39	*0*	*0*	*-2*	*0*	*0*
Belgium	66	66	66	48	48	*0*	*0*	*0*	*0*	*0*
Bulgaria	43	42	32	31	29	*0*	*0*	*0*	*0*	*0*
Croatia	36	35	18	20	18	*0*	*0*	*-1*	*0*	*0*
Cyprus	8	8	6	6	6	*0*	*0*	*0*	*0*	*0*
Czech Rep.	87	82	65	61	60	*0*	*0*	*3*	*0*	*0*
Denmark	64	63	63	50	49	*0*	*0*	*5*	*0*	*0*
Estonia	11	11	11	9	9	*0*	*0*	*0*	*0*	*0*
Finland	34	34	33	24	23	*0*	*0*	*1*	*0*	*0*
France	565	561	471	400	378	*0*	*0*	*1*	*0*	*0*
Germany	518	499	452	315	306	*0*	*0*	*60*	*0*	*0*
Greece	53	51	39	40	39	*0*	*0*	*-1*	*0*	*0*
Hungary	70	69	44	44	44	*0*	*0*	*0*	*0*	*0*
Ireland	121	121	121	112	95	*0*	*0*	*0*	*0*	*0*
Italy	314	282	227	231	226	*0*	*0*	*-4*	*0*	*0*
Latvia	17	17	17	13	13	*0*	*0*	*0*	*0*	*0*
Lithuania	42	39	39	29	27	*0*	*0*	*12*	*0*	*0*
Luxembourg	6	6	6	4	3	*0*	*0*	*0*	*0*	*0*
Malta	1	1	1	1	1	*0*	*0*	*0*	*0*	*0*
Netherlands	121	120	120	116	116	*0*	*0*	*2*	*0*	*0*
Poland	282	274	243	173	162	*0*	*0*	*81*	*0*	*0*
Portugal	47	47	46	33	30	*0*	*0*	*0*	*0*	*0*
Romania	154	145	107	103	97	*0*	*0*	*7*	*0*	*0*
Slovakia	25	22	22	15	15	*0*	*0*	*7*	*0*	*0*
Slovenia	16	15	16	11	10	*0*	*0*	*3*	*0*	*0*
Spain	448	433	264	264	235	*0*	*0*	*-3*	*0*	*0*
Sweden	51	51	51	38	36	*0*	*0*	*0*	*0*	*0*
EU-27	**3265**	**3156**	**2628**	**2234**	**2112**	***0***	***0***	***172***	***0***	***0***

Table A-76. VOC emissions [kt VOC] in the cost-optimal solutions for different $PM_{2.5}$ target levels for the border grid sensitivity case in 2050 (results of central analysis presented in Table 37 of main report), and difference to central analysis (+ve values where sensitivity emissions are higher than central case).

	Sensitivity case results					Difference to central results				
Member State	Baseline	Target 15ug/m^3	Target 10ug/m^3	Target 5ug/m^3	MTFR	*Baseline*	*Target 15ug/m^3*	*Target 10ug/m^3*	*Target 5ug/m^3*	*MTFR*
Austria	42	41	38	38	32	*0*	*0*	*0*	*0*	*0*
Belgium	66	65	65	59	51	*0*	*0*	*2*	*0*	*0*
Bulgaria	34	31	29	28	22	*0*	*0*	*0*	*0*	*0*
Croatia	30	25	14	15	14	*0*	*0*	*0*	*0*	*0*
Cyprus	4	4	3	3	3	*0*	*0*	*0*	*0*	*0*
Czech Rep.	95	89	66	71	54	*0*	*0*	*0*	*0*	*0*
Denmark	45	44	44	41	26	*0*	*0*	*1*	*0*	*0*
Estonia	10	10	10	10	7	*0*	*0*	*0*	*0*	*0*
Finland	46	45	40	31	24	*0*	*0*	*8*	*0*	*0*
France	425	419	376	388	327	*0*	*0*	*0*	*0*	*0*
Germany	590	569	475	474	375	*0*	*0*	*0*	*0*	*0*
Greece	74	72	55	57	49	*0*	*0*	*0*	*0*	*0*
Hungary	42	40	36	36	29	*0*	*0*	*0*	*0*	*0*
Ireland	49	47	47	47	33	*0*	*0*	*0*	*0*	*0*
Italy	517	498	381	382	372	*0*	*0*	*0*	*0*	*0*
Latvia	17	16	16	15	8	*0*	*0*	*1*	*0*	*0*
Lithuania	16	16	16	15	8	*0*	*0*	*1*	*0*	*0*
Luxembourg	6	6	6	6	4	*0*	*0*	*0*	*0*	*0*
Malta	2	2	2	2	1	*0*	*0*	*0*	*0*	*0*
Netherlands	122	120	120	114	90	*0*	*0*	*1*	*0*	*0*
Poland	280	263	237	242	194	*0*	*0*	*2*	*0*	*0*
Portugal	76	74	68	68	56	*0*	*0*	*-1*	*0*	*0*
Romania	92	75	70	71	55	*0*	*0*	*-1*	*0*	*0*
Slovakia	50	49	48	46	29	*0*	*0*	*1*	*0*	*0*
Slovenia	16	14	15	13	10	*0*	*0*	*1*	*0*	*0*
Spain	390	382	288	304	257	*0*	*0*	*7*	*0*	*0*
Sweden	68	65	65	60	53	*0*	*0*	*0*	*0*	*0*
EU-27	**3203**	**3079**	**2629**	**2635**	**2182**	***0***	***0***	***21***	***0***	***0***

Table A-77. PM$_{2.5}$ emissions [kt PM$_{2.5}$] in the cost-optimal solutions for different PM$_{2.5}$ target levels for the border grid sensitivity case in 2050 (results of central analysis presented in Table 38 of main report), and difference to central analysis (+ve values where sensitivity emissions are higher than central case).

	Sensitivity case results					Difference to central results				
Member State	Baseline	Target 15ug/m^3	Target 10ug/m^3	Target 5ug/m^3	MTFR	*Baseline*	*Target 15ug/m^3*	*Target 10ug/m^3*	*Target 5ug/m^3*	*MTFR*
Austria	10	10	10	6	6	*0*	*0*	*3*	*0*	*0*
Belgium	12	12	12	9	9	*0*	*0*	*0*	*0*	*0*
Bulgaria	11	9	7	5	5	*0*	*0*	*0*	*0*	*0*
Croatia	5	5	2	3	2	*0*	*0*	*-1*	*0*	*0*
Cyprus	1	1	0	0	0	*0*	*0*	*0*	*0*	*0*
Czech Rep.	11	11	9	8	8	*0*	*0*	*0*	*0*	*0*
Denmark	8	8	8	6	6	*0*	*0*	*0*	*0*	*0*
Estonia	2	2	2	1	1	*0*	*0*	*0*	*0*	*0*
Finland	9	9	9	8	8	*0*	*0*	*0*	*0*	*0*
France	81	80	62	62	59	*0*	*0*	*0*	*0*	*0*
Germany	62	61	58	53	50	*0*	*0*	*3*	*0*	*0*
Greece	19	18	14	14	13	*0*	*0*	*0*	*0*	*0*
Hungary	12	12	11	9	9	*0*	*0*	*2*	*0*	*0*
Ireland	6	6	6	6	5	*0*	*0*	*0*	*0*	*0*
Italy	49	43	38	38	38	*0*	*0*	*0*	*0*	*0*
Latvia	4	4	4	3	2	*0*	*0*	*1*	*0*	*0*
Lithuania	4	4	4	2	2	*0*	*0*	*1*	*0*	*0*
Luxembourg	1	1	1	1	1	*0*	*0*	*0*	*0*	*0*
Malta	0	0	0	0	0	*0*	*0*	*0*	*0*	*0*
Netherlands	12	11	11	10	10	*0*	*0*	*0*	*0*	*0*
Poland	52	52	39	33	31	*0*	*0*	*2*	*0*	*0*
Portugal	23	23	14	11	10	*0*	*0*	*0*	*0*	*0*
Romania	31	20	16	16	14	*0*	*0*	*0*	*0*	*0*
Slovakia	6	6	5	4	4	*0*	*0*	*1*	*0*	*0*
Slovenia	3	3	3	2	2	*0*	*0*	*0*	*0*	*0*
Spain	73	72	29	29	28	*0*	*0*	*0*	*0*	*0*
Sweden	13	13	13	12	12	*0*	*0*	*0*	*0*	*0*
EU-27	**521**	**495**	**387**	**352**	**335**	***0***	***0***	***11***	***0***	***0***

Cost-benefit analysis - application of the damage costs

It has not been feasible to recalculate all impacts included in the cost-benefit analysis following the full impact pathway approach (i.e. by re-running all models, including the air pollutant concentration and subsequent health impact models). However, to test the potential impact of this sensitivity on the BCR of the options, and their ranking, a more simplified damage cost approach has been followed to monetise the impacts of the options under the central and sensitivity case.

For comparison, the following table sets out the central analysis results, as presented in the main report, following the full, detailed appraisal methodology.

Table A-78 - Costs and net benefit of the policy options, relative to the baseline (EURm, 2015) (Table 72 from main report)

Impact		2030				2050		
		OPT20	OPT15	OPT10	OPT5	OPT15	OPT10	OPT5
TOTAL GROSS BENEFIT	Low	12,113	32,363	41,828	45,003	3,617	20,905	21,888
	High	36,295	93,775	121,363	130,758	12,059	69,813	73,042
Mitigation costs		-560	-3,280	-5,580	-7,020	-50	-4,670	-6,080
TOTAL NET BENEFIT	Low	11,553	29,083	36,248	37,983	3,567	16,235	15,808
	High	35,735	90,495	115,783	123,738	12,009	65,143	66,962
BCR	*Low*	*21.6*	*9.9*	*7.5*	*6.4*	*72.3*	*4.5*	*3.6*
	High	*64.8*	*28.6*	*21.7*	*18.6*	*241.2*	*14.9*	*12.0*

For this sensitivity, the benefits have been appraised applying the EEA's latest damage costs for each pollutant and MS[12]. First, in order to facilitate comparison to the central analysis, we have re-run the central analysis (as presented in the DFR), but instead applying the damage costs. The results are presented in the following table.

Table A-79 - Central costs and net benefit of the policy options applying damage cost, relative to the baseline (EURm, 2015)

Impact		2030				2050		
		OPT20	OPT15	OPT10	OPT5	OPT15	OPT10	OPT5
TOTAL GROSS BENEFIT	Low	11,915	33,452	44,498	50,566	5,838	37,457	43,759
	High	41,373	111,949	147,534	167,913	19,886	124,132	145,230
Mitigation costs		-560	-3,280	-5,580	-7,020	-50	-4,670	-6,080
TOTAL NET BENEFIT	Low	11,355	30,172	38,918	43,546	5,788	32,787	37,679
	High	40,813	108,669	141,954	160,893	19,836	119,462	139,150
BCR	*Low*	21.3	10.2	8.0	7.2	116.8	8.0	7.2
	High	73.9	34.1	26.4	23.9	397.7	26.6	23.9

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[12] https://www.eionet.europa.eu/etcs/etc-atni/products/etc-atni-reports/etc-atni-report-04-2020-costs-of-air-pollution-from-european-industrial-facilities-200820132017

As can be seen from the table, the estimated impacts differ from the central analysis. This is to be expected as a different methodology is followed, namely a much coarser approach applying damage costs. However, very similar patterns of results emerge in terms of the benefits, net benefits and BCR between options. Namely:

- The benefits increase as ambition increases, but at a diminishing rate
- Net benefits increase as ambition increases, but at a diminishing rate. The scenario with the largest net benefit in 2030 and 2050 is the most ambitious OPT5 scenario
- The BCR reduces with ambition.

The damage cost approach is then applied to the sensitivity case to explore how the effects would differ. The results are presented in the table below.

Table A-80 - Costs and net benefit of the policy options under sensitivity case, applying damage costs, relative to the baseline (EURm, 2015)

Impact		2030				2050		
		OPT20	OPT15	OPT10	OPT5	OPT15	OPT10	OPT5
TOTAL GROSS BENEFIT	Low	11,917	15,813	42,419	50,576	5,838	30,698	43,759
	High	41,380	54,203	140,593	167,946	19,886	102,005	145,230
Mitigation costs		-560	-992	-5,107	-7,020	-50	-3,704	-6,080
TOTAL NET BENEFIT	Low	11,357	14,821	37,312	43,556	5,788	26,994	37,679
	High	40,820	53,211	135,486	160,926	19,836	98,301	139,150
BCR	*Low*	21.3	15.9	8.3	7.2	116.8	8.3	7.2
	High	73.9	54.6	27.5	23.9	397.7	27.5	23.9

Table A-81 - Costs and net benefit of the policy options, applying damage costs, relative to the baseline (EURm, 2015) - comparison between sensitivity case and central analysis (+ve values show where impacts in sensitivity case are greater than those in the central analysis)

Impact		2030				2050		
		OPT20	OPT15	OPT10	OPT5	OPT15	OPT10	OPT5
TOTAL GROSS BENEFIT	Low	*-2*	*17,639*	*2,079*	*-10*	*0*	*6,759*	*0*
	High	*-7*	*57,746*	*6,941*	*-33*	*0*	*22,127*	*0*
Mitigation costs		*0*	*0*	*-2,288*	*-473*	*0*	*0*	*-966*
TOTAL NET BENEFIT	Low	*-2*	*15,351*	*1,606*	*-10*	*0*	*5,793*	*0*
	High	*-7*	*55,458*	*6,468*	*-33*	*0*	*21,161*	*0*

Comparing the results of the sensitivity case to the central case, several observations can be drawn:

- The sensitivity case has a stronger impact on some scenarios in some years, relative to others. Namely, emission reductions under OPT15 in 2030, and OPT10 in 2050 are significantly reduced, there is a smaller reduction of for OPT10 in 2030, but all other scenarios are broadly the same.

- Specific scenarios in specific years are affected depending on the concentrations in the border grid cells, including and excluding the non-EU element. For example, exclusion of the selected grid cells leads to easier attainment of the prescribed standards/targets for the 15µg/m3 case in 2030. This suggests that concentrations in the non-EU element are substantially above 15µg/m3, whereas concentrations in the EU element are closer to (or even at or below) 15µg/m3. Hence when the non-EU element is included in the grid cell, the weighted average concentration across the complete grid cell is much higher, and significant action is required. However, where this is excluded, the weighted average based only on EU elements is closer to 15µg/m3, and less action is required. For the 10µg/m3 target in 2030, the results are similar to the standard analysis presented in the main report, since typically there is a need for concentration reductions to achieve this level within the Member State (i.e. the concentration in the EU elements is substantially above 10µg/m3, so the solution is not driven by the border grid cell. For the 5ug/m3 target, results are essentially identical to the standard analysis.
- There is a similar impact on mitigation costs – for those scenario-years which see a decrease in emissions reductions, there is also a decrease in mitigation costs
- These results are driven by the adjustments to the concentrations in the border cells in the baseline. Under the sensitivity analysis, concentrations of air pollutants in these cells are lower. As such, less additional mitigation effort is required under the scenarios to reach to targeted levels of concentrations. As such, emissions reductions achieved by such actions are lower (as less action is taken), and hence also mitigation costs are also lower.
- The overall pattern of net benefits remains the same as the central case – net benefit increases with ambition (although the increase in net benefit from OPT20 to OPT15 in 2030 is now smaller).
- The pattern of results in terms of BCR is also consistent – i.e. BCR reduces as ambition increases.

Sensitivity: Health impact computation

Box – Sensitivity of the assessment to computation of health impacts

The analysis of the scenarios included calculations of the health impacts of air pollution, both in absolute terms (to assess the necessity of taking additional action on air pollution in the first place) and in relative terms (to assess the relative merits of different policy options considered). These calculations are based on the latest available evidence consolidated in the 2021 WHO AQGs and their underpinning scientific reviews. Since their publication, however, additional epidemiological studies have been published, including studies that focus on the risk of exposure to relatively low levels of air pollution. These point to a possibly quantifiable health impacts also below guideline exposure levels recommended by the WHO (i.e. the ‘cut-off value’), as well as to a supra-linear form of the exposure-response relationship (i.e. the ‘relative risk’, with a higher effect per additional exposure at low pollutant concentrations than at high concentrations). In addition, there is also uncertainty around the health impact computations associated with the source of pollution assessed (e.g. inclusion of non-anthropogenic sources or not), the morbidity pathways includes, and the air quality data used (i.e. resolution of modelling or application of bias correction or not). Sensitivity tests have therefore been performed to explore the sensitivity of the central results to key assumptions (i.e. related to ‘cut-off value’ and the ‘relative risk’).

The sensitivity test confirmed that the assumptions made have a significant impact on the absolute impact of air pollution, and the health impact figures presented in the central analysis are likely to underestimate the total health impact of air pollution. For the health impacts of $PM_{2.5}$ in 2015, for example, the estimates of premature mortality range from 213,900 to 524,200. This range of estimates of absolute impacts widens further (based on the relative difference between low and high estimates) for calculation for future years, as more and more people are expected to be exposed to air pollution at lower concentration levels only. Reassuringly, this sensitivity analysis also indicates that the effect on the relative benefits between the scenarios analysed in this impact assessment is only affected minimally. Under all sensitivity tests, the ranking of the net benefits or benefit-cost ratios between the scenarios does not change.

The methodology to calculate the health impact related to the (long-term) exposure to air pollution is based on some important assumptions. Amongst others, we rely on some premises regarding the air quality data and the concentration response functions that are used. Each of these assumptions has an influence on the final health impact, and to explore the uncertainty around the quantification of these impacts, a detailed sensitivity study has been carried out.

This annex provides an overview of the results of the following sensitivity tests:

- Sensitivity of the mortality impact to the concentration response functions
    - Quantify the mortality impacts below WHO Air Quality Guideline levels
    - Quantify the mortality impacts when different concentration response functions are applied (e.g. with more pronounced health effects at lower levels of pollution).
- Sensitivity of the mortality impact to the source of the pollution
    - Quantify the mortality impacts when considering anthropogenic sources only
- Sensitivity of the morbidity impact to the concentration response functions

    - Quantify the impact of alternative exposure response functions for morbidity estimates (e.g. based on the ELAPSE study and other meta-reviews).
- Sensitivity to the air quality data:
    - Comparing the historical results for various air quality input datasets with existing datasets (EEA mortality results and ETC air quality data)
    - Quantify the impact of uEMEP on top of EMEP
    - Quantify the sensitivity to the bias correction for future baseline maps and the impact of the scenarios.

Sensitivity of mortality impact to the concentration response functions

The first set of sensitivity studies focuses on the details of the concentration response functions. The following sensitivity tests are considered:

- Sensitivity runs that assume different cut-offs for mortality impacts, i.e. assessing impacts also below WHO Air Quality Guideline levels and as low as 0 µg/m^3 for all relevant pollutants.
- Sensitivity runs that assume a different relative risk (i.e. a different slope of the concentration response function), hence modelling a more pronounced health impact, as suggested by more recent studies focusing on Europe.
- Sensitivity runs that assume a different concentration response function, focussing on other functions that are regularly used in literature.
- Sensitivity runs that assume a different relative risk and cut-off value of the concentration response function in combination.

These sensitivities are guided by further research conducted following the completion of the WHO’s Air Quality Guideline updates, not least the work of the ELAPSE study and subsequent paper – not least (Hoffmann, Brunekreef, Andersen, Forastiere, & Boogaard, 2022).

The first set of sensitivity runs considers lower cut-off value than the one used in the main analysis. For particulate matter, besides the cut-off of 5 µg/m^3 applied in the main analysis, we also consider 2.5 µg/m^3 and 0 µg/m^3 as alternatives. For nitrogen dioxide, besides the cut-off of 10 µg/m^3 applied in the main analysis, we also consider 5 µg/m^3 and 0 µg/m^3 as alternatives. The second alternative omits any cut-off and assumes, for both pollutants, that negative health effects related to the exposure to air pollution occur already at very low concentrations. The first alternative is a central value in between the current analysis and the extreme scenario of the second alternative.

The second set of sensitivity runs considers the slope of the concentration response function. Recent epidemiological studies focusing on the risks related to the exposure to air pollution in Europe (ELAPSE study, Brunekreef & et al., 2021), have determined larger relative risks in comparison with those of the updated WHO concentration response functions. For particulate matter, the ELAPSE recommended relative risk is 1.118 [1.06; 1.179] instead of 1.08 [1.06; 1.09] as defined in the updated WHO functions. For nitrogen dioxide it is 1.045 [1.026; 1.065] instead of 1.02 [1.01; 1.04] as defined in the updated WHO functions.

The exposure response functions recommended by the WHO in its 2021 assessment use updated relative risks that differ significantly from the relative risks applied in preceding impact studies (e.g. Clean Air Outlook I and II) and assessment reports of the EEA. To facilitate a comparison of the results of the current project with those of these earlier assessment reports, the third set of sensitivity studies

Analysis	**Source**	**Pollutant**	**Metric**	**Vulnerable Population**	**Relative risks (slope of concentration**	
					Central estimate	**Lower value of 95 interval**
Main analysis	WHO (2021)	NO_2	Annual mean anthropogenic + natural	30-…	1.02	1.010
	WHO (2021)	$PM_{2.5}$		30-…	1.08	1.060
Sensitivity tests concerning cut-off value	WHO (2021)	NO_2	Annual mean anthropogenic + natural	30-…	1.02	1.010
	WHO (2021)	$PM_{2.5}$		30-…	1.08	1.060
	WHO (2021)	NO_2		30-…	1.02	1.010
	WHO (2021)	$PM_{2.5}$		30-…	1.08	1.060
Sensitivity tests concerning ELAPSE relative risks (and combined sensitivity runs)	ELAPSE	NO_2	Annual mean anthropogenic + natural	30-…	1.045	1.026
	ELAPSE	$PM_{2.5}$		30-…	1.118	1.06
	ELAPSE	NO_2		30-…	1.045	1.026
	ELAPSE	$PM_{2.5}$		30-…	1.118	1.06
	ELAPSE	NO_2		30-…	1.045	1.026
	ELAPSE	$PM_{2.5}$		30-…	1.118	1.06
Sensitivity tests concerning other existing exposure-response functions	HRAPIE	NO_2	Annual mean anthropogenic + natural	30-…	1.055	1.031
	HRAPIE	$PM_{2.5}$		30-…	1.062	1.040
	COMEAP	NO_2		30-…	1.023	1.008

focuses on the application of the relative risks used in the preceding studies, which are based on the HRAPIE CRFs (WHO, 2013). In addition, for NO_2, we also use the CRFs put forward in the reports of the Committee on the Medical Effects of Air Pollutants (COMEAP, 2015), as several national and regional administrations have relied on these CRFs to assess the health impact of air pollution.

Finally, we simultaneously run a selection of the sensitivity tests to understand their combined effect on the results. We combine the sensitivity tests for the slope of the concentration response function with the sensitivity test concerning the cut-off value. A detailed overview of all the sensitivity tests is provided in

Table A-82. The sensitivity will only be analyzed for health effects related to exposure to nitrogen dioxide and particulate matter.

Table A-82 Concentration response functions considered in the sensitivity test concerning the chronic mortality impact.

Analysis	Source	Pollutant	Metric	Vulnerable Population	Relative risks (slope of concentration response function)			Dose (ug/m^3)	Cutoff (ug/m^3)
					Central estimate	**Lower value of 95% interval**	**Upper value of 95% interval**		
Main analysis	WHO (2021)	NO_2	Annual mean anthropogenic + natural	30-…	1.02	1.010	1.040	10	10
	WHO (2021)	$PM_{2.5}$		30-…	1.08	1.060	1.090	10	5
Sensitivity tests concerning cut-off value	WHO (2021)	NO_2	Annual mean anthropogenic + natural	30-…	1.02	1.010	1.040	10	0
	WHO (2021)	$PM_{2.5}$		30-…	1.08	1.060	1.090	10	0
	WHO (2021)	NO_2		30-…	1.02	1.010	1.040	10	5
	WHO (2021)	$PM_{2.5}$		30-…	1.08	1.060	1.090	10	2.5
Sensitivity tests concerning ELAPSE relative risks (and combined sensitivity runs)	ELAPSE	NO_2	Annual mean anthropogenic + natural	30-…	1.045	1.026	1.179	10	10
	ELAPSE	$PM_{2.5}$		30-…	1.118	1.06	1.179	10	5
	ELAPSE	NO_2		30-…	1.045	1.026	1.179	10	5
	ELAPSE	$PM_{2.5}$		30-…	1.118	1.06	1.179	10	2.5
	ELAPSE	NO_2		30-…	1.045	1.026	1.179	10	0
	ELAPSE	$PM_{2.5}$		30-…	1.118	1.06	1.179	10	0
Sensitivity tests concerning other existing exposure-response functions	HRAPIE	NO_2	Annual mean anthropogenic + natural	30-…	1.055	1.031	1.080	10	20
	HRAPIE	$PM_{2.5}$		30-…	1.062	1.040	1.083	10	0
	COMEAP	NO_2		30-…	1.023	1.008	1.037	10	5

Sensitivity tests concerning cut-off value

We first focus on the sensitivity to the cut-off value. Figure A-121 shows the impact of the cut-off value on the baseline results for 2015 and 2030. The results indicate that the baseline absolute mortality is strongly dependent on the cut-off value that is being applied, with the differences spanning multiple orders of magnitude. The impact of the cut-off is (relatively) larger for the future years. Because the concentrations are below or near the cut-off level at many locations in 2030 and 2050, the underestimation related to the neglect of chronic mortality impact below the WHO air quality guidelines becomes more important for the future years than for the historical years.

More importantly for the study at hand, Figure A-122**Error! Reference source not found.** shows the impact of the cut-off value on the absolute and relative impact of the MFR scenario in 2030. The number of premature deaths avoided by introducing the MFR scenario (i.e. the absolute impact) of the scenarios clearly increases if the cut-off value is lowered, because also further reductions of the concentrations below the initial cut-off value of 5 µg/m^3 are considered. On the other hand, the relative impact of the scenarios (the percent reduction in the number of attributable deaths) is smaller if the cut-off is lowered, because the scenario does not affect a large part of the mortality related to the exposure to concentrations below the initial cut-off value of 5 µg/m^3.

Figure A-121 Impact of the cut-off of the concentration exposure function on the premature mortality for the baseline scenario in 2015 (left figure) and 2030 (right figure). The figure shows results for nitrogen dioxide (green) and particulate matter (blue).

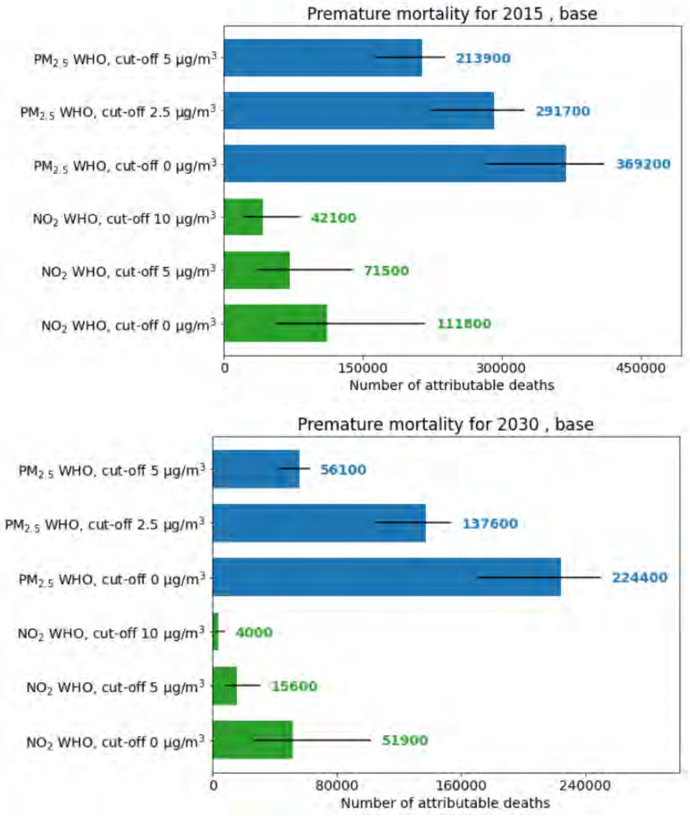
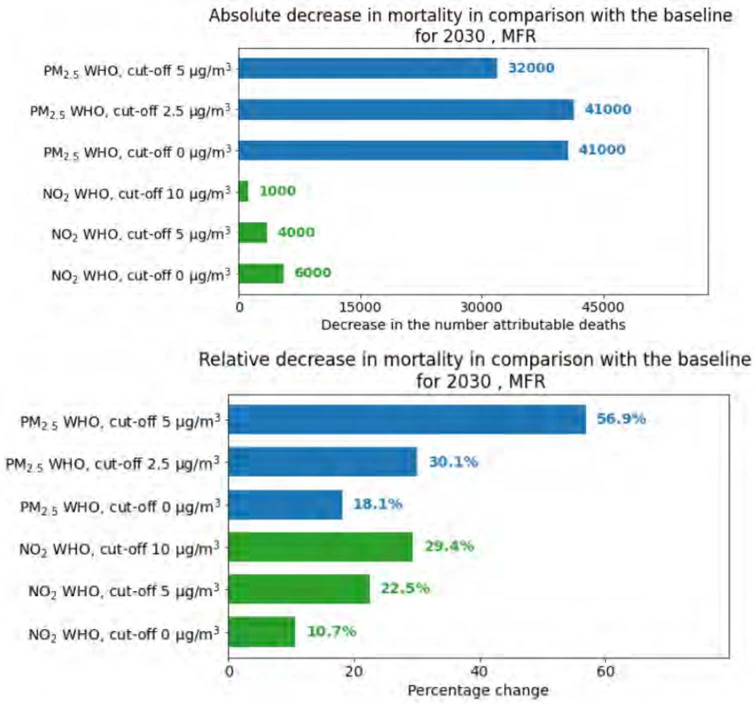


Figure A-122 Impact of the cut-off value of the concentration response function on the absolute (top figure) and relative (bottom figure) difference in premature mortality between the MFR and the baseline for 2030. The figure shows results for nitrogen dioxide (green) and particulate matter (blue).



Relative risks

Next, we focus on the sensitivity to slope of the concentration response function. Figure A-123 shows the impact of the relative risk on the baseline results for 2015 and 2030. The results indicate that the health impact becomes larger if the relative risks are increased (i.e. if the slope of the exposure response concentrations becomes steeper), but that the order of magnitude of the results (hundreds of thousands of deaths related to particulate matter exposure, and tens of thousands of deaths related to nitrogen dioxide exposure in 2015) is the same for all concentration response functions. The sensitivity to the slope of the concentration response function is hence smaller than the sensitivity to the cut-off value.

More importantly for the study at hand, Figure A-124 shows the impact of the relative risk on the absolute and relative impact of the MFR scenario in 2030. The number of premature deaths avoided by introducing the scenario (i.e. the absolute impact) of the scenarios increases if the relative risk is increased (i.e. if the slope of the exposure response functions becomes steeper). On the other hand, the relative impact of the scenarios (the percent reduction in the number of attributable deaths) is only minimally affected by the relative risks[13].

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[13] By applying Taylor expansion to the exposure computation, it can be proven mathematically that, for linear exposure response functions, the effect of the slope is of second order in the difference between both relative risks.

Figure A-123 Impact of the concentration response functions (relative risks) on the premature mortality for the baseline scenario in 2015 (left figure) and 2030 (right figure). The figure shows results for nitrogen dioxide (green) and particulate matter (blue).

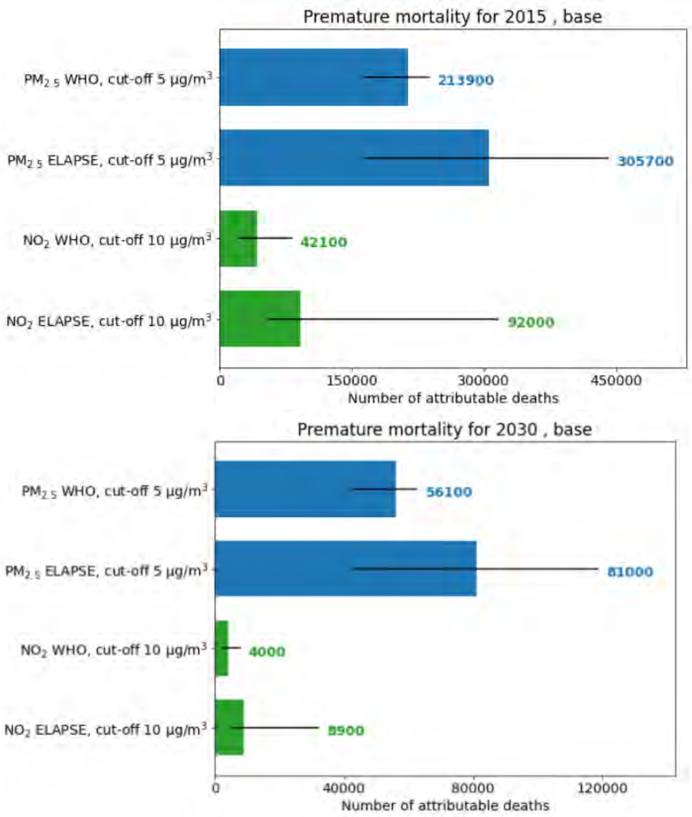
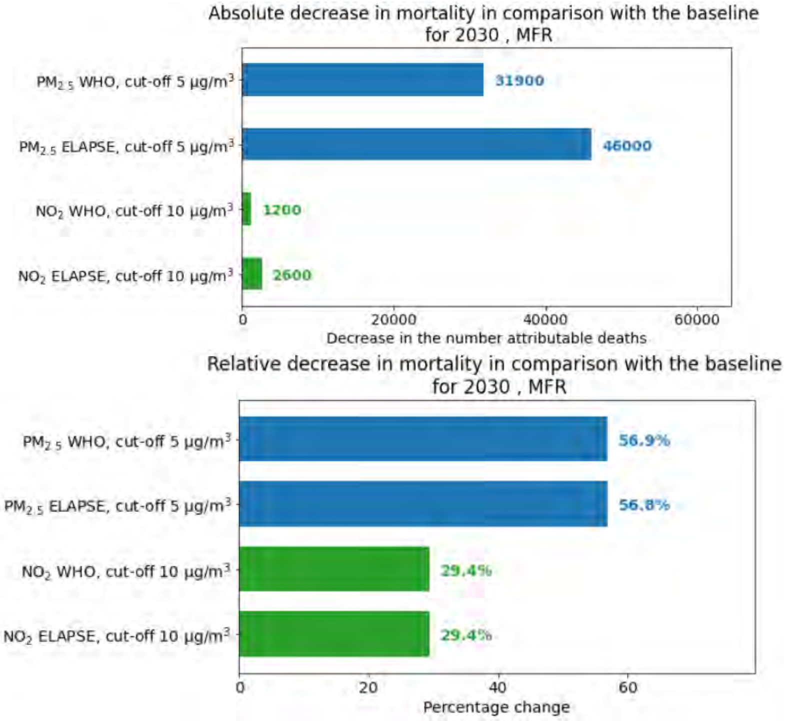


Figure A-124 Impact of the slope of the concentration response function (relative risk) on the absolute (top figure) and relative (bottom figure) difference in premature mortality between the MFR and the baseline for 2030. The figure shows results for nitrogen dioxide (green) and particulate matter (blue).



Comparison with existing CRFs

Figure A-125 compares the results of the main analysis with the results obtained using existing concentration response functions for the baseline results for 2015 and 2030. The health impact related to the exposure to particulate matter is somewhat higher when the HRAPIE concentration response functions are used instead of the new updated WHO concentration response functions from the main analysis. This difference is due to the absence of a cut-off value for the HRAPIE functions. The health effects related to the exposure to nitrogen dioxide are much lower when the HRAPIE functions are used, due to a combination of a higher slope and a higher cut-off value for the HRAPIE functions. The former difference increases the health impact, while the latter reduces it. The difference becomes especially large for the future years, as the concentrations are below 20 µg/m^3 for most locations in Europe. The COMEAP functions provide a slightly higher estimate, due to the lower cut-off values.

Figure A-126 compares the impact of the MFR of the main analysis with the results obtained using the existing concentration response functions for 2030. For particulate matter, the absolute impact of the MFR scenario is similar for HRAPIE and the updated WHO functions, but the relative impact is much larger for the updated WHO functions. For nitrogen dioxide, the absolute impact is much larger for the updated WHO functions than for the HRAPIE functions, mainly because the mortality is already very low for the baseline scenario if a cut-off of 20 µg/m3 is used. The absolute impact is somewhat larger for COMEAP, but the relative impact is lower.

Figure A-125 Impact of the concentration response functions on the premature mortality for the baseline scenario in 2015 (left figure) and 2030 (right figure). The figure shows results for nitrogen dioxide (green) and particulate matter (blue).

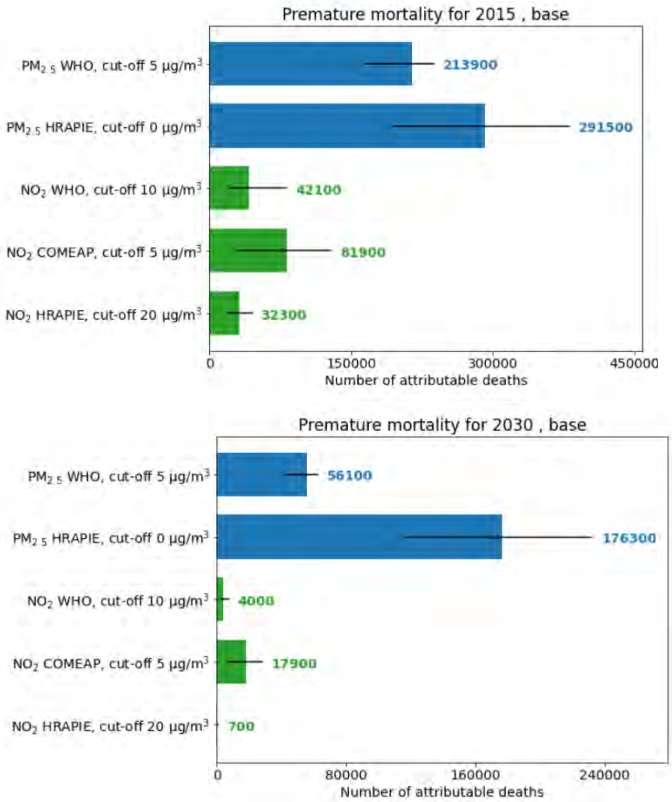
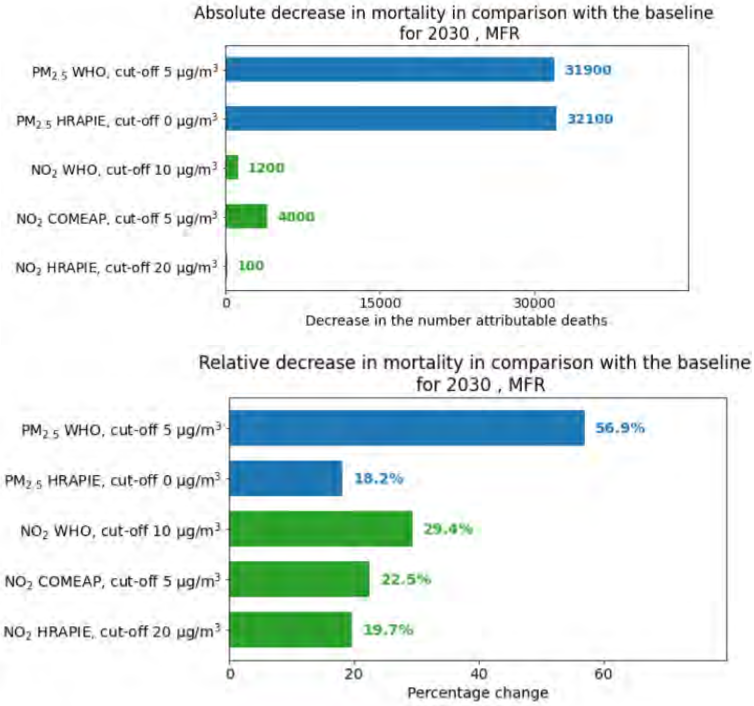


Figure A-126 Impact of the concentration response function on the absolute (top figure) and relative (bottom figure) difference in premature mortality between the MFR and the baseline for 2030. The figure shows results for nitrogen dioxide (green) and particulate matter (blue).



Combination of cut-off and relative risk

More importantly for the study at hand,

Figure A-128 shows the impact of the concentration response functions on the absolute and relative impact of the MFR scenario in 2030. The absolute impact spans a wide range, but the interval of the results is smaller than the one for the baseline mortality. For particulate matter, all the absolute decreases are in the order of tens of thousands of avoided premature deaths (ranging from 32,000 to 60,000 avoided deaths). Although the range of the baseline mortality spans multiple orders of magnitude, the range of the number of avoided premature deaths under the MFR scenario only spans a single order of magnitude. Even if a very wide range of concentration response functions is applied, the absolute impact of the MFR scenario for particulate matter can hence be estimated with a reasonable degree of certainty.

The range is larger for nitrogen dioxide (ranging from 100 to 12,000 avoided deaths), because the range of the cut-off values is much larger than for particulate matter. Note that this range of cut-off values actually considers very extreme cut-offs, some of which are outdated or for which no scientific basis exists. The (very high) cut-off value of the HRAPIE functions is 20 µg/m^3, which is twice the value of the current WHO guidelines, and which is hence far above the concentration for which health effects have been established in recent studies. On the other hand, some of the functions use a cut-off of 0 µg/m^3, hence estimating health effect up to the lowest concentrations, which is far beyond the current scientific knowledge. If these extreme cut-off values (0 µg/m^3 and 20 µg/m^3) are neglected, the absolute impact of the scenario lies between 1,200 and 7,800 avoided deaths, which is a range that only spans a single order of magnitude. Omitting the most extreme cut-off, we can still conclude that the absolute impact of the MFR scenario for nitrogen dioxide can hence be estimated with a reasonable degree of certainty.

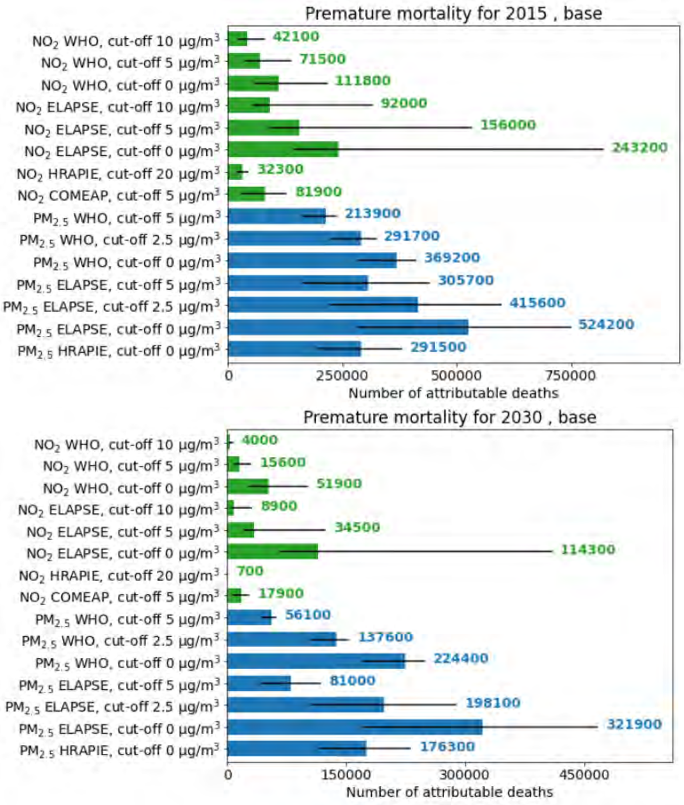
Figure A-127 shows the impact of the various concentration response functions considered in the current sensitivity analysis on the health impact results. The results indicate that there is a substantial uncertainty on the absolute number of cases, both for particulate matter and nitrogen dioxide. For both pollutants, the results span multiple orders of magnitude. These results are however obtained by considering a very wide range of concentration response functions, including vastly different cut-offs and relative risks.

More importantly for the study at hand,

Figure A-128 shows the impact of the concentration response functions on the absolute and relative impact of the MFR scenario in 2030. The absolute impact spans a wide range, but the interval of the results is smaller than the one for the baseline mortality. For particulate matter, all the absolute decreases are in the order of tens of thousands of avoided premature deaths (ranging from 32,000 to 60,000 avoided deaths). Although the range of the baseline mortality spans multiple orders of magnitude, the range of the number of avoided premature deaths under the MFR scenario only spans a single order of magnitude. Even if a very wide range of concentration response functions is applied, the absolute impact of the MFR scenario for particulate matter can hence be estimated with a reasonable degree of certainty.

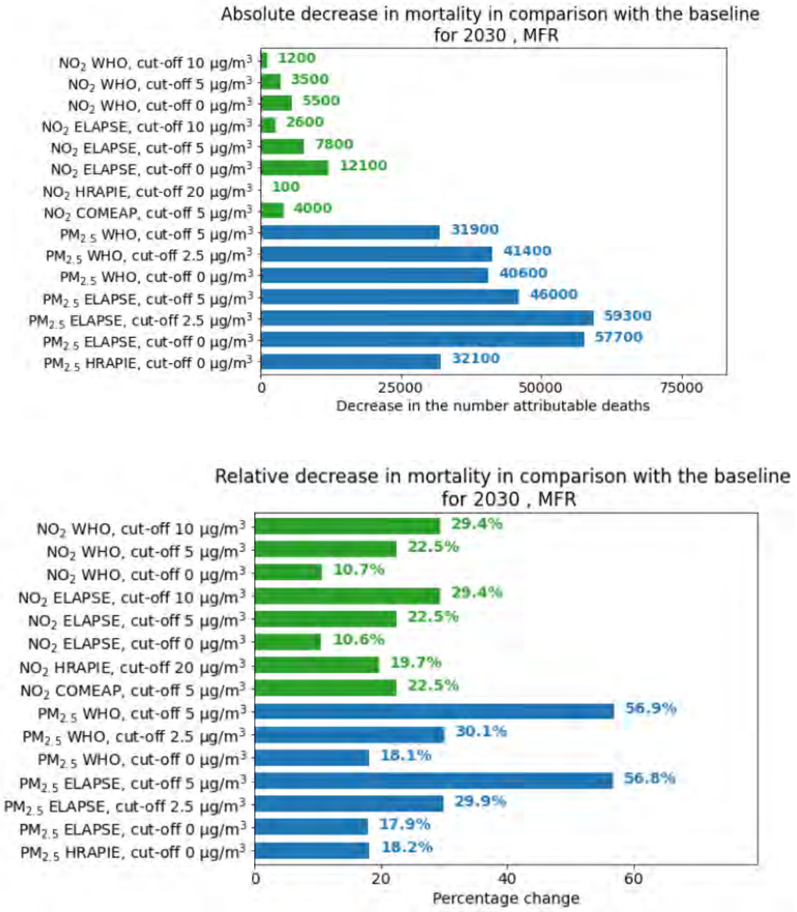
The range is larger for nitrogen dioxide (ranging from 100 to 12,000 avoided deaths), because the range of the cut-off values is much larger than for particulate matter. Note that this range of cut-off values actually considers very extreme cut-offs, some of which are outdated or for which no scientific basis exists. The (very high) cut-off value of the HRAPIE functions is 20 µg/m^3, which is twice the value of the current WHO guidelines, and which is hence far above the concentration for which health effects have been established in recent studies. On the other hand, some of the functions use a cut-off of 0 µg/m^3, hence estimating health effect up to the lowest concentrations, which is far beyond the current scientific knowledge. If these extreme cut-off values (0 µg/m^3 and 20 µg/m^3) are neglected, the absolute impact of the scenario lies between 1,200 and 7,800 avoided deaths, which is a range that only spans a single order of magnitude. Omitting the most extreme cut-off, we can still conclude that the absolute impact of the MFR scenario for nitrogen dioxide can hence be estimated with a reasonable degree of certainty.

Figure A-127 Comparison of the mortality calculated using all concentration-response functions considered in the sensitivity test. The figures show the premature mortality for the baseline scenario in 2015 (left figure) and 2030 (right figure), for nitrogen dioxide (green) and particulate matter (blue).



For both pollutants, there are also major differences between the relative impacts, which are mostly determined by the cut-off value. Concentration response functions that only differ in the slope of the concentration response function, provide an almost equal relative impact of the MFR scenario.

Figure A-128 Comparison of the mortality calculated using all concentration-response functions considered in the sensitivity tests. The figures shows results for the absolute (top figure) and relative (bottom figure) difference in premature mortality between the MFR and the baseline for 2030, for nitrogen dioxide (green) and particulate matter (blue).



Sensitivity of monetised health benefits outcomes related to combined relative risk & cut-off assumptions

Alongside reflecting on the scale of change in the quantified health impacts, it is also important to consider how this uncertainty could impact on the comparison between costs and benefits of the scenarios. To explore this, the change in mortality effects identified under the health sensitivity analysis tests above have been monetised and compared to the costs (and benefits) as presented in the central analysis.

The mortality effects are monetised following the same approach as applied in the central analysis – as set out in further detail in Appendix 6. Both the number of deaths and YLL have been monetised separately and presented in contrast as a low and high sensitivity. Given mortality effects associated with O_3 and morbidity effects have not been influenced in the sensitivity tests above, these remain fixed and are the same between the central and sensitivity test results – only the mortality effects associated with $PM_{2.5}$ and NO_2 change. Also, as in the central analysis, only mortality effects associated with $PM_{2.5}$ are included in the aggregate analysis for comparison to costs, to avoid overlaps and double-counting in the assessment of health effects.

The following tables present the monetized mortality impacts under the different sensitivity tests (replicating tables A-34, A-36, A-37 and A-39 in Appendix 6). The monetized health effects increase under all sensitivities – across all scenarios, changing the relative risk values has the smallest effect, aligning the cut-off values with the proposals of the ELAPSE study has a larger impact, but the combination of changing both the cut-off and relative risks produces the largest increase in the estimated monetised effects. The increase in effects is always larger for NO_2, relative to $PM_{2.5}$.

In the following tables, 'RelRisk' refers to the relative risk applied in the sensitivity, with the choice between the 'WHO' option (as applied in the central analysis) or 'ELAPSE' recommended sensitivity. The 'Cutoff' relates to the cut-off value below which no health impacts are modelling, again with the choice between the 'WHO' option (as applied in the central analysis) or 'ELAPSE' recommended sensitivity. The selection 'RelRiskWHO _CutoffWHO' represents the central analysis and is presented in all tables for comparison.

Table A-83 Value of health impacts per annum - baseline scenario (all values €m 2015 prices, EU27)

		2030			
Health outcome	**Pollutant**	RelRiskWHO _CutoffWHO	RelRiskWHO _CutoffELAPSE	RelRiskELAPSE _CutoffWHO	RelRiskELAPSE _CutoffELAPSE
Mortality (VOLY)	$PM_{2.5}$	202,004	495,374	291,494	713,162
Mortality (VOLY)	NO_2	14,570	56,323	32,133	124,228
Mortality (VSL)	$PM_{2.5}$	58,418	143,948	84,305	207,246
Mortality (VSL)	NO_2	4,294	16,497	9,472	36,386

Table A-84 Value of health impacts per annum - OPT15 scenario (all values €m 2015 prices, EU27)

		2030			
Health outcome	**Pollutant**	RelRiskWHO _CutoffWHO	RelRiskELAPSE _CutoffWHO	RelRiskWHO _CutoffELAPSE	RelRiskELAPSE _CutoffELAPSE
Mortality (VOLY)	$PM_{2.5}$	124,646	404,186	179,947	582,624
Mortality (VOLY)	NO_2	12,780	50,025	28,184	110,346
Mortality (VSL)	$PM_{2.5}$	35,653	117,190	51,475	168,938
Mortality (VSL)	NO_2	3,777	14,645	8,331	32,305

Table A-85 Value of health impacts per annum - OPT10 scenario (all values €m 2015 prices, EU27)

		2030			
Health outcome	**Pollutant**	RelRiskWHO _CutoffWHO	RelRiskELAPSE _CutoffWHO	RelRiskWHO _CutoffELAPSE	RelRiskELAPSE _CutoffELAPSE
Mortality (VOLY)	$PM_{2.5}$	102,201	373,048	147,634	538,037
Mortality (VOLY)	NO_2	12,201	48,895	26,907	107,866
Mortality (VSL)	$PM_{2.5}$	29,124	108,053	42,075	155,852
Mortality (VSL)	NO_2	3,604	14,315	7,949	31,579

Table A-86 Value of health impacts per annum - MTFR scenario (all values €m 2015 prices, EU27)

		2030			
Health outcome	**Pollutant**	RelRiskWHO _CutoffWHO	RelRiskELAPSE _CutoffWHO	RelRiskWHO _CutoffELAPSE	RelRiskELAPSE _CutoffELAPSE
Mortality (VOLY)	$PM_{2.5}$	87,116	346,473	125,819	499,828
Mortality (VOLY)	NO_2	10,284	43,625	22,676	96,263
Mortality (VSL)	$PM_{2.5}$	24,747	100,369	35,744	144,805
Mortality (VSL)	NO_2	3,026	12,751	6,673	28,136

The following table presents the aggregate estimates of all health effects (i.e. the mortality effects associated with $PM_{2.5}$ which change under the sensitivity tests, plus the mortality effects associated with O_3 and morbidity effects which both do not change under the sensitivity tests – the mortality effects of NO_2 are excluded to avoid overlaps in the quantification of mortality effects) under each sensitivity scenario, and the net impact relative to the baseline. This replicates table 51 in Section 8.2.1 of the main document.

The absolute results (i.e. non-net) show the same pattern as those described above for the individual absolute effects – all sensitivities produce an increase in the aggregate monetised health effects under all scenarios. The magnitude of increase ascends from the change in relative risks, to varying the cut-offs, to the largest change associated with simultaneously changing both cut off and relative risk parameters.

However, considering the net effects (comparing the results of the scenario relative to the baseline), a different pattern of results emerges. For the net effects, adjusting the relative risk has a greater influence on the impacts, in comparison to the cut-off. Hence although adjusting cut-off has a greater influence on the absolute effects under the baseline and scenarios separately, adjusting the relative risk has a greater impact on the difference between the two. That said, adjusting both these parameters simultaneously still induces the largest change in the observed net effect.

Table A-87 Costs and benefits ("NET" values) to society (valuation of health impacts - both mortality and morbidity) per year - central (all values €bn 2015 prices, EU27)

		2030			
Approach to valuing mortality	Scenario	RelRiskWHO _CutoffWHO	RelRiskWHO _CutoffELAPSE	RelRiskELAPSE _CutoffWHO	RelRiskELAPSE _CutoffELAPSE
VSL	Baseline	444	737	533	955
VSL	OPT15	352	632	407	810
VSL	OPT10	325	596	371	761
VSL	MTFR	303	562	341	715
VOLY	Baseline	140	226	166	289
VOLY	OPT15	109	190	124	242
VOLY	OPT10	100	179	113	226
VOLY	MTFR	92	168	103	212
Net VSL	*OPT15*	*92*	*106*	*126*	*145*
Net VSL	*OPT10*	*119*	*141*	*163*	*194*
Net VSL	*MTFR*	*141*	*175*	*192*	*240*
Net VOLY	*OPT15*	*31*	*35*	*41*	*47*
Net VOLY	*OPT10*	*40*	*47*	*53*	*62*
Net VOLY	*MTFR*	*48*	*58*	*63*	*77*

The following table presents a picture of how the sensitivity tests subsequently affect the comparison of costs to benefits, and the outturn NPV and BCR. Again, only the mortality effects associated with $PM_{2.5}$ are changing relative to the central (RelRiskWHO _CutoffWHO) analysis. This replicates Tables 71 and 72 in the Main Report (section 10.1.1 – noting that the BCR of the MTFR is not presented there given the focus is on assessment of the options but is presented here to help illustrate the trend as one shifts between the scenarios).

The key conclusions drawn from the table are:

- Under all sensitivity tests (flexing the relative risk, or cut-off, or both), the monetised benefits of the scenarios relative to the baseline increase. I.e. the central analysis underestimates the size of the benefits of the scenarios. The BCR ratios of OPT15, OPT10 and MFR are all higher under the sensitivity scenarios relative to the central analysis.
- Under all sensitivity tests, the ranking of the NPVs and BCRs between the scenarios does not change – i.e. as under the central analysis, OPT10 consistently has a higher NPV across all sensitivity tests relative to OPT15, but OPT15 has a higher benefit to cost ratio than OPT10.
- Following the trend in the net effects as explained above, the change (increase) in NPV and BCR for all options is smallest under the cut-off sensitivity, slightly higher under the change to relative risk, but greatest under the sensitivity which flexes both simultaneously.

Table A-88 Benefits of policy options, relative to the baseline (EURm, 2015)[14]

Impact		2030											
		RelRiskWHO_ CutoffWHO	RelRiskWHO_ CutoffWHO	RelRiskWHO_ CutoffWHO	RelRiskWHO_ CutoffELAPSE	RelRiskWHO_ CutoffELAPSE	RelRiskWHO_ CutoffELAPSE	RelRiskELAPSE_ CutoffWHO	RelRiskELAPSE_ CutoffWHO	RelRiskELAPSE_ CutoffWHO	RelRiskELAPSE_ CutoffELAPSE	RelRiskELAPSE_ CutoffELAPSE	RelRiskELAPSE_ CutoffELAPSE
		OPT15	OPT10	MTFR	OPT15	OPT10	MTFR	OPT15	OPT10	MTFR	OPT15	OPT10	MTFR
Human health	Mortality (VOLY)	25,182	32,394	38,660	29,175	38,994	48,567	35,247	45,329	53,549	40,725	54,492	67,429
	Mortality (VSL)	85,697	110,517	132,107	99,527	133,040	166,120	119,885	154,573	182,894	138,877	185,839	230,553
Other benefits	Low	7,180	9,435	11,341	7,180	9,435	11,341	7,180	9,435	11,341	7,180	9,435	11,341
	High	8,077	10,846	13,341	8,077	10,846	13,341	8,077	10,846	13,341	8,077	10,846	13,341
TOTAL GROSS BENEFIT	*Low*	*32,363*	*41,828*	*50,000*	*36,356*	*48,429*	*59,908*	*42,427*	*54,764*	*64,889*	*47,905*	*63,927*	*78,769*
	High	*93,774*	*121,363*	*145,447*	*107,604*	*143,886*	*179,460*	*127,962*	*165,419*	*196,234*	*146,954*	*196,685*	*243,893*
Mitigation costs		-3,280	-5,580	-24,060	-3,280	-5,580	-24,060	-3,280	-5,580	-24,060	-3,280	-5,580	-24,060
TOTAL NET BENEFIT	**Low**	**29,083**	**36,248**	**25,940**	**33,076**	**42,849**	**35,848**	**39,147**	**49,184**	**40,829**	**44,625**	**58,347**	**54,709**
	High	**90,494**	**115,783**	**121,387**	**104,324**	**138,306**	**155,400**	**124,682**	**159,839**	**172,174**	**143,674**	**191,105**	**219,833**
BCR	***Low***	***9.9***	***7.5***	***2.1***	***11.1***	***8.7***	***2.5***	***12.9***	***9.8***	***2.7***	***14.6***	***11.5***	***3.3***
	High	***28.6***	***21.7***	***6.0***	***32.8***	***25.8***	***7.5***	***39.0***	***29.6***	***8.2***	***44.8***	***35.2***	***10.1***

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[14] Macro-economic impact, including productivity impacts, are not included here.

Sensitivity of mortality impact to the source of the pollution

This sensitivity study focuses on the difference between the health impact if only the anthropogenic contribution to the total air pollutant concentrations is considered in the assessment of health impacts - in the main analysis total pollutant concentrations (i.e. from both anthropogenic and non-anthropogenic sources) is considered. This sensitivity test focuses only on $PM_{2.5}$ and considers the natural contribution to be the sum of the sea salt and dust concentrations. All other contributions to the total pollution levels are considered as anthropogenic contributions.

Because this type of sensitivity analysis is inextricably linked with the cut-off value used in the concentration response function, we use several distinct exposure response functions for the current analysis: the first one uses the standard cut-off value used in the main analysis (5 $\mu g/m^3$), whereas the second does not include a cut-off. In addition, for the total concentrations, we also use a concentration response function with half the cut-off value (2.5 $\mu g/m^3$). Table A-89 provides an overview of the combinations of concentration response functions and air quality input considered in the analysis.

Table A-89: Combinations of concentration response functions and air quality input considered in the sensitivity test concerning the chronic mortality impact.

Analysis	Source	Pollutant	Metric	Vulnerable Population	Relative risks (slope of concentration response function)			Dose (ug/m^3)	Cutoff (ug/m^3)
					Central estimate	**Lower value of 95% interval**	**Upper value of 95% interval**		
Main analysis	WHO (2021)	$PM_{2.5}$	Annual mean anthropogenic + natural	30-…	1.08	1.060	1.090	10	5
Standard air quality data without cut-off	WHO (2021)	$PM_{2.5}$	Annual mean anthropogenic + natural	30-…	1.08	1.060	1.090	10	0
Standard air quality data half cut-off	WHO (2021)	$PM_{2.5}$	Annual mean anthropogenic + natural	30-…	1.08	1.060	1.090	10	2.5
Only anthropogenic sources	WHO (2021)	$PM_{2.5}$	Annual mean anthropogenic	30-…	1.08	1.060	1.090	10	5
Only anthropogenic sources, without cut-off	WHO (2021)	$PM_{2.5}$	Annual mean anthropogenic	30-…	1.08	1.060	1.090	10	0

Figure A-129 and Figure A-131 show the impact of considering only the anthropogenic contribution as compared to the total pollution. For 2015, on a European wide scale, the difference between only considering the anthropogenic contribution or considering the total pollution is much smaller than the uncertainty due to the concentration response functions: when the same cut-off is applied to both sets of air quality data, the difference between the obtained mortality is smaller than 7%. The relative difference between both datasets becomes larger for 2030, as the anthropogenic concentrations decrease, while the non-anthropogenic concentration is kept constant.

When considering the results per country (see Figure A-130), a different behaviour is observed for the island states in the Mediterranean (Cyprus and Malta). For both countries, the mortality considering only the anthropogenic contribution but without cut-off is equivalent to the mortality considering the total contribution with half the cut-off (2.5 µg/m^3). Stated differently, for these countries, the average non-anthropogenic concentration is close to half the WHO limit value (2.5 µg/m^3). For all other countries, the results mimic the results concerning the European totals, with only a limited impact of omitting non-anthropogenic sources.

Figure A-129 Impact of the anthropogenic contribution on the premature mortality for the baseline scenario in 2015 (left figure) and 2030 (right figure).

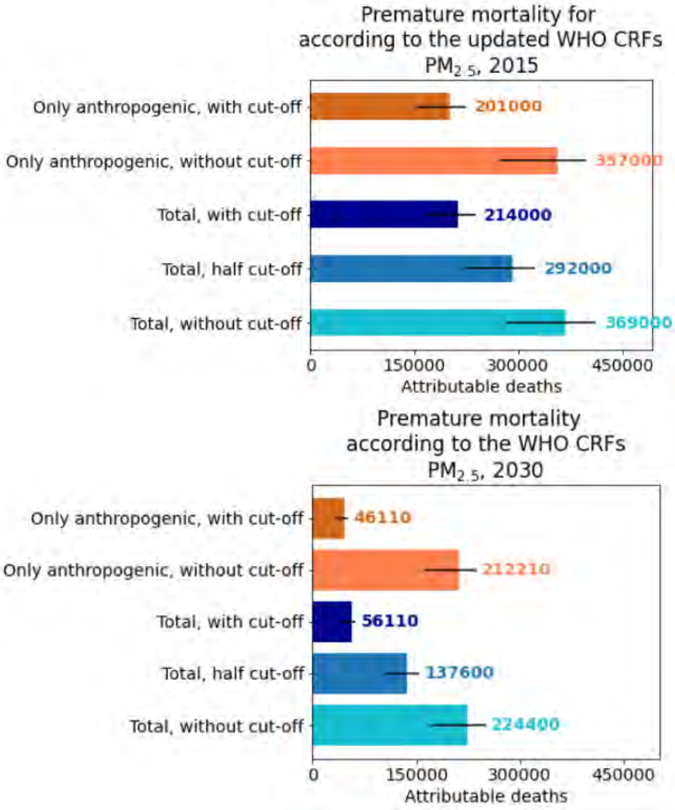


Figure A-130 Impact of the anthropogenic contribution on the premature mortality for the baseline scenario in 2015. The figure shows the mortality per 100.000 inhabitants per country.

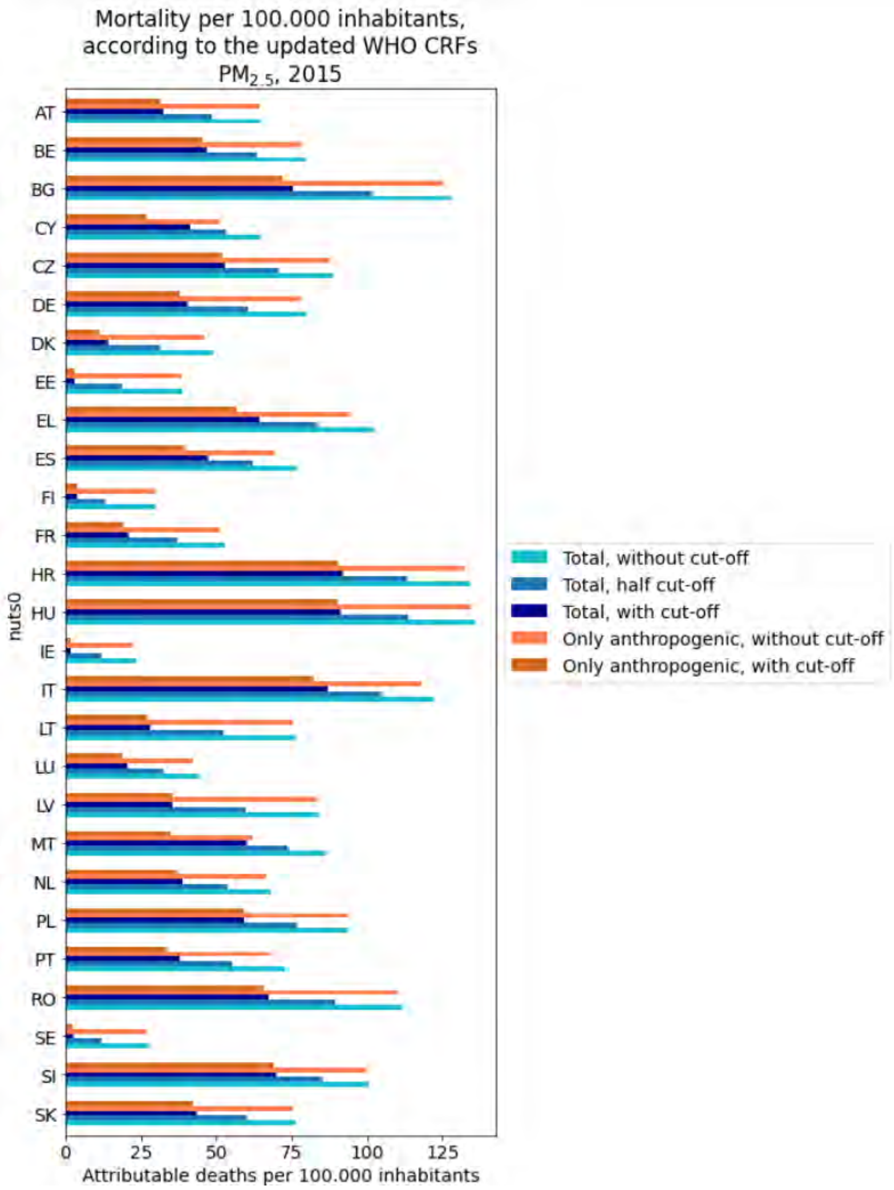
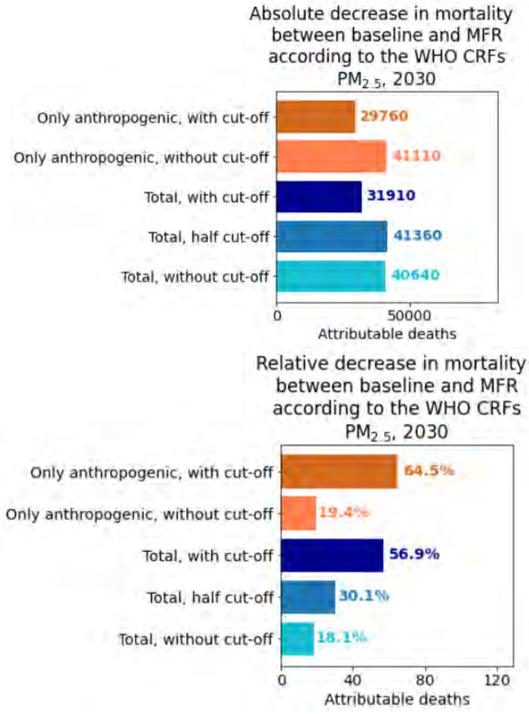


Figure A-131 Impact of the anthropogenic contribution on the absolute (top figure) and relative (bottom figure) difference in premature mortality between the MFR and the baseline for 2030.



Sensitivity of morbidity impact to the exposure response functions

This sensitivity analysis considers the sensitivity of the morbidity impact to the concentration response functions. Because the final concentration response functions for Tier three morbidity endpoints have not undergone the detailed review process of the WHO, the uncertainty on these relations is larger than the uncertainty on the relations for mortality (Tier 1). In addition, recent studies focusing on Europe (ELAPSE, Brunekreef & et al., 2021) suggest the concentration response functions from global meta-reviews might underestimate the effects in a European context. We therefore introduce an additional sensitivity analysis, in which we use the concentration response functions derived in the latest ELAPSE study and other alternatives from the literature review to quantify the sensitivity of the results for the primary endpoints of the third Tier of the morbidity analysis.

For each of the primary endpoints, we consider the alternative concentration response functions from the overview table concerning the health effects considered in Tier 3.

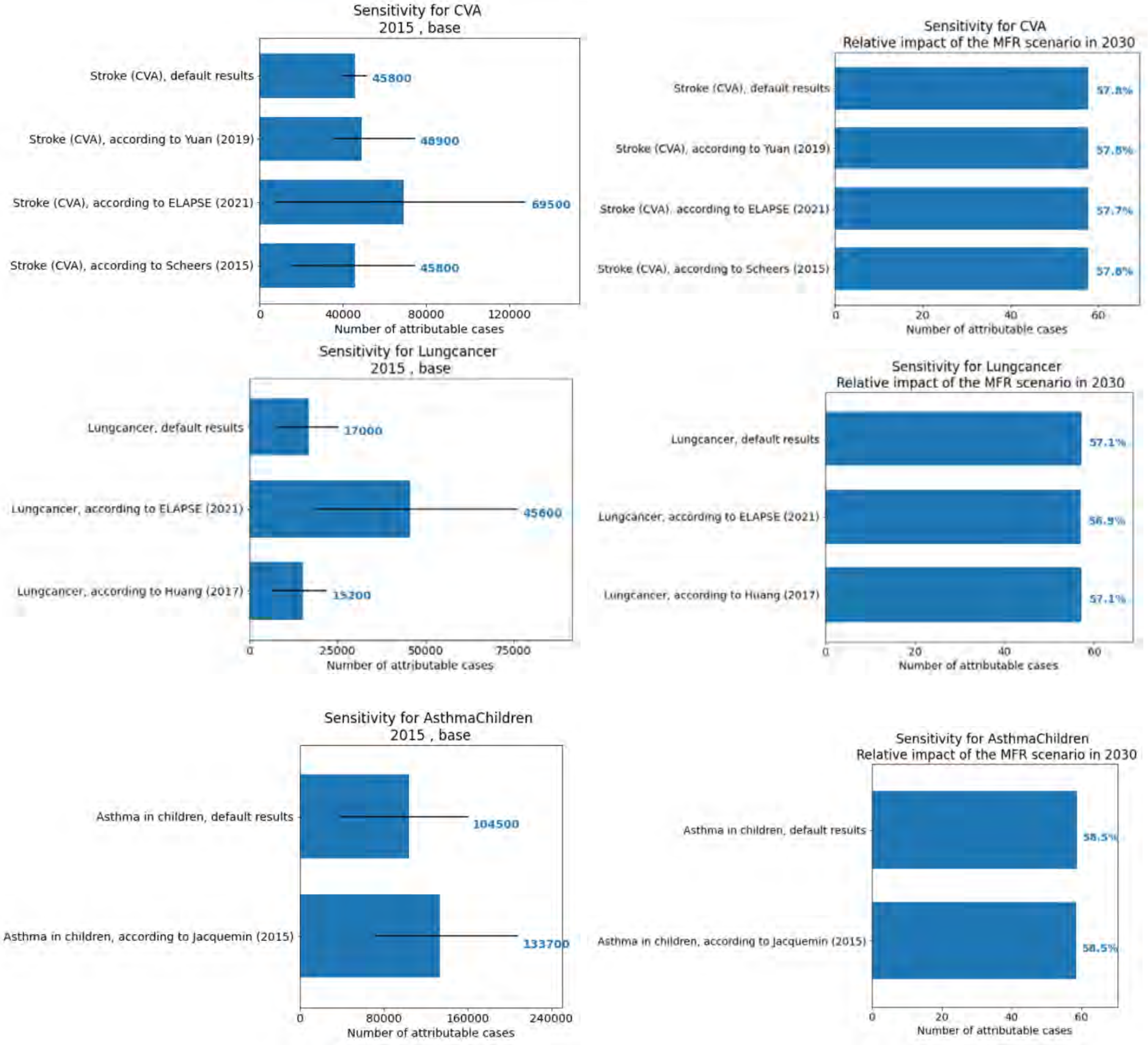
Table A-90 provides an overview of the functions that have been considered.

Table A-90 Concentration response functions considered in the sensitivity test concerning the morbidity impact.

Analysis	Source	Vulnerable Population	Relative risks (slope of concentration response function)			Dose (ug/m^3)
			Central estimate	**Lower value of 95% interval**	**Upper value of 95% interval**	
CVA (Stroke)	Main analysis	All ages	1.13	1.11	1.15	10
	Yuan (2019)	All ages	1.14	1.1	1.23	10
	Scheers (2015)	All ages	1.13	1.04	1.23	10
	ELAPSE (2021)	All ages	1.21	1.02	1.46	10
Lung cancer	Main analysis	All ages	1.09	1.04	1.14	10
	Huang (2017)	All ages	1.08	1.03	1.12	10
	ELAPSE (2021)	All ages	1.28	1.1	1.56	10
Asthma in children	Main analysis	0-15	1.03	1.01	1.05	1
	Jacquemin (2015)	0-15	1.04	1.02	1.07	1

Figure A-132 provides the results of the sensitivity test for the baseline results in 2015, and the relative impact of the MFR scenario in 2030. The results indicate that there is a substantial uncertainty on the absolute number of cases for all three endpoints, but the order of magnitude (tens of thousands of cases) is similar for all concentration response functions. In addition, the relative differences between the MFR scenario and the baseline are unaffected by the actual slope of the concentration response function, similar to the results for the sensitivity study on the slope of the concentration response function for mortality.

Figure A-132 Impact of the concentration exposure functions (relative risks) on the results for the primary endpoints of the Tier 3 analysis of the morbidity impact: CVA (top row), lung cancer (middle row) and asthma in children (bottom row). The left figures show the results for the number of attributable cases in 2015, the right figures show the relative difference between the MFR scenario and the baseline in 2030.



Sensitivity to air quality data

This section analyses the sensitivity of the health impact to the input pollutant concentrations. The rationale for this test is threefold:

- Quantify the impact of the high-resolution uEMEP model on top of the lower resolution EMEP model. In the main analysis we have used the (non-bias corrected) uEMEP results for the health impact analysis, whereas in this sensitivity test we use the lower resolution EMEP results instead.
- Quantify the sensitivity to the uEMEP bias correction for future baseline maps and the impact of the scenarios. In the main analysis we have used the (non-bias corrected) uEMEP results for the health impact analysis, whereas in this sensitivity test we use the bias corrected uEMEP results instead.

- Validate results for 2015 by comparing them with existing datasets.

The results for 2015 are provided in Figure A-133. This figure shows the results for the three air quality model datasets developed in the current project (EMEP, uEMEP and bias corrected uEMEP), and the results of two existing datasets. The EEA mortality results are taken from the yearly EEA assessment report[15] of 2018, which provides mortality statistics for 2015. We also consider the mortality statistics that are obtained by applying the methodology at hand to the[16] European Topic Center (ETC) air quality maps underlying the EEA results for 2015. This dataset is merely added to validate the current methodology. Note that we use the HRAPIE concentrations response functions to facilitate the comparison with the EEA results (given the EEA estimates are based on the HRAPIE functions).

The results for the total mortality in Europe (Figure A-133) indicate that for all pollutants, when the HRAPIE pathways are applied, the official EEA results (based on the ETC maps) are very similar to the results obtained by applying the methodology of this project to the ETC maps, thereby validating the current set-up, and confirming the conformity between the methodology at hand and the methodology of the EEA. We thus conclude that, if the HRAPIE pathways are used, there is a good correspondence between our estimates and the EEA results. Any differences between the results of the main analysis and that of the EEA can thus be attributed to the differences in the concentration modelling and the concentration response functions applied.

The mortality statistics computed in the main analysis[17] (uEMEP results) are somewhat lower than the results reported by the EEA for 2015, owing due to lower concentration in the concentration maps. The largest differences are observed for nitrogen dioxide, for which the results for uEMEP results are clearly lower than the EEA results. The EMEP results are similar (but somewhat larger health impact[18]) than the uEMEP results. Adding the bias correction to uEMEP diminishes the differences between the EEA results and the results of the current modelling, with somewhat larger mortality statistics for the bias corrected uEMEP results than for the EEA reporting. The difference between the results is much smaller for particulate matter, with a clear overlap between the uncertainty bars for all datasets. The results of EMEP and uEMEP are very similar to each other. Adding the bias correction to uEMEP further reduces the differences between the results of the current modelling and the EEA reporting. For ozone, the results are very similar for all air quality maps.

Figure A-134 provides the comparison between the EMEP, uEMEP, bias corrected uEMEP and ETC air quality data per country. Because we do not consider the EEA results in this comparison, we use the updated WHO concentration response functions. In general, the results per country mimic the results on the European scale, but there are some exceptions when the ETC and uEMEP air quality maps are considered. Applying the bias correction to uEMEP has larger effects for some countries than for others. The list of countries with a larger impact also depends on the pollutant. For particulate matter, a large impact is for instance observed for Czechia and Poland, whereas large effects for nitrogen dioxide are (amongst other) observed for Hungary, Italy, Germany, Bulgaria, Poland and Portugal. Also the difference between the ETC results and the uEMEP results varies from country to country. Some outliers

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[15] https://www.eea.europa.eu/publications/air-quality-in-europe-2018

[16] https://www.eionet.europa.eu/etcs/etc-atni/products/etc-atni-reports/etcacm_tp_2017_7_aqmaps2015

[17] The figure illustrates these results using the HRAPIE pathways, but similar conclusions are reached when the WHO concentrations response functions are applied.

[18] Because of the lower resolution of EMEP in comparison with uEMEP, more people are living at locations in exceedance of the 20 ug/m^3 threshold that is applied in the current analysis.

(particulate matter in Bulgaria, Greece, Slovakia and Romania; multiple countries for nitrogen dioxide) highlight the differences in the methodology between both air quality maps.

Figure A-133 Sensitivity analysis of the mortality results to the air quality data. The figure shows the number of yearly premature deaths in the EU-27 according to the HRAPIE concentration response functions for 2015 for three pollutants ($PM_{2.5}$, top-left, NO_2, top-right, O_3, bottom). The filled bars and the numbers refer to the central estimate (rounded to the nearest 100 for NO_2 and the nearest 1000 for $PM_{2.5}$, respectively), while the black lines provide the 95-percentage uncertainty estimate based on the uncertainty on the relative risks. The figure shows the results using the methodology developed for the current project for four underlying air quality maps (EMEP, uEMEP, bias-corrected (BC) uEMEP and ETC), and the results reported by the EEA in its yearly reporting.

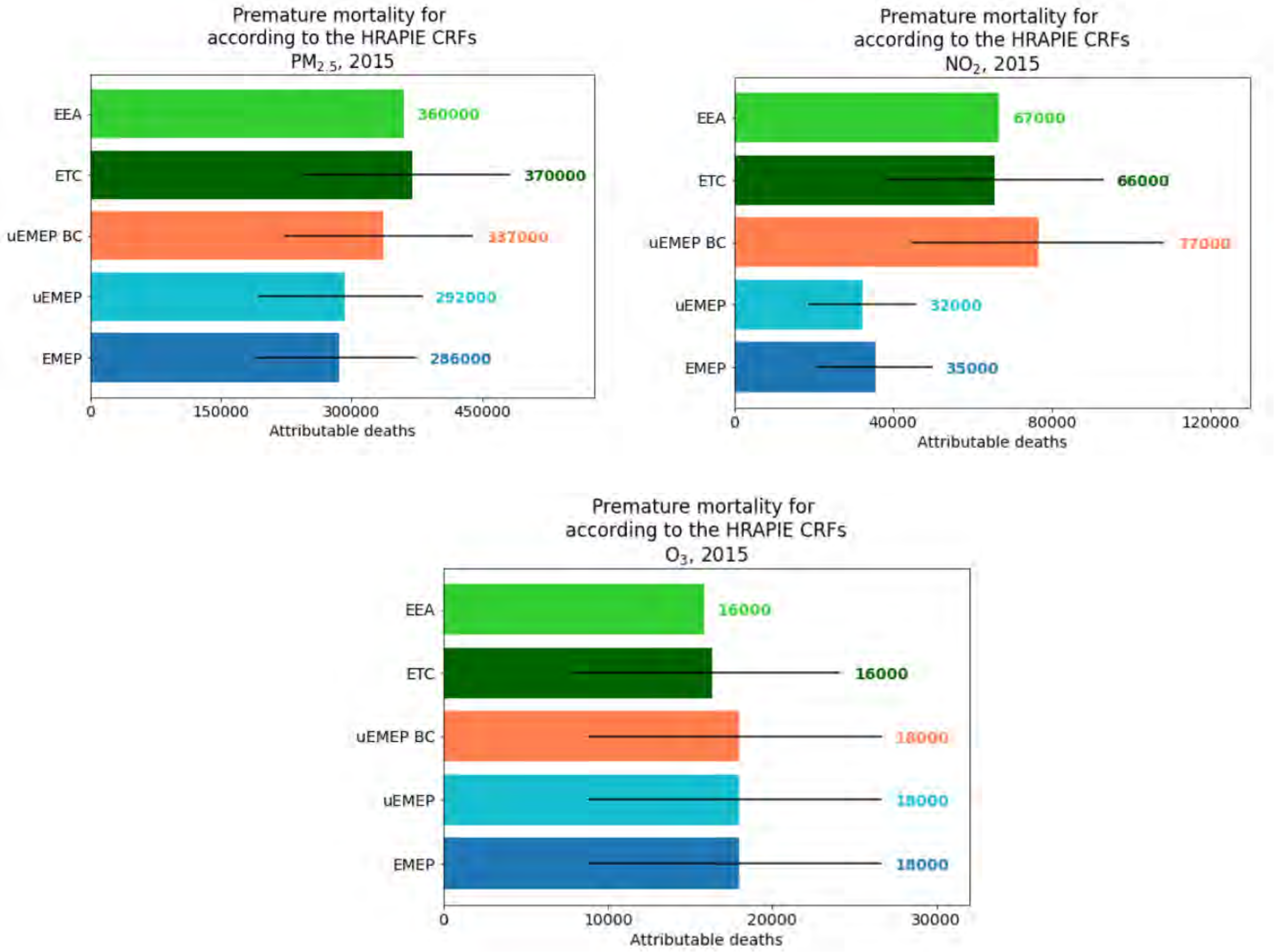
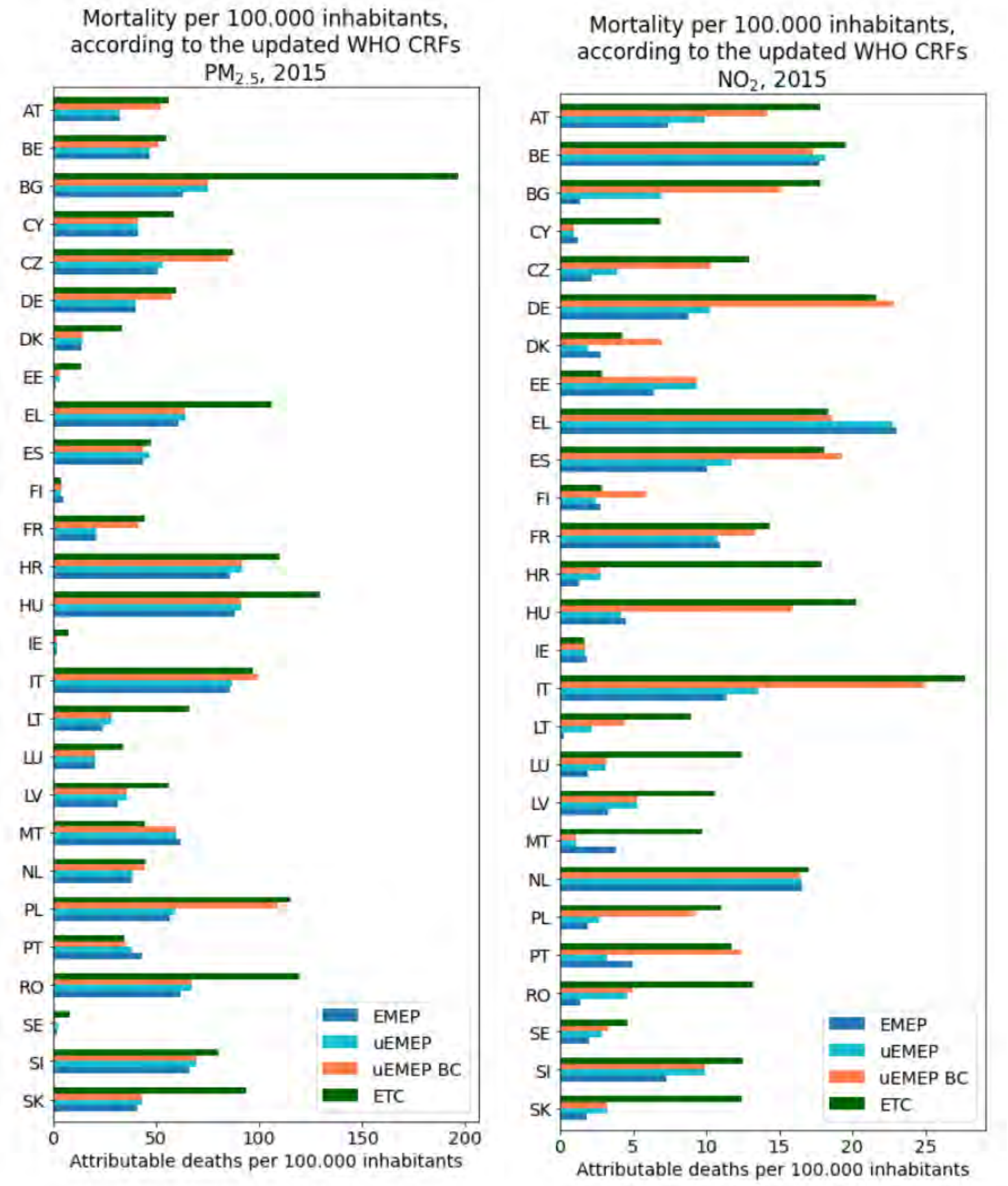


Figure A-134 Sensitivity analysis of the mortality results to the air quality data. The figure shows the number of yearly premature deaths per country according to the WHO concentration response functions for 2015 for two pollutants ($PM_{2.5}$, left, NO_2, right). The figure shows the results using the methodology developed for the current project for four underlying air quality maps (EMEP, uEMEP, bias-corrected (BC) uEMEP and ETC).



The results for the 2030 baseline are provided in Figure A-135

. The difference between the uEMEP and the bias corrected uEMEP mortality for the baseline scenario is clearly larger in 2030 than in 2015. Because the concentrations are close to the cut-off values for most locations, the effect of the bias corrections increases as some locations move either side of this cut-off. In general, the uncertainty on the air quality modelling becomes more important as the concentrations are closer to the cut-off values that are considered in the health impact assessment. Similar remarks explain the larger difference between the uEMEP and the EMEP results. Because of the lower resolution of EMEP in comparison with uEMEP, more people are living at locations in exceedance of the 10 ug/m^3 threshold that is applied in the current analysis.

Figure A-135 also shows the results for the MFR and the relative impact of the MFR (as compared to the baseline). The relative impact of the MFR scenario is approximately the same (around 50%) for all air quality datasets for particulate matter. For nitrogen dioxide, on the other hand, the impact of the MFR scenario is approximately the same for the uEMEP and the bias corrected uEMEP results, while the impact is somewhat lower for the EMEP results.

Figure A-136 compares the impact of all the scenarios both for the uEMEP and the bias corrected uEMEP air quality data. The relative impact of the scenarios (i.e. the relative differences between the scenarios and the baseline) is approximately the same, irrespective of the application of the bias correction. The conclusions in the main report concerning the (relative) health impact of the scenarios are thus independent of the applications of the bias correction.

Figure A-135 Number of yearly premature deaths in the EU-27 caused by the exposure to air pollution at levels above the WHO AQ guidelines for the baseline (top row) and MFR (middle row) scenario for 2030 for two pollutants ($PM_{2.5}$, left, NO_2, right). The bottom row shows the relative impact of the MFR scenario. Impacts for three different underlying air quality maps are shown (uEMEP, bias-corrected uEMEP and EMEP). The filled bars and the numbers refer to the central estimate (rounded to the nearest 100), while the black lines provide the 95-percentage uncertainty estimate based on the uncertainty on the relative risks.

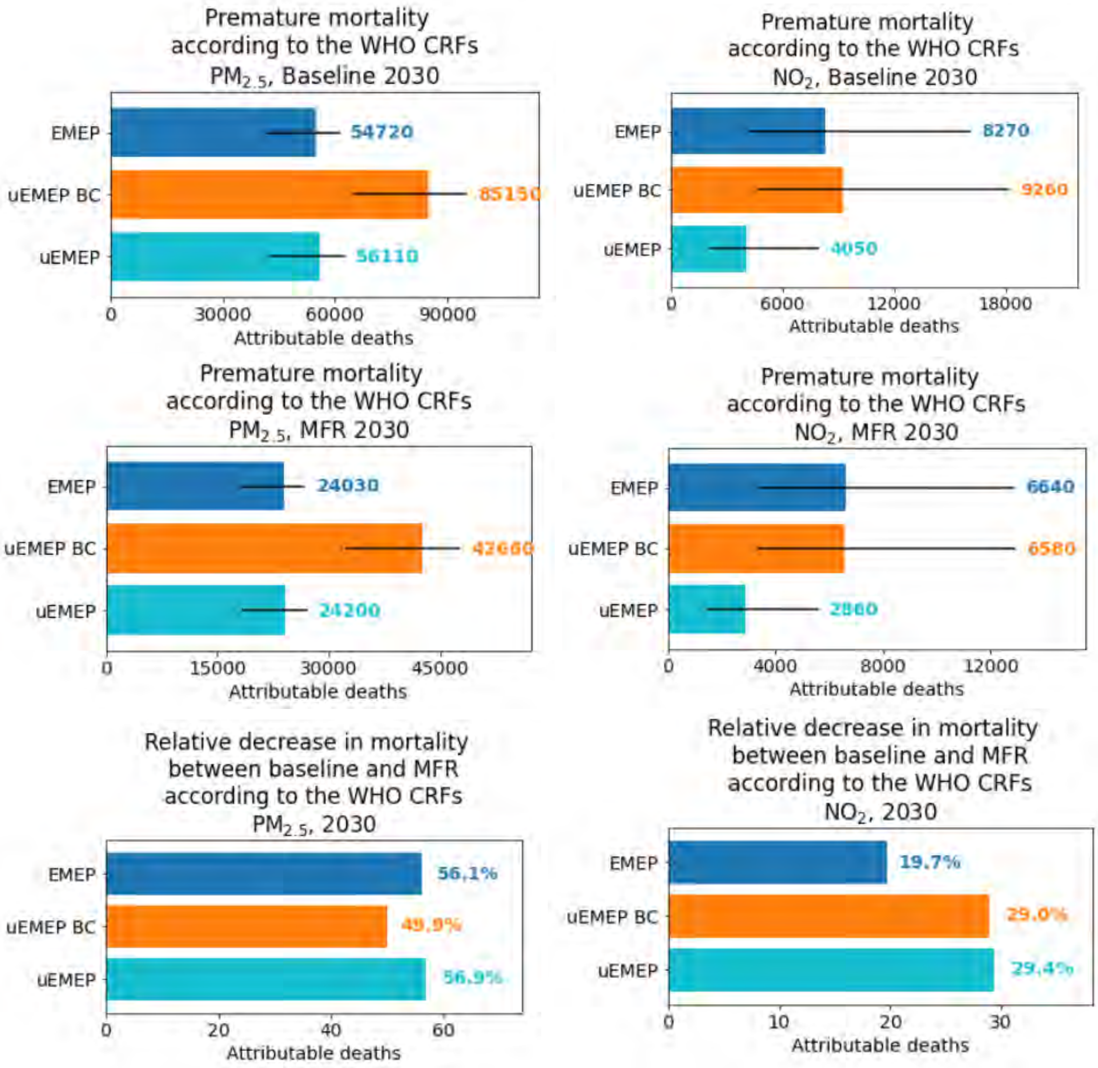
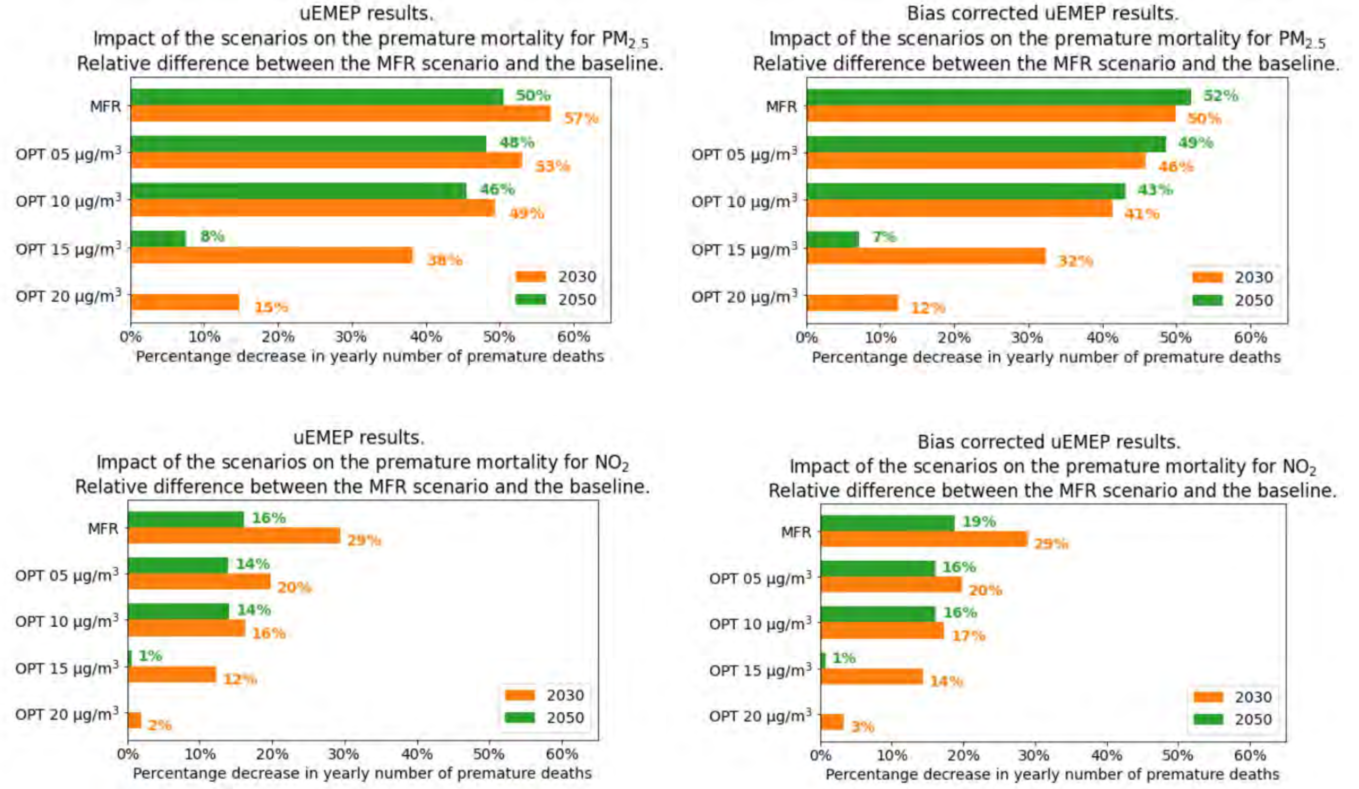


Figure A-136 Effect of the bias correction on the relative impact of the scenarios for two pollutants ($PM_{2.5}$, top row; NO_2, bottom row). All bars show the impact of the scenarios on the number of yearly premature deaths in the EU-27 caused by the exposure to air pollution at levels above the WHO AQ guidelines for three pollutants ($PM_{2.5}$, top row, NO_2, bottom row). Impacts for the two future reporting years considered in the study (2030 in orange and 2050 in green) are included. The filled bars and the numbers refer to the central estimate (rounded to the nearest 100 for NO_2 and the nearest 1000 for $PM_{2.5}$, respectively), while the black lines provide the 95-percentage uncertainty estimate based on the uncertainty on the relative risks. The left figure shows the results for the standard uEMEP results, the right figure the results for the bias-corrected uEMEP.



Sensitivity: Assumptions around IED in the baseline

Box - Sensitivity of the assessment to the policy baseline

This support study to the Impact Assessment of the revision of the AAQ Directives commenced in April 2021. In parallel, revisions were also being considered to the Industrial Emissions Directive (IED). Over the course of this study, the proposed revisions to the IED were published, alongside a supporting impact assessment (IA). However, the integrated impact modelling under this study was too advanced at that point to allow reflection and incorporation of the proposed IED updates into the central modelling for the present study. As such, the central baseline does not capture any potential effect of revisions to the IED proposed in 2022. For this sensitivity, an alternative baseline was developed based on assumptions around what the IED could deliver in terms of emissions reductions (although noting that precise estimates of the impacts are not available and as such illustrative assumptions were used).

Overall, additional emissions reductions included under the IED sensitivity in the sensitivity baseline lead to only small relative changes overall:

- Members State specific population weighted exposure to NO_2 and $PM_{2.5}$ changes by less than 0.2 ug/m^3, however effects locally can be more significant.
- Reduced concentrations at a small number of stations are observed with mostly moderate concentration levels.
- NO_2 and $PM_{2.5}$ exposure distribution for the EU27 population changes insignificantly.

Hence the key results and conclusions of the central analysis would not change substantially as a result of this sensitivity.

Rationale for the test

This support study to the Impact Assessment of the revision of the AAQDs commenced in April 2021. In parallel, revisions were also being considered to the Industrial Emissions Directive (IED). Over the course of this study, the proposed revisions to the IED were published, alongside a supporting impact assessment (IA)[19]. However, the integrated impact modelling under this study was too advanced at that point to allow reflection and incorporation of the proposed IED updates into the modelling for the present study. Also, the assessment of policy options in the IED IA was done predominantly in a qualitative manner, hence not yielding elements that could be directly implemented in the present study. As such, the central baseline presented in the main report does not capture any potential effect of revisions to the IED proposed in 2022.

Given the strong interaction between the two sets of legislation, this sensitivity test explores what impact the proposed revisions to the IED could have on the analysis undertaken around the proposed revisions to the AAQDs.

Specifically, this seeks to capture the effects of a revised IED in the baseline against which proposals for revisions to the AAQDs are assessed. The revisions to the IED are expected to deliver reductions in industrial emissions in the baseline, including changes for NH_3 emissions from agricultural activities. This in turn will have consequent effects on the populations exposed to different concentrations of different pollutants. Bringing down emissions in the baseline would likely make achieving more ambitious pollutant targets (as modelled under the scenarios in the central analysis) easier. I.e. less

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[19] https://eur-lex.europa.eu/resource.html?uri=cellar:6a2e6b16-b5a9-11ec-b6f4-01aa75ed71a1.0001.02/DOC_1&format=PDF

additional effort would be needed to meet more ambitious standards under the scenarios (relative to a baseline including the updated IED). This would also reduce the additional costs of mitigation action under the scenarios modelling more ambitious standards.

The sensitivity will be modelled by flexing the inputs and assumptions in the emissions modelling step in the GAINS model.

Impact of the revised IED on emission of air pollutants

The key assumption in the sensitivity test is the emissions reductions to be applied and the sectors to which these are applied. As a starting point, we reviewed again the proposals and analysis set out in the IED IA. Agriculture and non-agriculture sectors are considered separately as the depth of underlying evidence is different, and to inform our assumptions we also reflect on the trends depicted in the existing AAQD IA baseline.

IED IA - non-agriculture sectors

Our considerations around non-agriculture sectors are split into two strands: impacts on existing sectors covered by the IED, and impacts on new sectors proposed to be captured under a revised IED.

The IED currently captures a wide range of industrial sectors, for which multiple BREF documents have been developed – this includes several high-impact industrial sectors such as iron and steel, cement, refineries, textiles and waste treatment and incineration[20]. The IED IA baseline presented the following qualitative considerations around existing sectors covered by the IED:

For the baseline, the BREF process and BAT Conclusions would be expected in the future to continue [p61]…

With the continued development of further BAT conclusions for IED sectors, and the continued implementation of the IED with permit ELVs based on BAT, and the decoupled nature between industrial sector gross value added and emissions, it would be expected for the sectoral emissions from IED industries to decline further over time [p65].

A number of proposed revisions to the IED will influence emissions from these sectors, as defined under Problem Areas 1-4 in the IED IA. These include ensuring BAT-AELs (associated emission levels) are achieved, homogenising and enhancing enforcement, promoting innovation and enhancing resource efficiency. However, the majority of analysis around the proposed measures in the IED IA was qualitative, with only limited quantitative assessment being undertaken. The IED IA sets out in several places the limitations which prevented the quantitative estimation of effects:

The impacts of the IED and, therefore, any revisions are inherently dependent upon the independent BREF process and the associated BAT conclusions. Moreover, technological progress is very uncertain and, therefore, the evidence available has limitations as to the technologies that operators might adopt in the future as a result of changes to the IED, how much these might cost and the specific extent to which their adoption might lead to better environmental performance.

These and other limitations have meant that the impact analysis was built on a partial evidence base and complemented by informed expert judgement and opinion….[21]

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[20] For a complete list see: The baseline does not include data from the revision of the IED for agriculture that was published on the 5th April 2022.

[21] See section 1.4.2 of Annex 1 of the support study

The only measure for which quantitative estimates of the impacts on emissions was completed was for the proposed measure 'aligning AELs with lower end of the range of BATC'. The IED IA presented the following analysis:

To inform the potential scale of emission reductions that could occur when applying this measure, analysis of the Commission's BAT-AEL tool (European Commission, 2020) listing all BAT-AELs from BATC was carried out. This used, for an illustrative pollutant of NOx emissions, the average % of potential reduction from the upper to the lower end of BAT-AEL ranges across CLM, GLS, LCP, PP and REF BATC, together with the assumed proportion of installations that would be affected by the measure (10%), the NOx emissions by sector, and the average EU NOx damage cost to generate, at a high level, the possible illustrative NOx benefit for these five sectors from this measure. These illustrative NOx benefits were estimated to be between €0.9bn and €2.8bn per year.

Hence for existing sectors covered by the IED, this measure was illustratively estimated to save around 10% of NOx emissions, in addition to the effects of the ongoing rolling BREF improvement programme.

The proposed revisions to the IED also considered bringing a range of new sectors into the scope of the IED, for which BREF and BATC would be developed for the first time. The list is as follows:

- *(31) Include intensive cattle farming within the scope of the IED.*
- *(32) Amend the capacity thresholds of the intensive rearing of pigs and poultry considered under activity 6.6 of Annex I.*
- *(33) Introduce a tailored regulatory framework for installations carrying out intensive rearing of animals.*
- *(34) Extend the current sectoral coverage to also include battery production within the scope of the IED.*
- *(35) Extend the current sectoral coverage to also include ship building (other than coating) and ship dismantling within the scope of the IED.*
- *(36) Extend the current sectoral coverage to also include forging presses, cold rolling, with capacity exceeding 10 t/h, and wiredrawing, with capacity exceeding 2 t/h, within the scope of the IED (e.g., via Annex I, activity 2.3).*
- *(37) Extend the current sectoral coverage to also include finishing activities with the existing capacity thresholds in activity 6.2 (pre-treatment or dyeing of textile fibres or textiles.*
- *(38) Extend the current sectoral coverage to also include smitheries of 20 kilojoule per hammer with no threshold for the calorific power or reduce the capacity threshold for the calorific value to > 5 MW in activity 2.3(b) (from the current limit of 50 kilojoule per hammer and where the calorific power used exceeds 20 MW).*
- *(39) Facilitate the adoption of BAT conclusions for activity 5.4 landfills.*
- *(40) Revise the capacity threshold in Annex I for activity 5.4 landfills.*
- *(41) Include mining and quarrying industries (E-PRTR Annex I activities 3a and 3b) within the scope of the IED.*
- *(42) Include intensive aquaculture within the scope of the IED.*
- *(43) Include upstream oil and gas industries within the scope of the IED.*

Analysis of the agriculture sectors has been conducted separately, and is explored in further detail below.

For the non-agriculture sectors, again the IED IA did not estimate formal impacts of the inclusion of these sectors under the scope of the IED for the first time. Instead, the IED IA highlighted the total baseline emissions from these sectors as an illustration of the size of effects (although of course this represents a maximum bound of impacts should emissions from the sectors be reduced to zero). For example:

PO5-c landfill installations appear to contribute to 1.3% of total NMVOC from the industry covered by the IED, 1.9% of NH3 totals, and 1.4% of SOx totals, part of which can be abated as a result of the BREF and permitting processes. PO5-d mining and quarrying installations may lead to substantial emissions of PM10 equivalent to around 4.4% of total industrial emissions covered by the IED. Therefore, PO5-c, PO5-d and PO5-f are likely to have a positive impact on air quality, though further work is needed to, for example, ascertain the extent to which dust suppression techniques are already deployed in the mining and quarrying sector and the potential for further reductions. PO5-f upstream oil and gas installations appear to contribute around 0.75% of NOx totals in the IED and 1.75% of NMVOC totals. PO5-e is unlikely to have any significant impact on air quality.

In addition, the IED IA also considered the impacts of the implementation of BATC historically (for sectors already covered by the IED). The IED IA sets out the following analysis, based on emission data from the latest year of E-PRTR (comparing to reported emissions in the year where BATC were published):

To try to estimate at a very high level the typical (or possible) emission reductions for a sector as a whole associated with implementation of BATCs for key environmental issues (KEI), specific analysis on three sectors has been conducted. This has focussed on three sectors (pulp/paper, cement, glass) for which the sectors have completed the four-year implementation period following BAT Conclusions publication. Emissions data for three pollutants identified as KEI for each of these sectors have been extracted from E-PRTR and benchmarked against the activity (production) statistics reported for these sectors. The findings of this analysis, shown in Figure 5-14, suggest that reductions in emissions intensity (emissions per unit of production) dropped following implementation of the BATC by 37% to 67% (average 47%), with annual average reductions of 7% to 14% (mean 10%) (p66)

A second version of a BREF (and BAT conclusions) for a sector would not be expected to have such significant impacts on emission reductions as the first BAT conclusions. Following BATC implementation, it would be expected for there to be less divergence among installations' emissions performance. Hence the percentage emission reductions identified as having occurred in the sector during the period of (first) BAT conclusions implementation (averaging 47%) would be unlikely to be achieved for subsequent (second) BAT conclusions, unless transformational techniques (or processes) were identified as part of that BREF process.

For these three sectors, adopting BATC for the first time led to a reduction in emissions of between 37 to 67% (average 47%) per sector, across all emissions types assessed (SO_2, NOx and PM_{10}).

From the information in the IED IA we draw the following conclusions for this work:

- Only limited quantification of the potential effects of the IED is presented in the IA given limitations and uncertainty around the estimation
- For those sectors covered under the existing IED, the ongoing rolling BREF programme will continue to drive improvements in the baseline. However, future updates are unlikely to achieve

as significant reductions as previous iterations. Several policy options will deliver further emissions reductions, although very limited quantification is presented in the IA: only the effects of aligning BAT-AELs with the lower end of the range has been assessed, which is estimated to deliver around a 10% reduction in NOx emissions for 5 sectors. However, it is unclear how representative this is across all sectors and pollutants.

- For new sectors coming into the scope of the IED for the first time (excluding agriculture at this point), no estimation of the quantitative impacts on emissions is made. Analysis of historic emissions impacts for three sectors is presented associated with the first iteration of BATC for those sectors – impacts were between 37 to 67%. However, it is uncertain how representative this is for all sectors, and the new sectors coming into scope. Likewise this also does not capture other parameters which may influence effects going forward – e.g. the broader economic environment.

These factors aside, a key limiting factor on the potential additional impacts of the IED IA is the nature of the rolling BREF programme itself. Even where the proposed revisions could deliver emissions impacts, these will only be delivered in practice once the BREFs are reviewed and BATC developed. The BREFs notionally operate on a 10-year rolling cycle. Should the revised IED be put in place next year (2023), this allows 7 years over which the BREF revision process can be influenced before 2030 – so influencing only 70% of BREF reviews. Even then, once BATC have been adopted, there is a 4 year window within which permits need to be reviewed and updated, so total emissions impacts could only accrue fully at the end of this four year period – this reduces the proportion of BREFs and BATC influenced prior to 2030 to 30%. This also does not take into account the time required to actually update the BREF and BATC prior to adoption, nor the potential logistical problems of having a broader range of sectors to review, which may also impact on the timing of updated BATC being published and implemented.

For those sectors covered by the existing IED, these points together make it difficult to propose that the IED would deliver significant additional emissions reductions prior to 2030. As an illustration, where the revisions to the IED deliver 10% emissions reductions in existing sectors, if only 30% of updated BATC come into force by 2030, this necessarily limits the overall potential emissions impacts in these sectors as a whole to 3%. For new sectors, the impacts could be greater but again are uncertain – e.g. assuming that the first BATC for new sectors can achieve the same average impact as for existing sectors (47%), again assuming BATC can be determined and reflected in permits for 30% of new sectors by 2030, this limits the emissions impacts to 15% of total emissions for these sectors under stretching assumptions.

Non-agriculture emissions – reflections on the GAINS baseline

The IED sectors are represented in GAINS by distinguishing a wide range of industrial activities, including iron and steel (several processes distinguished separately), cement, refineries, textiles and waste treatment and incineration, etc.

After reviewing the information presented in the IED IA, in particular around historic emissions achievements, the baseline modelling for the AAQD IA was re-reviewed. This was done re-consider the progress in reducing the emission intensity from 2005 towards 2020 to assess the remaining potential, and compare this to the findings of the IED IA . The improvements in emissions intensity across the GAINS sectors which map to those covered by the IED are presented in the following table.

Table A-91 Improvement in emissions intensity in GAINS sectors

Industry	Improvement in emission intensity					
	SO_2 emission intensity		NO_x emission intensity		$PM_{2.5}$ emission intensity	
	2005-15	2005-20	2005-15	2005-20	2005-15	2005-20
Primary Al production	0%	14%	0%	0%	25%	25%
Secondary Al production	0%	0%	0%	0%	40%	42%
Cement	25%	31%	27%	32%	13%	51%
Glass	39%	46%	38%	40%	45%	45%
Iron and steel	21%	30%	23%	26%	21%	38%
Lime	18%	23%	14%	16%	52%	60%
Pulp and paper	29%	48%	22%	24%	24%	42%
Refinery	33%	46%	13%	15%	40%	45%

On reflection, it appeared that the AAQD IA baseline in the central analysis was presenting a reduction in emissions from IED industrial sectors that was somewhat less than the emissions reductions highlighted in the analysis of historic emissions in E-PRTR (as presented in the IED IA) over the same time period. I.e. the AAQD IA baseline could be somewhat underplaying the impacts of the IED relative to what has borne out in practice.

For example:

- For the cement sector, the GAINS model depicts that SO_2 emission intensities changed by 25% (2005-15) and 31% (2005-20), for NOx by 27 to 32% respectively over these time periods, and for $PM_{2.5}$ by 13 and 51%. With the exception of $PM_{2.5}$ in this case, the additional reduction achieved between 2015 to 2020 – the period over which IED was implemented and for which historic reductions in emissions intensities were observed) – is significantly lower than the 47% average reduction from the E-PRTR data
- For the glass sector, the GAINS model depicts that SO_2 emission intensities changed by 39% (2005-15) and 46% (2005-20), for NOx by 38 to 40% respectively over these time periods, and for $PM_{2.5}$ by 45% over both periods. For all pollutants, again the additional reduction achieved between 2015 to 2020 in the GAINS baseline is significantly lower than the 47% average reduction from the E-PRTR data
- For the paper and pulp sector, the GAINS model depicts that SO_2 emission intensities changed by 29% (2005-15) and 48% (2005-20), for NOx by 22 to 24% respectively over these time periods, and for $PM_{2.5}$ by 24 to 42% respectively. For all pollutants, again the additional reduction achieved between 2015 to 2020 in the GAINS baseline is significantly lower than the 47% average reduction from the E-PRTR data.

The same pattern of results is true for the other industry sectors in GAINS – again comparing the patterns of change in the GAINS baseline to the observed historic reductions in emissions intensity from the E-PRTR data (noting that these were only calculated for cement, glass and paper and pulp sectors).

IED IA – agriculture emissions

The proposal for the revision of the IED[22] also includes new requirements for farms with more than 150 livestock units (LSU) including pigs, poultry and cattle. The earliest entry into force is envisaged in 2027 but the proposal does not yet define the BATs.

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[22] (https://ec.europa.eu/environment/publications/proposal-revision-industrial-emissions-directive_en)

For the sensitivity scenario, we assume a combination of technologies with the highest removal efficiency available in the GAINS model. These measures include a combination of low nitrogen feed, covered storage, and efficient application of manures on land from 2027, gradually increasing their penetration as well as assuring that new animal houses (for farms >150 LSU) are reflecting the 'low emission housing' standards.

In this transition towards BAT technologies for the IED farms, the country- and livestock-specific implementation of current policies (as represented in GAINS) and applicability constraints for particular mitigation measures are considered, including country-specific physio geographical features like stony and steep slopes limiting use of some machinery for efficient application of manures, size structure and lifetime of technologies.

While the farm size threshold is defined (in the IED proposal), it is not obvious to determine in practice the actual number of farms that fall below or above the 150 LSU threshold, as information on the number of animals kept is not always known and, owing to changing structure of farms, has evolved (and will evolve) over time. We start from the data on country-specific farm structure from the years 1990 to 2010 from EUROSTAT[23] as a basis for extrapolating farm structure in the year 2030.

Although there are distinct differences in the development of farm structure from 2010 to 2030 across MS, the relative impact of the IED on livestock emissions is similar. Generally, relative emission reductions remain low in 2030 in all countries, assuming the agricultural-related aspects of the recent proposal for a revised IED are implemented in 2027 only, resulting in NH_3 reductions in order of less than 1% to about 4% of national emissions from livestock production.

Summary assumptions

Based on the above research, it was proposed to model the following assumptions for the sensitivity analysis:

- Non- agriculture sectors: assume a 20% reduction in emissions across all sectors falling into the remit of the revised IED (to the extent that they are included in the modelling framework (e.g. some smaller sectors, such as battery manufacture, are not split out in GAINS) – this reflects the additional emissions reductions which could be achieved by the revised IED by 2030, but also a potential underestimation in the AAQD IA baseline of the historic effects of the IED from 2015-2020.
- Agriculture sectors: country-specific and livestock category-specific NH_3 reduction rates were estimated for 2030 with the GAINS model assuming the IED proposal enters into force in 2027. Typically, this resulted in about 1% to 4% reduction of national NH_3 emissions (about 2% for the EU27 as a whole) beyond the AAQD IA baseline.

Given the nature of the evidence base underpinning the assumptions made, this analysis cannot go into representing the detailed effects that the revised IED would have on each industrial sub-sector, and can only provide some very rough indication of the effect of the revised IED. The assumed levels of decrease in emissions are based on the assumptions and statements presented in the IED IA.

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[23] https://ec.europa.eu/eurostat/databrowser/view/ef_olslsureg/default/table

Modelling approach

The approach used in the IED sensitivity simulation adopted the following steps:

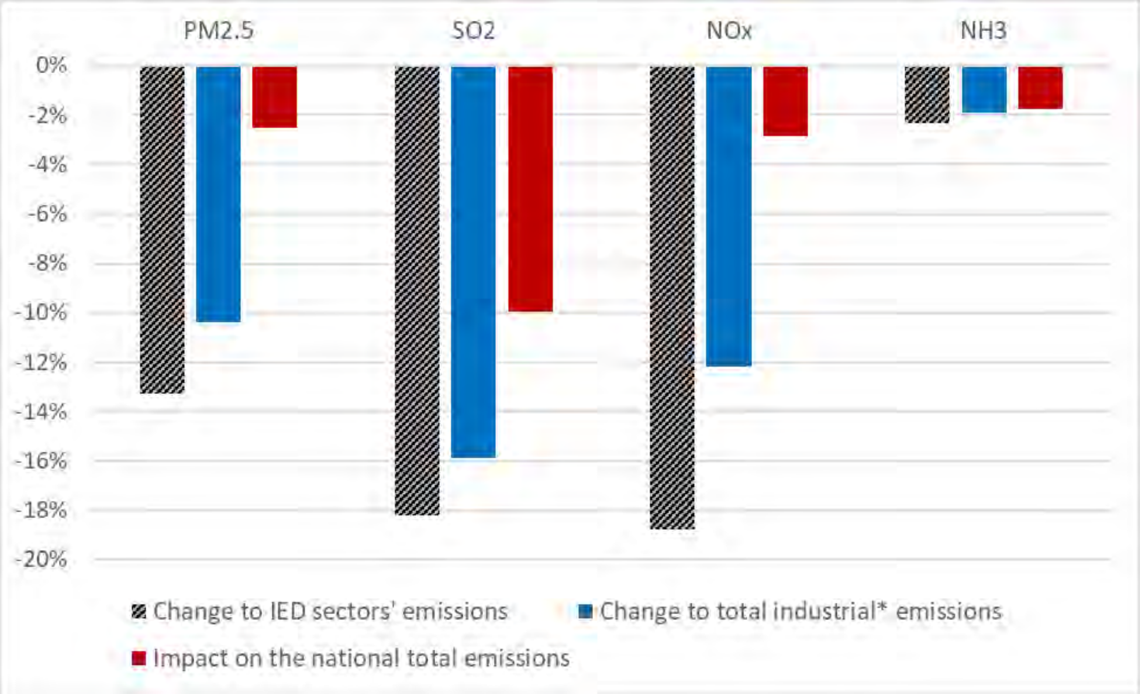
- Impact on country specific industrial emissions of $PM_{2.5}$, SO_2, NOx estimated for 2030
- Impact on country specific NH_3 emissions from agriculture in 2030
- The newly estimated emissions of all pollutants used in the EMEP model simulations for 2030 to estimate $PM_{2.5}$ and NO_2 concentrations, station compliance, and exposure.

For non-agriculture IED sectors, a reduction of maximum (the reduction does not exceed reductions estimated in the AAQD MTFR scenario) 20% from the AAQD baseline (national specific sectoral changes estimated – see next slide) for $PM_{2.5}$, SO_2, and NOx is assumed.

For agriculture (NH_3) impact of implementation of proposal for revision of IED is calculated based on the results of the ongoing CAO3 work, i.e., the relative reductions estimated in the CAO3 are used in the AAQD baseline.

A summary of the resulting emissions reductions is presented in the following chart.

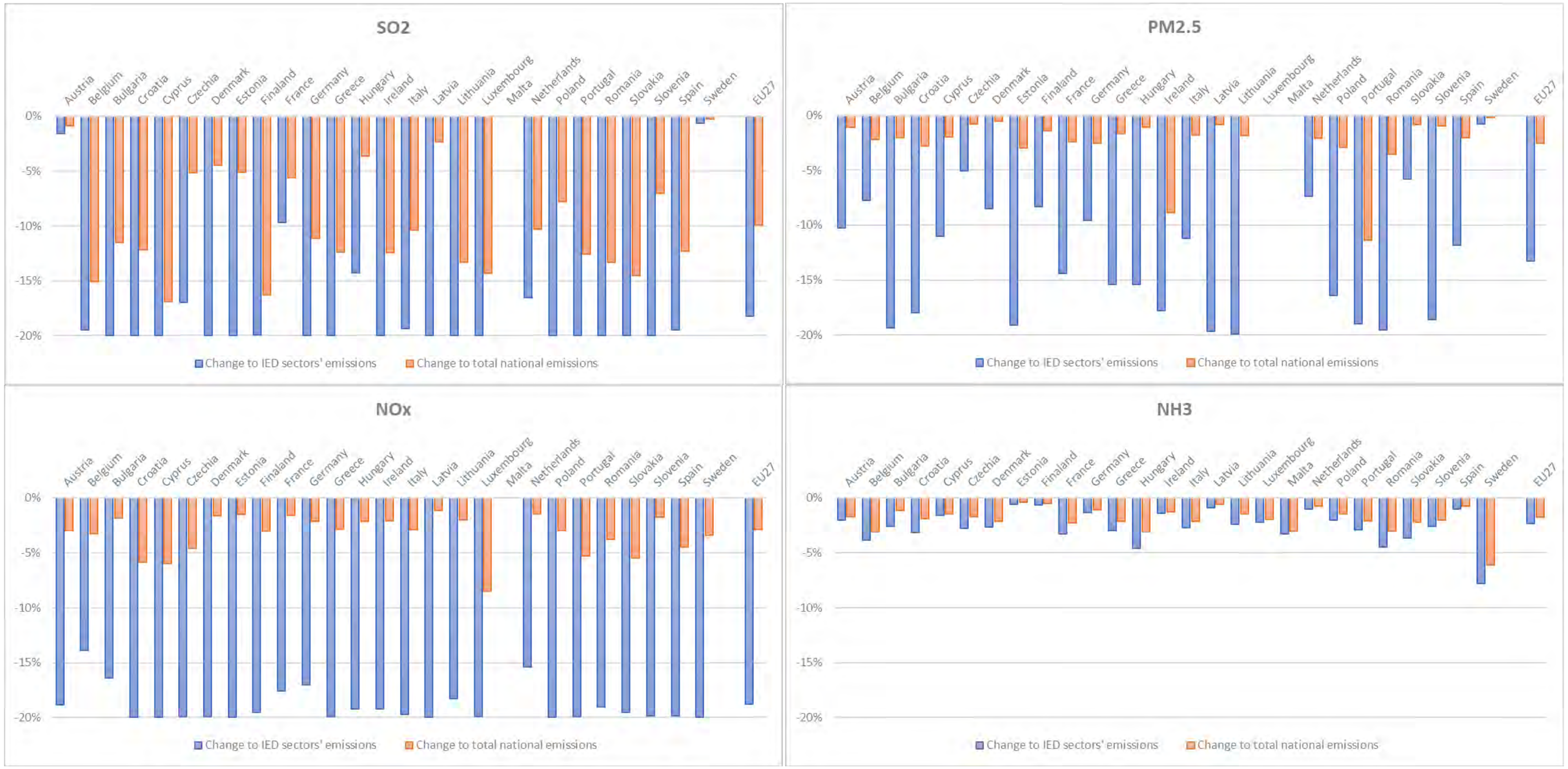
Figure A-137 IED sensitivity emission reductions applied



Notes: (*) For NH_3 refers to agricultural sources, i.e., livestock and mineral fertilizer application

Country specific emission changes in 2030 for IED sectors and total emissions in the baseline are presented in the following figure. The assumptions are not presented split by individual IED sector, however most sectors show nearly 20% reduction aligned with the overall input assumption (with some variance depending on how close to the MTFR each individual sector is in the baseline).

Figure A-138 Country specific IED sector and national total emission impacts in 2030



Results and conclusions

The following figures set out the results of the IED sensitivity analysis on the concentrations of pollutants.

Figure A-139 Annual mean $PM_{2.5}$ exposure - 2030 Base (top) and 2030 IED (bottom)

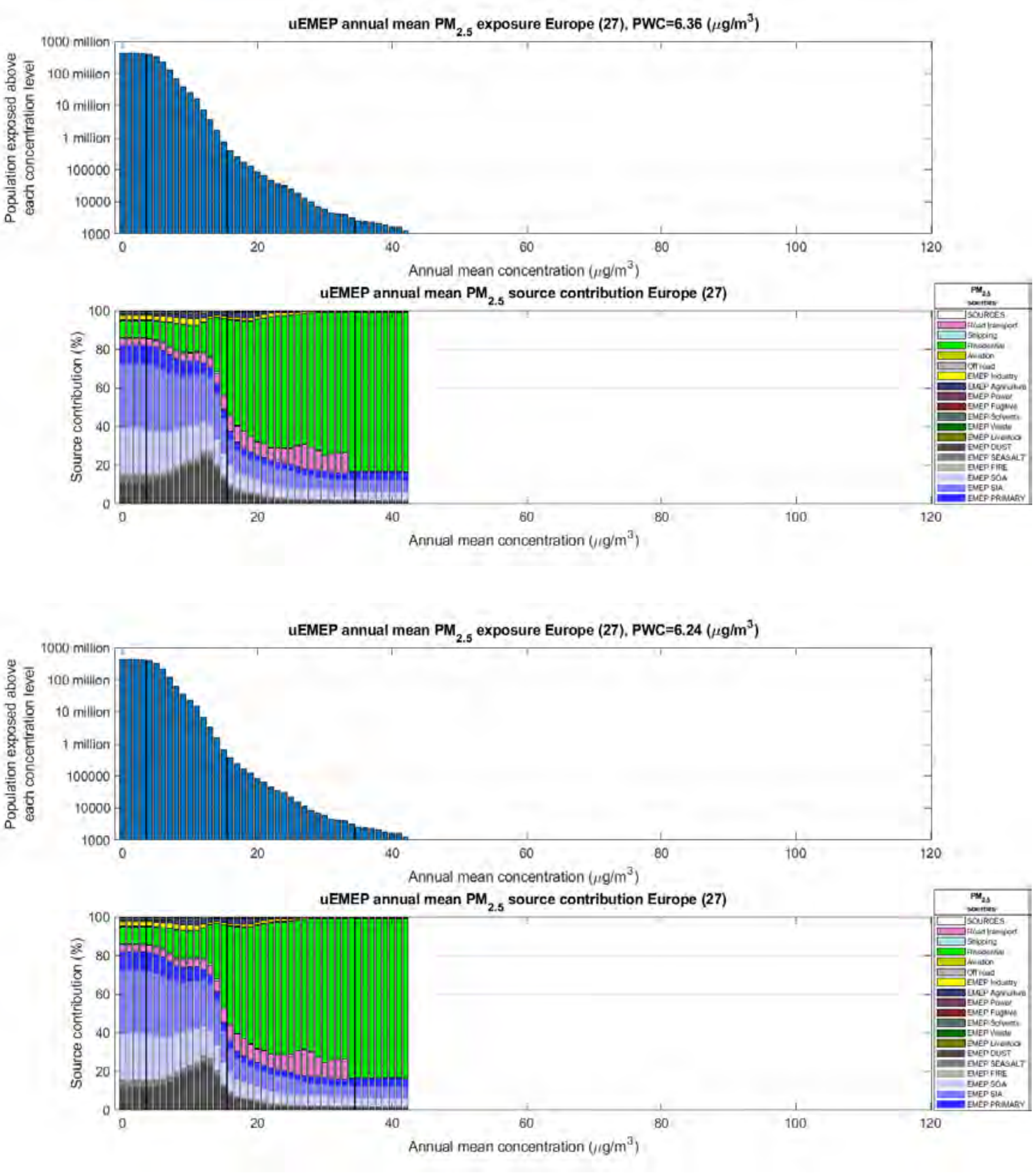


Figure A-140 Annual mean population weighted PM2.5 concentration with source contribution per country - 2030 base (top) and 2030 IED (bottom)

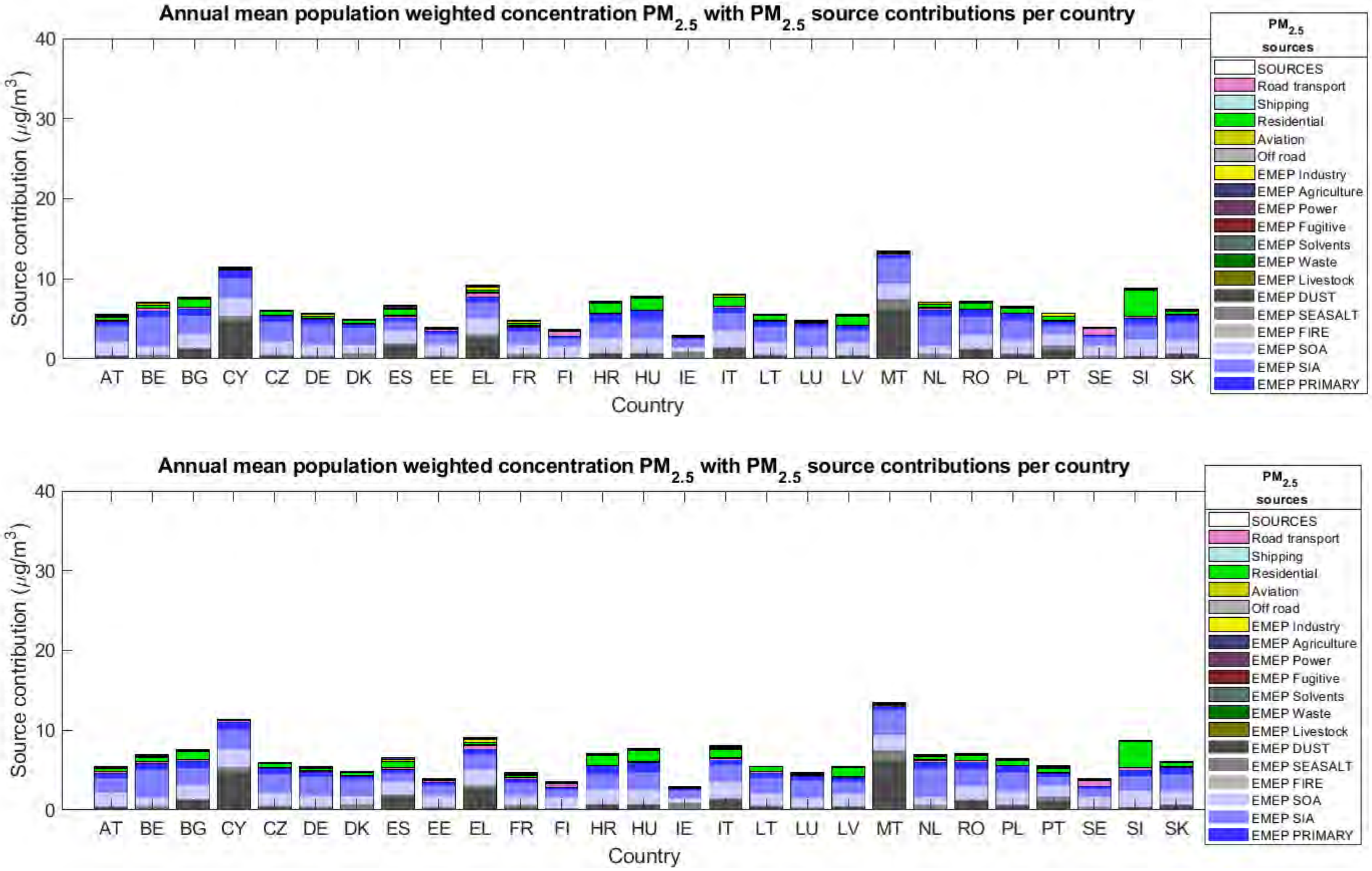


Figure A-141 Annual mean NO₂ exposure - 2030 Base (top) and 2030 IED (bottom)

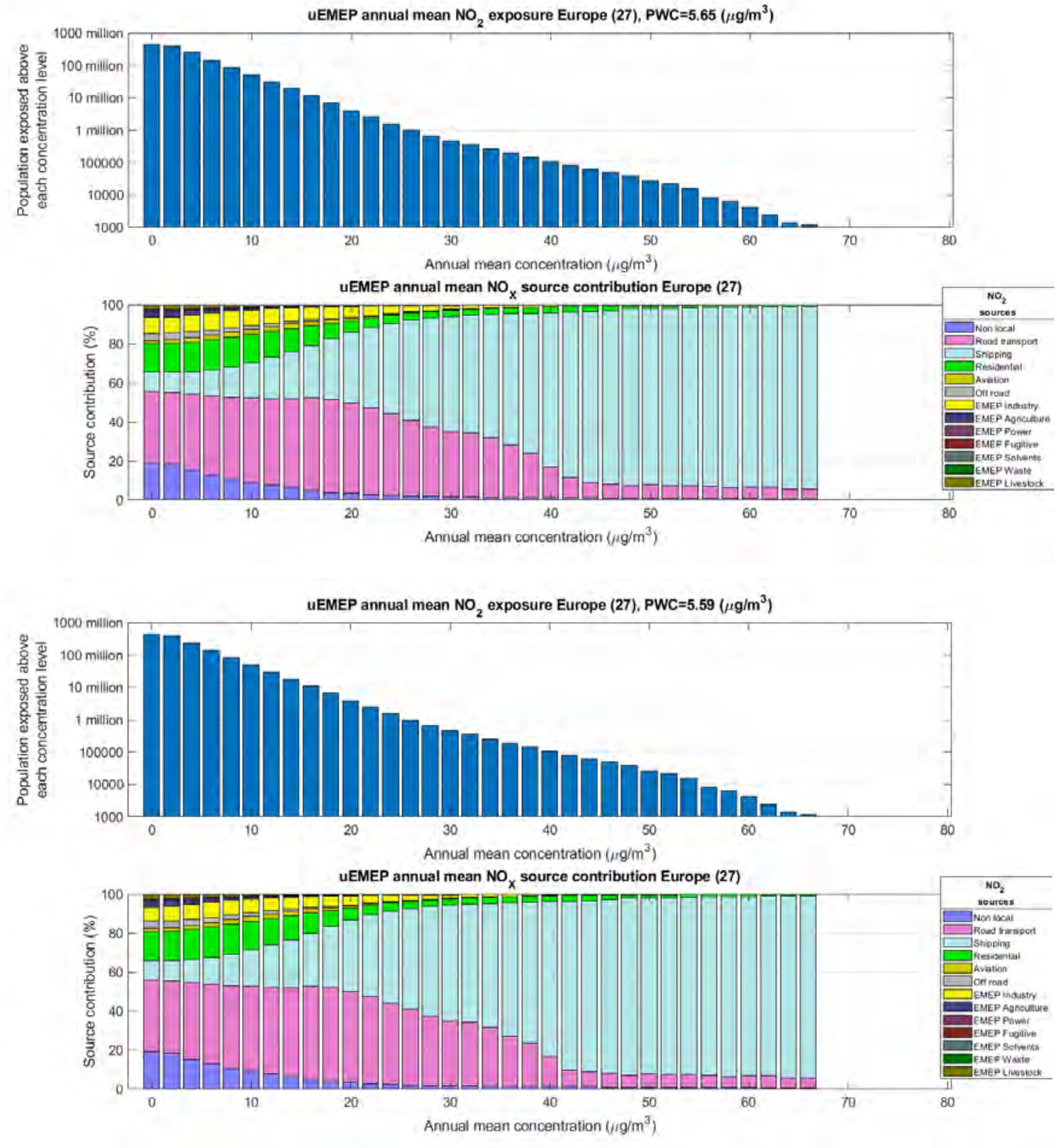


Figure A-142 Annual mean population weighted concentration of NO_2 with NOx split by source contribution per country - 2030 Base (top) and 2030 IED (bottom)

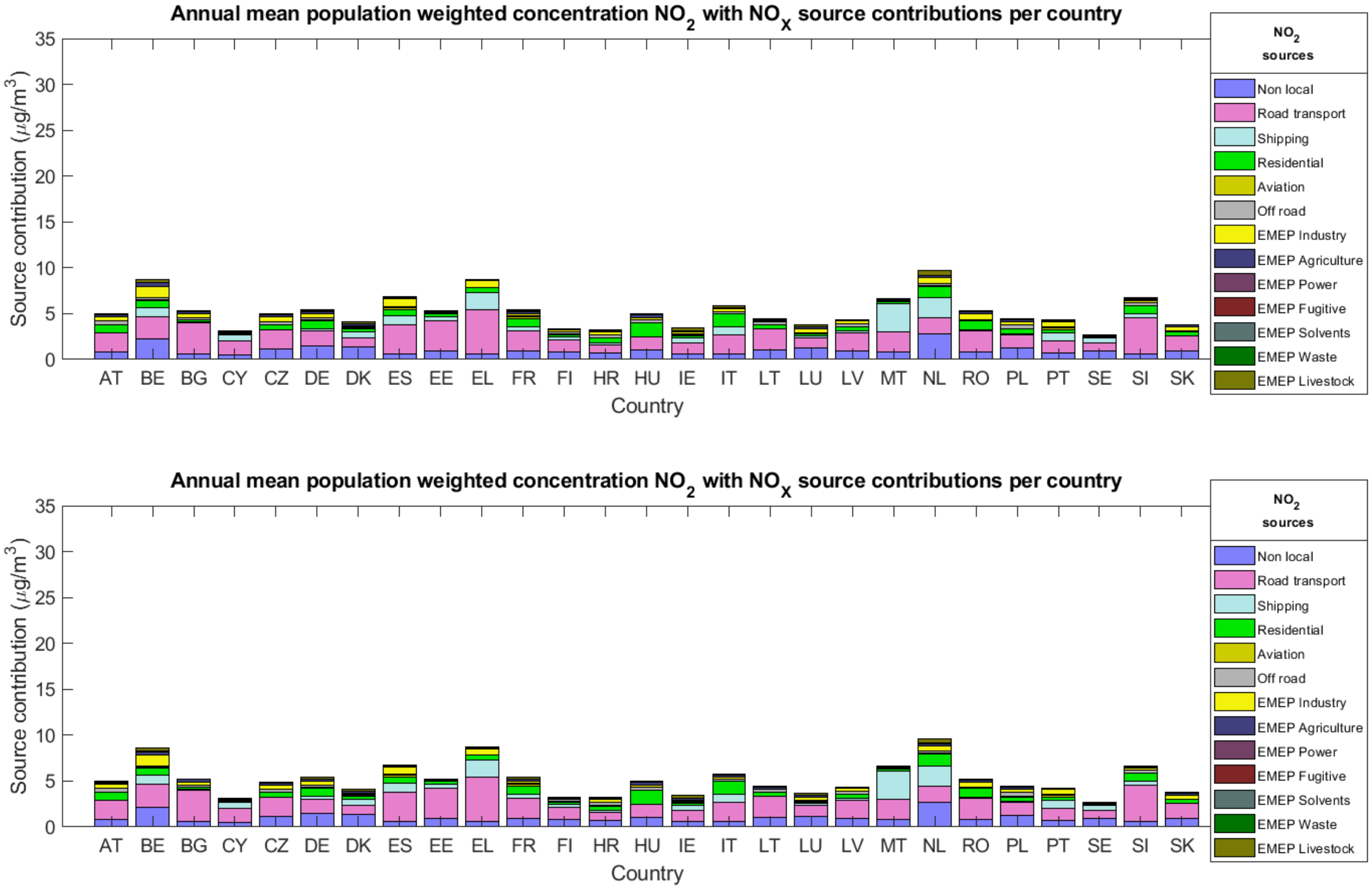
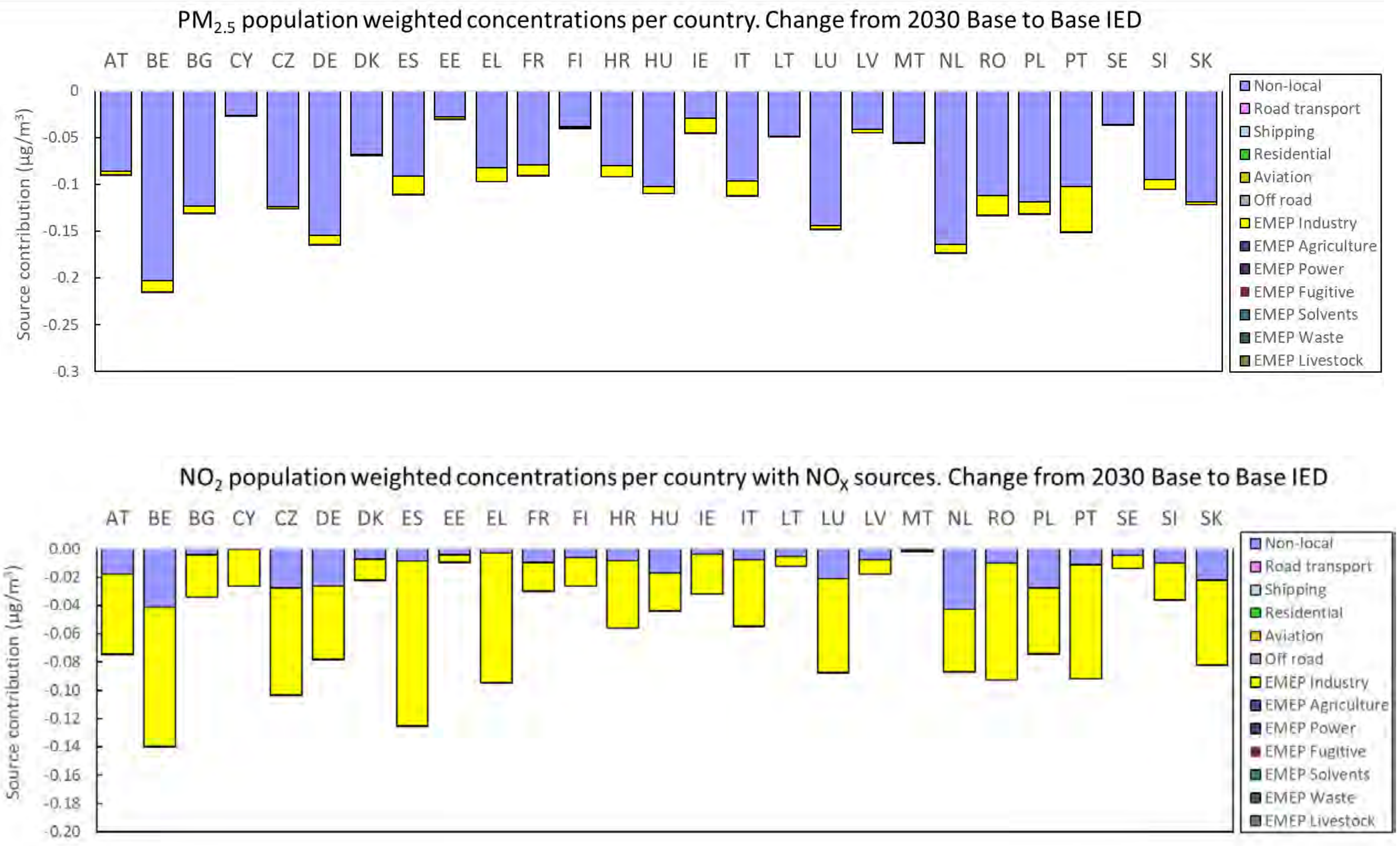


Figure A-143 Population weighted concentrations per country - change from 2030 Base to 2030 IED



The following figures show the quantity of population exposed to different levels of concentrations and mapped concentration change between 2030 baseline and IED.

Figure A-144 Population exposure distribution for annual mean PM2.5 concentrations

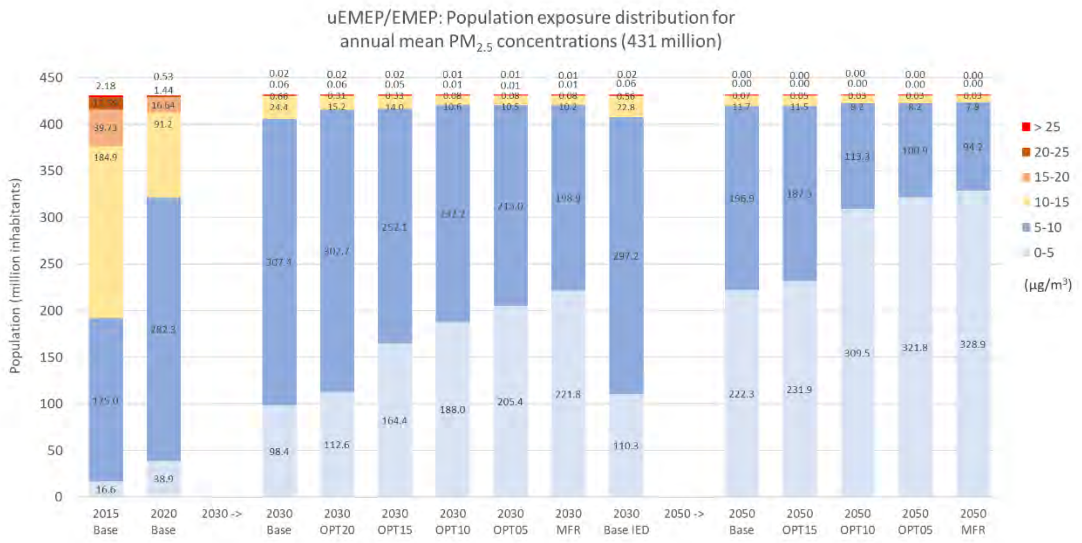


Figure A-145 Population exposure distribution for annual mean NO2 concentrations

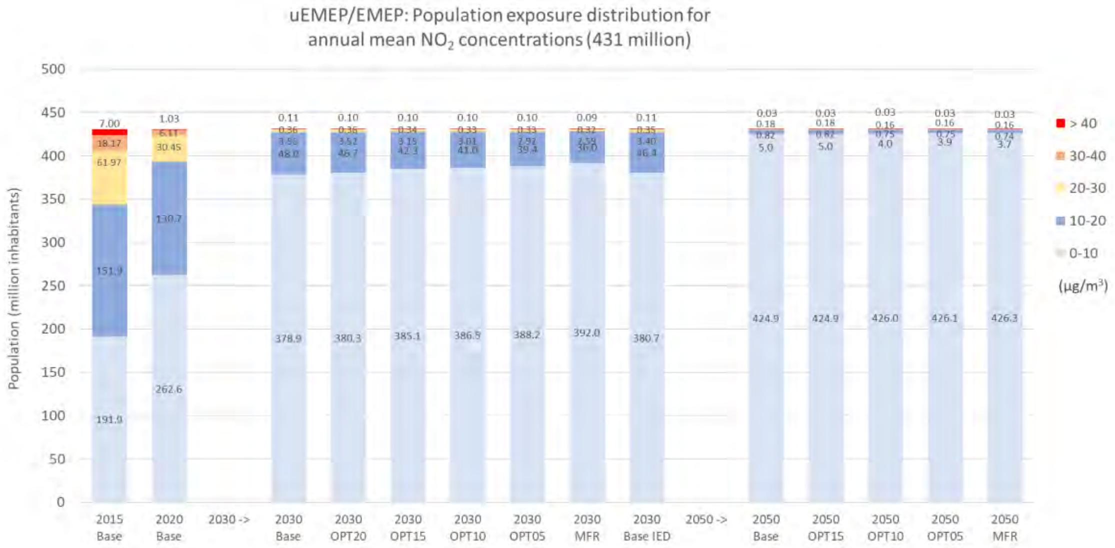
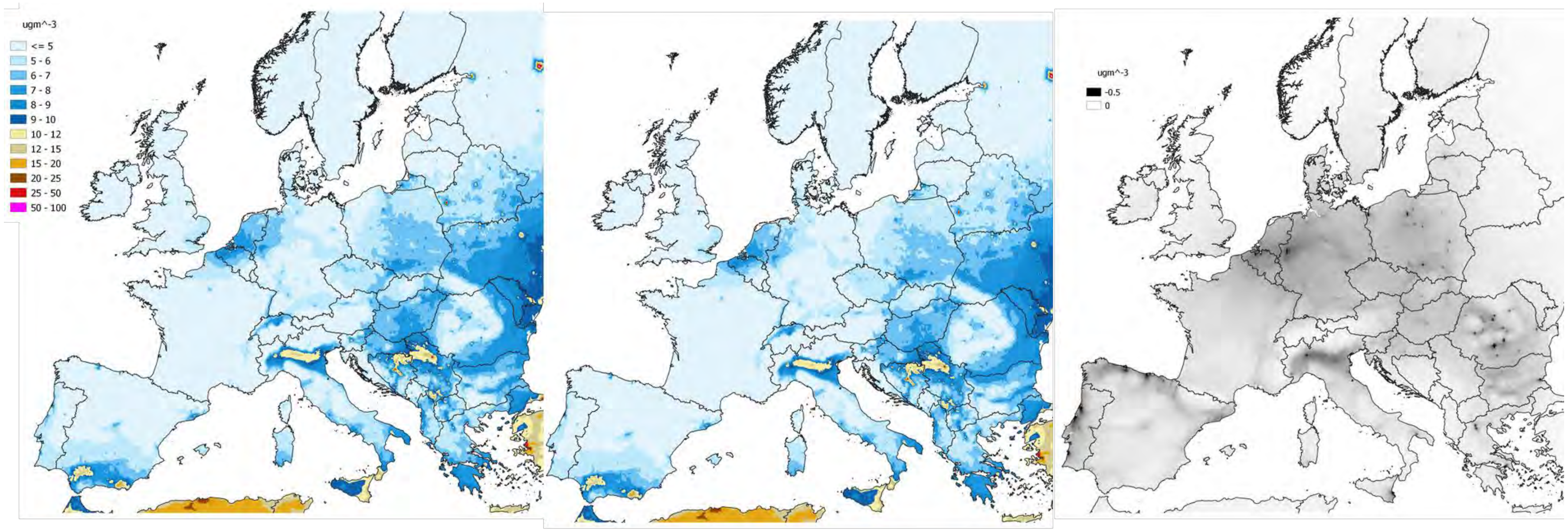


Figure A-146 Annual mean $PM_{2.5}$ concentrations for 2030 Baseline and the IED sensitivity case

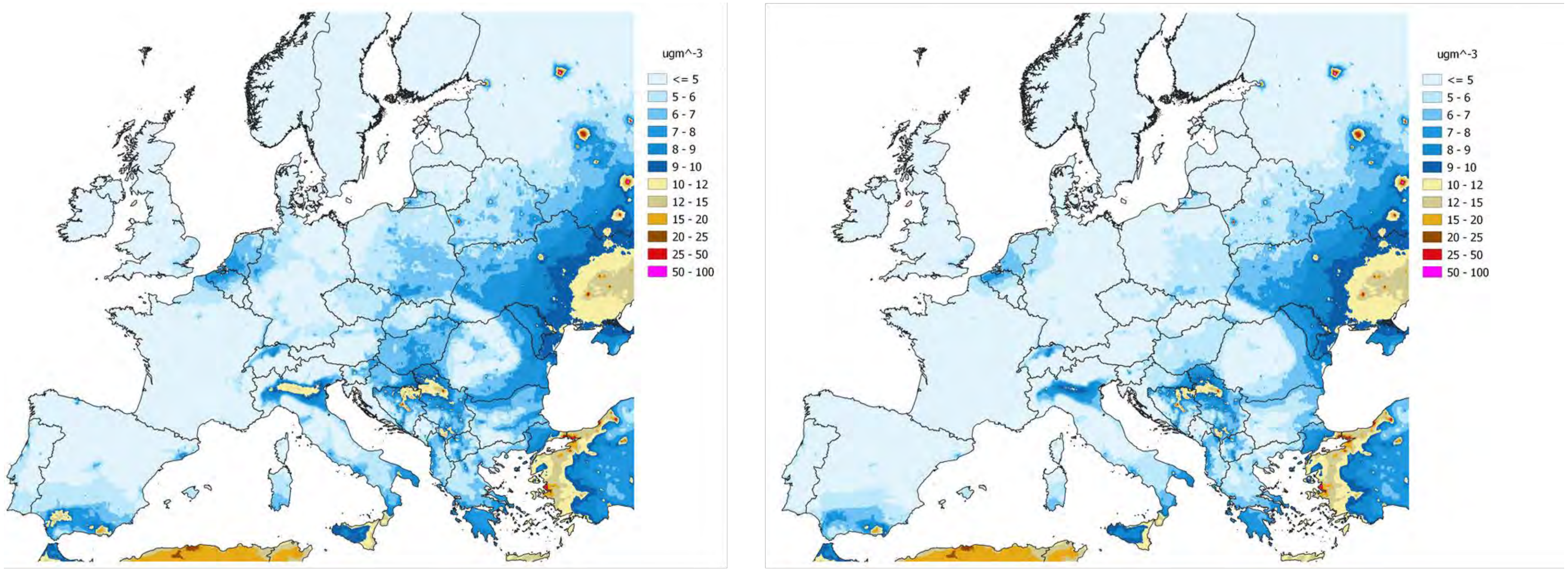


Baseline

IED sensitivity

Concentration change (IED-Base)

Figure A-147 Annual mean $PM_{2.5}$ concentrations for 2030 IED sensitivity and OPT10 cases



IED sensitivity

OPT10

The following tables present the change in station concentrations from the 2030 Base to the 2030 IED sensitivity. The location of the individual stations changing between concentration level groups have not been drawn out due to the limitations of the modelling with respect to individual station results - concentrations at individual stations cannot be expected to be perfectly matched with a Europe wide modelling approach but robust statements about the likely distribution of concentration levels across stations can be made. In addition, focusing specifically on these stations that change may be a misnomer as although the stations change concentration level group, the overall change at these stations may not be any greater than at other stations, they just happen to have concentration levels so close to the boundaries used for grouping that they change the bin they are counted in. Given that the density of stations with concentration levels close to these thresholds is large, which exact stations will change the bin cannot be robustly identified.

Table A-92 Change in station concentrations from the 2030 Base to the 2030 IED sensitivity

NO_2	Concentration absolute (µg/m^3)	Concentration relative (%)	0 - 10 (µg/m^3)	10 - 20 (µg/m^3)	20 - 30 (µg/m^3)	30 - 40 (µg/m^3)	> 40 (µg/m^3)
Change	-0.09	-0.89	17	-15	-2	0	0

$PM_{2.5}$	Concentration absolute (µg/m^3)	Concentration relative (%)	0 - 5 (µg/m^3)	5 - 10 (µg/m^3)	10 - 15 (µg/m^3)	15 - 20 (µg/m^3)	20 - 25 (µg/m^3)	> 25 (µg/m^3)
Change	-0.13	-1.6	35	-29	-6	0	0	0

Overall, additional emissions reductions included under the IED sensitivity lead to only small relative changes overall:

- Members State specific population weighted exposure to NO_2 and $PM_{2.5}$ changes by up to 0.2 ug/m^3, however effects locally can be more significant.
- Reduced concentrations at a small number of stations are observed with mostly moderate concentration levels.
- NO_2 and $PM_{2.5}$ exposure distribution for the EU27 population changes insignificantly.

Hence it is deemed that the key results and conclusions of the central analysis would not change substantially as a result of this sensitivity, and hence the results of the central analysis are robust to this omission from the central baseline.

Appendix 10 - Intervention assessment sheets

Assessment approach

Each intervention has been assessed on the basis of its effectiveness, efficiency and coherence, drawing on the initial assessment developed as part of the screening exercise. This assessment was elaborated through the evidence gathered over the study, drawing on the quantitative modelling, literature and data review and stakeholder engagement. A **cross-cutting qualitative approach** was deployed with five steps:

- A **qualitative scoring framework** was developed on a scale of (-3)-to-3 to rate each policy measure across effectiveness, efficiency and coherence based on the evidence collected and analysed. The scoring reflects the direction (positive or negative) and magnitude (weakly to strongly, limited or unclear). The measures have significantly different scale of impact, and it was judged early on that sufficient distance between the 'strongest' negative and positive ratings would be necessary to ensure a useful, comparable and internally coherent ranking of policy measures across the thirteen impact categories, costs and benefits.
- A **team of experts assessed the impacts** for each policy measure drawing on their existing knowledge and expertise, the outputs of the screening exercise, the available evidence and additional bespoke analysis and stakeholder engagement. In addition to any quantitative assessment of impacts, this exercise concluded on a score from the scale of (-3)-to-3 for each policy measure and impact category considered.
- The scorings for effectiveness, efficiency, and coherence were then **mapped to the 12 consistent assessment indicators**.
- A **re-calibration exercise** was carried out after every iteration of the assessment between the team of experts and Economist lead of the project. This exercise will focus on ensuring that the ratings will be internally coherent. The scope of the measures and evidence of the likely scale of impacts will be used to test the relative position of each measure in terms of their economic, environmental and social impacts.
- **Validation and quality assurance** activities were also undertaken by a small team of experts within the consultant team, focussed on a review of the evidence, outputs of the assessment, and a comparison of outputs to ensure coherence.

The outputs of this assessment generated a comparable rating of interventions across effectiveness, efficiency and coherence, and the 12 broad social, economic and environmental impact categories. In general, colour-coding is used to summarise the qualitative assessment of impacts referring to the direction (positive or negative) and magnitude (small or large) of any expected impacts (see Table 93).

Table A-93 Classification to determine the significance of impacts [Note: Where significance is classified as a range (to reflect multiple variants within an intervention), the colour coding is based on the most significant impact]

+++	very significant direct positive impact (similar to WHO full alignment)
++	significant direct positive impact
+	Small direct positive impact
(+)	indirect positive impact
+/-	Both direct positive and negative impacts, and balance depends on how implemented
0	No impact or only very indirect impacts
(-)	Indirect negative impact
-	Small direct negative impact
- -	Significant direct negative impact
- - -	Very significant direct negative impact (e.g. costs of maximum feasible technical potential (MFR) and more)

Assessment of interventions - Policy Area 2

A1

Intervention area A: How to ensure the timely adjustment of EU air quality standards to evolving scientific or technological knowledge?

Intervention / Measure

(A1) Introduce a mechanism for adjusting EU air quality standards upon publication of new scientific advice (including, but not limited to, the publication of new WHO Air Quality Guidelines).

The problem: Health outcomes shortcomings.

(Driver: Improvements and changes in our understanding of the risks and impacts of exposure to air pollution based on latest science.)

Description:

Appropriate mechanisms are needed to flexibly adapt to evolving science and new recommendations to protect human health. Directive 2008/50, Article 32 provided grounds for once off review on the basis of specific evidence (e.g. WHO guidance or reduction potentials in Member States), but does not provide a mandate for regular reviews.

Three possible intervention variants exist under this intervention to ensure that AAQ Directive reflects latest scientific advice:

1. Introduce a binding schedule of reviews of technical and scientific progress to be undertaken by the European Commission - under this variant the Commission would undertake a periodic review of technical and scientific progress related to air quality pollutants.

2. Introduce a mechanism for adjusting EU air quality standards upon publication of new WHO guidelines - under this variant the Commission would undertake a WHO guidelines related review of technical and scientific progress related to air quality pollutants, with a view to present a proposal to update the Directive to the European Parliament and the Council.

3. Introduce a mechanism for adjusting air quality standards based on (other) latest scientific advice. Under this variant the Commission would undertake a review new scientific knowledge of relevance for air quality pollutants of technical and scientific progress related to air quality pollutants, with a view to present a proposal to update the Directive to the European Parliament and the Council.

Purpose/operational objective: This intervention would require a review process by the Commission to assess an alignment with the latest science (defined by the specific chosen variant).

Who would be impacted and how:

Directly:

The administrative burden would rest with the Commission, who would be required to carry out and report on scientific knowledge review with relation to the AAQ Directive. This intervention would potentially increase the administrative burden due to more frequent/periodic scientific review.

Stakeholders raised that if air quality standards are legally binding they cannot change without an impact assessment, assessment of the technical feasibility, and stakeholder engagement. In this light revision of the air quality standards will not be possible solely by the European Commission (e.g. via delegated act). Any change in air quality standards will have large financial consequences therefore it should be discussed as thoroughly as possible. Socio-economic aspects should also be taken into the account during the to ensure the welfare of EU citizens, including individual Member States.

Indirectly:

This intervention on its own would not have any further indirect impact.

Risks for implementation:

1. Lack of scientific evidence consensus over what scientific knowledge should be considered (only variant 2 specifically relies on the WHO Guidelines as a basis for scientific knowledge).
2. Variants of this intervention would likely need to be combined for a fully effective solution.
3. Variant 3 (Introduce a mechanism for adjusting air quality standards based on (other) latest scientific advice) would potentially require additional technical body to be established by the Commission to review science base.
4. Member States may require this intervention to be complemented with additional consultation or review mechanism as they might the automatics revision of the standards as too far-reaching intervention. None of the variants addresses this concern.

Indicators											
1. Impact on Air Quality	2. Impact on Health	3. Impacts on Ecosystems	4. Climate change links	5. Costs to society	6. Mitigation costs	7. Impacts on Competitiveness	8. Impacts on Sensitive Groups	9. Societal benefits and burden sharing	10. Impacts on Employment	11. Policy synergies	12. Administrative Burden
++	(+)	(+)	+	0	0	0	(+)	0	0	+	(-)

Assessment

Effectiveness:

The scientific / epidemiological evidence base continues to grow and evolve, bringing improvements and changes in our understanding of the risks and impacts of short- and long-term exposure to air pollution. The latest scientific basis (e.g. WHO Guidelines) shows the need for more stringent standards compared to existing ones, as well as the need for standards relating to additional pollutants not currently in scope of the AAQ Directives. Introduction of a mechanism that will provide a basis for the alignment of the AAQ Directive with the latest scientific knowledge will therefore directly contribute towards reductions in air quality concentrations [Air Quality:++].

Meeting the direct objective of air quality reduction will subsequently indirectly protect EU population from harmful exposure to air pollution in general [Health: (+)] and will reduce impacts on sensitive groups [Sensitive Groups (+)]. It will also have an indirect positive effect on ecosystems [Ecosystems: (+)]. Given the direct link between the improvement of air quality and climate impacts (i.e. with many local air pollutants being also Short-Term Climate Pollutants), bringing the AAQ Directive in line with the latest science will have a direct benefit for climate change [Climate Change: +]. There is no evidence for societal benefits or burden sharing.

All three variants under review ensure that the revision mechanism is based on robust science. This will guarantee that health impacts of air pollution are thoroughly considered. WHO guidance is a recognised source on this front (variant 2). However, there could be a role for a supplementary action where the WHO guidance update is not timely to protect human health in the EU.

While stakeholders showed support for this intervention, there was no strong consensus over a specific variant. Stakeholders favoured a clearly defined scientific (health) evidence (variant 2) or a general, but periodic set or reviews (variant 1) over what is less concretely defined scientific evidence (i.e. other scientific evidence under variant 3). The majority of stakeholders thought that variants 1 and 2 were 'fully' or at least 'to a large extent' effective, versus less than a third for variant 3.

Respondents raised different effectiveness issues to consider when assessing the different variants. In summary, effectiveness of this intervention would depend on a) how it considers sources of the air pollution heath impacts scientific knowledge base; and b) considerations related to the frequency of updates. In more depth, the following issues were raised:

Health basis considerations

- Recommendations from the WHO constitute on their own the most a most appropriate scientific basis (variant 2). The Commission should continue supporting WHO's review process and influencing it to ensure a regular review of the science on health effects.
- The WHO recommendations should serve as the primary health evidence basis, but if there are good arguments for including other scientific advice then this could also be considered.
- The responsibility for the review should lie with an independent body/panel of EU health experts (not just the Commission on its own and separate from the WHO), who could assess the evidence and provide guidance to the Commission and Member States. The Advisory Board should be established and funded in a way that it ensures its independence from Member States and EU institutions. The Advisory Board would be responsible for evaluating the threshold of evidence needed to initiate the mechanism.
- Stakeholders suggested that a review should consider, as a minimum:
    - the best available and most up to date scientific evidence and advice regarding air pollution, its effects on human health and the environment;
    - the latest WHO guidelines existing at the time;
    - the impact of air pollution on sensitive population groups, species and habitats;
    - international commitments (including under the UNECE) and impacts;
    - the precautionary principle; and
    - the rectification at source principle.

Alternatively, a periodic review by the European Environment Agency of the most recent published scientific literature could be considered. This would be based on pre-determined criteria defined in the AAQ Directive to provide an objective assessment of whether new scientific knowledge is available and a revision AAQ Directive would be of value.

Frequency of review considerations

- Air pollution and its health effects need to be reviewed based on a regular, binding schedule with adequate time intervals (e.g. 5 years) to evaluate the need of updating the AAQ Directive.
- The WHO guidelines should not serve as the only source of scientific evidence, because the WHO air quality guidelines do not follow a regular update schedule. There are other competent and independent review processes, e.g. by the Health Effects Institute, which must not be neglected as they provide valuable input to the update of the evidence base on health effects.

Efficiency:

This intervention is expected to have small indirect negative impact on costs associated with the administrative burden increase of period review of health science [Administrative burden: (-)]. The main costs associated with this intervention are administrative. They would be related to the regular review of the evidence by the Commission. Additional administrative costs for Member States would arise from the evidence review prior to any decision on adapting new standards and then the implementation of AAQ Directive regulatory changes in the national legislation. Stakeholders note that any changes of the air quality standards should be discussed with Member States and considered within a feasibility study given the costs of implementation of revised AAQ Directive.

The establishment of the scientific committee to review the science base as proposed by some stakeholders would also impose additional administrative costs. Stakeholders suggested that to calculate these costs, the Scientific Advisory Board on Climate Change as well as the costs of the REVIHAAP and HRAPIE studies could be used as a benchmark. The health assessment conducted by relevant members of the International Society of Environmental Epidemiology (ISEE), Europe chapter could also be examined as an example.

There is no evidence that this intervention will impact costs to society, mitigation costs, impact on competitiveness and employment impacts [0].

Stakeholders raised the point that to be most efficient this intervention would need to be complemented with other EU policy review mechanisms (given the potential implications of the review). Many stakeholders raised the point that there are many exceedances of the current ambient air quality limit values and that therefore the challenge is the implementation of air quality plans rather than strictness of the AAQ Directive.

Coherence:

This intervention is expected to have direct small positive impact on achieving objectives of synergistic policies [indicator 11 is therefore evaluates as +] of the Zero Air Pollution Action Plan (ZPAP). Implementation of stricter standards will drive the same objectives as are being evaluated under sub-indicators for the ZPAP goals, including premature death reduction goal (already evaluated under indicator 2); ecosystem impact goal (already evaluated under indicator 3); as well as noise pollution and indoor air pollution by addressing the sources of the same pollutants.

Links to other interventions: [synergies / misalignment]

- This intervention will have linkages to most of PA1 interventions
- A2 – Scientific knowledge is lined to technical knowledge (+/-)
- A3 – Notification mechanism regarding standards strengthening by the MS (+/-)

- A4 – Emerging air pollutants are relevant for scientific review (+/-)
- B1 – Short term EU standards (+/-)
- B2 – Alert threshold definition (+/-)
- B3 – Expansion of exposure reduction target (+/-)
- B5 – Additional limit values (+/-)

Benefit to Cost ratio

High – Direct costs estimated with this intervention as are small administrative costs, while direct benefits could be large. Air quality provides high cost on society, so this intervention has potentially large indirect benefits. It is difficult to estimate indirect compliance costs.

Summary

Stakeholders are of a view that a mechanism to adjust EU air quality standards upon publication of new scientific advice would be effectively enhance the flexibility of the AAQ Directive to adapt to evolving science. There was no strong consensus over a specific variant.

A2

Intervention area A: How to ensure the timely adjustment of EU air quality standards to evolving scientific or technological knowledge?

Intervention / Measure

(A2) Introduce a mechanism for adjusting EU air quality standards based on technical progress in air pollution reduction.

The problem: Health outcomes shortcomings.

(Driver: The current AAQ Directive lack requirement to review air quality standards when new technologies that facilitate the achievement of air quality targets are available.)

Description:

This intervention would introduce a mechanism for adjusting EU air quality standards based on technical progress in air pollution reduction. Accordingly, the Commission would undertake regular reviews of technical progress related to air quality pollutants (this adjustment mechanism would look at new information related to the cost of implementing standards that are more stringent).

Purpose/operational objective: This intervention would require review process by the Commission to assess an alignment with the latest technical progress.

Who would be impacted and how:

Directly: The administrative burden would lay with the Commission, who would be required to carry out and report on technological knowledge review with relation to the EU AAQ Directive. This intervention would potentially increase the administrative burden due to more periodic technical review.

Indirectly: This intervention on its own would not have any further indirect impact. Further indirect impact on competent authorities and other stakeholders could be caused by the implementation of potential revision of the AAQ Directive due to technological potential.

Risks for implementation:

1. Lack of scientific evidence consensus over what technological knowledge should be taken into account.
2. Legal and technological feasibility challenges related to introducing stricter standards.

Indicators											
1. Impacts on Air Quality	2. Impact on Health	3. Impacts on Ecosystems	4. Climate change links	5. Costs to society	6. Mitigation costs	7. Impacts on Competitiveness	8. Impacts on Sensitive Groups	9. Societal benefits and burden sharing	10. Impacts on Employment	11. Policy synergies	12. Administrative Burden

(+)	(+)	(+)	(+)	0	0	0	0	0	0	(+)	(-)

Assessment

Effectiveness:

Technological progress can make compliance with air quality standards more feasible. As meeting air quality standards becomes easier, there is a chance to increase the ambition of these. It can be argued that technological progress is indirectly already being considered in the review of the AAQ Directive (e.g. via modelling of air pollutant concentrations, which considers best available technologies (BAT)). While health basis considerations should play the most prominent role, technical feasibility (and by extension socio-economic impact) is an important criterion This intervention would formalise these consideration in the AAQ Directive and could have a small positive indirect impact on improvements in air quality concentrations as advances in the technological knowledge might lead to revisions in the AAQ Directive due to the enhanced technical feasibility of its implementation [Air quality: (+)]. Consequently, a review of the Directive could have small indirect positive impact on health and ecosystems [Health, Ecosystems and]. Assessment of progress in technology to reduce air quality is likely to have small positive indirect impact on climate change links as some of the technologies to address impact of climate change and air pollution are likely to be the same [Climate change: (+)]. However, the process would be driven by technology considerations, not health considerations, and therefore addresses the objective of protecting human health, e.g. by targetting sensitive groups, only to some extent [Sensitive groups: (+)].

Overall, this intervention has received moderate support from stakeholders. It has been particularly supported by industry (showing support to large extent), with NGOs also showing support (as a complementary intervention to others under review). Stakeholders expressed views that scientific advice and knowledge on health effects of air pollution (as per intervention A1) should be of primary concern when it comes to setting and potentially adjusting air quality standards.

Stakeholders suggested that there may be a case to include such a mechanism for some specific circumstances. One example of where this mechanism could be useful, is where technical progress leads to much quicker progress to achieve compliance with the limit values than expected. It could then be appropriate to further tighten limit values to ensure that they continue to drive measures to reduce exposure and negative health effects, and to avoid any gaps in action planning.

However, stakeholders also noted some caution with this intervention in that health considerations should take priority when revising the AAQ Directive. Feedback noted that a mechanism for adjusting EU air quality standards based on technological progress in air pollution reduction would tie air quality standards to what was considered technically feasible, rather than what was considered safe or healthy. Thus, such a mechanism would only address the identified shortcomings to some extent. Notably:

- Air quality standard revisions should not wait for technological advancements. Appropriately set standards can foster technical innovation.
- New clean air technologies exist across different sectors but if standards are not set at an appropriate level, their business case isn't as good as alternatives.

However, other stakeholders (namely representing industry) found that technical progress in possibilities of air pollution reduction should always be considered when designing air quality standards to ensure that air quality standards could be realistically achieved. In this way, a mechanism to accommodate new technical possibilities could be more efficient than setting the standard at an appropriate level for health reasons. In addition, it was noted that a regular Commission report on technical progress to the Council and European Parliament could be useful to help with sharing best practices/knowledge in the EU.

Efficiency:

This intervention would increase administrative burden associated with conducting the review and therefore likely impose a small indirect negative impact on costs [Administrative burden: (-)]. The main costs associated with this intervention are administrative. They would be related to the regular review of the technological progress by the Commission. Additional administrative costs for Member States would arise from the evidence review prior to any decision on adapting new standards and then the implementation of AAQ Directive regulatory changes in the national legislation.

Stricter AAQ Directive standards will influence technological improvement to reduce emissions. Therefore, there is likely to be an impact on marginal abatement costs, as new standards help drive technology progress, bringing new BAT into the market and thereby reducing air pollution reduction costs.

There is no evidence to indicate that this intervention would have an impact on costs to society, mitigation costs, impact on competitiveness societal benefits and burden sharing; and employment [0].

Coherence:

This intervention needs to be aligned with other EU technology related policy review mechanisms linked to technology progress. The review of the best available technologies (BAT) and source-specific emission standards for industry (e.g. IED), cars (e.g. tailpipe emissions EURO 7), stoves, should be considered. The review of technical progress to achieve air quality improvement is likely to relieve stronger links with other EU policy goals, including Zero Air Pollution Action Plan goals [Policy synergies: (+)] and climate change [(+)].

Links to other interventions: [synergies / misalignment]

- A1 – alignment with review of science base (+/-)
- A3 – Notification mechanism regarding standards strengthening by the MS (+/-)
- B2 – impact of technology progress on meeting average exposure targets (+/-)
- G3 - Require a regular review of the assessment regime following clear criteria defined in the Directive (+/-)

Benefit to Cost ratio

Low: Direct costs estimated with this intervention as are small administrative costs. However, the economic benefits of reviewing the AAQ Directive on the basis of technological advancement to reduce emissions, without taking account of the progress in scientific understanding of the impacts of air pollution are low.

Summary

Stakeholders provided only a moderate support for a mechanism to adjust EU air quality standards to be based upon technological knowledge would effectively enhance the flexibility of the AAQ

Directive to adapt to evolving science. None of the stakeholders thought that this measure would be fully effective, 32% thought that it would be effective and 49% that it would be effective into an extent.

A3

Intervention area A: How to ensure the timely adjustment of EU air quality standards to evolving scientific or technological knowledge?

Intervention (A3) Introduce a provision to allow for EU Member States to adopt more stringent standards in light of the new technical and scientific progress coupled with an obligation to notify the European Commission.

The problem: Health outcomes shortcomings

(Driver: Information exchange between national and EU action on air quality might not be effective without a notification mechanism in case the EU Member States to impose stricter air quality standards than the EU AAQ Directive).

Description:

The European Commission would introduce a requirement to ensure that EU Member States are required to notify the Commission if they adopt a change in their standards adopt more stringent standards within their jurisdiction in light of the new technical and scientific progress.

EU Member States are already free to update their air quality standards to make them more stringent than the minimum required by the AAQ Directives. The intervention would put in place mandate to notify the European Commission where this occurs to collect appropriate information on technical and scientific knowledge and to identify where national/local standards surpass the EU standard, enabling information sharing across Member States.

Who would be impacted and how:

Directly: The administrative burden would lay with the EU Member States, who would be required to notify the European Commission upon adoption of more stringent standards. Additional impact would be borne by the EU Member States that implement more stringent standards, however this is difficult to estimate.

Indirectly: This measure would have indirect impact on competent regional/national authorities tasked with implementation of stricter standards and stakeholders who would have to comply.

Risks for implementation:

1. Risk that additional administrative burden to inform the EU Commission might deter EU Member States implementing stricter standards, however this
2. Legal and technological feasibility challenges related to introducing stricter standards.

Indicators

1. Air Quality	2. Impact on Health	3. Impacts on Ecosystems	4. Climate change links	5. Costs to society	6. Mitigation costs	7. Impacts on Competitiveness	8. Impacts on Sensitive Groups	9. Societal benefits and burden sharing	10. Impacts on Employment	11. Policy synergies	12. Administrative Burden

(+)	(+)	(+)	(+)	0	0	0	(+)	0	0	0	(-)

Assessment

Effectiveness:

Introduction of more stringent air quality standards is already a possibility for Member States under the EU treaties (Article 191,192 and 193 under the TFEU). Notification of stricter standards should be provided to the Commission to comply with an inspection procedure under the TFEU Article 191. This notification mechanism could be further specified to provide the Commission with additional information of relevance for air pollution action. This could specify the requirement to provide new scientific and technical data, environmental conditions in the EU Member State, costs and benefits estimates, and socioeconomic data. Thus, this intervention has been assessed under the assumption that it will enhance the Commission's evidence base regarding Member State policy action.

This intervention has a potential to have a small indirect impact on reducing air pollution concentrations [Air Quality: (+)] as additional strengthening of standards by the EU Member States will likely have local positive impact as well as potentially contributing towards information on scientific and technical data that can be used by other EU Member States. This measure would also have small positive impact on health, ecosystems, and sensitive groups [(+)].

Stakeholders moderately support this measure, with around 40% showing support fully, to a large extent or to some extent). Many stakeholders did not support or did not respond regarding their support. NGOs in particular showed disapproval, with 50% indicating 'not at all support'. In their responses NGOs expressed that the measure would not have any impact on the shortcomings identified as it would not mandate stricter standards by EU Member States. Some stakeholders expressed opinion that this measure might have negative impact on efficiency of air pollution responses as air pollution standards should be set at the EU level. Creating a situation where the overall plan to meet air quality standards differs (in terms of timing and values) could contribute to fragmentation and divergences, thereby limiting progress.

Stakeholders required further clarity over which aspects would of the measure would be voluntary and which mandatory. Many were of a view that Member States already have the right to set more stringent goals for air protection on the national level, which is voluntary and would remain so.

As different EU Member States have different conditions and abilities to meet the EU AAQ Directive standards, it might be possible for them to adopt more stringent standards. Moreover, they might have different domestic political circumstances to reach the WHO guidelines. For instance, Sweden has already (since 1998) adopted more stringent standards for NO_2 (more stringent hourly value and a daily limit value), O3 (no percentiles/exceedances allowed) and SO2 (more stringent hourly and daily limit values); and Norway (since 2016) has more stringent limit values for PM_{10} and $PM_{2.5}$ than the limit values in directive 2008/50/EC.

Stakeholders also expressed that the EU Commission should not demand the right to approve a decision to introduce stricter standards and any information shared should be for information only. Linked to the information sharing, national stakeholders queried whether there could there be EU-level infringement proceedings due to exceedances of nationally adopted standards or would potential infringement proceedings be limited to the EU AQ standards.

Stakeholders also pointed to the distinction between health basis related air quality standards vs. technology standards as both are noted in the measure. Air quality standards should be harmonized across the EU to protect human health across the whole EU to the same extent. They noted that emission control efforts will inevitably need to vary given the different natural boundary conditions (meteorology, orography), so there should be more freedom to reduce emissions. However, they noted, that additional information might be able to evaluate positive effect on transboundary air pollution which makes a large contribution to air quality levels in many countries.

Efficiency:

This intervention would have a small indirect negative impact on administrative burden given the potential increased reporting requirement by EU Member States [Administrative burden: (-)].There is no evidence that this intervention would have any direct impact on mitigation; costs to society, impact on competitiveness; employment and societal burden sharing [0].
Industry stakeholders noted that this intervention would facilitate different standards between Member States, putting the single market at risk and potentially leading to gold plating situations and legal uncertainties for operators.

Coherence:

This intervention should ensure coherence with other scientific and technology review mechanisms. It is expected to have an indirect positive impact on climate change (thanks to increased information base and impact on SLCPs) [(+)]. No impact on policy synergies is expected [0].

Links to other interventions: [synergies / misalignment]

- A1 – alignment with review of science base (+/-)
- A2 – alignment with review of technology information (+/-)
- A4 – Emerging air pollutants are relevant for scientific review (+/-)
- B1 – Short term EU standards (+/-)
- B2 – Alert threshold definition (+/-)
- B3 – Expansion of exposure reduction target (+/-)
- B5 – Additional limit values (+/-)

Benefit to Cost ratio

High - Direct costs estimated with this intervention are small administrative costs. Poor air quality leads to high costs on society, due to the health damage costs. This intervention could lead to improved air quality, health and ecosystems and therefore it has potentially large indirect benefits. The benefit cost ratio of this measure is considered high as low administrative burden would lead to an improved knowledge base.

Summary

This intervention has potential for high benefit compared to a low cost. While there is some concern amongst some stakeholders for this intervention as the introduction of more stringent air quality standards impacts Competent Authorities, it does bring societal benefits. a possibility for Member States. Stakeholders also expressed that the EU Commission should not demand the right to approve a decision to introduce stricter standards and any information shared should be for information only.

A4

Intervention area A: How to ensure the timely adjustment of EU air quality standards to evolving scientific or technological knowledge?

Intervention (A4) Keep and periodically update a list of priority air pollutants to ensure air pollutants of emerging concern are monitored.

The problem: Health outcomes shortcomings

(AAQ Directive does not fully address the potential impact of emerging pollutants on health and ecosystems. The AAQ Directive should give mandate to the Commission to be able to conduct a regular update of a pollutants "watch list" for emerging substances and require Member States to monitor concentrations of such.)

Description:

Directives 2004/107 and 2008/50 establish health based standards and objectives for a number of pollutants present in the air namely PM_{10}, $PM_{2.5}$ **, SO2,** NO_2, **Pb, CO,** C_6H_6, O_3, **As, Cd, Ni and Polycyclic Aromatic Hydrocarbons.** This intervention would mandate the Commission to establish and periodically update a list of additional priority air pollutants to ensure air pollutants of emerging concern are monitored. Accordingly, the Commission would regularly update a "watch list" for emerging substances as a part of the latest technical and scientific review and to demand monitoring of such at Member State level.

This measure would provide a first step for developing standards for air quality pollutants that are currently not covered in the AAQ Directive. The Commission would be responsible for the watch list, but Member States would need to contribute with monitoring.

Purpose/operational objective: This intervention would require monitoring technology and potentially modelling techniques to be used to collect information on priority air pollutants of emerging concern and to assess their impact.

Who would be impacted and how:

Directly: The administrative burden would lay with the EU Commission, who would be required to establish and periodically update a list of priority emerging air pollutants as well as ensure they are adequately monitored.

Indirectly: Additional burden could potentially be borne by the EU Member States if they are also required (or voluntarily choose to) monitor priority emerging air quality pollutants.

Risks for implementation:

1. Monitoring and data collection challenges for priority pollutants.
2. Clarity over health impacts for the priority pollutants

Indicators

1. Air Quality	2. Impact on Health	3. Impacts on Ecosystems	4. Climate change links	5. Costs to society	6. Mitigation costs	7. Impacts on Competitiveness	8. Impacts on Sensitive Groups	9. Societal benefits and burden sharing	10. Impacts on Employment	11. Policy synergies	12. Administrative Burden
(+)	(+)	(+)	(+)	0	0	0	0	0	0	0	-

Links to other interventions: [synergies / misalignment]

- A1 – alignment with review of science base (+/-)
- A2 – alignment with review of technology information (+/-)
- A2 – alignment with the EU MS introducing stricter standards, potentially also on emerging pollutants (+/-)
- L2 - Introduce obligations to monitor more pollutants

Assessment

Effectiveness:

This intervention is likely to have a small indirect impact on air quality if the identified priority pollutants become eventually regulated by the AAQ Directive [Air Quality: (+)]. There would be a potential small indirect impact on health, and ecosystems [(+)]. While there is a lot of uncertainty over the indirect impact of a specific air pollutant, additional impact assessment of a specific air pollutant on health, ecosystems and climate would be presumably conducted prior to regulating this pollutant on an EU level. This provides us with a confidence to indicate possible positive impact, rather than no impact.

Stakeholders expressed moderate support for this intervention. At least 50% of respondents across all categories expressed at least some support. Research and Academia as well as NGOs were particularly positive, with 80% showing at least some support. Stakeholders agreed that pollutants of emerging concern can have important negative health impacts. Black Carbon, Ultra Fine Particles and Ammonia have been specifically highlighted. A periodically updated list of these pollutants with an obligation to monitor them would pose an effective measure. The frequency of the update would be a key determinant of the effectiveness of this measure (a minimum 5 yearly update cycle has been suggested). Stakeholders also highlighted, that while monitoring is a key source of information for emerging pollutants, it must be accompanied by health and ecosystem impacts studies prior to legislative action. Scientific evidence should be the basis of any potential standards for these pollutants.

Efficiency:

This intervention would have medium to large negative impact on administrative burden given the potential increased costs for installation of monitoring samplers, their on-going maintenance and reporting requirement by EU Member States [Administrative burden: -]. Additional burden would potentially be borne by the EU Member States if they were required (or voluntarily choose) to monitor priority emerging air pollutants, in particular if the content of the list changed frequently. Stakeholders suggested that to manage the administrative burden and costs, a priority monitoring exercise should be voluntary and coordinated by AQUILA or JRC/EEA. Targeted monitoring of the priority list, rather than of a voluntary list of pollutants would provide focus and ensure that efforts to targeted on key pollutants only.

There is no evidence that this intervention would have any direct impact on mitigation; costs to society, impact on competitiveness; employment and societal burden sharing [0].

Coherence:

In general terms, this intervention is expected to deliver indirect benefits for climate change [(+)] but no impacts on policy synergies were identified [(0)]. Specific coherence issues might arise in relation to a specific pollutant once added to the emerging air pollutant list and subsequently considered for addition to the AAQ Directive. A good example is black carbon, which is also a short-lived climate pollutant and hence important also for mitigation action.

Benefit to Cost ratio

Low - Direct costs estimated with this intervention as are large monitoring costs, both capital and recurring costs plus small reporting administrative costs. It is not possible to estimate eventual indirect compliance costs to assess costs further. Direct benefits are difficult to estimate, given that this intervention is not likely to quickly lead to revision of the standards. If the identified priority pollutants became regulated via the AAQ Directive, this would likely be due to their significant impact on health, which would mean potentially large indirect benefits.

Summary

Stakeholders expressed moderate support for this intervention, with at least 50% of respondents across all categories expressing at least some support. This intervention is expected to have a small indirect effect on improving air quality and thereby small indirect impact on health. Finally, we consider this measure to have low benefit to cost ratio, associated with significantly high monitoring costs.

B1

Intervention area B: Which types of air quality standards or combination thereof are appropriate?
Intervention / Measure **(B1) Establish short-term EU air quality standards (daily or hourly) for additional air pollutants that currently only have annual or seasonal standards e.g.** $PM_{2.5}$ **.**
The problem: Health outcomes shortcomings. Driver: Exceedances of air pollutant concentrations above health guidelines and negative health impacts persist.
Description: The AAQ Directives sets short-term standards only for certain pollutants. There are cases where the WHO AQGs provide a recommendation for short-term exposure levels for additional pollutants. For example, for $PM_{2.5}$ there is an EU annual limit value, but no 24-hour standard; for SO_2 there are EU standards for 1-hour and 24-hour periods, but no 10-minute standard; for NO_2 there is an EU standard for 1-hour exposure, but no 24-hour standard. This intervention explores the regulatory change needed to underpin the formulation of additional short-term standards for various pollutants for which currently only long-term standards (annual-mean) exist, or alternative short-term averaging periods, to achieve greater alignment with the latest WHO AQGs.
Purpose/operational objective: Provide the regulatory basis for closer alignment with EU air quality standards with latest scientific knowledge and recommendations of WHO.
Who would be impacted and how: ***Directly***: The administrative burden would borne largely by the Commission, who would be required to carry out an assessment of scientific knowledge and further define standards in the EU AAQ Directive. This measure would potentially increase administrative burden for EU Member States. Where additional standards exist, Member States may need to put in place new monitoring and reporting arrangements. We expect that this would be limited and largely linked to reporting as most monitoring stations are already technically capable to take more frequent measurements. ***Indirectly:*** This measure on its own would not have any further indirect impact. There will be further direct and indirect impacts for competent authorities and other stakeholders depending on standard set and the resulting number of exceedances (but these are captured under O2, P2, Q2, R2, S2 and T1).
Risks for implementation: 1. Lack of consensus over which short term standards best target risks associated with exposure. 2. Challenges over monitoring requirements for short-term standards by public authorities within the EU Member States. 3. Setting standards on the basis of a single value to be achieved everywhere will not drive continual improvement where such standards are already met.

4. Multiple standards for a single pollutant increases the complexity for policy makers in terms of designing a response, and also communicating these standards to stakeholders (link to Intervention Area F).

Indicators

1. Air Quality	2. Impact on Health	3. Impacts on Ecosystems	4. Climate change links	5. Costs to society	6. Mitigation costs	7. Impacts on Competitiveness	8. Impacts on Sensitive Groups	9. Societal benefits and burden sharing	10. Impacts on Employment	11. Policy synergies	12. Administrative Burden
+	0	0	0	0	0	0	0	0	0	0	(-)

Assessment

Effectiveness:

The detrimental health impacts associated with exposure to air pollution are associated with both exposure over a long-term (chronic) and short-term (Acute). Although the focus is often on chronic exposure (in part as these effects are typically the ones captured in HIA), the health effects associated with short-term exposure can be significant. As such the WHO have defined a range of AQGs both for long and short-term exposure. Short-term peaks are not always driven by the same sources as long-term average concentrations, hence merit a separate standard to focus action here also. Furthermore, setting short-term limit values can complement the achievement of other standards (e.g. long-term limits) by effectively identifying and effectively implementing effective emission reduction measures for short-term peaks, which will also form part of the long-term averaging period. Hence this intervention could facilitate strengthened EU air quality regulation for air pollutants where health risks are not in line with the frequency of monitoring currently included in the AAQ Directive [Air Quality: +]. Improvement in air quality would deliver a consequent health benefit alongside other benefits and costs. However, the size of these impacts would depend on the standard set, which is considered by other interventions (O2, P2, Q2, R2, S2 and T1). Given this measure focuses on providing the Regulatory change to then set the standards, these indirect impacts are not associated with this measure specifically (Indicators 2-11: 0].

This intervention received mixed support from stakeholders. NGOs showed strong support for this measure, with 60% noting the intervention could be ‘fully effective’ and another 25% suggesting ‘effective at least to some extent’ in resolving the problem at hand. Only 40% of industry respondents to the TSS noted the intervention would be effective ‘to some extent’. Finally, almost 60% of respondents from public authorities and research & academia expressed that this intervention addresses shortcomings to ‘at least some extent’.

Stakeholders stressed that scientific evidence should the basis of deciding whether short term standards are needed. If there is scientific evidence of short-term effects of pollutants on health, it is not possible to ignore these. Stakeholder affirmed that based on the scientific evidence of health impact, the WHO AQGs include short term standards that are not included in the EU Directive. Furthermore, while the main health effects of air pollution are connected to long-term exceedances in guideline concentrations, short-term standards are necessary for pollutants with proven effects in the short-term (e.g. as is the case for $PM_{2.5}$). Stakeholders also noted that short term standards could be particularly effective to protect vulnerable/sensitive groups of population (e.g. asthma patients). With short term standards, the population would be better informed and able to easily evaluate their exposure to the short term pollution.

Stakeholders highlighted that $PM_{2.5}$ is the most important pollutant for which a new short-term standards should be defined. This will address both its short term impact as well as the fact that short-term standards help achieve long-term standards. Although PM_{10} (for which a daily limit value already exists) could highly correlate with $PM_{2.5}$, stakeholders generally supported that a daily limit for $PM_{2.5}$ is needed given that $PM_{2.5}$ is the more harmful fraction. Monitoring enabled by a daily limit value for $PM_{2.5}$ would be effective to protect vulnerable groups, but even 24h standard might hide peaks during specific parts of the day. Stakeholders highlighted studies that show short-term $PM_{2.5}$ peaks link with mortality and morbidity, including increased incidences of asthma symptoms (Second Position Paper on Particulate Matter', by CAFE Working Group on Particulate Matter, 20 December 2004). Stakeholders noted short-term exposure to $PM_{2.5}$ and PM_{10} is also strongly correlated with hospital admissions for cardiovascular diseases.

Finally, stakeholders noted that a short-term standard for $PM_{2.5}$ would be closely related to (and hence better target) wintertime episodes caused by solid fuel home heating (i.e. biomass) which can significantly exceed the annual standard. A daily $PM_{2.5}$ standard would allow a better identification of the impact of residential biomass use for heating purposes as its impact can be diluted in annual standards. This would also enable closer policy synergies, including greater alignment with the Zero Air Pollution Action Plan targeting indoor air pollution that is also linked to residential biomass use.

Efficiency:

We did not find any evidence for impact of this measure on costs to society, impact on competitiveness, impact on employment and policy synergies. While there might be additional mitigation costs to comply with further defined standards, again these impacts will depend on the level of ambition set and hence are captured in other interventions [Indicators 5, 6, 7, 9 and 10: 0].

This measure is expected to have small, direct negative impact on administrative burden. They would be related to the review of scientific evidence base by the Commission. Additional administrative costs for Member States would arise from the requirement for additional monitoring and reporting. [Administrative burden: -]. Stakeholders highlighted that the additional administrative cost should be relatively low since many of the relevant pollutants are already being monitored at time resolutions which provide adequate data to evaluate standards for short-term means. The majority of pollutants (except heavy metals and PAHs) are monitored using automatic monitoring stations, which provide the air quality data already now in near-real-time. This indicates that additional measurement associated with establishing, for example, a $PM_{2.5}$ 24 hourly limit, should not increase costs significantly and be possible for a reasonable cost. Short-term limits for heavy metals would increase costs substantially, due to analytical needs.

Coherence:

We did not find any coherence issues. Coherence issues might arise in relation to standards for a specific pollutant being further defined in the AAQ Directive. We do not however have any examples to provide at this stage.

Links to other interventions: [synergies / misalignment]

- A1 / A2 / A3 / A4 – these interventions propose regular reviews of the AAQ Directive based on scientific and/or technical advancements. These reviews could lead to changes in air quality standards (+/-)
- O2/ P2/ Q2 /R2/ S2/ T1 – intervention will be closely linked with the ambition of the standards set, which will determine the true impact of this intervention. Three is also an interaction between the impact of standards for different pollutants – e.g. there will be commonalities between underlying sources (and hence standards) for short-term peaks of $PM_{2.5}$ and PM_{10}.
- O1+3/ P1+3/ Q1+3 /R1+3/ S1+2 /B3 – there will be interaction between short and long-term standards for individual (and across pollutants)
- B5 – this will interact with consideration as to whether such standards should be limit or target values or other.
- H2/L2 – defining additional standards will impact on the requirements around monitoring.

Benefit to Cost ratio

High – Direct costs estimated with this intervention are small administrative costs. While there are no direct benefits, this would provide a basis for standards to be set under other interventions (O2, P2, Q2, R2, S2, T1) could be large depending on their ambition.

Summary

This is a facilitating measure. It goes hand-in-hand with (And the true impacts are determined by) the ambition of the standards set under other interventions (O2, P2, Q2, R2, S2 and T1). This intervention provides the facilitating legal basis for such standards to be set, and hence is an important component of a wider solution that could be effective in improving air quality and thereby improving health protection. As such this measure has only low direct costs, but the potential for high benefits. Stakeholders showed fairly strong support for this intervention, with 60% of respondents across all categories showing support at least to some extent.

B2

Intervention area B: Which types of air quality standards or combination thereof are appropriate?
Intervention / Measure **(B2) Define alert thresholds and information thresholds for all air pollutants as triggers for alerting the public and taking short-term action.**
The problem: Health outcomes shortcomings. (Driver: Alert thresholds are an essential tool to protect people, especially vulnerable groups, during high pollution events. AAQ Directive does not provide an alert thresholds for 'all' pollutants, which poses challenges for effective short term response and poses health risks for population. There is a need for alert thresholds and effective short-term action plans for all main pollutants, but mainly for PM 2.5.)
Description: This intervention would establish alert thresholds and information thresholds for some or all air pollutants that currently do not have alert thresholds or information thresholds, as triggers for alerting the public and taking short-term action.
Purpose/operational objective: This intervention would require an assessment process by the European Commission to define alert thresholds and information thresholds for some or all air pollutants that are currently lacking these in the AAQ Directive.
Who would be impacted and how: ***Directly:*** The administrative burden would be borne largely by the European Commission, who would be required to carry out an assessment of scientific knowledge and further define standards in the EU AAQ Directive. ***Indirectly:*** This measure would indirectly increase the administrative burden on the Competent Authorities within EU Member States due to the requirement to include more frequent monitoring and reporting of exceedances of the alert/information thresholds. Further indirect impact would be borne by competent authorities where exceedances of the thresholds require a short term action plan to be developed.
Risks for implementation: **1.** Available scientific and technological knowledge base to support decisions for setting alert and/or information thresholds for specific pollutants might pose a knowledge risk (i.e. is this effective for some or all air pollutants?) **2.** Concerns regarding effectiveness of measures taken in response to alert threshold breaches (e.g. via short term-action plans).
Indicators

1. Air Quality	2. Impact on Health	3. Impacts on Ecosystems	4. Climate change links	5. Costs to society	6. Mitigation costs	7. Impacts on Competitiveness	8. Impacts on Sensitive Groups	9. Societal benefits and burden sharing	10. Impacts on Employment	11. Policy synergies	12. Administrative Burden
+	+	(+)	(+)	0	0	0	+	0	0	(+)	(-)

Assessment

Effectiveness:

With the air pollutant alert thresholds providing a trigger to develop short term action, this intervention would potentially have direct positive impact on air quality concentrations, but this would be restricted to those infrequent times during episodic events when the action plan is enacted [Air Quality: (+)]. However, across Europe this impact is very small. Combination of short-term action and information thresholds resulting in better information for the population would however enable the population to take personal measures to reduce its exposure to harmful air pollution, thereby having direct small positive impact on human health [Health: (+)] as well as direct small positive impact on sensitive groups being able to benefit from enhanced information availability on air quality [Sensitive groups +]. The improvement in air quality would have small indirect positive impact also on ecosystems and climate change links [indicators 3 and 4 (+)]. We do not have any evidence to suggest impact on societal benefits and burden sharing [indicator 9 is 0].

Stakeholders showed moderate support for this intervention, with around half of respondents across all categories showing support at least to some extent. NGOs were particularly supportive, with over 90% of respondents supporting at least to some extent

Stakeholders stressed that scientific evidence of health impact should be the consideration for effectiveness of information and alert thresholds not included in the EU Directive. Although the long-term health impact of air pollution is much more important than the short term, the general public should be informed and/or alerted during episodes.

There was a fairly consistent stakeholder response indicating that the effectiveness of short-term emission reduction measures is low in reducing pollutant concentrations that cause air pollution episodes. Stakeholders noted that local measures, such as those included in short-term action plans, have almost no effect on avoiding the health effects caused by episodes. Informing and alerting the general public about the negative health effects during air pollution episodes increases awareness of the air pollution problem and can help to reduce personal exposure during pollution events. This is particularly important for vulnerable groups, such as people with cardiovascular diseases. There is also evidence of episodes increasing hospital admissions due to respiratory problems and an increase of cardio-pulmonary mortality.

Stakeholder views somewhat diverged over which pollutants should be included in this intervention. The general sense was that information thresholds currently in place for ozone are useful in the current form of an information trigger, especially for vulnerable population groups. The short-term health impact of particulate matter has been highlighted as having the same effects, so PM should also be included. Seasonal pollution episodes for PM and ozone are also usually caused by meteorological conditions and pollution masses that are travelling long distances. Where long distance transportation plays a major part, local (short term) actions therefore are less effective. While information alerts are useful, short term emission reduction measures to address episodes of these two pollutants should not be mandatory when not effective.

Efficiency:

This measure is likely to have small positive impact on societal costs associated with reduction of healthcare costs via enhanced protection during air pollution episode (e.g. via reduced hospital admissions). We, however, do not have a lot of information [societal costs: (+)]. We did not find any evidence for impact of this intervention on competitiveness, impact on employment and policy synergies; while there might be additional mitigation costs to comply with further alert/information thresholds, we are not able to assess these costs [i.e. indicators 6, 7, 9 and 10 are rated as 0]. Finally, this measure is expected to have small indirect negative impact on costs associated with the administrative burden of the AAQ Directive revision and subsequent monitoring and reporting costs [indicator 12 is evaluated as (-)]. The main direct costs associated with this intervention are administrative which are associated with the Commission to revise the AAQ Directive to include alert and information threshold for all or some air pollutants. Additional administrative costs for Member States would arise from the requirement for more frequent monitoring or alert and information thresholds and subsequent provision of information if the threshold was breached. Indirect costs would arise from the need to develop short term action.

Coherence:

Coherence issues might arise in relation to standards for a specific pollutant being further defined in the AAQ Directive. We especially see potential cross links for $PM_{2.5}$ and O3. We do not however have any examples to provide at this stage.

Links to other interventions: [synergies / misalignment]

- C4. Introduce an obligation for effective short-term action plans for each pollutant to prevent / tackle air pollution events (+)
- M1 & M2 – Assessment and cooperation on transboundary pollution (+)

Benefit to Cost ratio

Medium - This intervention is expected to have small direct administrative costs. Expected benefits are small and mostly indirect. Air quality leads to high societal costs due to the high health damage costs, so further protection of general population by taking additional action or by providing information that would be beneficial particularly to sensitive groups could be important. It is difficult to estimate indirect compliance costs.

Summary

Stakeholders showed moderate support for this intervention. This intervention is expected to have small effect on improving air quality. Enhanced information can however have direct small impact on health protection sensitive groups. Finally, we consider this measure to have low direct costs and potentially high benefits.

B3

Intervention area B: Which types of air quality standards or combination thereof are appropriate?

Intervention / Measure

(B3) Expand the application of the exposure reduction targets (relative reduction in exposure).

The problem: Health outcomes shortcomings.

Driver: Exceedances of air pollutant concentrations above health guidelines and negative health impacts persist

Description: The AAQ Directives includes average exposure obligations among the current provisions to regulate $PM_{2.5}$ concentrations. These complement the emission limit value for $PM_{2.5}$ by targeting areas with higher concentration values. Accordingly, the AAQ Directives set national $PM_{2.5}$ exposure reduction targets to protect human health (Article 15). The reduction target is a percentage reduction based on the initial concentration. To determine the initial concentration, an average exposure indicator is used (an average level determined on the basis of measurements at urban background locations throughout the territory of a Member State and which reflects population exposure).

This intervention explores whether the formulation of the average exposure reduction targets and obligations should be changed. According to the 2008/50 Directive, Article 15, the distribution and the number of sampling points on which the average exposure indicator for $PM_{2.5}$ is based should reflect the general population exposure adequately. Directive 2004/40, ANNEX XIV specifies Average Exposure Indicators (AEI) for $PM_{2.5}$. AEI is currently measured in urban background stations, which might not always be reflective of the general population exposure.) The following options are available:

(1) Introduce an exposure reduction target at regional or local level (rather than at national level only).
(2) Broaden the “average exposure indicator” metric to include locations other than urban background (e.g. rural background locations).
(3) Establish requirements for Member States to adopt air quality plans to meet exposure concentration obligations.

Purpose/operational objective: Improve the definition of average exposure standards, and the achievement of standards, to reduce the negative effects associated with air pollution.

Who would be impacted and how:

Directly: The administrative burden would borne largely by the Commission, who would be required to carry out an assessment of how to best expand the exposure reduction targets to new pollutants and recalibrate the definition of average exposure standards.

This measure would indirectly increase the administrative burden on the EU Member States through a potential need to expand monitoring, and provision of additional information on the progress against reformulated standards. Further direct impacts would be borne by competent authorities due to requirement to develop adopt air quality plans as a result to breaching average exposure indicators in the AAQ Directive.

Indirectly: Where new plans are put in place that identify the need for additional action, there will be air quality improvement benefits for citizens, and indirectly for industry and businesses, but also compliance costs associated with mitigation.

Risks for implementation:

1. Measurement basis for broadening of the average exposure reduction indicator metric (i.e. how to set up indicators for 'regional' or 'local' locations).
2. Allocation of responsibility (to different levels of public administration) for response measures to achieve relative reduction in exposure if the exposure reduction targets are set for new location.

Indicators

1. Air Quality	2. Impact on Health	3. Impacts on Ecosystems	4. Climate change links	5. Costs to society	6. Mitigation costs	7. Impacts on Competitiveness	8. Impacts on Sensitive Groups	9. Societal benefits and burden sharing	10. Impacts on Employment	11. Policy synergies	12. Administrative Burden
(+)	(+)	(+)	(+)	(+)	0	0	(+)	0	0	(+)	(-)

Assessment

Effectiveness:

With the objective to better target average exposure of air pollution, and/or require Member States to take action where standards are not achieved, this intervention is likely to lead to a small (indirect) improvement in air quality [Air quality: (+)]. The improvement in air quality would have small indirect positive impacts also on health, ecosystems, climate change and sensitive groups, depending on the pollutants affected [indicators 2-5, and 8 (+)]. This is due the fact that this measure might improve in the way that the average general population exposure reduction is being targeted - AEI is currently measured in urban background stations, which might not always be reflective of the general population exposure.

Stakeholders showed weak to moderate support for this intervention, with around 60% of respondents across all categories showing either 'large' support or support to 'at least to some extent'. The trend of responses was fairly consistent across all categories. From the three variants presented, stakeholders favoured the variant: "1. Introduce an exposure reduction target applicable at regional or local level (with 54% and of respondents across all categories showing either 'large' support or support to 'at least to some extent') over variant '2. Broaden the "average exposure indicator" metric to include locations other than urban background (for instance rural background locations as well) with 54% and of respondents across all categories showing either 'large' support or support to 'at least to some extent').

Stakeholders highlighted that exposure reduction targets might serve as an intermediate solution where limit values could not be achieved fast enough. They also offered that exposure reduction approaches in the current AAQ Directive have had little impact in practice due to the high limit values of $PM_{2.5}$. With reduced limit values alongside WHO guidelines in the revised AAQ Directive, this measure might increase in importance.

Stakeholders expressed that an approach to measurement of an exposure concentration should be representative of a population. To determine the most suitable variant, it is important to define where the population experience the greatest exposure, whether in currently regulated locations (urban background) or otherwise. This will determine whether the most effective solution is to revise or extend the scope of the average exposure indicator. Additionally, regional or local features that affect the accumulation of pollutants (i.e. mountain ranges, low wind speed) must be considered.

In terms of variants, stakeholders views can be summarized as follows:

- Including suburban or rural locations can be effective because there are suburban areas in agglomerations and because a large percentage of the population lives in rural areas.
- The percentage exposure reduction to be achieved within a given period could be determined depending on the existing exposure levels in each agglomeration measured at a defined number of representative monitoring sites or derived from air quality modelling, or a combination of both. Supplementing the current hotspot approach by a regional exposure reduction target can be effective to better target measures to achieve the required relative pollution reduction, which is often based on the spatially averaged $PM_{2.5}$ background concentration in residential urban areas. A regional exposure reduction target would provide authorities located in medium-polluted regions with a driver to bring forward additional measures (e.g. low-emission small combustion, ULEZ, ZEZ, cleaner (electric) NRMM, etc.). These measures would otherwise likely not be taken up, because these autohorities already meet the hot-spot limit values aready. This reduces possible effectiveness of this measure and prevents authorities from delivering positive health impacts.

Finally, stakeholders highlighted whether the current approach for calculating the Average Exposure Index (AEI), based only on data from a small number of monitoring stations, is not really fit-for-purpose. Inspiration should instead be taken from exposure studies that are carried out in Member States and the potential to strengthen the use of models (in combination with measurements) for assessing average exposure should be investigated.

Efficiency:

The main direct costs associated with this intervention are likely to be administrative. Additional burden will fall on the Commission in its consideration around a revised approach to defining population exposure measurement. Additional administrative costs will also accrue for Member States, through potential additional monitoring and reporting requirements for more frequent monitoring (e.g. potentially new measurement stations). In addition, additional burden will also arise through the need to develop air pollution action plans where average exposure standards are not being met.

Where a new AQ plan is drawn up requiring additional action, there may be additional indirect compliance costs. Depending on where these fall, there may be consequent impacts for competitiveness and employment. However, given average exposure standards are broadly achieved already, and where these aren't Member States are likely to have plans in place to tackle linked exceedances of long-term limit values, the costs are potentially negligible, but ultimately uncertain [Indicators 6, 7, 9, 10: 0].

In terms of efficiency, NGO stakeholders highlighted that it is also important to remember the uneven distribution of health impacts and exposure of air pollution at urban level and at regional level across

Europe[24]. Exposure reduction targets alone risk exacerbating such social injustice (reducing protection of lower socio-economic population) living in hotspots. Exposure reduction targets and differentiated standards across the EU would also risk worsening the divide between levels of pollution among regions of different average socio-economic status across Europe.

Coherence:

Expert judgement suggests that there are no coherence issues.

Links to other interventions: [synergies / misalignment]

- O3 / P3 / Q3 /R3 – links to average exposure standards for different pollutants being considered
- B4 - Provide guidance on the provisions concerning types of EU air quality standards and on the action to be taken in case of exceedance of different types of standards.
- B5 - Establish limit values for additional air pollutants (i.e. for air pollutants currently subject to target values).
- C4 - Introduce an obligation for effective short-term action plans for each pollutant to prevent / tackle air pollution events

Benefit to Cost ratio

High - Direct costs estimated with this intervention are small administrative costs, while benefits of better targeting population exposure could be large. This measure is likely to provide better targeting of general air pollution exposure reduction, so contributing towards further protection of general population from harmful air pollution and thereby reducing the air quality cost on society. It could also improve the effectiveness of implementing mitigation measures. It is difficult to estimate indirect compliance and potential mitigation costs.

Summary

Stakeholders showed weak to moderate support for this intervention, highlighting preference for variant 1, introducing an exposure reduction target applicable at regional or local level. This intervention is expected to have positive direct effect through better targeting exposure, thereby improving health protection as well as impacting on sensitive groups. This may also support easier implementation of measures and through better alignment of problem and mitigation (where e.g. measures can be implemented on a regional basis). Finally, we consider this measure to have low direct costs and potentially high benefits.

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[24] European Environment Agency, Unequal exposure and unequal impacts: social vulnerability to air pollution, noise and extreme temperatures in Europe, Report No 22/2018

B4

Intervention area B: Which types of air quality standards or combination thereof are appropriate?

Intervention / Measure

(B4) Provide guidance on the provisions concerning types of EU air quality standards and on the action to be taken in case of exceedance of different types of standards.

The problem: Health outcomes shortcomings.

(Driver: Air pollution response measures in case of exceedances are not standardised. Action plans introduced my Member States to address the same exceedance, under the same circumstances leads to different outcomes. There is also overlaps between short term action plans and air quality plans.)

Description:

Provide guidance on the provisions concerning types of air quality standards and on the action to be taken in case of exceedance of different types of standards. Includes guidance on how to respond to exceedances in terms of suitable air pollution response measures in case of exceedances, and on type of plans to be used. This measure would enable the Commission provide clearer coordination with the development and implementation of short-term action plans under Article 24 and air quality plans under Article 23 by clarifying the information to be provided in short-term action plans and ensure the requirements under short-term Air Quality Plans do not overlap with the requirements for air quality plans set in Annex XV of the 2008 AAQ Directive.

Purpose/operational objective: This intervention would require the Commission to prepare guidance materials for the EU Member States.

Who would be impacted and how:

Directly: The administrative burden would borne solely by the Commission, who would be required to develop guidance on provisions concerning types of EU air quality standards and/or carry out an assessment (or collate best practices) on the action manage exceedances.

Indirectly: Indirect impact would be on competent authorities, who would be expected to take into account the guidance documents on the AAQ Directive when developing their air quality plans or short-term air quality action plans.

Risks for implementation:

1. Considerations over what is considered as an effective action to respond to exceedances of different types of standards.
2. Varying circumstances (level of air pollution response level, technology availability, socio-economic situation, etc.) across different EU member states making the development of guidelines on effective action challenging.

Indicators

1. Air Quality	2. Impact on Health	3. Impacts on Ecosystems	4. Climate change links	5. Costs to society	6. Mitigation costs	7. Impacts on Competitiveness	8. Impacts on Sensitive Groups	9. Societal benefits and burden sharing	10. Impacts on Employment	11. Policy synergies	12. Administrative Burden
(+)	(+)	(+)	(+)	0	0	0	0	0	0	(+)	(-)

Assessment

Effectiveness:

The guidance might enable better understanding of the EU air quality standards and thereby development (or better coordination) of the action in case of exceedance of different types of standards. As a result, this intervention would therefore potentially have small indirect positive impact on air quality concentrations [Air Quality (+)]. Subsequently, we are likely to see small indirect positive impact on ecosystems and climate change links [Impacts on Ecosystems and Climate change links (+)]; as well on small indirect impact on improving health as well as generate impact on sensitive groups [Impact on Health and Impacts on Sensitive Groups (+)]. We do not have any evidence to suggest impact on societal benefits and burden sharing [Societal benefits and burden sharing (0)].

Stakeholders showed an overall moderate support for this intervention, with around 60% of respondents across all categories showing support at least to some extent. Percentage of respondents from public authorities and research & academia showed full support.

Stakeholders overall welcome receiving guidance and indicated its usefulness to aid the relevant authorities take the most cost-effective measures to address any exceedances. To ensure effectivity, stakeholders highlighted the below mentioned points.

EU air quality standards:

- Provide clarity of concepts that are more difficult to comprehend such as target values and their implications.
- Develop tailored guidance for different types of EU air quality standards as the air pollution exposure and the sources can vary significantly. Specific measures can be appropriate for certain types of standards, but less appropriate for others.

Actions to be taken in case of exceedances:

- Provide a list of non-exhaustive measures to reduce exceedances and enable countries to identify how to tackle air quality problems could be useful. Make sure measures are concrete and support the development of air quality plans.
- Effective measures to address secondary pollutants as ozone and PM2,5.
- Good practices from other Member States or regions.
- Top-down approach on best practice measures to improve harmonization between the regions.

Efficiency:

We did not find any evidence for impact of this measure on costs to society, impact on competitiveness, impact on employment. While better targeted air pollution action might have a positive impact on reducing mitigation, we are simply not able to assess these costs. [i.e. indicators 5, 6, 7 and 10 are rated as 0]. We would however expect that a targeted guidance on action to reduce air quality exceedances would consider other EU policy goals and objectives, so this intervention would have a small indirect impact on policy synergies [indicator 11 evaluated as (+)]. Finally, this measure is expected to have small indirect negative impact on the administrative burden related to the EU Commission need to develop AAQ Directive guidance [indicator 12 is evaluated as (-)].

Coherence:

We did not find any coherence issues.

Links to other interventions: [synergies / misalignment]

- C4 - Introduce an obligation for effective short-term action plans for each pollutant to prevent / tackle air pollution events

Benefit to Cost ratio

Medium - Direct costs estimated with this intervention are small administrative costs, while this measure could provide small indirect benefits across different indicators. This measure could contribute towards better targeting of air pollution action, thereby contributing towards either more cost-effective response to exceedances or reducing the air quality cost on society by further protection of general population from harmful air pollution. It is difficult to estimate indirect compliance and potential mitigation costs.

Summary

Stakeholders showed weak to moderate support for this intervention, highlighting preference for variant 1, introducing an exposure reduction target applicable at regional or local level. This intervention is expected to have small direct effect on improving air quality and thereby improving health protection as well as impacting on sensitive groups. Finally, we consider this measure to have low direct costs and potentially high benefits.

B5

Intervention area B: Which types of air quality standards or combination thereof are appropriate?

Intervention / Measure

(B5) Establish limit values for additional air pollutants (i.e. for air pollutants currently subject to target values).

The problem: Health outcomes shortcomings.

Driver: Exceedances of air pollutant concentrations above health guidelines and negative health impacts persist

Description: Not all the pollutants are being regulated via the strongest, binding air quality standards. Limit values have been an essential tool to drive reductions of some pollutants, such as PM. Other pollutants are being regulated via target values, which some consider as weaker, non-binding air quality standards. This intervention explores the establishment of limit values for additional air pollutants (i.e. for air pollutants currently subject to target values).

Intervention options for additional limit values include:

1. Establish limit values also for air pollutants that tend to depend on transboundary precursors and /or annual variations in meteorology (e.g. as is the case for ozone).
2. Establish limit values also for air pollutants that tend to correspond to specific point source emissions (e.g. as is the case for most heavy metals).
3. Establish limit values also for air pollutants that tend to correspond to emissions from specific widespread practices (e.g. as is the case for most poly-aromatic hydrocarbons).

Purpose/operational objective: This intervention would require the European Commission to establish (or evaluate setting) limit values for some or all pollutants where the Directive uses target values based on a review of technical and scientific knowledge.

Who would be impacted and how:

Directly: The administrative burden would be borne by the Commission, who would be required to carry out an assessment on which pollutants could be effectively regulated via limit values.

Indirectly: Indirect impact would be on competent authorities, who would be expected to incorporate new standards into their air quality assessment and reporting processes, and if appropriate within their Air quality plans. Where new plans are put in place that identify the need for additional action, there will be air quality improvement benefits for citizens, and indirectly for industry and businesses, but also compliance costs associated with mitigation.

Risks for implementation:

1. Considerations over how to categorise pollutants and which pollutants should be considered for limit values.

2. Under variant 1, this measure would need to address how to treat transboundary pollution. One reason for setting target values rather than limit values is to take account of the specific formation mechanisms, for example in the case of ozone (also due to a strong role of transboundary sources and annual variations in meteorology for this air pollutants).

Indicators

1. Air Quality	2. Impact on Health	3. Impacts on Ecosystems	4. Climate change links	5. Costs to society	6. Mitigation costs	7. Impacts on Competitiveness	8. Impacts on Sensitive Groups	9. Societal benefits and burden sharing	10. Impacts on Employment	11. Policy synergies	12. Administrative Burden
++	+	+	+	+	-	0	+	0	0	0	(-)

Assessment

Effectiveness:

Limit values have proved very effective in reducing air pollutant concentrations to guidance ‘limit’ levels. Introduction of limit values for all pollutants, where these would prove feasible, would strengthen the AAQ Directive. Target values have proven less effective than limit values when considering air quality in traffic planning, permitting/regulation of industrial pollution and regional/local planning, and not least when assessing the need to take local, regional and national measures for improving air quality. Hence as limit values are binding, they facilitate better implementation and enforcement of the Directives. Depending on the variant chosen, this intervention is therefore expected to have medium to large direct positive impact on air quality concentrations [indicator 1 ++]. Likewise, we expect a see small indirect positive impact on ecosystems and climate change links [indicators 3 and 4 (+)]. Direct improvement in air quality concentrations is expected to have small direct impact on improving health [indicators 2 and 5: +] and generate a positive impact on sensitive groups, who are more likely to be exposed to higher levels of ozone [indicator 8 +]. We do not expect any impact on societal benefits and burden sharing [Societal Benefits: 9 is 0].

Stakeholders showed an overall moderate support for this intervention. Around 60% of respondents from public authorities, industry and research & academia showed support at least to some extent. Over 80% of stakeholders from NGO viewed this measure as being effective to at least large extent. Stakeholders favoured establishing limit values for air pollutants that tend to correspond to specific point source emissions (e.g. heavy metals) and specific widespread practices (e.g. poly-aromatic hydrocarbons), but not for air pollutants that tend to depend on transboundary precursors and /or annual variations in meteorology.

Stakeholders noted that there is a role in the AAQ Directive for both limit and target values, depending on a specific air pollutant. Limit values have resulted in the health effects of relevant air pollutants being taken more seriously and have put pressure on authorities to take measures to limit pollution levels. Experience suggests that previous and current guideline values and target values do not seem to have the same effect in improving air quality as quickly as limit values. Target values are relevant for large scale air pollution events like ozone episodes and problems related to long-range transport of air pollution. Other instruments for abatement and emission control were highlighted to be considered in these cases (i.e. NECD, Gothenburg protocol).

Stakeholders expressed the following views over different variants within this intervention:

1. Air pollutants dependent on transboundary precursors and /or annual variations in meteorology (e.g. ozone).
    - Transboundary precursor should be reduced in the country of their origin and cannot be controlled in the necessary amount outside the country of origin.
    - Ambitious emission reduction targets for ozone precursors, but will not be realistic in the short term. The ozone concentrations in air masses that enter Europe via western air currents and that are not impacted by European emissions of ozone precursors, are currently at 70-80 µg/m^3. These are higher concentrations than the WHO guideline of 60 µg/m^3. It will not be possible to attain the WHO guideline in the short term without stringent global emission reductions.
2. Air pollutants corresponding to specific point source emissions (e.g. heavy metals).
    - Limit values and air quality plans would be effective tool to lower the concentration level of heavy metals.
    - Industrial installations are the major source of heavy metals, so exisiting control technologies to reduce emissions should be applied for the measure to be effective.

3. Air pollutants from specific widespread practices (e.g. as is the case for most poly-aromatic hydrocarbons).
    - Limit values for air pollutants that are linked with widespread practices (e.g wood burning) can lead to extra incentives to reduce the emissions from these sources.
    - Ammonia is also caused by widespread practices is (e.g. from agriculture and breeding farms). It would require stringent legislation on emissions.
    - and PAHs.
    - Target value for B(a)P is not prescriptive enough to motivate authorities to take action. The introduction of a binding limit value is an essential element to address this serious problem.

Efficiency:

We did not find any impact of this measure on costs to society, impact on competitiveness, impact on employment. We are not able to assess the impact on mitigation costs either [i.e. indicators 7 and 10 are rated as 0]. For areas currently exceeding target values, setting a limit value may require additional abatement action, bringing with it compliance costs [Indicator 6: -]. Introducing limit values for further air pollutants might have impact on policy synergies. In particular establishing limit values for air pollutants that tend to correspond to specific point source emissions can be aligned with the revision of the Industrial Emissions Directive to ensure policy synergies. We evaluate this indicator as small potential indirect positive [policy synergies: (+)]. Direct costs associated with this intervention are small indirect administrative costs borne by the Commission to review science base and propose further limit values to be integrated in the Directive [indicator 12 is evaluated as (-)]. In addition, depending on the pollutant Competent Authorities may be required to carry out additional monitoring for assessment purposes. For instance, stakeholders suggested that especially PAH-monitoring might become extremely costly when done at a reasonable number of sites with the necessary data quality.

Coherence:

We did not find any coherence issues.

Links to other interventions: [synergies / misalignment]

- R1-3, V1, W1, X1, Y1, Z1 – standards for pollutants which are currently expressed as TVs

- C4 - Introduce an obligation for effective short-term action plans for each pollutant to prevent / tackle air pollution events
- E2 + E4 – limit values better support enforcement.

Benefit to Cost ratio

Medium - Direct costs estimated with this intervention are medium administrative costs, associated with the review of the AAQ Directive as well as additional monitoring needs (which would depend on the selection of pollutants for which limit values would be defined). This measure could have direct positive impact on health as well as ecosystems, also assessed as medium, given uncertainty over which pollutant would be selected. It is difficult to estimate indirect compliance and potential mitigation costs.

Summary

Stakeholders showed moderate support for this intervention, highlighting preference for variants focused on air pollutants related to specific point source emissions (e.g. heavy metals) and specific widespread practices (e.g. poly-aromatic hydrocarbons), but not dependent on transboundary precursors and /or meteorology (i.e. ozone). Limit values better aid the implementation and enforcement of the Directives. Where there is widespread compliance with existing TVs (i.e. heavy metals), the impacts of this measure would be small and affect a limited number of sites, but could help maintain this positive performance going forward. For PaH and ozone, where current compliance with TVs is much lower, the impacts would be higher. Although there is likely to be further improvement in compliance going forward over the baseline, the feasibility of setting limit values for ozone is questionable given the importance of transboundary sources and natural factors, and relative limitations around control options. This intervention is expected to have a small direct effect on improving air quality and thereby improving health protection as well as impacting on sensitive groups. Finally, we consider this measure to have medium benefit to cost ratio.

C1

Intervention Area C: What action should be mandated in case air quality standards are not respected?

Intervention / Measure

(C1) Further specify the obligation to take measures to keep exceedance periods as short as possible.

The problem: Air quality Implementation shortcomings

(Driver: Air quality plans and measures have often proven ineffective)

Description: This intervention would maintain the obligation to set out "appropriate measures, so that the exceedance period can be kept as short as possible" while further defining the 'type of measures' that competent authorities must take to ensure that exceedance periods can be kept as short as possible. The type of measures to consider will depend on the type of pollutant, the source of pollution, or other factors. To this purpose the revised AAQDs would contain a checklist of relevant abatement measures that Competent Authorities can consider and select from. The measures set out currently in Annex XV could be updated and applied to Article 23 instead. Competent authorities will have to demonstrate that they have considered all relevant measures in the checklist of measures and if they decided not to implement a relevant measure, this should be justified (unlike currently, where air quality plans are not required to include reasoning behind the measures adopted). This means that this intervention would strengthen the information requirements that competent authorities need to make available in air quality plans.

This intervention would build on requirements set in Article 23.1 of the 2008/50 Directive. It should be noted that the Directive does not refer to the consequences of not complying with the Exposure Concentration Obligation (ECO) and Average Exposure Index (AEI).

The rationale behind this intervention is that air quality plans have often proven ineffective due to inadequate or not sufficiently ambitious measures to reduce air pollution to achieve compliance.

In the Targeted Stakeholder Survey, participants who supported this intervention, suggested the provision should include a list of measures that competent authorities would need to consider. Those who did not support it seem to have misunderstood the intervention, mistaking it with intervention C2 on defining 'as soon as possible' with a more specific period. An interview with a regional authority however stressed that it would not be effective for the European Commission to define these measures in the Directive arguing that effective measures would differ from country to country and that EU legislators cannot know what those measures should be. The same stakeholder further added that this clause should remain as an emergency clause to be applied only in cases in which the deadline has been missed. The first part of Article 23 should be formulated more clearly and strongly to ensure timely implementation of the air quality plans to avoid that the majority of agglomerations miss their attainment period.

Purpose/operational objective:

Increase in the relevance and ambition of action (and therefore indirectly, a positive impact on air quality); Strengthening the legal framework.

Who would be impacted and how:

Directly:

Competent Authorities would be impacted directly as their administrative burden may be increased / decreased.

Indirectly:

Indirect impacts are foreseen on competent authorities (in terms of policy synergies), citizens' health and on society (in terms of air quality; ecosystems, climate change; costs to society, societal benefits and burden sharing and policy synergies).

For further details see 'Indicators' box below.

Risks for implementation:

1. Funds - The fact that the type of measures to be included in air quality plans is further defined does not guarantee these measures will be taken (implementation risk remains). Availability of funds was identified by stakeholders as essential for the actual implementation of measures[25] (this risk can be considered slightly indirect as it does not hinder the implementation of the intervention but it does hinder its effectiveness)
2. Properly trained staff - The success of this intervention relies on the capability (knowledge, skills, competences) of competent authorities in charge of designing Air quality Plans to design effective plans.[26]

Indicators

1. Air Quality	2. Impact on Health	3. Impacts on Ecosystems	4. Climate change links	5. Costs to society	6. Mitigation costs	7. Impacts on Competitiveness	8. Impacts on Sensitive Groups	9. Societal benefits and burden sharing	10. Impacts on Employment	11. Policy synergies	12. Administrative Burden
(+)	(+)	(+)	(+)	(+)	0	0	0	(+)	0	(+)	--

Assessment

Effectiveness:

Further specifying the obligation to take measures to keep exceedance periods as short as possible by defining the 'type of measures' that competent authorities must take, would facilitate the drafting of effective air quality plans. In turn, when implemented, such measures would contribute to the reduction of concentrations. Hence this intervention can be considered to have an 'indirect' positive effect on air quality [i.e. Air Quality (+)] protecting human health [i.e. Health (+)], as well as ecosystems [i.e. Impacts on ecosystems (+)] from adverse impacts.

Efficiency:

This intervention will not necessarily increase costs as the intervention will define the measures to be taken but the air quality plan will still need to be developed. Moreover, in the absence of this

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[25] Targeted Stakeholder Survey

[26] Targeted Stakeholder Survey

intervention, authorities would also need to implement measures. Because if this intervention gets implemented, the air quality plan will be more focussed on measures that have proven effective to reduce emissions, this in turn would result in improved air quality and hence reduced costs to society (reduced costs of respiratory hospital admissions) and therefore its societal impact overall can be seen as positive [this effect would be indirect i.e. Societal benefits and burden sharing (+)].

The fact that this intervention could spare costs for society was raised by a couple of NGOs in the Targeted Stakeholder Survey and interviews. To build the case, a few stakeholders pointed us at studies with quantitative data on this:

- The Fitness Check on the AAQDs concluded that "Good air quality makes good economic sense" and found that the costs of implementing the AAQDs (EUR 70 to 80 billion per year) are significantly lower than the costs caused by air pollution to society, health and economic activities (between EUR 330 and 940 billion, per year).
- A study on the costs of not implementing EU environmental law[27] concludes that every unit of air pollution above the current legal limit value costs money and should provide an urgent economic incentive to Member States to take measures to reduce exceedances as much as possible as fast as possible as not doing so costs far more. The study suggests that in 2017, exceedances of $PM_{2.5}$ cost 137.9 EUR per person per µg/m^3 of exceedance in Belgium, 163.1 EUR per person per µg/m^3 of exceedance in Germany, and 161.9 EUR per person per µg/m^3 of exceedance in Poland. The cost of PM_{10} exceedances were estimated to be up to 107 EUR per person per µg/m^3 of exceedance across the whole of the EU that year. The result is that it was predicted that for 2018 exceedances alone (that is, not the cost of air pollution generally) would cost up to 40 billion EUR.
- Estimates show that a 1µg/m^3 increase in PM2. 5 concentration (or a 10% increase at the sample mean) causes a 0.8% reduction in real GDP that same year. Ninety-five per cent of this impact is due to reductions in output per worker, which can occur through greater absenteeism at work or reduced labour productivity.[28]

The indirect positive effects on health of this intervention would result in less lost labour days and reduced health care costs (i.e. Costs to society (+)). The administrative burden overall may decrease or increase slightly for Competent Authorities. Since authorities would be provided with a long-list of measures to select from, that would provide them with a systematic approach to drafting an air quality plan and spare them time brainstorming about potential measures. Systematically having to consider all measures and justifying why a certain measure may not be used might slightly increase administrative burden although the proper consideration of such measures is an intrinsic part of air quality plan development.

This intervention will not result in any relevant direct costs for competent authorities (implementing the actual measures will result in costs but given the measures that will be implemented are not known, these indirect costs cannot be estimated neither if these costs will be higher than the costs of the measures that would be implemented if this intervention were not in place). The only costs generated by this intervention are those for revising the text to include a list of measures. These costs, to be borne by the European Commission, would be negligible though.

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[27] European Commission, Directorate-General for Environment, The costs of not implementing EU environmental law study: final report", Publications Office, 2019

[28] OECD (2019) THE ECONOMIC COST OF AIR POLLUTION: EVIDENCE FROM EUROPE, ECONOMICS DEPARTMENT WORKING PAPERS No. 1584

No impact is expected in terms of employment neither of EU competitiveness upon the implementation of this measure.

Stakeholders responding to the Targeted Stakeholder Survey mentioned that in order to increase efficiency (minimise costs of action by seizing synergies) the measures proposed to be implemented should be coherent with measures in city plans across other areas such as mobility, climate change, noise. Administrative burden was not seen as an issue by respondents.

Coherence:

As many sources of air pollution and greenhouse gas emissions are similar, the measures implemented to reduce air pollution is likely to have a positive impact on greenhouse gas emissions (i.e. Climate change links (+)]. Similarly, because air pollution can significantly damage the quality of soil and water resources, this intervention can be considered to indirectly support the zero-pollution action plan of the EU (i.e. Policy synergies (+))

Links to other interventions: [synergies / misalignment]

- **C2:** *Reformulate the term “as short as possible” with a defined time period:* C1 and C2 are twin measures and hence synergistic [Synergy]
- **C5:** *Mandate regular updates of air quality plans*. C1 and C5 are synergistic [Synergy] as regular updates to plans would need to consider the measures in C1.
- **M2:** *Require transboundary cooperation and joint action on air quality if assessments of transboundary air pollution/contributions above certain thresholds (to be defined):* The attainment of C1 may in some cases be dependent on effective transboundary cooperation and therefore these measures are synergistic [Synergy].

Benefit to Cost ratio

Medium– The intervention itself will not generate additional relevant costs to Member States while it holds the potential to result in more effective measures which in turn can bring positive benefits in terms of air quality and related impacts. However it will lead to significant administrative costs.

Summary

There is medium to high support from stakeholders overall for this intervention, with several public authorities, research and academia, and NGOs showing large to full support for such. There are a couple of risks linked to this intervention relating to funds for implementation of measures and properly trained staff on the side of competent authorities. There are also a couple of synergies with other interventions concerning action to mandate in case air quality standards are not respected (C2, C5) and with an intervention concerning transboundary pollution (M2). The Benefit to Cost ratio is Medium to High.

C2

Intervention Area C: What action should be mandated in case air quality standards are not respected?

Intervention / Measure

(C2) Reformulate the term “as short as possible” with a defined time period.

The problem: Air quality Implementation shortcomings

(Driver: Air quality plans and measures have often proven ineffective)

Description:

This measure would entail amending the text of the Directive 2008/50, Article 23.1 to define the specific time period within which competent authorities must bring emissions down below the exceedance threshold. This would replace the current wording “as short as possible”. This current provision is open to interpretation and risks that exceedances remain systematic and persistent. In practice, since air quality plans must be finished within two years from the exceedance, measures are usually implemented after 3 years at the earliest. Thus, the purpose of this intervention is to prompt competent authorities to take measures to reduce air pollution to a safe level in a timely manner. The need for this is reflected in the responses received to the Targeted Stakeholder Survey. Namely that there is a need to ensure that action is taken faster and that there is no room for different interpretations of what ‘as soon as possible’ means. A national authority responding to the Targeted Stakeholder Survey added that the shortcomings that this measure aims to tackle will remain unless more pressure is set on Member States and/or local authorities to act so that the current long time between the determination of the exceedances and any legal consequences is shortened drastically.

Purpose/operational objective:

Reduction in the time delay of measures being introduced (and indirectly therefore positive impact on air quality). Leaving no room for differing interpretations.

Who would be impacted and how:

Directly:

No direct impacts identified.

Indirectly:

This intervention would impact competent authorities responsible for developing air quality plans, providing a timeframe in which an exceedance is addressed. The legal clarity thus provided is expected to benefit competent authorities by providing them with a legal basis to enforce faster action. Competent authorities responsible for developing air quality plans would also benefit indirectly from policy synergies. Further, this intervention would indirectly benefit citizens/individual (through an indirect impact on health) and society (indirect impacts on air quality, ecosystems, climate, costs to society and societal benefits and burden sharing). In addition,

For further details see ‘Indicators’ box below.

Risks for implementation:

1. No one-size-fits-all - All exceedance situations are different and therefore it is unlikely that one universal time period would be suitable for different zones in various Member States dealing with different pollutants caused by different pollution sources.[29]
2. The presence of fixed timeframes in the current Ambient Air Quality Directives have not prevented widespread exceedances – Introducing a specific timeframe risks giving more time than necessary to certain Member States, and prompting slower Member States to seek extensions to the time-frames anyway, thereby making the mechanism redundant (as has occurred as a result of Article 22 in the current provisions, whereby many zones and agglomerations with exceedances of NO_2 limit values sought and obtained five-year extensions of the attainment deadlines but little progress was made during the extension and the limit values continued to be breached after the new deadline and, in many cases, still persist)[30]
3. Weakening of previous interpretation by courts – Several Member States have defined “as short as possible” (e.g. the German court definition of "as short as possible" for NO_2 requires that safe compliance with the limit value must be ensured in the following year at the latest and maximum exceedances of 5% are permitted) and if the EU were to define a new period, this should not be less stringent.
4. Several measures cannot be implemented in the short term such as big infrastructure projects, creation of Park & Ride system or low emission zones.[31]
5. Air quality is not only dependent on emissions but also on other factors that may be difficult to influence (e.g. Transboundary air pollution) or impossible to influence (e.g. weather, geography).[32]

Indicators

1. Air Quality	2. Impact on Health	3. Impacts on Ecosystems	4. Climate change links	5. Costs to society	6. Mitigation costs	7. Impacts on Competitiveness	8. Impacts on Sensitive Groups	9. Societal benefits and burden sharing	10. Impacts on Employment	11. Policy synergies	12. Administrative Burden
(+)	(+)	(+)	(+)	(+)	0	0	0	(+)	0	(+)	--

Assessment

Effectiveness:

Further defining the specific time period within which competent authorities must bring emissions down below the exceedance threshold would speed up the implementation of air quality plan measures. When implemented, such measures would contribute to the reduction of air pollutant concentrations. Hence this intervention can be considered to have an ‘indirect’ positive effect on air quality [i.e. Air Quality (+)] protecting human health [i.e. Health (+)] as well as ecosystems [i.e. Impacts on ecosystems (+)].

There are challenges with this intervention as introducing a specific time period would need to be realistic to each situation and be set per pollutant. The time period would also need to reflect the starting point and local characteristics of a place. This is again reflected in the responses to the Targeted Stakeholder

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[29] Targeted Stakeholder Survey
[30] Targeted Stakeholder Survey
[31] Targeted Stakeholder Survey
[32] Targeted Stakeholder Survey

Survey. Namely that one time period is not adequate to resolve different exceedance situations in places that differ also orographically and meteorologically. One option proposed by a regional authority is to cap the time period permitted at two years which would address the issue of systematic and persistent exceedances while allowing flexibility. The effectiveness of this intervention will be dependent on the timeframe defined.

A coupled of NGOs noted that this intervention could spare costs for society (reduced costs of people going to the hospitals with respiratory problems) in their responses to the Targeted Stakeholder Survey and interviews.

The extent to which short-term action can effectively address air quality pollution is questioned by one national authority, noting that air quality management in accordance to the 2008/50 Directive is primarily reactive (action plans are to be produced following an observed exceedance), and that a more pro-active, long-term approach to introducing measures to improve air quality would likely be more cost-effective (in response to the Targeted Stakeholder Survey).

Efficiency:

The indirect positive effects on health of this intervention would result in less lost labour days and reduced health care costs [i.e. Costs to society (+)]. As such its societal impact overall can be seen as positive [i.e. Societal benefits and burden sharing (+)]. This intervention will not necessarily lead to additional costs not directly and neither indirectly (the intervention is aimed at action being taken timely but that does not mean than 'more' measures will have to be taken than those which would have to be taken in the absence of this intervention).

The costs of this intervention are assessed as negligible (no quantitative information available). Implementing measures in a defined timeframe (and likely shorter timeframe) is not expected to generate any additional costs (neither to reduce costs). No impact is expected on employment or on EU competitiveness. No additional / reduced administrative burden is expected from this measure.

Coherence:

The measures implemented to reduce air pollution will also have a positive impact on greenhouse gas emissions [i.e. Climate change links (+)] (because the sources of air pollution and greenhouse gas emissions tend to be the same). This intervention can be considered to indirectly support the zero pollution action plan of the EU [i.e. Policy synergies (+)] (because air pollution can significantly hurt the quality of soil and water resources).

Links to other interventions: [synergies / misalignment]

- **C1:** *Further specify the obligation to take measures to keep exceedance periods as short as possible:* C2 and C1 go hand in hand. C1 has to do with 'what' measures need implementing, while C2 refers to 'when' those measures need to be implemented. In this sense they are synergistic [Synergy].
- **C5:** *Mandate regular updates of air quality plans*. C2 and C5 are synergistic [Synergy] as regular updates to plans would hopefully help the effectiveness of measures and would therefore lead to concentrations reductions faster.
- **E1:** *Introduce minimum levels for financial penalties*. Penalties should serve ensure compliance with C2 and so C2 and E1 are synergistic [Synergy]
- **E2:** *Introduce specific provisions that guarantee a right to compensation for damage to health*. Non-compliance with C2 should lead to compensation for victims [Synergy]
- **E4:** *Introduce an explicit 'access to justice' clause in the Ambient Air Quality Directives*. Non-compliance with C2 should lead to compensation for victims [Synergy]

Benefit to Cost ratio

Medium – The intervention will not generate additional costs for Member States or for the European Commission while it holds the potential to result in faster action which in turn can bring indirect positive benefits in terms of air quality and related impacts. Introducing a fixed timeframe will serve as a baseline, improving the speed of response rates in many cases, however, there is a risk that a fixed timeframe will slow down action in some cases.

Summary

The Targeted Stakeholder Survey shows that the views from public authorities, research and academia, and NGOs with regards to this intervention are mixed. Industry representatives in the survey were negative about this intervention (although it should be noted the sample of this stakeholder category was very small).

There are several implementation risks challenging for this intervention such as the fact that there is no one-size-fits-all timeframe; that not all measures cannot be implemented in the short term; that air quality is not only dependent on emissions but also on other factors that may be difficult to influence; that a specific timeframe risks giving more time than necessary to certain Member States and prompting slower ones to seek extensions, and that it may weaken previous interpretation by national courts. Several potential synergies have been identified concerning action mandated in case air quality standards are not respected (C1, C5) and with interventions concerning penalties (E1, E2, E4). The Benefit to Cost ratio is 'medium'.

C3

Intervention Area C: What action should be mandated in case air quality standards are not respected?

Intervention / Measure

(C3) Require a clearer coordination between short-term action plans and air quality plans.

The problem: Air quality Implementation shortcomings

(Driver: Air quality plans and measures have often proven ineffective)

Description: This intervention consists of requiring clear coordination between the development and implementation of short-term action plans (under Article 24 of the Ambient Air quality Directive 2008/50) and air quality plans (under Article 23 and in Annex XV). It should be noted that this intervention is relevant for Member States in which alert thresholds are exceeded.

Coordination between short term action plans and air quality plans is not a requirement in the current Directive. As result, not all Member States coordinate these. Since short term action plans and air quality plans may be responsibility of authorities at different levels (for example, the former may be responsibility of local authorities, while the latter of regional authorities), coordination is not guaranteed. Also because the scope of these types of plans differs: air quality plans are prepared for an air quality zone, while short term action plans are setup for a city/settlement or for an entire region.

The Targeted Stakeholder Survey provided a few insights regarding the benefits and dis-benefits of this potential invention. The arguments for support revolve around ensuring measures in the short and long term are coordinated with each other; arguments against have to do with certain Member States not feeling this applies to them, not seeing the value of short-term action plans in improving air quality (in the long term). According to several respondents, the revised Directive could require that short term action plans are included in air quality plans.[33] Also, to facilitate this linkage between the two types of plans, the revised Ambient Air Quality Directive should include of the minimum content that short-term action plans should contain. It should be noted that the aim of short term action plans should remain preventing pollution peaks exceeding alert thresholds, and consequently triggering measures within a few hours/days, while the aim of air quality plans should remain the main instrument of air quality management, considering measures of a more medium/long-term character (months, years).

Purpose/operational objective:

Increase in the relevance of action (and indirectly, positive impact on air quality) by seizing synergies and avoiding lack of inefficient action by public authorities.

Who would be impacted and how:

Directly:

Direct impacts are foreseen for this intervention in terms of administrative burden for competent authorities.

Indirectly:

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[33] Targeted Stakeholder Survey

This intervention will indirectly impact citizens/individuals (in terms of health) and society as a whole (in terms of air quality, health, ecosystems, costs to society, and societal benefits and burden sharing).

For further details see 'Indicators' box below.

Risks for implementation:

1. Governance risk – It may become an issue if both types of plans are co-ordinated by two different teams.

Indicators

1. Air Quality	2. Impact on Health	3. Impacts on Ecosystems	4. Climate change links	5. Costs to society	6. Mitigation costs	7. Impacts on Competitiveness	8. Impacts on Sensitive Groups	9. Societal benefits and burden sharing	10. Impacts on Employment	11. Policy synergies	12. Administrative Burden
(+)	(+)	(+)	0	(+)	0	0	0	(+)	0	0	-

Assessment

Effectiveness:

Coordination between short term action plans and air quality plans would lead to synergies among actions and avoid inefficiencies. Hence this intervention can be considered to have an 'indirect' positive effect on air quality [i.e. Air Quality (+)] protecting human health [i.e. Health (+)], including sensitive groups [i.e. Impacts on sensitive groups (+)], as well as ecosystems [i.e. Impacts on ecosystems (+)] from adverse impacts. This intervention will indirectly spare costs to society and therefore its societal impact overall can be seen as positive [i.e. Societal benefits and burden sharing (+)].

Despite how positive several types of stakeholders are regarding this intervention, no arguments were given to support the linkages between this intervention and the above mentioned indicators. The fact that this intervention could spare costs for society (reduced costs of people going to the hospitals with respiratory problems) was raised by a couple of NGOs at the Targeted Stakeholder Survey.

Efficiency:

Efficiencies are expected due to the fact that several actions taken on short-term action plans (e.g. transport measures) are the same as measures in air quality plans and that the process for plan development, including stakeholder engagement and consultation, is similar for both types of plans.

In terms of the indicators analysed in this factsheet, the indirect positive effects on health of this intervention would result in less lost labour days and reduced health care costs [i.e. Costs to society (+)]. Some administrative burden is expected from this measure from having to coordinate both types of plans [Administrative burden -].

The costs of this intervention – related to coordination - have been considered negligible based on expert judgement. This intervention will lead to low, minimal additional costs for competent authorities in Member States where short term action plans and air quality plans are currently not coordinated, generated by the need to coordinate actions among these plans better; costs will be non-existent for

Member States which already have coordination mechanisms in place. No impact is expected neither in terms of employment nor of EU competitiveness upon the implementation of this measure.

Coherence:

The indirect impacts on climate change or policy synergies are considered negligible.

Links to other interventions: [synergies / misalignment]

- **C5:** *Mandate regular updates of air quality plans.* C3 would require C5 to consider short term action plans. This is not necessarily a synergy nor a misalignment.
- **N1:** *Refine the minimum information to be included in an air quality plan.* C3 should be aligned with N1 in terms of information required to be reported about the (short term) air quality plans.

In addition, a national authority respondent to the Targeted Stakeholder Survey stated that intervention C3 should go hand in hand with clear requirements on the contents of short term air quality plans and air quality plans, so that competent authorities need less time to understand what needs reporting and at the same time to avoid time spent in preparing information to report which may be unnecessary.

Benefit to Cost ratio

Medium – The benefits of this intervention (stemming from the synergies generated and inefficiencies reduced), are indirect and presumably modest to medium. Its costs are negligible.

Summary

Overall all stakeholders types except for industry (for this latter the sample was small) believed in the effectiveness of this measure with NGOs being only positive about it. Among public authorities, and research and academia a minority do not support the measure at all. This intervention would be synergistic with one other intervention on action to be mandated in case air quality standards are not respected (C5) and with an intervention related to the minimum information to be included in an air quality plan (N1). The only potential risk has to do with governance issues that could arise if both types of plans were to be drafted by different teams. The Benefit to Cost ratio is ‘medium’.

C4

Intervention Area C: What action should be mandated in case air quality standards are not respected?

Intervention / Measure

(C4) Introduce an obligation for effective short-term action plans for each pollutant to prevent / tackle air pollution events.

The problem: Air quality Implementation shortcomings

(Driver: Air quality plans and measures have often proven ineffective)

Description: This intervention consists of introducing in the revised AAQDs the obligation to adopt effective short-term action plans for all pollutants to prevent and tackle pollution events. This should be done by amending Article 24 of the 2008/50 Directive.

The 2008/50 Directive requires that action plans are drawn up indicating the measures to be taken in the short term "where there is a risk of an exceedance of one or more alert thresholds" (in order to reduce that risk and to limit its duration). However, alert thresholds (as defined in Annex XII of the 2008/50 Directive) only exist for NO_2 and SO2, and therefore short term action plans are not required for other pollutants such as PM_{10}.[34]

The Targeted Stakeholder Survey provided a few insights to this intervention. From those in favour of this measure, some suggest to expand the obligation to natural pollutants which have adverse effects on health as well, such as pollen and sand/dust storms. Those against this intervention argue either that short term action plans are not effective (e.g. an argument given by a national authority was that most pollution episodes cannot be influenced by local measures) or that it is not sensible to have such for each pollutant (.g. an argument by a national authority was that for secondary pollutants it is not straightforward identifying measures). In addition, a suggestion was made that the Ambient Air Quality Directives could also include a list of best practices in terms of short-term emergency measures, requiring competent authorities to consider such a list, when drawing up short-term plans.

Further, a regional authority at an interview remarked that short term action plans should remain an emergency tool for the abatement of alert threshold exceedances and therefore function as a last measure if attainment periods are missed. This was the aim of the Directive 96/62/EC of 27 September 1996 on ambient air quality assessment and management.[35]

Purpose/operational objective:

Strengthened regulation across the EU and protection of vulnerable groups (avoided negative health impacts caused by pollution events). Raising public awareness.[36]

Who would be impacted and how:

Directly:

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[34] The Fitness Check of the Ambient Air Quality Directives
[35] Targeted Stakeholder Survey (regional authority), Interview with Regional Authority
[36] Targeted Stakeholder Survey, Interview with Regional Authority

Direct impacts are expected in terms of air quality, health, sensitive groups and ecosystems affecting therefore citizens and society, as well as in terms of administrative burden for competent authorities.

Indirectly:

This intervention will impact competent authorities (mitigation cots, policy synergies), industry (mitigation costs, competitiveness), and society as a whole (climate, costs to society, employment, societal benefits and burden sharing). In addition the intervention may have an indirect effect on citizens as short-term measures may affect their behaviour for instance by limiting their access to private vehicle use.

For further details see 'Indicators' box below.

Risks for implementation:

1. Time-lag risk – For short-term action plans to be effective, these should be enacted quickly (to reduce emissions immediately). However, with episodic pollution events meteorological conditions can influence concentration levels very quickly (hours) which often does not allow sufficient time for measures within the STAP to take effect to control emissions.
2. Separation of source and pollution - Many pollution episodes cannot be influenced by local measures. In the case of O3 and $PM_{2.5}$, for example, the effectiveness of measures taken in a location would be limited and short-term action plans may not lead to air quality improvement. Short term measures can therefore be effective only for few pollutants[37]

Indicators

1. Air Quality	2. Impact on Health	3. Impacts on Ecosystems	4. Climate change links	5. Costs to society	6. Mitigation costs	7. Impacts on Competitiveness	8. Impacts on Sensitive Groups	9. Societal benefits and burden sharing	10. Impacts on Employment	11. Policy synergies	12. Administrative Burden
+	+	+	(+)	(+)	0 to -	(-)	+	(+)	(-)	(+)	-

Assessment

Effectiveness:

An obligation for effective short-term action plans for each pollutant would prompt further action to bring emissions and concentrations down compared to the current situation as agreed by the majority of stakeholders including authorities, NGOs and researchers. Hence this intervention can be considered to have an 'direct' positive effect on air quality [i.e. Air Quality (+)] protecting human health [i.e. Health (+)], including sensitive groups [i.e. Impacts on sensitive groups (+)], as well as ecosystems [i.e. Impacts on ecosystems (+)] from adverse impacts. In addition, short term action plans are effective above all to increase public awareness.[38]

Efficiency:

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[37] Targeted Stakeholder Survey (regional authority), Interview with Regional authority

[38] Targeted Stakeholder Survey (regional authority)

The indirect positive effects on health of this intervention would result in less lost labour days and reduced health care costs [i.e. Costs to society (+)]. As such its societal impact overall can be seen as positive [i.e. Societal benefits and burden sharing (+)]. Additional administrative burden is expected from this intervention as it imposes additional requirements (i.e. additional work) to competent authorities. The magnitude of the costs is difficult to estimate and would depend on each Member State considering the number of plans being developed and what the threshold will be for needing to develop one. A range has been provided based on expert judgement. This intervention builds on existing requirements but implies adding additional pollutants. Recurring costs would be associated with the need to continually develop the plans to be aligned with exceedances. Also, should action plans be enacted during an episodic event, mitigation costs could be high for the duration of the event. [i.e. Administrative burden].

The fact that this intervention could spare costs for society (reduced costs of people going to the hospitals with respiratory problems) was raised by a couple of NGOs at the Targeted Stakeholder Survey and interviews.

The impact of this intervention on costs is negligible or slightly negative. Countries which do not exceed alert thresholds will not be affected by this intervention [i.e. Mitigation costs (0)]. Countries which do, will have to bear the costs of having to prepare additional short term action plans for pollutants other than NO_2 and SO_2 [i.e. Mitigation costs (-)]. For these latter, this intervention will in addition carry indirect costs for different stakeholders such as competent authorities (as they will need to implement the measures drafted in their short term action plans) , business (stopping industrial operations).

If this intervention resulted in more rigorous measures to reduce emissions (e.g. stopping industrial and transport emissions) then employment and competitiveness could be impacted on those infrequent occasions during episodic events.

Coherence:

Because the sources of air pollution and greenhouse gas emissions tend to be the same, the measures implemented to reduce air pollution will also have a positive impact on greenhouse gas emissions [i.e. Climate change links (+)]. Because air pollution can significantly hurt the quality of soil and water resources, this intervention can be considered to indirectly support the zero pollution action plan of the EU [i.e. Policy synergies (+)]

Links to other interventions: [synergies / misalignment]

- **B2:** *Define alert thresholds and information thresholds for all air pollutants as triggers for alerting the public and taking short-term action:* When the public is alerted, an action plan is needed so that population is not gripped by panic. As such B2 requires C4 and these measures can be considered synergistic [Synergy]
- In addition, C4 will also be synergistic with all measures under Policy Area 1 which revise short-term air quality standards as if new daily limits are introduced (e.g. for $PM_{2.5}$) or existing daily PM_{10} or NO_2 are revised, these will have to be covered by short-term action plans in the new provisions. [Synergy]:
- O2 Introduce short-term air quality standards and/or alert/information thresholds
- P2 Revise short-term air quality standards and/or alert/information thresholds
- Q2 Revise (1hr) short-term air quality standards and/or alert/information thresholds
- R2 Revise short-term air quality standards and/or alert/information thresholds
- S2 Revise short-term air quality standards and/or alert/information thresholds

T1 Revise short-term air quality standards

Benefit to Cost ratio **Medium** – The benefits of this measure, stemming from the actions that would need to be taken, quickly, in the face of pollution episodes. As long as alert thresholds remain rare, costs would be low though. Costs would result from the need to having to produce short term action plans for pollutants.
Summary There is medium to high support from all stakeholders except for industry with NGOs being the most positive about the measure. Risks linked to this intervention have to do with time-lag risk and separation of source and pollution. This intervention is synergistic with a large number of other interventions such as and an intervention concerning quality standards (i.e. B2) and several interventions under Policy Area 1 revising short-term quality standards (i.e. O2, P2, Q2, R2, S2, T1). The Benefit to Cost ratio pf this intervention would be medium.

C5

Intervention Area C: What action should be mandated in case air quality standards are not respected?

Intervention / Measure

(C5) Mandate regular updates of air quality plans.

The problem: Air quality Implementation shortcomings

(Driver: Air quality plans and measures have often proven ineffective)

Description: This measure would introduce a legal duty for competent authorities to update air quality plans at regular intervals to keep exceedance periods as short as possible. Specific frequency of the update would be determined taking into account the administrative burden such updates entail. Based on feedback received from the Targeted Stakeholder Survey, updating air quality plans every 3 years is seen as reasonable by stakeholders[39].

This measure is intended to enhance effectiveness of air quality plans by ensuring the relevance of air quality plans and associated measures in a changing air quality context for a specific location (i.e. to ensure that measures in air quality plan address new challenges for air quality). It would be important to define what such updates entail i.e. to what extent air quality plans should be updated. Feedback from regional authorities received in response to the Targeted Stakeholder Survey note that:

- Updates should not necessarily require an update of all underpinning data/studies on emissions/sources and of scenario model runs but evaluate the effectiveness of the implemented measures and consider whether more measures are needed.
- New measures to tackle emerging exceedances could be adopted within existing plans, without having to draft a new plan.
- Updates should contain an evaluation of measures included in previous plans, and, if relevant, a motivation why these have not been taken or have not achieved the envisaged effects.

Purpose/operational objective:

Mandatory regular updates would be intended to increase the effectiveness of air quality plans by ensuring that measures in air quality plans address new challenges for air quality. Updates would also serve to assess the extent to which adopted measures have been effective to address air quality exceedances and to facilitate implementation (by having to regularly evaluate both the implementation and performance of the previous plan).

Who would be impacted and how:

Directly:

Direct impacts are foreseen for this intervention in terms of mitigation costs and administrative burden for competent authorities responsible for the updating of air quality plans and implementation of measures.

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[39] Based on responses to Targeted Stakeholder Survey where replies ranged from requiring revisions yearly to every 10 years, with a few stakeholders – including national and regional authorities - mentioning three (3) years as adequate.

Indirectly:

This intervention will indirectly impact competent authorities (policy synergies), the public (health) and society (indirect benefits to air quality, health, ecosystems, climate, costs to society, societal benefits and burden sharing, policy synergies).

For further details see ‘Indicators’ box below.

Risks for implementation:

Long process – Drafting air quality plans can take years (subject to consultation with multiple stakeholders e.g. regional governments, citizens and other) and need to be approved by the government.[40]

Indicators

1. Air Quality	2. Impact on Health	3. Impacts on Ecosystems	4. Climate change links	5. Costs to society	6. Mitigation costs	7. Impacts on Competitiveness	8. Impacts on Sensitive Groups	9. Societal benefits and burden sharing	10. Impacts on Employment	11. Policy synergies	12. Administrative Burden
(+)	(+)	(+)	(+)	(+)	-	0	0	(+)	0	(+)	----

Assessment

Effectiveness: Requiring regular updates of air quality plans would increase the effectiveness of plans and thus have an ‘indirect’ positive effect on air quality [i.e. Air Quality (+)] protecting human health [i.e. Health (+)] as well as ecosystems [i.e. Impacts on ecosystems (+)] from adverse impacts. Improvement to the effectiveness of the plans is expected as a result of updating the measures to ensure they are relevant as well as assessing the effectiveness of existing measures and their implementation.

This intervention will indirectly spare costs to society and therefore its societal impact overall can be seen as positive [i.e. Societal benefits and burden sharing (+)]. The fact that this intervention could spare costs for society (reduced costs of people going to the hospitals with respiratory problems) was raised by a couple of NGOs at the Targeted Stakeholder Survey and interviews.

Efficiency: The indirect positive effects on health of this intervention would result in less lost labour days and reduced health care costs [i.e. Costs to society (+)]. Through this intervention Member States would have to review air quality plans more frequently than they do now. As such this intervention will lead to direct costs for competent authorities responsible for updating the plans (i.e. regional authorities and local authorities) [i.e. Mitigation costs -]. Direct additional administrative burden is expected from this measure from having to update air quality plans more often. The costs will depend on the frequency of the updates of air quality plans mandated by the Commission. They would be associated with the number of plans (likely to be high) and the work needed to update them. Expert judgement suggests a high recurring cost as this is likely to be needed approximately every 3 years. [i.e. Administrative burden ---].

Some examples were provided by respondents to the Targeted Stakeholder Survey. In Czechia the cost associated with air quality plans development is circa ten million CZK (around 409,000 euro) for ten air quality plans covering the whole country. This amount does not include costs in terms of official

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[40] Targeted stakeholder survey (regional authorities)

adoption and consultation with local municipalities. The remaining cost is difficult to assess and it can range from 30 person-days for municipalities to couple of hundreds person days for the Ministry of the Environment. Another example was provided in the case of Berlin, for which it was estimated that a review of the local air quality plan would require 100-200k € for support studies/evaluations.

A national authority's reply to the Targeted Stakeholder Survey calls for involvement of the European Commission in the development of air quality plans to ensure that measures taken by each Member State complement each other and to ensure that elements with respect to transboundary air pollution are taken into account. If this were to be considered, the costs for the European Commission would be huge.

According to one national authority in response to the Targeted Stakeholder Survey, there is potential for cost savings whereby an effective air quality plan could end an exceedance sooner, thus removing the obligation to have an air quality plan and the associated administrative burden over a longer timeframe.

Coherence: The measures implemented to reduce air pollution will also have a positive impact on greenhouse gas emissions [i.e. Climate change links (+)] (because the sources of air pollution and greenhouse gas emissions tend to be the same). This intervention can be considered to indirectly support the zero pollution action plan of the EU [i.e. Policy synergies (+)] (because air pollution can significantly hurt the quality of soil and water resources).

Links to other interventions: [synergies / misalignment]

- **C1:** *Further specify the obligation to take measures to keep exceedance periods as short as possible*: Updates to air quality plans are time consuming. As such specifying the measure to be included in such plans further would be helpful [Synergy]
- **C2:** *Reformulate the term "as short as possible" with a defined time period*: Updates to air quality plans may take years which is at odds with the purpose of intervention C1. More regular updates could help align these two interventions [Synergy]
- **C3:** *Require a clearer coordination between short-term action plans and air quality plans*: C3 requires C5 to consider short term action plans in air quality plan updates. This is not necessarily a synergy nor a misalignment.
- **D1:** *Establish a requirement for Member States to involve specific actors in air quality plan development and to specify coordination arrangements for the development and implementation of air quality plans*. D1 would require bringing relevant stakeholders together every time an air quality plan is updated. This is not necessarily a synergy nor a misalignment.

Benefit to Cost ratio

Medium – This intervention can bring high indirect benefits resulting from more effective air quality plans. For countries (regions and municipalities) which face exceedances, this measure will result in additional costs for having to update plans regularly and so the Benefit to Cost ratio will be 'medium'.

Summary

This intervention received very high support by all stakeholders except for industry, and was considered the most effective intervention in intervention area C. The intervention would be synergistic with a couple of other measures mandating action if air quality standards are not complied with (C1, C2). The only risk identified with regards to this measure have to do with the fact that process of drafting air quality plans tends to be long. The Benefit to Cost ratio of the intervention is medium.

M1

Intervention Area M: How to assess and address transboundary air pollution in local/regional air quality management?

Intervention / Measure

(M1) Require the use of an agreed methodology when assessing transboundary air pollution/contributions to local/regional air pollution.

The problem: Air quality Governance shortcomings

(Drivers: Local air quality is impacted by emissions outside control)

Description:

This measure consists of an update Article 25 of the 2008/50 Directive to require Member States at bordering countries to use an agreed methodology for assessing transboundary air pollution and its contribution to local/regional air pollution. Such a common methodology would help competent authorities to assess the relevance of transboundary transport, avoiding disagreements on the evidence and magnitude of transboundary pollution, and in turn facilitate bilateral discussions.

Member States face intra-EU transboundary air pollution as well as air pollution from non-EU countries. Currently Article 25 of the 2008/50 Directive states that Member States concerned with transboundary pollution 'shall' cooperate to mitigate air pollution (for instance through drawing joint or coordinated air quality plans). The Fitness Check findings highlight that the lack of coordination is likely to affect the understanding of which measures may prove most useful and effective. By offering a common methodology to assess transboundary air pollution, such coordination can be enhanced.

It should be noted that at the Targeted Stakeholder Survey some regional authorities, who were in favour of such an intervention, mentioned that there should be freedom of choice.

Purpose/operational objective:

Such a standardised methodology will facilitate Member States at bordering countries to calculate transboundary air pollution and its contribution to local/regional air pollution helping avoid potential disagreements on the evidence and magnitude of pollution. This will in turn serve to determine the extent to which the pollution reduction can be achieved and will inform air quality plans especially on hotspot zones near country boundaries.

Who would be impacted and how:

Directly:

Competent authorities in Member States where transboundaryy pollution is an issue would be impacted directly (in terms of administrative burden) by this intervention as they are the users of the methodology.

Indirectly:

Citizens across Europe and beyond would benefit if wider co-operation on transboundary pollution leads to improved air quality plans that consequently resulted in better air quality. Therefore, in terms of the indicators assessed below citizens would be impacted indirectly (in terms of health), and so would society as a whole (air quality, climate, ecosystems). Competent Authorities would also be indirectly impacted, in terms of mitigation costs and policy synergies.

Risks for implementation:

1. Governance risk as it may be unclear where the responsibility lies for transboundary pollution assessment and action e.g. regional authorities or national authorities.
2. Assessment expertise as estimating transboundary contributions to pollutions can be complex involving chemistry models. There is a risk that this expertise capacity is limited in some Member States and more likely to be available at the national rather than local level.

Indicators

1. Air Quality	2. Impact on Health	3. Impacts on Ecosystems	4. Climate change links	5. Costs to society	6. Mitigation costs	7. Impacts on Competitiveness	8. Impacts on Sensitive Groups	9. Societal benefits and burden sharing	10. Impacts on Employment	11. Policy synergies	12. Administrative Burden
(+)	(+)	(+)	(+)	0	0 to (+)	0	0	0	0	(+)	--

Assessment

Effectiveness:

A legal agreed common methodology to assess transboundary air pollution is not yet in place, although there are agreements for many aspects through the Cooperative Programme for Monitoring and Evaluation of the Long-range Transmission of Air Pollutants in Europe (EMEP) and specifically their Task Force on Measurements and Modelling. However, the effectiveness of this intervention to improve air quality is impacted by the willingness of Member States to co-operate, agree and implement mitigation measures within a joint air quality plan.

As such, this intervention is expected to have an impact indirectly on air quality [i.e. Air quality (+)] and in turn on public health [i.e. Impact on Health (+)] and on ecosystems [i.e. Impacts on Ecosystems].

Efficiency:

Implementing this intervention would imply additional costs for Member States who do not have the adequate competency to measure and model transboundary pollution in place [i.e. Administrative burden -]. As raised by an academic/research institution in response to the Targeted Stakeholder Survey, in order to quantify sources (including precursors) of transboundary air pollution, seamless interplay of i) dense enough networks of comprehensive observations , ii) accurate monitoring of basic air pollutants (including aerosol particle number concentrations and black carbon) and iii) state-of-the-art atmospheric modelling are required. In addition, the costs of this measure would depend on the level to which existing models and data (e.g. EMEP/CAMS) on background level concentrations are used in this method or not as modeling techniques can be very time demanding with respect to the preparation of the input data and also with respect to running the modeling exercise itself. On the other hand this intervention would facilitate initiating talks and cooperation on transboundary air pollution, sparing Member States time negotiating and trying to agree on the evidence concerning air pollution, thereby reducing administrative burden [i.e. Administrative Burden -]. This is however not expected to be sufficient to offset the increased administrative burden of having to put the aforementioned competency in place, and so for countries who do not have that in place, administrative burden would decrease.

In addition, the intervention is expected to lead indirectly to additional mitigation costs [0/(-)] as competent authorities across Member States where transboundary pollution is an issue will have to adapt their air quality plans and implement further measures to reduce transboundary pollution.

A national authority in the Targeted Stakeholder Survey mentioned that reliable modelling would require transboundary exchange of emission data requiring more work from competent authorities.

Coherence:

Transboundary air pollution is primarily addressed by the NEC Directive (Directive 2016/2284/EU) and the Convention on Long-range Transboundary Air Pollution (CLRTAP) and so provisions on transboundary air pollution in the Ambient Air Quality Directives should be in line and complementary to this. In particular, the methodology used in the EMEP (European Monitoring and Evaluation Programme) for international co-operation to solve transboundary air pollution problems under the CLRTAP should be taken into account. In addition, this intervention is also linked to the Charter of the United Nations and the principles of international law, in which countries have the responsibility to ensure that activities within their jurisdiction or control do not cause damage to the environment of other Member States or of areas beyond the limits of national jurisdiction. In this regard policy synergies can be considered positive, again this impact being indirect [i.e. Policy synergies]. Also, since the measures implemented to reduce air pollution tend to also have a positive impact on greenhouse gas emissions, the potential joint cooperation stemming from having a joint methodology to calculate transboundary pollution can be considered to have an indirect positive effect on climate change too [i.e. Climate change links (+)].

Links to other interventions: [synergies / misalignment]

- M2: *Require transboundary cooperation and joint action on air quality if assessments of transboundary air pollution/contributions above certain thresholds (to be defined)*. The harmonised approach for assessing transboundary pollution (M1) is a necessary requirement to provide the database for further international collaboration in M2 [Synergy]

Benefit to Cost ratio:

High – The benefits of the intervention, albeit indirect, are likely to outweigh expected costs. Additional costs are unlikely to apply to all Member States dealing with transboundary issues in bordering countries as many will already be taking transboundary emission contributions into account within their modelling systems.

Summary:

The Targeted Stakeholder Survey showed that there is very high to full support from all stakeholders for this intervention. Work would need to be done to align the provision with other legislation were transboundary air pollution is considered such as the NEC Directive. The risks linked to the implementation of this measure have to do with governance and with having sufficient assessment expertise. The only synergy identified with this measure have to do with M2 on requiring transboundary cooperation and joint action. Its Benefit to Cost ratio is high.

M2

Intervention Area M: How to assess and address transboundary air pollution in local/regional air quality management?

Intervention / Measure

(M2) Require transboundary cooperation and joint action on air quality if assessments of transboundary air pollution/contributions above certain thresholds (to be defined).

The problem: Air quality Governance shortcomings

(Drivers: Local air quality is impacted by emissions outside control)

Description: The AAQD would require EU Member States at bordering countries to engage in joint action on air quality with neighbouring non-EU countries in cases where air pollution reaches a certain threshold.

Member States face intra-EU transboundary air pollution (as well as pollution coming from non-EU countries) which cannot be reduced by one country alone. Article 25 of the 2008/50 Directive states that Member States concerned with transboundary pollution 'shall' cooperate to mitigate air pollution for instance through drawing joint or coordinated air quality plans. However, such action is currently voluntary and the provision does not specify above which thresholds Member States should seek this cooperation which, in practice, results in lack of cooperation.

Purpose/operational objective:

Specifying the thresholds clarifies when Member states need to cooperate with their non-EU neighbours and requiring cooperation in such cases leaves Member States no choice but to act.

Who would be impacted and how:

Directly:

Competent authorities can expect to be impacted directly regarding costs as well as administrative burden.

Indirectly:

Indirect impacts are expected indirectly for citizens (on health) and society (air quality, ecosystems, climate change, costs to society and policy synergies).

Risks for implementation:

1. Enforcement - Member States do not have the authority to the demand any actions to be taken by another Member State.[41]
2. Costs – This intervention would not solve the problem identified by the Fitness Check linked to the low transboundary cooperation taking place namely the lack of resources at local/regional authority level to solve issues.
3. Acceptability - It may be controversial to make polluters pay for improving air quality in downwind regions.[42] Therefore there is a risk that this intervention will not be acceptable to Member States, business or polluters who may be faced with additional costs.

Indicators

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[41] Targeted Stakeholder Survey (national authority)

[42] Targeted Stakeholder Survey (National level research bodies, metrological offices and environment agencies)

1. Air Quality	2. Impact on Health	3. Impacts on Ecosystems	4. Climate change links	5. Costs to society	6. Mitigation costs	7. Impacts on Competitiveness	8. Impacts on Sensitive Groups	9. Societal benefits and burden sharing	10. Impacts on Employment	11. Policy synergies	12. Administrative Burden
(+)	(+)	(+)	(+)	(+)	-	0	0	0	0	(+)	-

Assessment

Effectiveness:

Requiring joint transboundary cooperation above a specific threshold would foster transboundary cooperation and in turn improve air quality in bordering regions [i.e. Air quality]. protecting human health [i.e. Health (+)], as well as ecosystems [i.e. Impacts on ecosystems (+)] from adverse impacts. The impact on sensitive groups in particular is considered small. The intervention would indirectly spare costs to society and therefore its societal impact overall can be seen as positive [i.e. Societal benefits and burden sharing (+)]. Further, because the sources of air pollution and greenhouse gas emissions tend to be the same, joint cooperation to reduce air pollution is expected to also have a positive impact on greenhouse gas emissions (i.e. Climate change links (+)]. In a similar vein, because air pollution can significantly damage the quality of soil and water resources, this intervention can be considered to indirectly support the zero pollution action plan of the EU (i.e. Ecosystems (+) and Policy synergies (+)).

There were mixed views from stakeholders from the Targeted Survey at what government level should be responsible for transboundary pollution co-operation. A national authority supported that it should be dealt with at the EU level, not by Member States. A regional authority indicated that transboundary cooperation should be required if transboundary pollution is above 5 or 10% on the exporting country's end. An interview with another regional authority indicated that adequate threshold for the Ambient Air quality Directive to demand joint cooperation in the form of a joint air quality plan could be 20/30%.

Efficiency:

The indirect positive effects on health of this intervention would results in less lost labour days and reduced health care costs (i.e. Costs to society (+)).

Implementing this intervention would imply additional costs for competent authorities in bordering countries were transboundary pollution is an issue. This costs would stem from having to mobilise resources (e.g. appoint a responsible person) for having to design join air quality plans [i.e. Mitigation costs -]. One NGO respondent to the Targeted Stakeholder Survey mentioned that complying with this intervention (including measuring transboundary pollution of M1) would require one air quality specialist per country, amounting approximately 50.000 EUR per year. Another NGO at an interview mentioned potential additional costs of translation of air quality plans (albeit negligible).

In the same vein, administrative burden would increase [i.e. Administrative burden -] due to the time that will have to be spent on cooperating, negotiating etc. A high one-off cost associated to this intervention would be incurred by competent authorities in those bordering Member States were transboundary pollution is an issue. Expert judgement suggests that costs would stem from having to mobilise resources to design joint air quality plans, carry out regional scale modelling and assess the impact of transboundary mitigation measures.

Coherence:

Transboundary air pollution is primarily addressed by the NEC Directive (Directive 2016/2284/EU) and the Convention on Long-range Transboundary Air Pollution (CLRTAP) Gothenburg Protocol and so provisions on transboundary air pollution in the Ambient Air Quality Directives should be in line and complementary to this.

Links to other interventions: [synergies / misalignment]

- D2: Introduce a requirement for Member States to harmonise air quality plans and air quality zones (and require a 'one zone, one plan' approach). The 'one zone one plan' approach could be a barrier for transboundary cooperation between countries [Misalignment]
- M1: *Require the use of an agreed methodology when assessing transboundary air pollution/contributions to local/regional air pollution*. The harmonised approach for assessing transboundary pollution (M1) is a necessary requirement to provide the database for further international collaboration in M2 [Synergy]

Benefit to Cost ratio:

Medium – The benefits of this intervention are numerous – albeit indirect – but the costs and admin burden generated by it are also significant.

Summary:

There is very high to full support for this intervention from all stakeholders overall as for Member States suffering from transboundary air pollution, reducing concentrations is to a certain or large extent dependent on dealing with transboundary pollution. Some public authorities and research & academia showed some reservations against this measure. The risks of implementation linked to this intervention have to do with enforcement, costs (or lack of funds) at local/regional authority level and acceptability of authorities and industry to implement measures to bring air improvements elsewhere. This intervention is synergistic with M1 on requiring an agreed methodology when assessing transboundary air pollution as is in misalignment with D2 on requiring a 'one zone, one plan' approach. Its Benefit to Cost ratio is medium/high.

D1

Intervention Area D: Who should be involved in the preparation of air quality plans, and how should their preparation and implementation be coordinated?

Intervention / Measure

(D1) Establish a requirement for Member States to involve specific actors in air quality plan development and to specify coordination arrangements for the development and implementation of air quality plans.

The problem: Air quality Governance shortcomings

(Driver: Some measures may seem disproportionate, ineffective)

Description: This measure would require Member States to involve all relevant actors in the drafting of air quality plans and coordinate better with these. Actors may include national/regional/local competent authorities, sectoral representatives from polluting industries, research institutes, civil society and local citizens. To this purpose, the revised AAQ Directives (Article 24 and / or Annex XV of the Directive 2008/50) should include the following concerning the preparation of air quality plans 1) a requirement for consulting and involving government authorities at various levels, and 2) a new 'public participation' clause for the development of air quality plans. The revised Directives should specify which aspects of the planning process should be open to public consultation and what this should involve.

The problem that this measure is trying to address is that since there are no requirements on how to allocate roles and responsibilities in air quality plans, cooperation between government authorities at various levels is not a given. This can lead to insufficient action being taken by public authorities or to a mismatch of action, and therefore to air quality plans and measures being insufficient, inefficient and/or ineffective. In addition, while air quality remains a top environmental concern for EU citizens, citizens are not systematically consulted in the development of air quality plans. This could contribute to air quality plans and measures proving ineffective.

The Targeted Stakeholder Survey provided several suggestions for the ins and outs of this measure. The importance of source apportionment in identifying which actors are the most important to involve was raised by a national authority. Another national authority called for the involvement of the European Commission for aspects such as transboundary air pollution. NGOs added that however, it is essential that the Ambient air Quality Directives either identify one single authority that is overall responsible for compliance or explicitly identify the responsibilities attributed to national, regional and local authorities in implementing the measures. An industry representative proposed that such bringing together of relevant actors is done via the establishment of working groups.

Purpose/operational objective:

Increase in the acceptance and relevance of action (and indirectly therefore positive impact on air quality), help clarify responsibilities of each government level and hence increase in effectiveness and efficiency of the measures adopted.

Who would be impacted and how:

Directly:

The only direct impacts expected from this measure is on mitigation costs (in some cases) and administrative burden (in some cases).

Indirectly:

This intervention will indirectly impact air quality, health and ecosystems.

For further details see ‘Indicators’ box below.

Risks for implementation:

1. Missing out on important actors – If the revised Directive were to prescribe which actors to involve, there is the risk that either important actors will be missed or that actors that are not so relevant are involved. Source apportionment of air pollution can vary between countries, regions and cities.[43]
2. Agreement - Even if a comprehensive list of specific actors for inclusion in the drafting of air quality plans was included in the revised Directive, there could still be issues of gaining acceptance for measures and ensuring responsibility for measures taken.[44]

Indicators

1. Air Quality	2. Impact on Health	3. Impacts on Ecosystems	4. Climate change links	5. Costs to society	6. Mitigation costs	7. Impacts on Competitiveness	8. Impacts on Sensitive Groups	9. Societal benefits and burden sharing	10. Impacts on Employment	11. Policy synergies	12. Administrative Burden
(+)	(+)	(+)	0	0	0 to -	0	0	0	0	0	--

Assessment

Effectiveness:

Requiring Member States to involve specific actors in air quality plan development and to specify coordination arrangements for the development and implementation of air quality plans would increase the effectiveness of these. Hence this intervention can be considered to have an ‘indirect’ positive effect on air quality [i.e. Air Quality (+)] protecting human health [i.e. Health (+)] as well as ecosystems [i.e. Impacts on ecosystems (+)] from adverse impacts.

Efficiency:

The costs that this intervention is expected to generate are related to increased interaction / communications between various government authorities and between these and other stakeholders [i.e. Mitigation costs -] in the case of Member States which do not have such a requirement / do not do this yet.[45] Similarly, the measure is expected to cause direct additional administrative burden [i.e. Administrative burden ---] just for those Member States who currently do not do the effort to include all stakeholders. Each Member State will have several plans but not all of their regions will likely need to have one. Expert judgement suggests the recurring costs associated with this measure would be high as for each plan, it would imply consulting and engaging with several stakeholder groups.

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[43] Targeted Stakeholder Survey (national authorities)
[44] Targeted Stakeholder Survey (national authorities)
[45] In several Member States, such consultation across government levels and with the public is already done

No impact is expected in terms of employment nor of EU competitiveness upon the implementation of this measure.

Coherence:

No clear links are seen between the intervention and the indicators that have to do with efficiency.

An NGO respondent to the Targeted Stakeholder Survey made the remark that public participation on draft air quality plans is mandatory under the Public Participation Directive 2003/35/EC. Another NGO suggested that the Ambient Air Quality Directives take inspiration from the provisions in the NEC Directive (EU) 2016/2284, regarding multilevel governance and involvement of stakeholders (Article 6(5) NEC Directive and Annex III).

Links to other interventions: [synergies / misalignment]

- **C5:** *Mandate regular updates of air quality plans:* D1 would require bringing relevant stakeholders together every time an air quality plan is updated. This is not necessarily a synergy nor a misalignment.
- **D2:** *Introduce a requirement for Member States to harmonise air quality plans and air quality zones (and require a 'one zone, one plan' approach):* D1 and D2 seem to be synergistic [i.e. +] in the sense that D1 has to do with involving all relevant stakeholders and the 'one zone one plan' approach is expected to require the involvement of more stakeholders.
- **M2:** *Require transboundary cooperation and joint action on air quality if assessments of transboundary air pollution/contributions above certain thresholds (to be defined):* D1 would require that all relevant transboundary stakeholders are considered in transboundary action. This is not necessarily a synergy nor a misalignment.
- **N1:** *Refine the minimum information to be included in an air quality plan:* D1 would require that the governance and coordination activities are included in the information of the air quality plan. This is not necessarily a synergy nor a misalignment.

Benefit to Cost ratio

High – stakeholder involvement is widely considered to be the means to more effective and ambitious air quality plans while the costs of involving stakeholders would not be very significant (and many countries already do it so it would not imply additional costs to them).

Summary

This measure received high support from all stakeholders overall in the Targeted Stakeholder Survey, although among public authorities and research and academia a couple of stakeholders did not consider it effective. NGOs and industry were only positive about this intervention. The risks of this intervention are not many and the Benefit to Cost ratio is high.

D2

Intervention Area D: Who should be involved in the preparation of air quality plans, and how should their preparation and implementation be coordinated?
Intervention / Measure **(D2) Introduce a requirement for Member States to harmonise air quality plans and air quality zones (and require a 'one zone, one plan' approach).**
The problem: Air quality Governance shortcomings (Drivers: Some measures may seem disproportionate, ineffective; Local air quality is impacted by emissions outside control)
Description: This measure would further define the requirements for drawing air quality plans in Article 23 of the 2008/50 Directive to require that one zone has to fully overlap with one plan (and hence avoiding zones with multiple plans and plans for multiple zones). This measure aims to increase the effectiveness of the Ambient Air Quality Directives by tackling the current mismatch between the zones of air quality monitoring and air quality plans. From the Targeted Stakeholder Survey it seems that for those countries following the 'one zone one plan' approach, this is the most cost-efficient approach (e.g. Czechia) but that for Member States who do not follow this approach, the administrative effort required to change their systems would be large. Arguments against this intervention in the Targeted Stakeholder Survey revolve around changes that would be needed in terms of governance / responsibilities as well as around additional administrative burden that the intervention would lead to (see the box on 'Risks' for further details).
Purpose/operational objective: Increase in the relevance of action (i.e. increase in effectiveness of air quality plans), clearer division of roles / responsibilities / distribution of tasks leading to more effective implementation, and harmonization of approaches across the EU.
Who would be impacted and how: ***Directly:*** The only direct impact that this intervention will lead to is administrative burden. ***Indirectly:*** No indirect impacts are foreseen for this intervention. For further details see 'Indicators' box below.
Risks for implementation: • Geographical challenge - Difficult to administrate an air quality plan in zones that are geographically very large but not very densely populated (e.g. Sweden).[46]

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[46] Targeted Stakeholder Survey (national authority)

- Governance challenge – It is not clear which authority would then adopt an air quality plan for an entire zone. While currently local municipalities tend to adopt plans, adopting a plan for a zone would likely shift this responsibility to national or regional authorities, while exceedances will have to still be tackled to a large extend with local measures.[47]
- Governance challenge - In Member States where plans are managed by municipalities, a 'one zone, one plan' approach will require authorities to either combine existing air quality plans, change the number of zones or move the responsibility of air quality management to another level of government.[48]
- Geographical challenge – The approach for drafting air quality plans depends on air quality zoning in a Member State. For smaller countries, one zone could include more than one city and therefore it would not be very effective to make one plan for a whole zone.[49]
- Unnecessary increase in administrative burden - As emission sources linked to exceedances are often the same in different zones (and thus can be dealt in one plan), a 'one zone one plan' approach would increase administrative burden unnecessarily and could lead to fragmentation of strategies instead of a common and consistent approach[50].

Indicators

1. Air Quality	2. Impact on Health	3. Impacts on Ecosystems	4. Climate change links	5. Costs to society	6. Mitigation costs	7. Impacts on Competitiveness	8. Impacts on Sensitive Groups	9. Societal benefits and burden sharing	10. Impacts on Employment	11. Policy synergies	12. Administrative Burden
0	0	0	0	0	0	0	0	0	0	0	--

Assessment

Effectiveness:

No clear links are seen between the intervention and the indicators that have to do with effectiveness. Overall responses by various types of stakeholders to the Targeted Stakeholder Survey suggest that the 'one zone one plan' is not decisive for the successful enforcement of measures.

Efficiency:

No clear links are seen between the intervention and the indicators that have to do with efficiency with except from administrative burden which would increase [i.e. Administrative burden --]. A reason for this provided at the Targeted Stakeholder Survey was that more actors would need to be involved, making the process for adopting plans even more complicated.[51] A medium recurring cost is expected to be incurred by Member States to continuously harmonise current and future air quality plans with air quality zones, as there are generally a large number of both of them.

Coherence:

No clear links are seen between the intervention and the indicators that have to do with efficiency.

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[47] Targeted Stakeholder Survey (national authority)
[48] Targeted Stakeholder Survey (national authority)
[49] Targeted Stakeholder Survey (national authority)
[50] Targeted Stakeholder Survey (national authority, regional authority)
[51] Targeted Stakeholder Survey (national authority)

No remarks concerning coherence with regards to this intervention have been extracted from the stakeholder consultation activities.

Links to other interventions: [synergies / misalignment]

- **D1:** *Establish a requirement for Member States to involve specific actors in air quality plan development and to specify coordination arrangements for the development and implementation of air quality plans:* D1 and D2 seem to be synergistic [i.e. +] in the sense that D1 has to do with involving all relevant stakeholders and the 'one zone one plan' approach is expected to require the involvement of more stakeholders.
- **M2:** *Require transboundary cooperation and joint action on air quality if assessments of transboundary air pollution/contributions above certain thresholds (to be defined):* The 'one zone one plan' approach could be a barrier for transboundary cooperation between countries. There is thus misalignment between these measures (-).

Benefit to Cost ratio

Low – The benefits and added value of this intervention are unclear while it would generate some costs (and considerable administrative burden).

Summary

Mixed results were obtained in the Targeted Stakeholder Survey with regards to the effectiveness of this measure. The majority of public authorities, industry and academia supported the intervention to some extent or to a large extent, but several others not supporting it at all. The views are particularly mixed for public authorities, with some of these supporting the measure 'fully' but a large number not supporting it at all. Overall it is unclear what the added value of this intervention would be (it does not seem to solve a big problem) and a global approach does not seem helpful as air quality plans and air quality zones are very specific to local conditions.

E1

Intervention Area E: What legal tools should be available to address breaches of the obligations

Intervention / Measure

(E1) Introduce minimum levels for financial penalties.

The problem: Air quality Implementation shortcomings

(Driver: Insufficient penalties and compensation linked to exceedances)

Description:

This intervention aims to expand the current provisions on penalties in the Ambient Air Quality Directives (Article 30 of Directive 2008/50/EC) to specify the magnitude of the financial penalties to be paid. in cases of failure to comply with air quality standards by establishing a minimum level for such. These penalties would be directed to competent authorities as well as industry and should lead to penalties or sanctions that are high enough to be effective and dissuasive.

The need for such an intervention is derived from the Fitness Check which concluded that damages linked to exceedances are not always addressed sufficiently. While penalties are a matter for Member States, the Fitness Check of the Ambient Air quality Directives concluded that there is potential for a stronger role for the European Commission to enforce the use of penalties.

Moreover, there is a general perception by several stakeholders[52] that financial penalties given to Member States seem not to be sufficient to discourage exceedances of air quality standards. In addition, the number of continued exceedance situations can be seen as an indication that Member State penalties are not sufficiently effective, proportionate nor dissuasive, with the effect that the legislation has not been adequately implemented. Further, financial sanctions at the moment differ from Member State to Member State leading to an uneven playing field across the EU.

The Targeted Stakeholder Survey provided suggestions on how to put this intervention into practice. An NGO argued that the provision in the Directive should include the following list of factors to be taken into account when calculating penalties:

- Level of exceedance - the nature, gravity and duration of the infringement;
- The intentional or negligent character of the infringement;
- First time vs recurring - any relevant previous infringements in the relevant zone or agglomeration;
- Length of exceedance - the environmental impact and the health effects, taking into account the likely population level impact of the infringement;
- The need to ensure that the penalty itself is a deterrent to further infringements.
- Costs incurred by exceedance (e.g. hospital costs).

In addition, the same NGO remarked that penalty system should issue fines to be paid periodically while there is ongoing non-compliance, ending only once the breach has been remedied and added that 'obligations' under this intervention would encompass:

- Exceedances of *limit values*;

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[52] As demonstrated by inputs from stakeholders to the Inception Impact Assessment of the Ambient Air quality Directives and later on confirmed by the replies to the Open Public consultation and Targeted Stakeholder Survey.

- Breaches of the obligation to attain compliance with the *national exposure reduction target* and *exposure concentration obligations*;
- Breaches of the obligation to take the necessary steps in the event of *information or alert thresholds* being exceeded;
- Breaches of the obligation to *assess* ambient air quality.

Purpose/operational objective:

Establishing minimum requirements on penalty levels should discourage Member States from breaching air quality standards (and therefore lead to better air quality). In addition, the aim of such an intervention would also provide further clarity and harmonisation of rules across all Member States.

Who would be impacted and how:

Directly:

Local and regional competent authorities in Member States would be impacted by this intervention when breaching air quality standards. Central governments would need to adapt their penalties to these new minimum levels demanded by the EU. In addition, emitters of pollution (business/industry) would be directly impacted as they would be liable to fines, dependent on how the Member State cascades the fines to the local level.

This intervention would not carry direct impacts with it in terms of the indicators assessed below.

Indirectly:

Indirect impacts for competent authorities and business/industry (in terms of mitigation costs), for citizens/individuals (in terms of health) and for society (in terms of air quality, ecosystems, climate, costs to society ad societal benefits and burden sharing) are expected from this intervention.

Further elaboration on the impacts is found below under the 'Indicators' section.

Risks for implementation:

- Determining accountability - The causes of beaches are many and sometimes difficult to identity and as such, it is difficult to hold one legal entity responsible for such breaches.[53] Even when the cause is known, it may be hard to determine who is responsible for it. For instance, take NOx emitted by diesel cars, there are many actors including vehicle manufacturing, the EU who set the required emission control legislative standards and Member States who provide incentives to encourage the uptake of diesel cars to local authorities who can implement local traffic control measures.[54]
- In many countries one administration (for instance the national government) cannot penalize another one (for instance, a municipality)[55]
- Enforcement– For minimum penalty levels to be effective, Member States need to have a working legal system that are going to enforce this[56].
- Agility of process – For minimum penalty levels to be effective, action against air quality breaches needs to be timely[57] and consequently, infringement procedures need shortening significantly.[58]

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[53] Targeted Stakeholder Survey (National authority)

[54] Interview with regional authority

[55] Targeted Stakeholder Survey (National level research bodies, metrological offices and environment agencies)

[56] Interview with NGO

[57] Targeted Stakeholder Survey (NGO)

[58] Interview with regional authority

Indicators											
1. Air Quality	2. Impact on Health	3. Impacts on Ecosystems	4. Climate change links	5. Costs to society	6. Mitigation costs	7. Impacts on Competitiveness	8. Impacts on Sensitive Groups	9. Societal benefits and burden sharing	10. Impacts on Employment	11. Policy synergies	12. Administrative Burden
(+)	(+)	(+)	(+)	(+)	(-)	0	0	(+)	0	(+)	(-)

Assessment

Effectiveness:

Effective minimum penalty levels should discourage competent authorities and industry from breaching air quality standards. As such this intervention is considered to have an indirect positive effect on bringing emissions and concentrations down [i.e. Air Quality]. The link between higher penalties and better air quality is mainly made by NGO respondents to the Targeted Stakeholder Survey.

As such, this intervention would indirectly improve the health of the public [i.e. Impacts on health (+)] and protect ecosystems and nature [i.e. Impact on ecosystems].

Efficiency:

This intervention, if effective, would lead to competent authorities and industry implementing more measures to avoid breaches (and therefore avoid the high fines) and as such will indirectly generate additional costs for these actors. The impact of this intervention on administrative burden is negligible.

The indirect positive effects on health of this intervention would result in less lost labour days and reduced health care costs [i.e. Costs to society (+)]. As such its societal impact overall can be seen as positive [i.e. Societal benefits and burden sharing (+)]. In this regard, NGO respondents to the Targeted Stakeholder Survey stress that financial costs of inaction would be far greater than the costs of adopting this new policy.

A low one-off cost [Administrative burden: -] is potentially expected to be incurred by the Member States related to setting the financial penalties if the Commission only sets the criteria for this to be done.

Coherence

The actions that lead to the reduction of air pollution would also have a positive impact on greenhouse gas emissions [i.e. Climate change links (+)] (because the sources of air pollution and greenhouse gas emissions tend to be the same). This intervention can be considered to indirectly support the zero pollution action plan of the EU [i.e. Policy synergies (+)] (because air pollution can significantly hurt the quality of soil and water resources).

Links to other interventions: [synergies / misalignment]

- C2: *Reformulate the term "as short as possible" with a defined time period*. Penalties should align to ensure compliance with C2 [Synergy]
- E3: *Set up a fund to be fed by the payment of penalties and which can be used to compensate material damage or finance air quality measures*. The payments for breaching air quality as per E1 would be used to set up such a fund [Synergy]

Benefit to Cost ratio:

Medium/High – Although positive impacts on air quality generated by this intervention would be only indirect, they are numerous and would outweigh the indirect costs generated by the intervention.
Summary: This intervention is the most supported intervention from intervention area E with the majority of stakeholders across the various categories of stakeholders supporting the intervention very much or fully. Some public authorities and research & academia respondents were against it though. The risks for implementation have to do with determining who is accountable for breaches, difficulties with enforcement and the need for an agile system. The intervention would be synergistic with another measure concerning penalties (i.e. E3) and with a measure concerning action to be mandated in case air quality standards are not respected (i.e. C2). The Benefit to Cost ratio of this intervention is Medium/High.

E2

Intervention Area E: What legal tools should be available to address breaches of the obligations

Intervention / Measure

(E2) Introduce specific provisions that guarantee a right to compensation for damage to health.

The problem: Air quality Implementation shortcomings

(Driver: Insufficient penalties and compensation linked to exceedances)

Description:

This intervention would introduce an explicit statement within the revised Ambient Air Quality Directives codifying the right to compensation for damage to health caused by breaches to the Ambient Air Quality Directives. The principle of state liability allows for individuals to seek compensation in a domestic setting for harm suffered as a result of Member State non-compliance with any EU law. The application of this principle of state liability to breaches of Member States' obligations under the Ambient Air Quality Directives is the subject of a preliminary reference currently before the CJEU in Case C-61/21 Minister de la Transition écologique and Premier minister. The preliminary reference in Case C-61/21 provides an opportunity to clarify explicitly the right of individuals affected by air pollution to receive compensation for breaches of the AAQD.

The reason for this intervention is that while there is overwhelming epidemiologic evidence on the negative health impacts of air pollution on the population, exceedances still take place (albeit the frequency, extent and magnitude of these has generally improved since 2008) and damages linked to these are not always addressed sufficiently.

Purpose/operational objective:

While the main purpose of this intervention is to enable compensation damage claims by those who suffered health impacts from excessive levels of air pollution, it also serves to encourage Member States to reduce emissions to achieve compliance with limit values.

Who would be impacted and how:

Directly:

This intervention would directly affect citizens who have experienced harm to their health as a consequence of air pollution above legal limits, who would receive compensation for the damages caused. It would also affect competent authorities and industry (polluters) (in terms of mitigation costs and administrative burden).

Indirectly:

This intervention if effective would indirectly affect citizens (health) and society (air quality, ecosystems, climate, costs to society, societal benefits and burden sharing). It would also affect competent authorities (policy synergies,).

Risks for implementation:

- Difficulty to prove – Estimating / proving damage to health by breaches of air quality standards is very complex since health is also impacted by other factors besides air pollution e.g. lifestyle, indoor air pollution.[59]
- Accountability – It can be difficult to determine who should be held responsible for the breaches of air quality standards.[60]
- Risk of abuse - The intervention could lead to a large increase in unjustified lawsuits by citizens / civil society.[61]

Indicators

1. Air Quality	2. Impact on Health	3. Impacts on Ecosystems	4. Climate change links	5. Costs to society	6. Mitigation costs	7. Impacts on Competitiveness	8. Impacts on Sensitive Groups	9. Societal benefits and burden sharing	10. Impacts on Employment	11. Policy synergies	12. Administrative Burden
(+)	(+)	(+)	(+)	(+)	-	0	0	(+)	0	(+)	0

Assessment

Effectiveness:

Ideally this intervention would work as an effective incentive for competent authorities and industry/business to implement more measures, which in turn would lead to a reduction of emissions and concentrations [i.e. Air quality (+)], and consequently improve public health [i.e. Impact on Health (+)] and ecosystems [i.e. Impact on ecosystems (+)]. Although stakeholders have not provided solid arguments on 'how' the causal link between compensation obligation and air quality improvement would materialise, based on expert judgement we believe that a political storm of high-profile compensation claims would work as an incentive to encourage competent authorities to take action to improve air quality.

From a few Targeted Stakeholder Survey responses by NGOs, 'state liability' is mentioned often, assigning responsibility for compensation to national government. A few national and regional authorities responding to the Survey provided a few arguments against this measure such as that it is very difficult to prove damage to health and to separate such from other (indoor) air pollution effects; and that hence it is not straightforward to identify who can be held responsible. A national authority further mentioned the fact that not even WHO guidelines can offer full health protection and that therefore authorities should not be held accountable for damage to heath. A regional authority stated that such issues should be dealt with as currently, through complaining and pursuing rights in a court trial. Although several stakeholders supported this intervention, the qualitative responses to the Targeted Stakeholder Survey fail to explain 'how' damages claims would lead to a more effective implementation of the Ambient Air quality Directives.

Efficiency:

This intervention, if implemented, would require competent authorities and/or industry (polluters) to pay fines to those who have suffered damage to health from air pollution and would therefore carry mitigation

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[59] Targeted Stakeholder Survey (national authority, regional authorities)
[60] Targeted Stakeholder Survey (national authority)
[61] Targeted Stakeholder Survey (national authority, National level research bodies, metrological offices and environment agencies)

costs for these in the case that they are hold accountable for breaches in air quality standards [i.e. Mitigation costs -]. The indirect positive effects on health of this intervention would result in less lost labour days and reduced health care costs [i.e. Costs to society (+)]. As such its societal impact overall can be seen as positive [i.e. Societal benefits and burden sharing (+)]. In this regard, NGO respondents to the Targeted Stakeholder Survey stress that financial costs of inaction would be far greater than the costs of adopting this new policy.

Assuming full compliance with existing requirements, Member States would face no further costs [Administrative burden: 0]. In practice, given there is not complete compliance, high recurring costs are expected to arise in Member States as the number of claims for health damage increases due to this intervention. This is based on expert judgement suggestions stating that legal proceedings are expensive.

Coherence

The measures implemented to reduce air pollution will also have a positive impact on greenhouse gas emissions [i.e. Climate change links (+)] (because the sources of air pollution and greenhouse gas emissions tend to be the same). This intervention can be considered to indirectly support the zero pollution action plan of the EU [i.e. Policy synergies (+)] (because air pollution can significantly hurt the quality of soil and water resources).

Links to other interventions: [synergies / misalignment]

- C2: *Reformulate the term "as short as possible" with a defined time period*. Non-compliance with C2 should lead to compensation for victims [Synergy]
- E4: *Introduce an explicit 'access to justice' clause in the Ambient Air Quality Directives*. In order for E2 to be possible, E4 needs to be in place [Synergy]

Benefit to Cost ratio:

Medium – The Intervention brings a few indirect benefits while also leads to direct mitigation costs (and additional admin burden). However, it only applies to exceedance situations, so costs are inherently low.

Summary:

Stakeholders responding to the Targeted Stakeholder Survey were divided around this intervention and it was overall the least supported intervention of intervention area E, the main reason given for this being that the causal link between of air pollution and health effects are too difficult to prove. Public authorities and industry were in particular negative about the intervention. Based on expert knowledge however, we consider that a wave of compensation claims could be an effective incentive for Competent Authorities and polluters to act, and thus is considered beneficial. The risks related with the implementation of this intervention have to do with difficulty to prove the causal link between pollution and long-term health effects, accountability (who is held responsible), and risk of abuse from the public. This intervention would be synergistic with another intervention concerning mandating action in the case that air quality standards are not respected (i.e. C2) and with another intervention concerning penalties (i.e. E4). Costs are low for this intervention as it only applies to exceedance situations.

E3

Intervention Area E: What legal tools should be available to address breaches of the obligations

Intervention / Measure

(E3) Set up a fund to be fed by the payment of penalties and which can be used to compensate material damage or finance air quality measures.

The problem: Air quality Implementation shortcomings

(Driver: Insufficient penalties and compensation linked to exceedances)

Description: This intervention consists of setting up a "clean air fund" to be fed by the payment of penalties when Members infringe the rules established by the AAQDs and which would be used to compensate victims of air pollution as well as to finance air quality measures. The fund could be established either at EU-level (an EU-wide fund) or at national level (with each Member State having their own fund).

Purpose/operational objective:

With such a financial fund in place, there would be a source of finance in place to support the implementation of pollution abatement measures as well as to compensate victims of air pollution in such a way that penalties are reinvested in society.

Who would be impacted and how:

Directly:

The only direct impact expected from this intervention is on administrative burden to be borne by the EU or by central government across Member States. Member States paying penalties would benefit from this intervention and hence this measure is irrelevant as long as a Member State has not had to pay penalties.

Indirectly:

Indirect impacts are dependent on how the fund is used by competent authorities (see indicators section below) and could affect competent authorities (in terms of mitigation costs to be borne by these, policy synergies), society (in terms of air quality, costs to society and societal benefits and burden sharing) and individuals (health).

The links between this intervention and the indicators is further elaborated below in the 'Indicators' box.

Risks for implementation:

1. Conflict of interest – If the fund is to be managed by the same competent authorities responsible for achieving compliance with air quality standards then there is a risk of a conflict of interest. Even where local authorities are responsible for meeting the air quality targets, they often depend (strongly) on measures taken at the Member State level.[62]
2. Acceptability by Member States – There is a risk that such a fund is regarded as interfering with Member State competency, where governments hold responsibility for where national funding is allocated.

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[62] Targeted Stakeholder Survey (National authority, NGO respondent)

3. Acceptability by other EU institutions – There is a general direction towards mainstreaming of Union environmental and climate expenditure, thus moving away from dedicated funding for specific environmental issues (with the exception of the LIFE budget programme, which is comparatively a very small funding stream compared to other budget programmes in the Multiannual Financial Framework).

Indicators

1. Air Quality	2. Impact on Health	3. Impacts on Ecosystems	4. Climate change links	5. Costs to society	6. Mitigation costs	7. Impacts on Competitiveness	8. Impacts on Sensitive Groups	9. Societal benefits and burden sharing	10. Impacts on Employment	11. Policy synergies	12. Administrative Burden
0 to (+)	0 to (+)	0 to (+)	0 to (+)	0	0 to (+)	0	0	(+)	0	0 to (+)	(-)

Assessment

Effectiveness:

The link between this intervention and air quality improvement, and consequently improvements on health, ecosystems etc. is dependent on how the fund is used by Competent Authorities (hence indicators have been rated '0' or '(+)'). On the one hand, having a dedicated fund available would facilitate access to funds to support the implementation of mitigation measures (leading to measures being more readily implemented) [i.e. Air Quality (+)]. However, it could also lead to Competent Authorities using these funds to finance measures that they would have implemented in any case, without leading to 'more' (i.e. additional) measures being implemented [i.e. air quality 0]. In addition, the effectiveness of E3 requires a solid framework of penalties and procedures (administrative, legal) that ensure that these penalties are duly paid where appropriate. Setting up a fund, from penalties for failure to comply with AAQ Directive, that is ring-fenced for air quality improvements sends a clear message that air quality is important. However, to what extent any fund can support the measures needed to achieve compliance is unknown, but likely that further national measures may be needed which are usually at high cost, especially if limit values are lowered.

The Targeted Stakeholder Survey responses contained several suggestions regarding the benefits and dis-benefits for this intervention. One national authority responding to the Targeted Stakeholder Survey proposed that tax payments from operators for air pollution should also go to this fund. As for as the spending part, a national authority proposed that only measures that reduce emissions at source should be considered (and not measures for additional air quality monitoring). An NGO stated that only measures that are effective for pollution in general should be eligible for funding (and not measures targeting hotspots e.g. air filters adjacent to a monitoring station should be excluded). The same NGO stressed that it is essential that the fund is independently managed with the active participation of civil society groups (e.g. environmental organisations, associations of patients and health protection groups), and not by the same Competent Authorities responsible for achieving compliance with air quality standards then there is a risk of a conflict of interest and of lack of deterrent effect.

Efficiency:

The fund set up in this intervention would among others fund air quality measures hence reinvesting money in society. Depending on whether these funds are used to fund additional air pollution mitigation measures or the measures that would anyways be implemented, mitigation costs for competent authorities will remain the same or decrease. [i.e. Mitigation costs 0/(+)]. Setting up and administering such a fund will generate additional burden (assumption is that the fund will be administered within each EU Member State) [i.e. Administrative Burden -]. We expect however that administration costs will be relatively low, as Member States have administration systems in place. In addition, administrative burden for Member States may decrease as it could save them time finding budgets (which can take a long time) and therefore mitigation measures and compensation can be more quickly implemented.

The indirect positive effects on health of this intervention would result in less lost labour days and reduced health care costs [i.e. Costs to society (+)]. As such its societal impact overall can be seen as positive [i.e. Societal benefits and burden sharing (+)].

Coherence

The impact of this intervention on climate change and policy synergies will be none or indirectly positive depending on whether these funds are used to fund additional air pollution mitigation measures or the measures that would anyways be implemented. The measures implemented to reduce air pollution will also have a positive impact on greenhouse gas emissions [i.e. Climate change links (+)] (because the sources of air pollution and greenhouse gas emissions tend to be the same). This intervention can be considered to indirectly support the zero pollution action plan of the EU [i.e. Policy synergies (+)] (because air pollution can significantly hurt the quality of soil and water resources).

Links to other interventions: [synergies / misalignment]

- E1: *Introduce minimum levels for financial penalties*. The higher the penalties in E1, the bigger the "clean air fund" will become [Synergy]
- E2: *Introduce specific provisions that guarantee a right to compensation for damage to health*. E3 would be a tool to make E2 work in practice and requires [Synergy]

Benefit to Cost ratio:

Low - Competent Authorities would be able to reinvest funds from paid penalties for implementing measures. However, while the administration costs are low the benefits to air quality are also low.

Summary:

Based on the responses to the Targeted Stakeholder Survey, Public authorities and academia in particular were divided around this intervention, which only obtained clear medium to high support from NGOs. Industry were quite negative about it. The main issues to clarify are what air quality measures can be funded by such fund and who is going to manage it. In particular what measures will be eligible for funding will determine the positive impacts that this intervention can generate (in terms of air quality, and consequently health and ecosystems among others). A risk identified with regards to the implementation of the intervention is potential conflict of interest in the case Member States administer the fund.- There are a couple of synergies identified with other measures related to penalties (i.e. E2, E4).

E4

Intervention Area E: What legal tools should be available to address breaches of the obligations

Intervention / Measure

(E4) Introduce an explicit ‘access to justice’ clause in the Ambient Air Quality Directives.

The problem: Air quality Implementation shortcomings

(Driver: Insufficient penalties and compensation linked to exceedances)

Description: This intervention introduces a new binding provision on ‘access to justice’ in the Ambient Air Quality Directives.

The Fitness Check[63] of the Ambient Air Quality Directives (2009) found that enforcement action by civil society actors in front of national courts has proven to be important to accelerate downward trends for air pollution. This has been confirmed by the Roadmap, which notes that “the effectiveness of legal enforcement action by civil society is linked to the functioning of access to justice at national level”. However, access to justice rules vary widely between different EU Member States. Studies such as the 2012/2013 access to justice report (the ‘Darpö report’) and the 2019 Milieu Study on the implementation of the Aarhus Convention in the area of access to justice in environmental matters, demonstrate that there are still significant hurdles to effective access to justice at national level.

Purpose/operational objective:

Timely access to justice and a level playing field in terms of administrative and judicial support at EU level for citizens and other members of the public (e.g. NGOs) who initiate lawsuits concerning air quality. Strengthening the legislative framework on ambient air quality.

Who would be impacted and how:

Directly:

The only direct effect of this intervention concerns administrative burden, which would increase for EU Member States (national government).This intervention would directly affect citizens, who would be able to demand access to justice in case of damage to health and competent authorities (in terms of administrative burden).

Indirectly:

This intervention if effective would indirectly affect citizens (health) and society (air quality, ecosystems, climate change, costs to society, and societal benefits and burden sharing). It would also affect competent authorities and industry (polluters) (in terms of mitigation costs).

The impacts between this intervention and the various indicators is further explained under the ‘Indicators Assessment’ section below.

Risks for implementation:

- Risk of abuse - The intervention could lead to a large increase in unjustified lawsuits by citizens / civil society.[64] Capacity – An increase in claims could pose challenges to Member States in terms of having sufficient legal capacity to manage proceedings.

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[63] https://ec.europa.eu/environment/air/pdf/ambient_air_quality_directives_fitness_check.pdf

[64] Targeted Stakeholder Survey (national authority, National level research bodies, metrological offices and environment agencies)

Indicators											
1. Air Quality	2. Impact on Health	3. Impacts on Ecosystems	4. Climate change links	5. Costs to society	6. Mitigation costs	7. Impacts on Competitiveness	8. Impacts on Sensitive Groups	9. Societal benefits and burden sharing	10. Impacts on Employment	11. Policy synergies	12. Administrative Burden
(+)	(+)	(+)	(+)	(+)	(-)	0	0	(+)	0	0	0

Assessment

Effectiveness:

This intervention would work as an effective incentive for Competent Authorities and industry/business to implement more measures, which in turn would lead to a reduction of emissions and concentrations [i.e. Air quality (+)], and consequently improve public health [i.e. Impact on Health (+)] and ecosystems [i.e. Impact on ecosystems (+)]. The fitness check concluded that citizen and NGO legal proceedings have helped drive pollution down and this intervention is likely to increase such access to justice legal claims working as an incentive to encourage Competent Authorities to take action to improve air quality (similar to E2).

Next to that, while a number of CJEU preliminary rulings have laid strong foundations for the right to clean air and access to justice in the EU in air quality matters, according to an NGO[65] access to justice problems persist in certain jurisdictions - particularly in Central and Eastern Europe, where national courts routinely ignore the case law of the CJEU, denying individuals and NGOs standing to challenge air quality plans. Even in those countries where individuals and NGOs have standing, there may be other access to justice problems (including length of proceedings, costs and lack of effective remedies).[66]

Efficiency:

Where full compliance with existing requirements is assumed, Member States would face no further costs [Administrative Burden: 0]. However, in practice, given there is not currently full compliance, the implementation of this intervention would lead to administrative burden for EU Member States (probably central / national government) as an increase in lawsuits may be expected if such a clause is explicitly included in the Directive.

This intervention would facilitate proceedings which in turn may conclude that Competent Authorities and/or industry (polluters) need to pay fines to / compensate those who have suffered damage to health from air pollution and would therefore carry indirect mitigation costs for these [i.e. Mitigation costs -].

The indirect positive effects on health of this intervention would result in less lost labour days and reduced health care costs [i.e. Costs to society (+)]. As such its societal impact overall can be seen as positive [i.e. Societal benefits and burden sharing (+)]. In this regard, NGO respondents to the Targeted Stakeholder Survey stress that financial costs of inaction would be far greater than the costs of adopting this new policy.

Coherence:

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[65] Position Paper NGO (Client Earth)

[66] Position Paper NGO (Client Earth)

The measures implemented to reduce air pollution will also have a positive impact on greenhouse gas emissions [i.e. Climate change links (+)] (because the sources of air pollution and greenhouse gas emissions tend to be the same). This intervention can be considered to indirectly support the zero pollution action plan of the EU [i.e. Policy synergies (+)]

Further, the provision on 'access to justice' in the Ambient Air Quality Directives should be in line with Article 47 of the EU Charter on right to an effective remedy and to a fair trial. The revision of the AAQ Directives should also consider the Communication on improving access to justice in environmental matters in the EU and its Member States (COM(2020) 643) which identifies as a priority area that the co-legislators "include provisions on access to justice in EU legislative proposals made by the Commission for new or revised EU law concerning environmental matters" (paragraph 33).

Links to other interventions: [synergies / misalignment]

- C2: *Reformulate the term "as short as possible" with a defined time period:* E4 would be useful when competent authorities do not comply with C2 [Synergy]
- E2: *Introduce specific provisions that guarantee a right to compensation for damage to health*. An 'access to justice' clause would include provisions on compensations [Synergy]

Benefit to Cost ratio:

High – Evidence from the Fitness Check on the AAQ Directives concluded that access to justice helped drive a downward trend in pollution levels. As such, the costs to society (which are large across Europe) are likely to decrease from this intervention while mitigation costs are likely to increase to drive action to improve air quality.

Summary:

On the one hand there seems to be a gap in the Ambient Air Quality Directives in this regard and such a clause seems quite a coherent step to include in the legislation, in line with other Directives. On the other hand, stakeholders responding to the Targeted Stakeholder Survey were divided about this intervention. Mixed views were obtained from public authorities; industry on the other hand were quite negative, while NGOs were highly or fully supportive of the intervention. The implementation of the intervention carries risks in terms of potential abuse by citizens / civil society and in terms of capacity from Member States to deal with additional legal claims. The intervention would be synergistic with an intervention concerning action to demand in case that air quality standards are not respected (i.e. C2) and with an intervention concerning penalties (i.e. E2). Its Benefit to Cost ratio is 'high'.

F1

Intervention Area F: How to best inform the public on air quality?

Intervention / Measure

(F1) Introduce more specific requirements to ensure regular reporting of up-to-date data / information (instead of allowing Member States to report data as available).

The problem: Air quality Information shortcomings

(Drivers: Concerns about health impacts have increased, not addressed; Public information is not always available, and not harmonised)

Description: This intervention aims to tackle the problem that the general public is not always sufficiently informed regarding air quality and its potential health impacts, and the problem that public information on air quality in Member States is not always timely. In addition, NGO stakeholders have consistently raised the issue that the current discretion given to Member States to determine when and how they provide information is sometimes leading to Member States reporting only on days on which air quality is good.

The intervention explores further specifying Article 27 of the Directive 2008/50 by introducing regular reporting requirements to ensure up-to-date data / information is made available to the public, specifying:

- the timeframe for reporting
- the data/information to be reported
- obligation to display such information / data on air quality on screens in key points of cities and towns.

From the TSS, a national authority replied that it is not only about making data regularly available but about ‘how’ you make it available, that is, appropriate tools should be employed to disseminate air quality data / information; this was corroborated by a regional authority at an interview.

Another national authority replied that clearer and more specific requirements are needed not only regarding the timeframe for reporting but also concerning the feedback mechanism/approach to check and properly inform data providers when requirements are not being met.

With regards to what data/information should be published a regional stakeholder at an interview suggested that a clause is added to the Directive 2008/50 to require reporting on the effectiveness of measures (i.e. evidence on the effects of measures). A regional authority and a research stakeholder stated that while at the local scale, only data from the monitoring network are subject to a reporting obligation, there are many other types of data available (real-time maps, air quality forecast at the communal level...) for which reporting is not mandatory and therefore requirements in this regard could be developed.

An NGO interviewee added that in the cases where data cannot be provided, Member States should have a valid excuse for not providing data or providing it late (e.g. power outage).

Purpose/operational objective:

Citizens across all Member States are consistently informed with up-to-date, good quality, air quality data and information.

Who would be impacted and how:

Directly: This intervention will affect competent authorities as they are responsible for informing the public. With regards to the indicators assessed below, the intervention will lead to additional administrative burden for competent authorities.

Indirectly: This intervention will indirectly impact the health of citizens in general and of sensitive groups.

Risks for implementation:

1. Accuracy – Real-time data sometimes is corrected retrospectively, which could lead to inaccurate information being published (and hence unnecessary worries).[67]
2. Political – Informing the public better and timely will lead to a more aware public which in turn can generate more pressure for action from competent authorities.
3. Not all citizens will see different forms of communication
4. When provided with information, citizens need to understand the information and know what responses they can take to change behaviour and reduce exposure.

Indicators

1. Air Quality	2. Impact on Health	3. Impacts on Ecosystems	4. Climate change links	5. Costs to society	6. Mitigation costs	7. Impacts on Competitiveness	8. Impacts on Sensitive Groups	9. Societal benefits and burden sharing	10. Impacts on Employment	11. Policy synergies	12. Administrative Burden
0	(+)	0	0	0	0	0	(+)	0	0	0	--

Assessment

Effectiveness:

Up-to-date data and information on air quality would allow citizens to make decisions that may impact on their health, such as deciding not to participate in outdoor leisure activities or opting for a cleaner transport route [i.e. Impact on Health ++]. Having such information / data would be particularly important for vulnerable groups [i.e. Impacts on Sensitive Groups ++].

Efficiency:

No relevant impacts are expected on costs as the technology to report real-time is already available [i.e. Mitigation costs: 0][68].

Several stakeholders stated in the TSS, many countries already publish (nearly) real-time data. Additional costs would come from having to report other additional local data if this were the case, but authorities in the Targeted Stakeholder Survey seemed to agree that these costs would be very small. Administrative burden is expected from having to translate data into clear language in order to get the information to the people [i.e. Administrative burden -].

Links to other interventions: [synergies / misalignment]

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[67] Targeted Stakeholder Survey (national authorities)

[68] Interviews with two different regional authorities as well as with an NGO

- F2: *Require Member States to provide specific health / and health protection information to public as soon as exceedances occur*. F2 can be seen as an additional clause to add to F1 [Synergy]
- F3: *Mandate specific communication channels with citizens including user-friendly tools for public access to air quality and health risks information and monitoring to use (for example, smartphone apps and/or social media dedicated pages)*: The difficult part is not publishing real-time data but translating data into clear language and getting the information to the people. As such implementing F1 would be facilitated by specifications on F3 [Synergy]
- F4: the AQ index could form part of the information communicated.

Benefit to Cost ratio:

Medium to High – The benefits of the intervention will directly impact health, particularly those who are vulnerable to air pollution. Actions from individuals to prevent exposure could directly reduce hospital admissions and lost labour days and therefore there will be a high benefit to societal costs. Administrative burden will slightly increase within Member States that do not currently publish up to date information.

Summary:

Up-to-date data and information on air quality would allow citizens to make decisions that may impact on their health, such as deciding not to participate in outdoor leisure activities or opting for a cleaner transport route. Hence there is a benefit in ensuring consistent access for citizens across Member States to real-time, appropriate information, which is publicly accessible. Having such information / data would be particularly important for vulnerable groups. The TSS showed that there is medium to high support overall for this intervention. Public authorities were somewhat divided about this measure, NGOs were particularly positive and industry mostly not supportive. There would be some additional administrative burden for member states. It is also worth highlighting the risks around the accuracy of real-time information, and that no single communication channel would achieve universal coverage.

F2

Intervention Area F: How to best inform the public on air quality?

Intervention / Measure

(F2) Require Member States to provide specific health / and health protection information to public as soon as exceedances occur.

The problem: Air quality Information shortcomings

Drivers: Concerns about health impacts have increased, not addressed; Public information is not always available, and not harmonised

Description: This intervention would require Member States to provide information to the public as soon as exceedances of alert thresholds occur. The issue that this intervention is trying to solve is that currently when alerts are made public, it is often too late to protect the health of the population because pollution peaks often do not last long. A response to the TSS from a regional authority stated that it would be important to standardise the approach to providing information about the negative health effects in a simple, understandable form.

Purpose/operational objective: Citizens including vulnerable groups (such as chronic respiratory patients, children, and the elderly) would be aware of exceedances and would be able to adjust their behaviour. Harmonisation across the EU in terms of how timely information is provided will ensure consistent access for (and protection of) all EU citizens.

Who would be impacted and how:

Directly: This intervention will affect competent authorities as they are responsible for informing the public.

Indirectly: This intervention will indirectly impact the health of citizens in general.

Risks for implementation:

1. Finding the right balance between providing information to the public and worrying the public.[69]
2. Accuracy – Real-time data sometimes is corrected retrospectively, which could lead to inaccurate information being published (and hence unnecessary worries).
3. Not all citizens will see different forms of communication
4. When provided with information, citizens need to understand the information and know what responses they can take to change behaviour and reduce exposure.

Indicators

1. Air Quality	2. Impact on Health	3. Impacts on Ecosystems	4. Climate change links	5. Costs to society	6. Mitigation costs	7. Impacts on Competitiveness	8. Impacts on Sensitive Groups	9. Societal benefits and burden sharing	10. Impacts on Employment	11. Policy synergies	12. Administrative Burden

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[69] Targeted Stakeholder Survey (regional authority)

0	(+)	0	0	0	0	0	0	0	0	0	-

Assessment

Effectiveness:

Information on health (protection) would allow citizens to make decisions that may impact on their health such as deciding not to sport outdoors or opting for a cleaner route when going somewhere [i.e. Impact on Health (+)]. Health impacts are more commonly associated with chronic, long-term exposure. However, health impacts of acute exceedances can be very important, in particular where the peak is significant or lasts a number of hours or days.

In addition, the provision of information raises expectations of action to improve air quality. If the public are informed about potential health risks, they are likely to put pressure on Competent Authorities to address the poor air quality.[70]

Efficiency:

No clear links are seen between the intervention and the indicators that have to do with efficiency. Mitigation costs would not increase as the intervention does not require any additional action. In addition, administrative burden is also judged to be very small if not negligible - Member States already inform the public when peaks occur, and the intervention simply requires them to do this ‘as soon as possible’ (hence bringing activity forward). Indeed through the TSS NGOs and regional authorities stated the costs of this intervention are “irrelevant”.

Small one-off costs are expected [Administrative cost -] to be incurred by the Member States as a result of this intervention depending on the health data required. Systems will have to be established to collect and produce this data. On the basis that the information is required annually there will be a small recurring cost. Low recurring costs are expected to be incurred by the European Commission to check if Member States are reporting as soon as exceedances happen (expert judgement).

Links to other interventions: [synergies / misalignment]

- B2: *Define alert thresholds and information thresholds for all air pollutants as triggers for alerting the public and taking short-term action*. Threshold alerts go hand in hand with health information and so F2 Define alert thresholds and information thresholds for all air pollutants as triggers for alerting the public and taking short-term action. [Synergy]
- C4: *Introduce an obligation for effective short-term action plans for each pollutant to prevent / tackle air pollution events*. Information on alerts should be followed up by action on the short-term [Synergy]
- F1: *Introduce more specific requirements to ensure regular reporting of up-to-date data / information (instead of allowing Member States to report data as available)*. F2 can be seen as an additional clause to add to F1 [Synergy]
- F3: *Mandate specific communication channels with citizens including user-friendly tools for public access to air quality and health risks information and monitoring to use (for example, smartphone apps and/or social media dedicated pages):* Implementing F2 would be facilitated by the specifications on F3 [Synergy]

Benefit to Cost ratio:

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[70] Targeted Stakeholder Survey (regional authority)

Medium – the benefits of this intervention, albeit indirect, outweigh the costs (and administrative burden) which are considered nil.
Summary: This was the intervention in area F most supported by stakeholders in the Stakeholder Targeted survey. It generated some mixed views from public authorities and research & academia (although it seems some of these didn't understand that the catch of this intervention were the words 'as soon as possible' as some replied that "sufficient information on air quality levels and their health effects is already published"). NGOs were the most positive about it. The intervention would be synergistic with a few interventions across different areas and its Benefit to Cost ratio would be 'high'. Ensuring that information is provided at the point it is most relevant and can allow citizens to take timely action would increase the effectiveness of information provided, whilst the costs are considered negligible since relevant information and the systems to provide it are already in place.

F3

Intervention Area F: How to best inform the public on air quality?

Intervention / Measure

(F3) Mandate specific communication channels with citizens, including user-friendly tools for public access to air quality and health risks information (for example, smartphone apps and/or social media dedicated pages).

The problem: Air quality Information shortcomings

Drivers: Concerns about health impacts have increased, not addressed; Public information is not always available, and not harmonised

Description: This intervention would mandate the use of specific user-friendly communication channels to reach out to citizens (for example, smartphone apps, social media, text messages, forecasts on TV (similar to weather forecasts)) so that they have access to air quality and health risks information and monitoring.

The issue this intervention is trying to solve is that citizens do not always know where to access air quality information and that governments do not know how to best provide information. Tools and the quantity and quality of information provided to citizens varies between Member States.

An NGO mentioned that whatever the selected communications selected, it is important to intensively promote access across society.

Purpose/operational objective:

A more harmonised approach across Member States concerning how information is shared with citizens. Ensuring sufficient information is shared and that the public feel informed and engaged.

Who would be impacted and how:

Directly: This measure will impact competent authorities who must provide information, in particular where the prescribed channels are not in place.

Indirectly: This intervention will indirectly impact the health of citizens in general and of sensitive groups.

Risks for implementation:

1. Rapid development in the area of communication channels could make a provision on this in the Directive obsolete if very specific / prescriptive.[71]
2. No one-size-fits-all - There are significant differences in how people from different countries use social media, apps, news channels (incl. if they watch national TV) and the like. Therefore, putting the same obligations on every country – if specific channels are to be prescribed - would not take these differences into account.[72]
3. Deviating resources from measures which actually improve air quality - If certain apps or social media maintenance are included as a mandatory requirement in the revised Ambient Air Quality Directive, there is a risk that monetary and personnel capacities will be tied up that would be better used to implement targeted air quality improvement measures.[73]

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[71] Targeted Stakeholder Survey (national authority)

[72] Targeted Stakeholder Survey (regional authority)

[73] Targeted Stakeholder Survey (NGO)

4. When provided with information, citizens need to understand the information and know what responses they can take to change behaviour and reduce exposure.

Indicators

1. Air Quality	2. Impact on Health	3. Impacts on Ecosystems	4. Climate change links	5. Costs to society	6. Mitigation costs	7. Impacts on Competitiveness	8. Impacts on Sensitive Groups	9. Societal benefits and burden sharing	10. Impacts on Employment	11. Policy synergies	12. Administrative Burden
0	0	0	0	0	0	0	(+/-)	0	0	0	---

Assessment

Effectiveness:

Obliging competent authorities to use a set of information channels could lead to a better informed public who can make decisions that may impact on their health such as deciding not undertake leisure activities outside or opting for a cleaner travel route, although the impact is likely to be small if not negligible [i.e. Impact on Health 0]. Being well informed is particularly important for vulnerable groups, however some vulnerable groups will engage with certain communication channels more than others (e.g. elderly may tend less to use social media, apps or websites) [i.e. Impacts on Sensitive Groups (+/-)].

Efficiency:

Obliging Competent Authorities to use a set of information channels would increase administrative burden notably [i.e. Administrative burden ---] for those Member States who do not have such channels in place, and/or existing channels which are different or require alignment with the prescribed channels. From the TSS, the costs and administrative burden of this intervention appear negligible though, presumably because several countries (who responded to the Survey) already have a wide range of communication channels in place.

Coherence:

An NGO respondent to the TSS remarked that the new framework on air quality information must be tightly linked to the emerging EU common digital spaces such as the - currently under construction - European Health Data Space (EHDS).

Links to other interventions: [synergies / misalignment]

- F1: *Introduce more specific requirements to ensure regular reporting of up-to-date data / information (instead of allowing Member States to report data as available)*. F3 is a way for translating data in F1 into clear language and getting the information to the people. As such implementing F1 would be facilitated by specifications on F3 [Synergy]
- F2: *Require Member States to provide specific health / and health protection information to public as soon as exceedances occur*. Implementing F2 would be facilitated by the specifications on F3 [Synergy]

Benefit to Cost ratio:

Low - The benefits of this intervention are indirect but its costs seem to be fairly small.

Summary:

The intervention is synergistic with all the other Intervention Area F interventions. Up-to-date data and information on air quality would allow citizens to make decisions that may impact on their health, such as deciding not to participate in outdoor leisure activities or opting for a cleaner transport route. Obliging competent authorities to use a set of information channels would lead to a better, and consistently informed public. Some channels may provide faster, more accessible access to information for some groups. However, some groups (and in particular some vulnerable groups) will engage with certain communication channels more than others. Furthermore, the cost of developing (in particular where these are not currently in place) specific, high-tech channels may be more costly, which may divert resources from other, more productive, means.

F4

Intervention Area F: How to best inform the public on air quality?

Intervention / Measure

(F4) Require Member States to use harmonised air quality index bands.

The problem: Air quality Information shortcomings

Drivers: Public information is not always available, and not harmonised

Description: This intervention consists of including a provision in the Directive 2008/50 to require Member States to use harmonised air quality index bands, namely those used in the European Air Quality Index. Member States (and regions and cities therein) would therefore still be allowed to use their own indices, but the bands would need to be harmonised. This way a one-size-fits-all where everyone adopts the same index is avoided, acknowledging that different countries and regions have their own characteristics which make different pollutants relevant.

The problem that this intervention is aiming to solve is the current absence of a common metric used for publicised Air Quality Indices. At the moment Member States (and even regions within in some cases) have different air quality indices whose bands and thresholds differ from the European Air Quality Index provided by the European Environmental Agency (EEA). This often means that the same data is presented in different ways in different locations. Although there is no consensus on whether and how air quality indices can be harmonised, what is known[74] is that there is not much support for all Member States adopting the European Air Quality Index. As such adopting the bands alone seems the most feasible compromise which has obtained wide support in the stakeholder consultation activities carried out by this contract.

Purpose/operational objective: Common index bands would help harmonisation in the information presented to the public, giving higher credibility to the air quality information provided to the public as well as allowing comparability between Member States, and all this without requiring every Member State to adopt a same index.

Who would be impacted and how:

Directly: Impact on Member States competent authorities who would need to adapt their indices.

Indirectly: Impact on the public in general, who would be exposed to harmonised information.

Risks for implementation:

1. The EEA is considered to have its flaws - The traditional type of quality index such as the one used by the EEA, has long been criticised by health experts on many aspects. Firstly, because it is based on short term exposure while air quality has health effects in the long term as well.[75] Secondly, the index value is determined only using the pollutant with the highest concentration in relation to its defined index bands. As such this method does not take account the additive effects of multiple air pollutants, which can lead to an underestimation of the actual risk of exposure to air pollution. Alternative indexes, often

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[74] From the SR9 study

[75] Targeted Stakeholder Survey (national authority)

called Air Quality Health Index (AQHI) have therefore been developed to give a better representation of the actual health risks, for example in Canada and more recently in Stockholm.[76]

Indicators

1. Air Quality	2. Impact on Health	3. Impacts on Ecosystems	4. Climate change links	5. Costs to society	6. Mitigation costs	7. Impacts on Competitiveness	8. Impacts on Sensitive Groups	9. Societal benefits and burden sharing	10. Impacts on Employment	11. Policy synergies	12. Administrative Burden
0	(+)	0	0	0	0	0	(+)	0	0	0	-

Assessment

Effectiveness:

Information on health (protection) would allow citizens to make decisions that may impact on their health such as deciding not to sport outdoors or opting for a cleaner route when going somewhere [i.e. Impact on Health (+)]. Reliable and consistent information would be particularly important for vulnerable groups [i.e. Impacts on Sensitive Groups (+)]. But some stakeholders (Authorities) express doubts around the effectiveness of the European Air Quality Index (e.g. around its ability to represent multi-pollutant effects), and complete harmonization may restrict the ability of Member States to tailor advice and information to the specific situation in each Member State. However others expressed that it would address the lack of transparency on the part of the Competent Authorities, causing citizen complaints and resulting in citizens opting for other information tools that use unvalidated data or models, such as applications mobile phones of unofficial entities.

Efficiency:

The intervention will increase administrative burden for competent authorities (regional or national) [i.e. Administrative burden -] as it will require these to adapt their index bands. Based on the TSS, high costs are not expected, however it is pointed out by a national authority respondent that it would constitute a waste resources put by authorities in developing their index.

Links to other interventions: [synergies / misalignment]

- Harmonisation of the air quality index could improve the information provided to the public under F1 and F2

Benefit to Cost ratio:

Medium – the benefits of this intervention (harmonized bands) will be indirect, while the measure will lead to small administrative burdens.

Summary:

Consistency in the information provided to citizens will aid clarity and uniformity in the opportunity provided to all EU citizens to take action to reduce their exposure. Several variants exist, including adopting the Europe Air Quality Index in full, to adopting consistent bands. Some stakeholders have expressed doubts around the effectiveness of the European Air Quality Index (e.g. around its ability to represent multi-pollutant

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[76] Targeted Stakeholder Survey (national authority)

effects), and complete harmonization may restrict the ability of Member States to tailor advice and information to the specific situation in each Member State. The TSS showed there is very high support for this measure particularly from NGOs followed by public authorities. Industry was more carefully positive while NGOs were particularly positive. Among public authorities and research & academia some were negative regarding this intervention. In any case it seems that any homogenisation in terms of bands should go along a review of the EEA's Air Quality Index itself in order to tackle its flaws.

Assessment of interventions - Policy Area 3

G1

Intervention Area G: How to improve air quality assessment regimes, including the scope to combine monitoring, modelling and other assessment methods?

Intervention G: Allow / continue to allow the use of indicative monitoring to substitute fixed monitoring as part of air quality assessment.

The problem:

Air quality Monitoring and assessment shortcomings.

(Driver: Flexibilities may sometimes impact the comparability of data; Monitoring rules offering flexibility are ‘stretched’ in instances)

Description:

The use of indicative monitoring could substitute fixed monitoring stations in the air quality assessment process. However, the minimum number of fixed monitoring stations are still required to assess main temporal and spatial trends.

Possibilities under which circumstances indicative measurements could substitute fixed monitoring include:

(1) Where there is a need to measure air quality but it is not possible to place a fixed monitoring station that meets the requirements of the Directive

(2) Where the combination of different measurements (e.g. via data fusion) allows reaching data quality objectives.

Purpose/operational objective:

The use of indicative monitoring for air quality assessment may result in an increase in sampling points and contribute to a better understanding of the spatial air pollution patterns.

Who would be impacted and how:

Direct: The administrative burden may increase on Competent Authorities to setup additional indicative monitoring campaigns. Such indicative monitoring requires careful and strategic planning (where to measure, siting criteria of the sampling locations), technical preparation of the campaign (calibration of the samplers), deployment of the indicative monitors, data collection, lab analysis, data analysis and interpretation of the results.

Indirect:

Via citizen science projects, the public at large might be involved in the indicative monitoring. When setup carefully, this might contribute to awareness raising and further engagement of the citizen communities.

Risks for implementation:

- Substitution of fixed monitoring stations by lower quality indicative monitoring devices is seen by many stakeholders as a major risk to degrade an important pilar in air quality management.

Indicators											
1. Air Quality	**2. Impact on Health**	**3. Impacts on Ecosystems**	**4. Climate change links**	**5. Costs to society**	**6. Mitigation costs**	**7. Impacts on Competitiveness**	**8. Impacts on Sensitive Groups**	**9. Societal benefits and burden sharing**	**10. Impacts on Employment**	**11. Policy synergies**	**12. Administrative Burden**

(+)	(+)	(+)	0	(+)	0	0	0	(+)	0	0	---

Assessment

Effectiveness:

When used to supplement fixed monitoring (not substitute), such as in places where it is not possible to place a fixed monitoring station that meets the requirements of the Directive, additional indicative monitoring contributes to a better overall understanding of the air quality assessment process since additional sampling data is at hand. The additional data can also be used for model validation. This contributes to an overall improved air quality assessment process [Air Quality (+)] with positive indirect impact on health and ecosystems [Impact on Health: (+) and Impacts on Ecosystems: (+)]. Social costs could gain benefit indirectly as more monitoring could lead to further action to improve society [Societal benefits and burden sharing: (+)]

An issue raised by many respondents is that indicative monitoring should be encouraged to supplement fixed monitoring but strong feeling that it should not substitute it. Such a substitution would be seen as a backward step. This is most strongly felt in NGO community but also supported by the other stakeholder groups.

With respect to the variants:

(1) Most respondents considered that indicative measurements could substitute fixed monitoring, to some extent, in those places where there is a need to measure air quality but it is not possible to place a fixed monitoring station that meets the requirements of the Directive

(2) A majority of stakeholders considered this variant effective. About a third answered that indicative measurements could substitute fixed monitoring, to some extent, where the combination of different measurements (e.g. via data fusion) allows reaching data quality objectives. Meanwhile, about a quarter of them believed that this could be fully done.

It should be notes that for some respondents it is unclear what data fusion method is being suggested under variant (2).

Efficiency:

There is a general confirmation by the different stakeholders that indicative monitoring is less expensive than fixed monitoring. Substitution of fixed monitoring stations by indicative monitoring will likely result in cost savings [Costs to society: (+)]. However, such a substitution is not supported by many stakeholders. When the indicative monitoring comes on top of the fixed network, it is an increase in costs and administrative burden [Administrative Burden: --].

Coherence:

There are no foreseen impacts on policy synergies or climate change links [Climate and Policy 0]

Links to other interventions: [synergies / misalignment]

- G2: *Make the use of air quality modelling mandatory as part of air quality assessment (in some circumstances):* Indicative monitoring has the potential to provide valuable additional information for model validation, on top of the fixed monitoring network. [Synergy]
- G3: *Require a regular review of the assessment regime following clear criteria defined in the Directive:* Indicative monitoring can provide relevant additional information about the spatial patterns of actual concentration levels, key information in a review of assessment regimes. [Synergy]

- H1: *Change the minimum number of sampling points that are required per air quality zone:* Indicative monitoring complements fixed monitoring stations. [Synergy]
- H2: *The minimum number of sampling points for measuring* PM_{10} *and* $PM_{2.5}$ *will be considered independently from each other:* Indicative monitoring complements fixed monitoring stations. [Synergy]
- H3: *Simplify the definitions of types of monitoring station and/or sampling point locations - and only differentiate for them to distinguish between hotspots or background concentrations:* A comprehensive assessment of the sampling point location will be more labour intensive for indicative monitoring campaigns mostly including a larger number of sampling points. The intervention H3 will support the implementation of indicative monitoring. [Synergy]
- J3: *Introduce the concept of a spatial representative area which should be estimated (and reported) for each sampling point (irrespective of exceedances being measured or not):* Indicative monitoring is identified as a suitable methodology (Tier 2 or Tier 4 in combination with model) to assess spatial representativeness of (fixed) monitoring stations. [Synergy]

Benefit to Cost ratio:

High: indicative monitoring can be setup at a rather low cost bringing high benefits in terms of better air quality assessment.

Summary:

The added value of indicative monitoring is recognized by almost all of stakeholders although most of them indicate that the intervention will only partly address the shortcoming. Authorities are most positive about the impact of the intervention. Sufficient attention should be paid to the QA/QC process of indicative monitoring and data quality standards should be met before the indicative monitoring can be used in air quality assessment.

Many stakeholders expressed a strong objection to substitute fixed monitoring stations by lower quality devices. Indicative monitoring should complement the fixed monitoring network.

G2

Intervention Area G: How to improve air quality assessment regimes, including the scope to combine monitoring, modelling and other assessment methods?

Intervention / Measure: G2 Make the use of air quality modelling mandatory as part of air quality assessment (in some circumstances).

The problem: Air quality Monitoring and assessment shortcomings.

(Driver: Modelling ability has improved, allows for much more detail.)

Description: Modelling techniques can provide valuable information to supplement fixed measurements. Observations from fixed stations are limited to the sampling locations itself whereas modelling systems most often provide air quality maps with a full spatial coverage that can be used to derive specific indicators. Modelling can also help to disentangle the origin of the observed concentrations (source apportionment, long range transport) or extrapolate into the future (short term forecasts, future projections). In practice several variants exist for this intervention – related to the possible use of air quality modelling:

(1) For short term air quality forecasting (up to a few days ahead);
(2) For assessment of air quality for compliance checking purposes;
(3) For air quality near real time mapping and informing the public;
(4) For evaluation of monitoring network design;
(5) For estimation of population exposure and exceedance situation indicators;
(6) For source apportionment estimations;
(7) For assessment of long-range air pollutant transport;
(8) For future projections in support of air quality management and planning;
(9) As alternative to fixed monitoring (when placing such monitoring in line with the Directive is not possible).

Purpose/operational objective: This intervention would require modelling techniques to be used in varying circumstances to provide a more quantified, encompassing assessment of the air quality situation to improve the evidence for taking action.

Who would be impacted and how:

Directly: The administrative burden may increase on competent authorities, who would be required to carry out and report on modelling in the varying use cases. The increase is likely to depend on the current modelling capability and practices within each Member State. Robust assessments require good quality emission estimates, which are limited in many Member States as emission projections are not always fully reported within Member State National Air Pollution Control Plans. Hence, additional assessments would require considerable time and capability to compile, which may further add to the administrative burden. However, if carried out following good practice, modelling can provide competent authorities with a more rigorous assessment of air quality which may lead to more focussed air quality plans, decreasing the administrative burden of their development and implementation, as well as the overall societal cost of implementation, while potentially increasing the effectiveness of actions taken. Mapped modelling data has the added benefit that it can be used to inform the general public on air quality levels across a geographical area.

In addition, modelling can support a more robust source apportionment assessment. This could impact how competent authorities control and permit emissions sources, which should align with requirements under the Industrial Emissions Directive for industrial sources.

Indirectly:. Variants of this intervention which require future projections of air quality in support of air quality plans would more readily inform the public about when and what impact of policy measures can be expected. Business and industry may benefit from such further quantification of air quality. In particular, the source contribution from various sectors to an exceedance situation and the potential impacts from measures proposed by competent authorities is likely to be more clearly presented using data from models. This may enable the business and industry community to increase their engagement in consultation activities and play their full role in the air quality management process. Consequently, this may benefit business corporate sustainability commitments.

Risks for implementation:

3. Lack of modelling guidance, available data sources to support modelling, and a Modelling Quality Objective consensus plus lack of agreement on a data fusion methodology.
4. Lack of resources for training and capacity building across Member States required
5. Many variants of this intervention would likely improve information on air quality but may not lead to measures to directly improve air quality
6. Member States may view the introduction of a mandatory requirement of modelling as a reason to reduce their monitoring network to the minimum required by the AAQ Directives.

Indicators

1. Air Quality	2. Impact on Health	3. Impacts on Ecosystems	4. Climate change links	5. Costs to society	6. Mitigation costs	7. Impacts on Competitiveness	8. Impacts on Sensitive Groups	9. Societal benefits and burden sharing	10. Impacts on Employment	11. Policy synergies	12. Administrative Burden
(+)	(+)	(+)	0	0	0	0	(+)	(+)	0	0	---

Assessment

Effectiveness:

Generally speaking, use of air quality modelling will result in better air quality monitoring and assessment, thus allowing for a better understanding of air quality concentrations. This in turn would in most cases be a prerequisite for more effective and more targeted air quality management [i.e. Air quality (+)]. It would also allow to improve local air quality management to protect human health and ecosystems from adverse impacts [i.e. Health (+) and Ecosystems (+)]

The vast majority of stakeholders were in favour of introducing mandatory modelling in air quality assessment for most of the proposed variants to this intervention in at least some instances, although there is little support for the use of modelling to assess compliance. In particular, there was strong support for the mandatory introduction of modelling to support short term air quality forecasting, mapping of air quality, estimation of population exposure and long-range transport of air pollution and for assessing the impact of air quality plans. This strong support was across all stakeholders, though many in the business and industry community reported no opinion. The reasons given for the strong support of modelling included:

1. Today's modelling enables a high spatial resolution of concentrations which is important in hotspots. It is also valuable to identify gaps in monitoring networks. This also allows for vulnerable groups to be better informed about local risks [i.e. Societal benefits (+) and Sensitive groups (+)]
2. It helps with planning in the short-term if modelling is used to forecast pollutant levels over a few days and also over the long-term to support the assessment of pollution with and without measures for the development of air quality plans.
3. It is a useful tool for source apportionment helping to ensure the most relevant sources of emissions are tackled. Modelling is essential to determine the transboundary pollution increment.

Despite this strong support, though not for compliance assessment, many respondents raised the following issues to be addressed for this intervention to be fully successful.

1. Models should not substitute fixed monitoring.
2. Modelling quality should be addressed to support its mandatory use. Public authorities, while very supportive on the whole, were clear that emission data as inputs to models are not always adequate, and technical guidance on models and associated tools, their use and quality assurance processes is essential. Reference was made to the value that FAIRMODE[77] provided in their technical guidance including the Modelling Quality Objective, but both public authorities and NGOs referred to the need for binding guidance, possibly through CEN. All stakeholders recognised that model quality and robustness is reliant on sufficient monitoring stations, located in representative areas to validate the models.
3. The revised Directive should be clear about locations/situations where modelling is to be made mandatory. Public authorities in particular thought it was not necessary for all pollutants and not appropriate for those zones where pollution levels were low but could be valuable where levels are above the Upper Assessment Threshold, where monitoring is obligatory, in which cases it may be used to validate the models.

Overall, our expert judgement is that modelling is an essential tool for air quality management. It can be used to good effect to quantify key sources of emission, assess the impact of proposed measures, produce spatial pollution maps and should be used to inform the public on air quality issues. Models are now used across Europe but their mandatory use in these circumstances, together with compliance with model quality performance metrics and with technical guidance can help drive air quality action.

Efficiency:

In general, models have evolved into reliable tools for air quality assessment and forecasting. They can provide more information at higher detail at much lower costs compared to monitoring networks. While most Member States have access to modelling skills, the use of models varies significantly, with some Member States being regular users of models for most of the use cases (often on a daily basis), while others use models in an ad hoc manner. Some use advanced chemistry models for many of the use cases while others use simple screening models in a limited way. Capacity building would therefore likely be necessary in at least some Member States should modelling become mandatory.

It is difficult to estimate costs for this intervention as the implementation pathway not only varies between Member States, but it is also highly variable depending on the use case of the proposed intervention variant.

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[77] https://fairmode.jrc.ec.europa.eu/

However, should a national scale model, down to local/street level be set up for assessing air quality on an annual basis, the administrative costs to develop and implement these proposals have been estimated as anywhere between €0.5 million – €1.5 million per year per Member State (based on estimates from Sweden provided in the targeted survey). The span of these cost estimates is quite large as costs are highly dependent on the level of ambition and the specific requirements that are placed on the different modelling applications. On top of these potentially increased administrative costs at a national level, there would also be continued costs for local and regional authorities, some of which do their own modelling and will likely continue to do so even if national results and tools are available. It was reported by Sweden that it should, however, be noted that without an annual national modelling study and freely available modelling tools, costs for this intervention would be much greater as all municipalities and regions covered by the requirements would need to carry out the modelling activities themselves and many do not have sufficient competence and/or capacity for these tasks.

The view from a Municipality Authority (Berlin) was that on average over the last decade the city authority has spent around €100,000 per year for various model applications, ranging from short-term forecasting, source apportionment, city-wide assessment of the air quality, and medium/long-term projections underpinning the air quality plan to checking the proper siting of air quality monitoring stations.

There was consensus that when air quality modelling was sufficiently supported it was valuable and more cost effective than monitoring alone. The associated increase in administrative burden for implementing this intervention will mostly fall on public authorities [i.e. Administrative burden ---]

Coherence:

The introduction of the mandatory use of modelling will not inherently improve air quality. However, with improved information, at a high resolution and of good quality, modelling data will present policy makers with evidence to further develop measures that can be more targeted, efficient and effective, to inform the public and to improve air quality through the air quality planning process. Any indirect improvement in concentrations may lead to better health and lower ecosystem impacts bringing economic and societal benefits.

Emission estimates are an essential input for air quality models. Therefore, alignment with the requirements to report on emissions estimates and future projections under National Air Pollution Control Plans (NAPCP) under the NEC Directive should be considered to ensure coherence.

Links to other interventions: [synergies / misalignment]

- **G1:** *Allow / continue to allow the use of indicative monitoring to substitute fixed monitoring as part of air quality assessment:* Adequate monitoring is essential to validate models, and the use of indicative monitoring can help verify modelling results especially the increased spatial patterns that are resolved by the indicative measurements [Synergy].
- **H1:** *Change the minimum number of sampling points that are required per air quality zone:* As monitoring data are required to validate the models, an increase in sampling points would be beneficial, equally a decrease would be detrimental to the mandatory use of models [Synergy].
- **H2:** *The minimum number of sampling points for measuring* PM_{10} *and* $PM_{2.5}$ *will be considered independently from each other:* The independent consideration of the two measurements (of PM_{10} and $PM_{2.5}$) would result in a potential increase in monitoring for the assessment of air quality which may be valuable for model validation [Synergy].
- **K3**: *Introduce a standardized 'modelling quality objective' as a quality control mechanism to assess whether a modelling-based assessment is fit-for-purpose:* This intervention is viewed as essential to support the mandatory use of models [Synergy].

- **G3**: *Require a regular review of the assessment regime following clear criteria defined in the Directive*. Use of modelling data is a proposed criteria for the review of the assessment regieme_[Synergy].

Benefit to Cost ratio

High (most variants) - Many Member States already use models for most of the above variant use cases. The level of ambition that mandatory modelling would represent reflects this current use of models, and the fact that some variants of this intervention may not even require modelling on an annual basis (e.g. for evaluation of monitoring network design) or could be focused on limited areas e.g. hotspots.

Medium (variant that make modelling mandatory for compliance checking) – for compliance assessment a national scale model, with high spatial resolution, is required. Currently only Belgium is reporting modelling for compliance assessment in Dataflow G. Such a modelling system requires an equally highly spatially resolved emissions inventory, and resources for the elaboration of this are high.

Summary

There is strong support across all stakeholder types for the mandatory use of modelling for most of the nine use case variants in at least some instances,. Some respondents, however, explained further that modelling should be (strongly) recommended in most of these use cases but only made mandatory for all Member States in one case, i.e. for future projections in support of air quality management and planning. Although our expert view is that there is great benefit to be gained by using models to assess compliance, the set up and annual costs are high. For all modelling our expert view is that further technical guidance to enhance and harmonise modelling quality is essential for the successful implementation of this intervention

G3

Intervention Area G: How to improve air quality assessment regimes, including the scope to combine monitoring, modelling and other assessment methods?

Intervention/Measure: (G3) Require a regular review of the assessment regime following clear criteria defined in the Directive.

The problem: Air quality Monitoring and assessment shortcomings.

(Drivers: Monitoring rules offering flexibility are 'stretched' in instances; Modelling ability has improved, allows for much more detail.)

Description: Regular review of the assessment regime is expected to ensure that the assessment techniques for air quality evolve with scientific advancements and knowledge. It also allows for improved and increased evidence on air quality including the use of models and more efficient monitoring networks. This would require the amendment of existing articles and Annex II point B to include set criteria. These criteria could be based on the following variants of this intervention:

(1) Based on fixed monitoring
(2) Based on indicative measurements
(3) Based on objective estimation
(4) Based on air quality modelling

In addition, the interval at which a review should be done was queried with the options of every 10, 5, 3 or 1 years.

Purpose/operational objective: This intervention would require Member States to follow set criteria in their reviews of their assessment regime which rely on monitoring and/or modelling data. This would provide a more harmonised review of air quality assessment across Europe leading to a more transparent and coherent view of air quality status for wider public access.

Who would be impacted and how:

Direct: Competent Authorities responsible for the assessment of air quality are likely to be impacted though the level to which their administration burden would change depends on the stringency of the assessment criteria. Many Member States already review their assessment regime using all the variants suggested, and this process is relatively straightforward. Those Member States who do not regularly carry out a review of their assessment regime are likely to have extra administrative burden depending on the stringency of the new requirements, but thereafter this would be less demanding.

Indirect: The public and interested groups wishing to scrutinise air quality will benefit from a more harmonised system where Member States report on their air quality assessment regime. This is likely to enhance the ability to compare and contrast efforts made in various Member States and ensure a comprehensive review is reported by each Competent Authority.

Risks for implementation:

- Administrative burden increase would be large should the interval for review be changed to every year. There may be a lack of resources to support the implementation of this intervention on this basis

Indicators:

1. Air Quality	2. Impact on Health	3. Impacts on Ecosystems	4. Climate change links	5. Costs to society	6. Mitigation costs	7. Impacts on Competitiveness	8. Impacts on Sensitive Groups	9. Societal benefits and burden sharing	10. Impacts on Employment	11. Policy synergies	12. Administrative Burden
0	0	0	0	0	0	0	0	0	0	0	(-)

Assessment

Effectiveness:

A common system to review each Member States' assessment regime would increase harmonization and comparability of air quality data used in their compliance assessment. A combination of fixed monitoring and air quality modelling should provide the most reliable information on concentrations within air quality zones. Where indicative measurements are available, these should also be considered, although due to the lower requirements on data quality, these cannot always provide enough evidence for this purpose. This is a particular issue when it comes to short-term values, which allow a certain number of exceedances per year, and which are difficult to assess using methods providing data for limited periods during a calendar year. In a survey, Public Authorities mainly thought that that while results from objective estimation are generally less reliable than results from monitoring and modelling, these should therefore be of secondary importance when reviewing assessment regimes. However, where results from air quality modelling and fixed or indicative monitoring are missing, objective estimation can provide valuable data that can be appropriate for reviewing an assessment regime [Air Quality (+)].

Currently the requirements to review are on a 5 yearly period and the majority of all stakeholder respondents favoured the retention period of 5 years.

Efficiency:

All Member States have ready access to fixed term monitoring, and most have modelling capability, so our expert view is that the costs for this intervention are insignificant. From the stakeholder survey most respondents did not view much change in the administrative burden or cost for such reviews but many did caveat that this depends on the stringency of new assessment criteria authorities [Administrative burden -].

Coherence:

There are no foreseen impacts on policy synergies or climate change links [Climate and Policy 0]

Links to other interventions: [synergies / misalignment]

- **G1:** *Allow / continue to allow the use of indicative monitoring to substitute fixed monitoring as part of air quality assessment:* Adequate monitoring is essential to assess air quality, and the use of indicative monitoring can help elaborate the assessment [Synergy]
- **G2:** *Make the use of air quality modelling mandatory as part of air quality assessment (in some circumstances:* Modelling data are useful to supplement monitoring data as part of the assessment regime [Synergy].

- **H1:** *Change the minimum number of sampling points that are required per air quality zone:* As monitoring data are required to validate the models, an increase in sampling points would be beneficial, equally a decrease would be detrimental to the mandatory use of models [Synergy].
- **H2:** *The minimum number of sampling points for measuring* PM$_{10}$ *and* PM$_{2.5}$ *will be considered independently from each other:* The independent consideration of the two measurements (of PM$_{10}$ and PM$_{2.5}$) would result in a potential increase in monitoring for the assessment of air quality, as well as provide an increased clarity on the number of samplers required [Synergy].

Benefit cost ratio:

Low: Benefit gained from this intervention is a more harmonized approach to assessment across Europe which brings value to the public through increased transparency and brings clarity to competent authorities on the assessment review process. Costs appear minimal compared to the current requirements.

Summary: While this intervention is likely to bring only an indirect positive impact to air quality, there is value to be gained with new clearer criteria to review the assessment regime on a regular basis. A more transparent approach offers rigorous scrutiny to ensure action is taken where public health is at risk.

H1

Intervention Area H: How to improve the minimum number and type of sampling points required for measuring air pollution concentrations?

Intervention/Measure: (H1) Change the minimum number of sampling points that are required per air quality zone.

The problem: Air quality Monitoring and assessment shortcomings.

(Drivers: Monitoring rules offering flexibility are 'stretched' in instances; Modelling ability has improved, allows for much more detail.)

Description: The minimum number of sampling points per air quality zone for each pollutant should be revised with latest scientific knowledge. Possibilities to which extent would the below specific interventions address the above identified shortcomings include:

(1) Increase the minimum number of sampling points for all pollutants and all zones
(2) Increase the minimum number of sampling points for some pollutants
(3) Increase the minimum number of sampling points for some zones
(4) Decrease the minimum number of sampling points for all pollutants and all zones
(5) Decrease the minimum number of sampling points for some pollutants
(6) Decrease the minimum number of sampling points for some zones
(7) Require a minimum of 2 sampling points per zone per pollutant (i.e. to monitor both hotspots and background concentration levels)
(8) Establish a minimum number in the vicinity of point sources in view of emission densities
(9) Establish a minimum number of sampling points for measuring pollution hotspots specifically
(10) Establish a minimum number of sampling points for measuring population exposure

Purpose/operational objective: The change of the minimum number of sampling points required has potential for an increase or decrease in monitoring for the assessment of air quality, depending on the variant.

Who would be impacted and how:

Direct: Public Authorities responsible for the maintenance of their Member State monitoring networks would be impacted as their administrative burden would either increase in the case of further monitoring requirements or decrease should monitoring requirements be reduced. This could either increase or compromise their ability to rigorously assess air quality and implement appropriate measures where air quality may be in exceedance.

Indirect: Dependent on the variant of this intervention, either more or less monitoring data would be reported to the public for their general information. Short term forecasts on episodic events rely on good quality monitoring data for model validation. These forecasts which inform the public in the event of high pollution levels when public health may be at increased risk. Longer term public health may also be impacted should monitoring decrease, as sampling points to assess compliance and evaluate the impact of measures in air quality plans to protect health and the environment would be jeopardised.

Risks for implementation:

- For any variant requiring an increase in monitoring, costs will be large, access to both capital and maintenance costs are a risk
- Skilled resources are required for data management of monitoring networks, and any increase in monitoring risks a lack of such resources
- Time required to establish new sites can be extensive and this intervention may risk the foreseen beneficial impact of increasing new sites to air quality in the short term
- Any decrease in monitoring, particularly in areas of exceedance, is likely to be met with concern over public health which should require communications to inform the public of the appropriateness of the intervention. This risks a delay to the implementation.

Indicators

1. Air Quality	2. Impacts on Health	3. Impacts on Ecosystems	4. Climate change links	5. Costs to Scoiety	6. Mitigation costs	7. Impacts on Competitiveness	8. Impacts on Sensitive Groups	9. Societal benefits and burden sharing	10. Impacts on Employment	11.Policy synergies	12. Administrative Burden
+	+	+	0	+/-	0	0	0	0	0	0	---

Assessment

Effectiveness:

Fixed sampler monitoring to assess air quality is inherently limited to those locations and their representative areas. Should Member States operate networks based on the minimum number of samplers there will undoubtedly be areas within air quality zones which are poorly represented. Therefore, any decrease in monitoring will likely exacerbate this situation. On the other hand, any increase in monitoring will likely improve it. However, many Member States operate above the current minimum number of stations requirements, at least in densely populated air quality zones, so an increase in the Directive requirements may have little impact. While establishing a minimum number of sampling points to assess air quality in relation to industrial point sources, within pollution hotspots and population exposure is of benefit for increased clarity, it should also be noted that monitoring network design should be based on wider criteria such as pollution levels in relation to the ambient air quality standard; to population density and emissions sources and levels within the zone.

From the stakeholder survey there was strong consensus that a reduction in the minimum number of monitoring stations would be detrimental to air quality, public health, ecosystems and costs to society but lessen administrative burden. Overall, an increase in the minimum number of stations was supported, which brings a positive impact to Air Quality, Health and Ecosystem but increases Administrative Burden [+ for these indicators].

In air quality zones with lower pollution levels and population density, a minimum of two sampling points is suggested, one at a background station and the other in a pollution hotspot. There was support for this by all stakeholder types.

Efficiency:

Increased number of stations significantly increases costs for Public Authorities. In particular, it means more costs for laboratory analysis, more staff are required for servicing and maintenance and data management. An estimated station capital cost is € 100,000 with on-going costs for maintenance and service of €10,000 per year [Administrative burden ---]. However, many Member States already have more than the minimum number of monitoring stations in their most densely populated air quality zones and depending on how stringent this revision is, it may have no impact on many Member States in terms of costs. As there was little/no support for a decrease in the minimum number of stations cost savings are unlikely in practice.

Due to the potential for indirect benefit to public health costs to society could be increased or reduced dependent on the variant [Costs to society +/-]

Coherence:

There are no foreseen impacts on policy synergies or climate change links [Climate and Policy 0]

Links to other interventions: [synergies / misalignment]

- **G2:** *Make the use of air quality modelling mandatory as part of air quality assessment (in some circumstances:* Modelling validation requires sufficient high-quality data from monitoring sampling locations. Increasing the minimum number of sampling points would offer such data [Synergies]. However, any decrease in monitoring would compromise the use of models [Misalignment]
- **L2:** *Require monitoring of additional air pollutants at a minimum number of sampling points and with relevant data quality requirements:* This intervention should align with that for setting a minimum number for emerging pollutants. [potential for synergy or misalignment]
- **H2***: The minimum number of sampling points for measuring* PM_{10} *and* $PM_{2.5}$ *will be considered independently from each other (and cannot substitute one another)* [Synergy]
- **J1:** *Further clarify (and reduce flexibilities related to) the macro-siting criteria for sampling points.* A reduction in flexibilities to place new sampler locations may bring challenges to meeting the requirements for a higher minimum number of sampling points [Misalignment]
- **J2:** *Further clarify (and reduce flexibilities related to) the micro-siting criteria for sampling points.* A reduction in flexibilities to place new sampler locations may bring challenges to meeting the requirements for a higher minimum number of sampling points [Misalignment]
- **J3:** *Introduce the concept of a spatial representative area which should be estimated (and reported) for each sampling point (irrespective of exceedances being measured or not).* Estimating and reporting on a spatial representative area may highlight monitoring network gaps even when the minimum number of sampler points has been achieved. A decrease in monitoring would compromise this intervention [Misalignment], while an increase in monitoring would support it [Synergy]

Benefit Cost Ratio: Medium: [variants leading to an increase in monitoring] Increases in the minimum number of samplers for some pollutants especially where concentration of pollution is above the Upper Assessment Threshold would help support model validation and better inform the public at risk from high pollution levels.

Summary: There is little/no support for any decrease in the minimum number of sampling points and our expert view is that the current minimum number of sampling points should be increased for some pollutants so that a minimum of two sampler locations are in place in the least populated air quality zones where concentrations are above the Upper Assessment Threshold. While additional monitoring is associated with high costs, many Member States report monitoring above the current required number of sampling locations, and therefore in practice an increase in monitoring required is overall beneficial.

H2

Intervention Area H: How to improve the minimum number and type of sampling points required for measuring air pollution concentrations?
Intervention/Measure: (H2) The minimum number of sampling points for measuring PM_{10} **and** $PM_{2.5}$ **will be considered independently from each other.**
The problem: Air quality Monitoring and assessment shortcomings. (Drivers: Monitoring rules offering flexibility are 'stretched' in instances; Modelling ability has improved, allows for much more detail.)
Description: This intervention de-couples of the current minimum number of sampling points for PM_{10} and $PM_{2.5}$, which should be set independently and cannot substitute one another.
Purpose/operational objective: To give further weight and clarity to monitoring for the assessment of $PM_{2.5}$
Who would be impacted and how: ***Direct:*** Competent Authorities responsible for monitoring networks will be impacted if a change in the Directive increases the requirements for $PM_{2.5}$ monitoring. This will add cost for the purchase and maintenance of new samplers but also administrative burden for data management and operation of the samplers. However, many Member States report data for $PM_{2.5}$ sampler numbers above the minimum requirements. ***Indirect:*** As this intervention would set new minimum requirements for monitoring of $PM_{2.5}$, information on pollutant levels will be enhanced, the public can be better informed, and more data could be available to support action to reduce levels where they are found in exceedance of the standards. As $PM_{2.5}$ brings key public health risks more data could support better public health protection. However, in practice as many Member States already report data above the minimum number of samplers required, there may be little value to the public.
Risks for implementation: • Costs for new monitoring samplers is often high, and comes with on-going maintenance costs • There may be a lack of resources to support this intervention in some Member States as staff is needed to support sampler operation and data management • Time required to establish new sites can be extensive and this intervention may risk impact to air quality in the short term

Indicators

1. Air Quality	2. Impacts on Health	3. Impacts on Ecosystem	4. Climate change links	5. Costs to Society	6. Mitigation costs	7. Impacts on Competitiveness	8. Impacts on Sensitive Groups	9. Societal benefits and burden sharing	10. Impacts on Employment	11. Policy Synergies	12. Administrative Burden
(+)	(+)	0	0	(+)	0	0	0	0	0	0	---

Assessment

Effectiveness:

$PM_{2.5}$ is a key pollutant for public health risk assessment. Given its important impacts on mortality and morbidity, our expert view is that it is essential for it to be considered and assessed independently from PM_{10}. The sources of these can be different and the current provisions are considered too vague and are not in line with the current the widespread exceedance of the WHO guideline values in Europe [Air Quality and Health (+)].

From the stakeholder survey there is widespread support that amendments to the legal framework are needed to increase the number of $PM_{2.5}$ fixed monitoring. There is strong consensus amongst all stakeholders that $PM_{2.5}$ should be considered independently from PM_{10}.

Efficiency:

A high one-off cost would be incurred by Member States as it will require the instrumentation and installation of further monitoring sampling points for measuring PM10 and PM2.5 independently from each other [Administrative burden ---]. Regarding the recurring costs, expert judgement has suggested that these would be medium where the minimum number increase is significant to low where the minimum number increase is less demanding.

In addition, some Member States have increased their number of $PM_{2.5}$ sampling points in recent years and dependent on the revised number in the Directive significant additional costs are not foreseen. However, in those Member States who operate monitoring networks at minimum requirements then costs to increase $PM_{2.5}$ monitoring will be high [estimated €80,000 for new sampling site]. However, due to the potential for indirect benefit to public health costs to society could be reduced [Costs to society (+)]

Coherence:

There are no foreseen impacts on policy synergies or climate change links [Climate and Policy 0]

Links to other interventions: [synergies / misalignment]

- **G2:** *Make the use of air quality modelling mandatory as part of air quality assessment (in some circumstances:* Modelling validation requires sufficient high-quality data from monitoring sampling locations. Increasing the minimum number of sampling points would offer such data [Synergy].
- **H1:** *Change the minimum number of sampling points that are required per air quality zone* [Synergy].
- **J1:** *Further clarify (and reduce flexibilities related to) the macro-siting criteria for sampling points.* A reduction in flexibilities to place new sampler locations may bring challenges to meeting the requirements for a higher minimum number of sampling points [Misalignment]
- **J2:** *Further clarify (and reduce flexibilities related to) the micro-siting criteria for sampling points.* A reduction in flexibilities to place new sampler locations may bring challenges to meeting the requirements for a higher minimum number of sampling points [Misalignment]
- **J3:** *Introduce the concept of a spatial representative area which should be estimated (and reported) for each sampling point (irrespective of exceedances being measured or not).* Estimating and reporting on a spatial representative area may highlight monitoring network gaps even when the minimum number of sampler points has been achieved [Misalignment]

Benefit to cost ratio: High: more information on a key public health pollutant is seen as high value and additional costs to most Member States who are operating above the current minimum required sampler numbers is viewed as relatively low. Where Member States will be required to install and operate new samplers costs are medium, although these can be reduced if a current sampling location for other pollutants is used.

Summary: High value to be realised by this intervention and all stakeholder types support it. $PM_{2.5}$ has a high public health impact leading to substantial mortality and morbidity outcomes where exposure is high. Clarifying and giving more focus on the assessment of this pollutant in the revised Directive would bring benefit to driving action in areas of exceedance to improve public health protection. Many Member States have already increased their sampling of $PM_{2.5}$ so in practice this intervention is unlikely to involve large costs, though for those Member States who monitor at minimum levels only costs may be significant.

H3

Intervention Area H: How to improve the minimum number and type of sampling points required for measuring air pollution concentrations?

Intervention/Measure: (H3) Simplify the definitions of types of monitoring station and/or sampling point locations - and only differentiate for them to distinguish between hotspots or background concentrations.

The problem: Air quality Monitoring and assessment shortcomings.

(Drivers: Monitoring rules offering flexibility are 'stretched' in instances; Modelling ability has improved, allows for much more detail.)

Description:
Currently station classification includes a number of categories such as Urban, Suburban, Rural, Industrial, Roadside etc. Station classification could be simplified to identify sites as hotspots or background locations.

Purpose/operational objective: Simpler definitions would allow for an increased clarity on air quality monitoring data particularly for public information

Who would be impacted and how:

Direct: Competent authorities would be required to reclassify their monitoring sites. This could provide an opportunity to highlight the emission sources of concern as part of the new "hotspot" class i.e. residential combustion, roadside or industrial which may aid public communication of air quality.

Indirect: It has previously been reported in the Fitness Check that the public are unclear on the differences between current sampling site types. Simplifying the site classification should enhance clarity for the public on this issue.

Risks for implementation:

- A reclassification without more elaborated guidance may be difficult to achieve a harmonized approach to this across Europe. For example, specific criteria should be set for reclassifying a current "suburban" site to a background or hotspot site. There will remain a risk that different Member States interpret guidance differently
- A more simplified classification risks loss of clarity and misunderstanding on the site differences and main sources of pollution. The full reporting of site meta data under the IPR and e-reporting by all Member States and clarification of terms further in the AAQ Directive could greatly help to address this shortcoming.

Indicators											
1. Air Quality	2. Impacts on Health	3. Impacts on Ecosystem	4. Climate change links	5. Costs to society	6. Mitigation costs	7. Impacts on Competitiveness	8. Impacts on Sensitive Groups	9. Societal benefits and burden sharing	10. Impacts on Employment	11.Zpolicy synergies	12. Administrative Burden
0	0	0	0	0	0	0	0	0	0	0	--

Assessment

Effectiveness:

The current site classification system has been long established with a requirement to report site meta data. These meta data, if reported in full, enable scrutiny of monitoring site details. These meta data are particularly valuable for model validation. The current site classification system is by and large effective, in our expert view. However, one of the issues with the current classification system is that hotspot locations are usually reflected by traffic orientated sites or industrial sites. Other sources of emission are important to control, particularly emissions from residential combustion, but these locations are not currently reflected in the monitoring classification system. Elaborating a hotspot site to include such sources within the current classification system may be a more effective solution.

From the stakeholder survey many public authorities also do not see difficulties with the current system which is established. Most views expressed reflect this intervention as an introduction of an overly simplistic system of just hotspot and background which may cause more confusion as it does not adequately reflect the variety of sites in place. However, NGOs welcome the proposal to simplify the definitions. Their view however is that this simplification needs to be accompanied by a clear demarcation between hotspot stations and background stations.

Overall, this intervention does not have any impact on any of the indicators [Air quality, Health, Ecosystems, Sensitive groups and Employment 0].

Efficiency:

As this intervention is a desk task to reclassify the current sites it is unlikely to have any real impact on administrative burden. As this intervention implies a simplification of definitions, expert judgement suggests both a low one-off cost in terms of the revising the station classification procedure [Administration burden -].

There are no foreseen impacts on other related costs [Society, Mitigation, Competitiveness, Employment 0]

Coherence:

There are no foreseen impacts on policy synergies or climate change links [Climate and Policy 0]

Links to other interventions: [synergies / misalignment]

- **J1:** *Further clarify (and reduce flexibilities related to) the macro-siting criteria for sampling points.* A reduction in flexibilities on siting criteria for various site types may cause difficulties reclassifying these into a simplified system [Misalignment]
- **J2:** *Further clarify (and reduce flexibilities related to) the micro-siting criteria for sampling points.* A reduction in flexibilities on siting criteria for various site types may cause difficulties reclassifying these into a simplified system [Misalignment]

Benefit cost ratio: Low: A simplification of monitoring site types does not appear to be beneficial on its own, without more clarity in macro and micro-siting criteria. However, the cost of this intervention is negligible and is a one-off desk-based task. There is benefit in revising the classification system to highlight other key sources of emission in hotspot locations, especially residential combustion.

Summary: While the benefit cost ratio of this intervention is neutral, there is no overall consensus on its value (Public authorities and research academics are on the whole not supportive; NGOs call for more clarity but refers to separate interventions on revisions in the macro and micro-siting criteria). The use of a very simple system as proposed risks loss of clarity on the main sources of pollution e.g. traffic, industrial, residential combustion. In addition, it risks the loss of the difference between a rural and urban background site. However, the current classification system is missing a key source of pollution, residential combustion and the introduction of a new site type to reflect this would highlight it as a source for further control. The full reporting of site meta data under the IPR and e-reporting by all Member States would greatly help to address this shortcoming.

I1

Intervention Area I: **How to ensure continuity in the monitoring of air quality?**

Intervention / Measure: (I1) Specify that sampling points with exceedances of limit values for any of the pollutants measured under the Ambient Air Quality Directives should be maintained for a defined number of years.

The problem: Air quality Monitoring and assessment shortcomings.

(Drivers: Flexibilities may sometimes impact the comparability of data;
Monitoring rules offering flexibility are ‘stretched’ in instances; Modelling ability has improved, allows for much more detail.)

Description:
Flexibilities in the AAQ DIRECTIVES enable monitoring sites to close or be relocated (except for PM_{10} if exceeding limit values), but this disrupts trend analysis and causes uncertainty in areas of exceedance. This intervention would prevent sampling point closure within a defined number of years following site establishment. Possibilities under which circumstances can relocations of sampling points take place include:
(1) Due to requirements of local spatial development
(2) If and when siting criteria are no longer met (macro-scale siting or micro-scale siting)
(3) If overlap between monitoring at ‘old’ and ‘new’ sampling point is guaranteed and reported (for a defined time period ensure monitoring at both locations to assure calibration)

Purpose/operational objective:
Providing clarity on the circumstances when sampling points may be relocated would reduce flexibility to close stations but allow for increased datasets for pollutant trend analysis. Should a monitoring site show exceedance of an air quality standard a requirement for continue monitoring would ensure transparency and available public information.

Who would be impacted and how:

Direct: Public Authorities responsible for the maintenance of monitoring networks would be impacted as they would only be able to close a monitoring station by exception. Where that is the case their administration burden would be increased as the sites would be required to relocated. Setting up a new site is time consuming and also as a consequence of having to carry out parallel measurements whenever relocation happens.

Indirect: As this intervention would set new requirements to operate sampling points over the longer term, it would allow higher quality pollutant trend analysis. This better data could be available to support action to reduce levels where in pollution hotspots to better enable action to improve public health.

Risks for implementation:

- Requirements to maintain sampling points for a set number of years will create inflexibilities above the current allowed. This risks the expert views from Member States should there be a valid case for site closure (apart from the stated exceptions).
- There may be a lack of resources for Competent Authorities required to carry out parallel measurements and/or relocate sampling points.

Indicators

1. Air quality	2. Impacts on Health	3. Impacts on Ecosystem	4. Climate change links	5. Costs to society	6. Mitigation costs	7. Impacts on Competitiveness	8. Impacts on Sensitive Groups	9. Societal benefits and burden sharing	10. Impacts on Employment	11.Policy synergies	12. Administrative Burden
(+)	(+)	(+)	0	0	0	0	(+)	0	0	0	0

Assessment

Effectiveness:

Overall, requiring a set timeframe for the operation and maintenance of sampling points with exceedances of limit values for any of the pollutants under the AAQ Directives would result in better datasets for assessment and trend analysis. This would in most cases be a prerequisite for more effective and more targeted air quality management [i.e. Air quality (+)]. It would also allow to improve local air quality management to protect human health and ecosystems from adverse impacts [i.e. Health (+) and Ecosystems (+)].

The vast majority of stakeholders were in favour of allowing the relocation of sampling points only under specific circumstances (i.e. stations that initially did not meet the criteria; landscape changes that reduce timeseries; and stations under the effect of constant proven contamination that cannot be addressed). Sampler relocations should follow clear criteria and expert judgement and all relocation changes should be reported to the Commission. This was particularly emphasised by both national and regional authorities, who felt it was of vital importance that monitoring stations are not moved without proper consideration, since long trends are of great importance for the assessment of air quality.

Efficiency:

Costs for this measure would be incurred at the national level. Most stakeholders, particularly national and regional authorities considered them to be either minimal, neutral or not relevant. Effort would most likely be needed to investigate adequate sites for continuing the monitoring whenever relocations were necessary.

Coherence:

There are no foreseen impacts on policy synergies or climate change links [Climate and Policy 0]

Links to other interventions: [synergies / misalignment]

- **I2:** *Include the requirement to monitor long-term trends if fixed monitoring stations are discontinued (by assessing air quality via indicative measurements or air quality modelling):* This intervention is essential to support the circumstances or exceptions under which sampling points with exceedances of limit values can be relocated without affecting trend data [Synergy]
- **I3:** E*stablish a protocol to follow should a sampling point have to be re-located due to, for example, infrastructure development or changes in the assessment regimes:* This intervention is essential to support the circumstances or exceptions under which sampling points with exceedances of limit values can be relocated without affecting trend data [synergy].
- **G1:** *Allow / continue to allow the use of indicative monitoring to substitute fixed monitoring as part of air quality assessment:* Adequate monitoring is essential for trend analysis, and the use of indicative monitoring can help maintain trend analysis under the circumstances where monitoring stations need to be relocated [Synergy]

- **H1:** *Change the minimum number of sampling points that are required per air quality zone:* As the sampling points with exceedances of limit values for any of the pollutants must be maintained for a set timeframe, changes in their numbers, particularly a decrease in them, may cause issues with relocation [possible misalignment]

Benefit Cost Ratio: High: It is essential for public health protection to maintain sampling points should exceedances of air quality standards be observed and trends in pollution can be assessed. While administrative burden is temporarily increased should a sampling point have to be relocated, this is only a slight increase.

Summary: Achieving compliance with limit values is crucial for health protection and therefore, in our expert view, it is essential that montioring stations where exceedances are observed are maintained for a set number of years. At sampling points where compliance/exceedance is marginal it is important to track the evolution of concentrations over a number of years where measures are being implemented to fully ensure compliance can be guaranteed. Flexibility in relocating a sampler is a benefit to monitoring network managers.

I2

Intervention Area I: How to ensure continuity in the monitoring of air quality?

Intervention / Measure: (I2) Include the requirement to monitor long-term trends if fixed monitoring stations are discontinued (by assessing air quality via indicative measurements or air quality modelling).

The problem: Air quality Monitoring and assessment shortcomings.

(Drivers: Flexibilities may sometimes impact the comparability of data;
Monitoring rules offering flexibility are 'stretched' in instances; Modelling ability has improved, allows for much more detail.)

Description:
Currently, flexibilities in the AAQ Directives enable monitoring sites to close or be relocated, but this disrupts trend analysis. Under the circumstances where stations are discontinued a requirement could be introduced to continue to monitor for long-term trends using indicative measurements or modelling.

Purpose/operational objective:
Including a requirement to monitor long-term trend in the cases of relocation of fixed monitoring stations would allow for increased datasets for pollutant trend analysis.

Who would be impacted and how:
Direct: The administrative burden may increase on competent authorities to setup additional indicative monitoring stations or assess air quality via modelling to comply with the long-term assessment of trends if fixed monitoring stations need to close or be relocated. However, the resulting monitoring of long-term trends without disruption can provide authorities with a more rigorous assessment of air quality which may lead to more focussed air quality plans, decreasing the administrative burden of their development and implementation.

Indirect: Scientific researchers interested in the air quality levels and trends will benefit from a better dataset.

Risks for implementation:

- Time required to set up indicative monitoring devices to monitor long-term trends.
- The set up of low-quality indicative monitoring devices, to comply with the monitoring of long-term trends where fixed stations are discontinued, could degrade the quality of the data obtained.
- Resources required to do air quality modelling.

Indicators

1. Air quality	2.Impacts on Health	3. Impacts on Ecosystem	4. Climate change links	5. Costs to society	6. Mitigation costs	7. Impacts of Competitiveness	8. Impacts on Sensitive Groups	9. Societal benefits and burden sharing	10. Impacts on Employment	11.Policy synergies	12. Administrative Burden
(+)	(+)	(+)	0	0	0	0	0	0	0	0	(-)

Assessment
Effectiveness:

The mandatory requirement to assess air quality via indicative measurements or air quality modelling whenever fixed stations are discontinued would result in a more complete long-term data set. Analysis of air quality trends is key to understanding sources and evaluating measures which is a prerequisite for more effective and more targeted air quality management [i.e. Air quality (+)]. Similarly, it would also allow to improve local air quality management to protect human health and ecosystems from adverse impacts [i.e. Health (+) and Ecosystems (+)].

Despite the fact that long term trends were seen as important by stakeholders in general, many of them, particularly national authorities, considered that neither indicative measurements nor modelling could fully replace a discontinued fixed monitoring station, as the uncertainty of the results is too high. Contrarily, national level research bodies, meteorological offices and environment agencies and some regional authorities considered that indicative measurements could well replace fixed measurements for long-term trends by using data gap filling methods.

Efficiency:

Costs for this intervention depend on the variant. National authorities in general expressed that administrative burden and costs of monitoring could increase as the amount of fixed monitoring stations would remain the same while it may be required to increase indicative measurements at all previous fixed measurement locations for long term trend monitoring and analysis [Administrative burden -]. However, where fixed monitoring stations could be replaced by indicative monitoring or modelling a cost saving is likely

Coherence:

There are no foreseen impacts on policy synergies or climate change links [Climate and Policy 0]

Links to other interventions: [synergies / misalignment]

- **I1:** *Specify that sampling points with exceedances of limit values for any of the pollutants measured under the Ambient Air Quality Directives should be maintained for a defined number of years* [Synergy]
- **I3:** *Establish a protocol to follow should a sampling point have to be re-located due to, for example, infrastructure development or changes in the assessment regimes:* This intervention is essential to support the circumstances or exceptions under which sampling points with exceedances of limit values can be relocated without affecting trend data [Synergy].
- **G2:** *Make the use of air quality modelling mandatory as part of air quality assessment (in some circumstances):* Indicative monitoring has the potential to provide valuable additional information long-term trend analysis, on top of the fixed monitoring network [Synergy].

Benefit Cost Ratio: **Low**: There is a likely cost saving in replacing a fixed sampler with indicative measurements or modelling. While there is benefit to scientific understanding and policy development to have access to a long-established network of monitors, the different assessment technique brings a step change in the data trend and with a larger uncertainty. Thus, the overall benefit is relatively low.

Summary: Assessing long term trends in pollution data is important for the assessment and management of air quality. Maintaining a monitoring network to enable trend analysis is important, though care is needed to ensure data quality is also maintained. For this intervention to be fully successful, it is important to align with those proposed interventions with the objective of improving quality of indicative monitoring and modelling.

I3

Intervention Area I: **How to ensure continuity in the monitoring of air quality?**											
Intervention / Measure: (I3) Establish a protocol to follow should a sampling point have to be re-located due to, for example, infrastructure development or changes in the assessment regimes.											
The problem: Air quality Monitoring and assessment shortcomings. (Drivers: Flexibilities may sometimes impact the comparability of data; Monitoring rules offering flexibility are 'stretched' in instances; Modelling ability has improved, allows for much more detail.)											
Description: Currently, flexibilities in the AAQ Directives enable monitoring sites to close or be relocated, but this disrupts trend analysis. Whenever the circumstances of station discontinuation or sampling point relocation due to infrastructure development or changes in the assessment regime arise, a protocol establishing the requirements for such change should serve as guidance.											
Purpose/operational objective: A protocol could include an assessment of site representativeness, co-location of monitoring for a minimum time period, to assist in the assessment of data quality for trend analysis from the old and new sampling points and hence increase robustness and transparency especially when areas are in exceedance.											
Who would be impacted and how: ***Direct:*** Public authorities responsible for the maintenance of their Member State monitoring networks would be impacted as they would have to familiarise themselves with and apply the new protocol. ***Indirect:*** Scientific researchers interested in the air quality levels and trends will benefit from a better dataset.											
Risks for implementation: • Reduced flexibility to relocate samplers when necessary, may risk increased administration burden on Member States to find an alternative monitoring location • An approved site closure process risks encouraging Member States to consider this option, which will be detrimental to assessing long term pollution trends.											
Indicators											
1. Air quality	2. Impacts on Health	3. Impacts on Ecosystem	4. Climate change links	5. Costs to society	6. Mitigation costs	7. Impacts on Competitiveness	8. Impacts on Sensitive Groups	9. Societal benefits and burden sharing	10. Impacts on Employment	11. Policy synergies	12. Administrative Burden
(+)	0	0	0	0	0	0	(+)	0	0	0	-
Assessment ***Effectiveness:***											

This intervention is highly appropriate to ensure that any re-location of sampling points is done in a harmonised and appropriate manner. There are many factors that should be considered when re-locating sampling points (e.g. need for parallel measurements where possible, use of modelling, indicative measurements and or/measurement campaigns to find similar locations or other hotspot locations). A common protocol to follow would provide good support to authorities in the practical implementation of the directive. This intervention is likely to be helpful for greater assessment harmonisation and gave some benefit to air quality (+) and impact on sensitive groups (+).

On the whole, all stakeholders were in favour of a protocol to follow to relocate sampling points.

Efficiency:

The costs for this intervention are low. Some NGOs suggested that a protocol should include consultation with the public which would increase the administrative burden, while some regional authorities stated that relocating an sampling point already has high administrative burden and a protocol should not lead to additional burden. Expert judgement suggests that Member States would likely incur a low one-off cost related to the modifications in current sites where sampling points need to be relocated, and further low recurring maintenance related to running the new devices which might be needed (i.e. data management costs). [Administrative burden -]

Coherence:

There are no foreseen impacts on policy synergies or climate change links [Climate and Policy 0]

Links to other interventions:

I1: *Specify that sampling points with exceedances of limit values for any of the pollutants measured under the Ambient Air Quality Directives should be maintained for a defined number of years* [Synergy]

I2: *Include the requirement to monitor long-term trends if fixed monitoring stations are discontinued (by assessing air quality via indicative measurements or air quality modelling):* This intervention is essential to support the circumstances or exceptions under which sampling points with exceedances of limit values can be relocated without affecting trend data [Synergy].

Benefit Cost Ratio:

Medium: This intervention is low cost/administrative burden and brings the benefit of a set protocol to follow for Member States. This intervention would have the benefit of clarifying and harmonising parameters for consideration in this process and overall will increase the comparability of data.

Summary:

The harmonisation of air quality monitoring is important for the comparability of data. This proposed protocol should improve harmonisation. Dependent on the protocol detail, administrative burden could slightly increase or decrease. Either way, the benefit of this intervention to improve the comparability of data is clear.

J1

Intervention Area J: How to ensure the reliable micro and macroscale siting of monitoring stations?
Intervention J1 - Further clarify (and reduce flexibilities related to) the macro-siting criteria for sampling points.
The problem: Air quality Monitoring and assessment shortcomings. (Driver: Flexibilities may sometimes impact the comparability of data; Monitoring rules offering flexibility are stretched in instances)
Description: The siting of sampling points can have a significant impact on the levels of air pollutants that are measured. In this intervention the macro-siting criteria for sampling points are clarified and flexibilities in the interpretation are further reduced.
Purpose/operational objective: This intervention would allow for an increased harmonisation and comparability of measurement data of air pollutants over Europe.
Who would be impacted and how: ***Direct:*** Competent authorities and monitoring network managers are responsible for the selection of new monitoring sites according to the AAQ Directives siting requirements and for the documentation and reporting of macro-siting criteria of existing sampling points. When the intervention is implemented a proper assessment of the relevant siting criteria should be made for (new) each sampling point. ***Indirect:*** Academics, researchers and NGOs, who scrutinise air quality data, would benefit from better precision on siting criteria to enable robust data comparison.
Risks for implementation: • A reduction of flexibilities related to macro-siting criteria may cause (serious) problems for finding suitable locations for (new) sampling points. This might compromise the design of an effective monitoring network.

Indicators											
1. Air Quality	2. Impact on Health	3. Impacts on Ecosystems	4. Climate change links	5. Costs to society	6. Mitigation costs	7. Impacts on Competitiveness	8. Impacts on Sensitive Groups	9. Societal benefits and burden sharing	10. Impacts on Employment	11. Policy synergies	12. Administrative Burden

(+)	(+)	(+)	0	0	0	0	(+)	0	0	0	--

Assessment

Effectiveness:

The siting criteria are open for interpretation and not implementing the intervention could compromise the harmonisation and comparability of air quality measurement data within the EU [Air Quality: (+) Health (+) and Ecosystems (+)]. This could lead to an inconsistent implementation of the AAQ Directive's requirements. Inconsistencies can impact on the number of monitoring stations, the number and extent of exceedances identified, the need for measures to improve air quality, and the costs associated with these activities. This could also lead to issues of inequality and fairness in the implementation of the requirements and affect the proportionality of any potential infringement action.

A majority of stakeholders indicates that the intervention addresses the shortcoming fully or to a large extent.

It is important to note that many stakeholders indicate that it can be hard to find an optimal location for a monitoring site. Some flexibility is absolutely needed to deal with practical situations during the implementation of a monitoring network.

With respect to the variants:

(1) According to the majority of stakeholders, harmonising the macro-scale siting criteria laid down in Annex III and Annex VIII of Dir. 2008/50/EC and Annex III of Dir. 2004/107/EC – aligning with 2008/50/EC provisions would further clarify the macro-siting criteria. Taken together, 60% of answers ranged from to some/large extent, while 25% answered fully.

(2) Most stakeholders considered that clarifying whether macro-scale siting criteria are applicable to sampling points for indicative measurements in addition to sampling points for fixed measurements would address the issue to a large extent.

(3) Taken together, more than half of respondents considered that clarify whether specific locations should be explicitly excluded, even if there is public access to these would effectively address the issue. Answers ranged from to some extent to a large extent (in roughly equal numbers). On the exclusion of specific locations even if there are public access opinions are less aligned. Some stakeholders strongly argue that the AAQ Directives limit values should apply everywhere whereas others bring this requirement in relation with general population exposure.

Efficiency:

Additional requirements for the siting criteria of sampling points will increase administrative burden for the competent authorities [Administrative Burden: -] in terms of sampling point evaluation and reporting of the relevant indicators.

Coherence:

There are no foreseen impacts on policy synergies or climate change links [Climate and Policy 0]

Links to other interventions: [synergies / misalignment]

J2: *Further clarify (and reduce flexibilities related to) the micro-siting criteria for sampling points:* Macro-siting criteria are closely related to the micro-siting criteria. An intervention related to clarification and reduction of flexibilities should cover both aspects. [Synergy]

J3: *Introduce the concept of a spatial representative area which should be estimated (and reported) for each sampling point (irrespective of exceedances being measured or not):* Spatial representativeness of sampling points is an essential element of the macro-siting criteria. [Synergy]

Benefit to Cost ratio: **Medium**: stakeholders indicate that the costs related to this intervention are expected to be rather small. In some cases, station locations will not fulfill the new requirements which might result in a reallocation of monitoring sites and substantially larger costs. Benefits are mainly associated to a more harmonized European wide monitoring network and comparability of air quality data.
Summary: This intervention further clarifies and reduce the flexibilities related to macro-siting criteria of sampling points. Most stakeholders support the implementation of this intervention since it increase the comparability and harmonisation of air quality data over Europe. However, the same stakeholders indicate that some flexibility is still required in order to deal with practical selection and installation of sampling points.

J2

Intervention Area J: How to ensure the reliable micro and macroscale siting of monitoring stations?
Intervention • **(J2) Further clarify (and reduce flexibilities related to) the micro-siting criteria for sampling points.**
The problem: Air quality Monitoring and assessment shortcomings. (Drivers: Monitoring rules offering flexibility are 'stretched' in instances; Modelling ability has improved, allows for much more detail.)
Description: This intervention to revise the micro-siting criteria has the following variants: (1) Harmonise the micro-scale siting criteria laid down in Annex III and Annex VIII of Dir. 2008/50/EC and Annex III of Dir. 2004/107/EC – aligning with 2008/50/EC provisions. (2) Clarify whether micro-scale siting criteria are applicable to sampling points for indicative measurements in addition to sampling points for fixed measurements. (3) Clarify the flexibility related the unrestricted flow around the inlet of sampling points. (4) Clarify the flexibility related to the height of the inlet of sampling points. (5) Clarify the flexibility related to the distance to the kerbside (or other metrics) of traffic-oriented sampling points.
Purpose/operational objective: Clarification of the micro-siting criteria for sampling points would allow for an increased harmonisation on measurement of air pollutants
Who would be impacted and how: ***Direct:*** Competent Authorities responsible for monitoring networks. All monitoring sites would need to be reviewed to assure compliance with any revised micro-siting criteria. In some instances, this may mean changes to the management of the site (height of site inlet) or may mean sites may have to be re-located. ***Indirect:*** Academics, researchers and NGOs, who scrutinise air quality data, would benefit from better precision on siting criteria to enable robust data comparison.
Risks for implementation: • Risk to long term time series should revision in micro-siting criteria result in non-compliance with existing long established monitoring sites. e.g. Sweden report that sites have been established on roof-tops, which are representative of urban background exposure. It is very important that the provisions in the future directive do not disqualify stations with long time-series that have been shown to be fit-for-purpose. • Risk to the establishment of new sites should micro-siting criteria become narrow too which results in difficulty to find a location that meet the requirements especially for traffic-oriented sites. • Risk of inflexibility to enable monitoring at the location of highest concentrations.
Indicators

1. Air Quality	2. Impacts on Health	3. Impacts on Ecosystem	4. Climate change links	5. Costs to Society	6. Mitigation costs	7. Impacts on Competitiveness	8. Impacts on Sensitive Groups	9. Societal benefits and burden sharing	10. Impacts on Employment	11.Policy synergies	12. Administrative Burden
(+)	0	0	0	(+)	0	0	(+)	0	0	0	--

Assessment

Effectiveness:

Urban areas are complex environments. Dispersion conditions and pollution emission volumes can change within short distances, impacting concentrations. Expert view is that generally the current micro-siting criteria are fit for purpose and a level of flexibility is required to monitor at the most representative location where concentrations are high. However, revising the micro-siting criteria within Directive 2004/2004/107/EC – aligning with 2008/50/EC provisions brings clear benefit for harmonization. However, the heavy metals and BaP monitoring network has been long-established and any revision may impact long term trends. Likewise for indicative monitoring, any new micro-siting criteria applied to this type of monitoring brings harmonization which is welcome but any disruption to current monitoring risks long term trend analysis. In addition, there are a number of clarifications that would benefit harmonization of monitoring and such further clarity could be given in technical guidance and best practice examples, e.g. to show distance to kerb situations and whether or not to include cycle lanes, bus lanes etc. This intervention could be strengthened to ensure a more systematic and effective evaluation of the implementation of these provisions and to identify further specific issues where more guidance is needed.

On the whole, this intervention variant to clarify the application of micro-siting criteria to indicative monitoring could result in an indirect benefit on air quality [Air Quality (+)] and also could lead to better identification of hot spots to protect sensitive groups [sensitive groups (+)].

From the stakeholders, public authorities do not support reducing flexibility in micro-siting criteria for fixed samplers. They argue that clarification was made to the inlet height in Commission Directive (EU) 2015/1480 and there is no requirement for further revision. Revisions to the distance to kerb (and other metrics) risks the non-compliance for long established monitoring sites. There was support amongst many Public Authorities that micro-siting criteria should apply to indicative monitoring. AQUILA has suggested some clarification on the unrestricted flows for the sampler inlet, to increase harmonization. There was no consensus on revisions to the distance from the kerb for siting samplers.

NGOs on the other hand are strongly recommending that micro-siting criteria flexibility is reduced to ensure comparability of data. They suggest that sites should be further than 25m from a major junction, as the ventilation around a junction can lower concentrations. They argue that other parameters should be introduced including traffic volume, road width and building height for roadside sites.

Efficiency:

Revisions to micro-siting criteria which apply these to indicative monitoring may have an indirect benefit to society costs due to an indirect improvement on public health [Society (+)]. However, they are unlikely to have administrative burden impacts although should these result in the disqualification of existing sites then administration burden would be high [Administrative burden -].

There are no foreseen impacts on other related costs [Mitigation, Competitiveness, Employment 0]

Coherence:

There are no foreseen impacts on policy synergies or climate change links [Climate and Policy 0]

Links to other interventions: [synergies / misalignment]

(J1) *Further clarify (and reduce flexibilities related to) the macro-siting criteria for sampling points.* Revisions to macro-siting criteria should align with micro-siting criteria [synergy]

Benefit cost ratio:

Medium: There is likely benefit gain if micro-siting criteria is applied to indicative monitoring although where that is fixed and long term this risks the long-term dataset necessary for trend analysis. Where new indicative monitoring is being planned this intervention may give access to a higher quality monitoring dataset to assist air quality assessment. Where appropriate this could further underpin air quality action. Costs are relatively low, particularly if this intervention does not result in the disqualification of established long term sampling locations.

Summary:

The most concern raised by stakeholders about micro-siting criteria for sampling points is related to roadside sites, particularly in urban areas. However, these are complex environments with pollution concentrations varying in small micro-environments. Some level of flexibility is needed to local monitoring network managers to ensure monitoring effectiveness and efficiency. However, benefit to air quality managers would be gained should micro-siting criteria be clearly application to new indicative monitoring. Such monitoring could be used to validate models and underpin air quality plans. However, for this intervention to be fully successful technical guidance and best practice examples is needed to fully address the shortcoming and help improve the comparability of data.

J3

Intervention Area J: How to ensure the reliable micro and macroscale siting of monitoring stations?

Intervention J3

Introduce the concept of a spatial representative area which should be estimated (and reported) for each sampling point (irrespective of exceedances being measured or not)

The problem:

Air quality Monitoring and assessment shortcomings.

Driver:

Flexibilities may sometimes impact the comparability of data;

Monitoring rules offering flexibility are 'stretched' in instances;

Modelling ability has improved, allows for much more details

Description:

For every sampling location, a spatial representativeness (SR) area should be estimated and reported. This area of representativeness is an essential indicator of the sampling location.

A Tiered approach is available to assess SR of monitoring sites:

- Tier 1: assessment based on expert judgement;
- Tier 2: assessment based on proxy data or indicative measurement campaigns;
- Tier 3: assessment based on fit-for-purpose modelling according to FAIRMODE Guidance;
- Tier 4: assessment based on combination of modelling and indicative monitoring.

Purpose/operational objective:

The concept of an SR area helps to clarify and harmonize air quality assessment based on monitoring data. It serves multiple purposes in this process: assessment of population exposure and exceedance situation indicators based on the monitoring data, monitoring network design and selection of stations for model validation and data assimilation.

Who would be impacted and how:

Direct:

Competent Authorities and monitoring network managers have to assign an SR area to each sampling point location. A Tiered approach can be followed to accomplish this task. Higher tier methods could be used for the fixed monitoring stations whereas lower Tier methodologies could be applied for indicative monitoring. The methods and guidance to define the SR area are expected to be incorporated into Technical Guidance rather than the AAQ Directives.

Indirect:

Academics, researchers and NGOs, who scrutinise air quality data, would benefit from better precision on siting criteria to enable robust data comparison.

Risks for implementation:

- Methodologies of different Tier levels will give different estimates of SR area. This could hamper a proper intercomparison of monitoring locations.

Indicators

1. Air Quality	2. Impact on Health	3. Impacts on Ecosystems	4. Climate change links	5. Costs to society	6. Mitigation costs	7. Impacts on Competitiveness	8. Impacts on Sensitive Groups	9. Societal benefits and burden sharing	10. Impacts on Employment	11. Policy synergies	12. Administrative Burden
(+)	(+)	(+)	0	(+)	0	0	(+)	0	0	0	---

Assessment

Effectiveness:

A robust assessment of the spatial representativeness of sampling point locations will contribute to the overall comparability and harmonization of air quality data. It will also support the use of monitoring data in the assessment process, more specifically the estimation of the population exposure [Impact on health: (+)] and the exceedance indicators [Air Quality: (+) and Impact on Ecosystems: (+)]. This will also likely bring a positive indirect benefit to costs to society (+) and impacts on sensitive groups (+),

About halve of the stakeholders support this intervention fully or to a large extend. An additional 30% of the stakeholders believe this intervention will address the shortcoming to some extent. Most of the stakeholders refer to the ongoing work of FAIRMODE and AQUILA and welcome consolidated guidance in this respect.

Efficiency:

The requirement to systematically report the SR area of all sampling point location and the reduction in flexibilities to assess this indicator may cause more administrative burden [Administrative Burden: -]. When modelling capacity is already available costs might be limited since fit-for-purpose modelling results can be used (as higher Tier method) in the SR assessment process.

Coherence:

There are no foreseen impacts on policy synergies or climate change links [Climate and Policy 0]

Links to other interventions: [synergies / misalignment]

- **G1** *Allow / continue to allow the use of indicative monitoring to substitute fixed monitoring as part of air quality assessment:* Indicative monitoring can contribute (as Tier 2) to the SR assessment process. [Synergy]
- **H3** *Simplify the definitions of types of monitoring station and/or sampling point locations - and only differentiate for them to distinguish between hotspots or background concentrations*: A properly defined SR area can contribute to the definition of station types. [Synergy]
- **J1** *Further clarify (and reduce flexibilities related to) the macro-siting criteria for sampling points:* An SR area is closely linked to the macro-siting of a sampling point [Synergy]

Benefit to Cost ratio:

Medium: a robust assessment of an SR area of each sampling point requires an effort, depending on the specific Tier level that is selected. Lower Tier approaches (e.g. expert judgement) come with a smaller cost whereas costs might increase for higher Tiers methods. For the later one, the costs also depend on the modelling capabilities that are available for the Air Quality Zone.

Summary:

A proper assessment of the spatial representativeness of sampling point locations will contribute to the overall comparability and harmonization of air quality data. The Tiered approach offers a valuable framework for practical implementation of this intervention. When modelling capacity is available higher Tier methods are rather straightforward to apply, as demonstrated by the tests in the FAIRMODE CT8 community.

Apart from our expert judgment, different views of stakeholders exists on the introduction of a spatial representative area. A clear majority indicates that this intervention would fully or at least to a large extent address the shortcoming. Stakeholders indicate that there is a clear need for better definition for spatial representativeness and it would be useful to introduce this concept to the AAQ Directives in order to ensure comparability between Member States.

K1

Intervention Area K: Which requirements on data quality are needed to assess and report air quality?

Intervention • (K1) Further define the data quality requirements for sampling points / measurements used for air quality assessments.

The problem: Air quality Monitoring and assessment shortcomings.

(Drivers: Monitoring rules offering flexibility are 'stretched' in instances; Modelling ability has improved, allows for much more detail.)

Description:
To further define data quality including measurement uncertainty and data capture. Variants for this intervention include:
(1) Further align data aggregation requirements to be met for specific periods (e.g. hourly, daily, 8-hour or annual) or the whole year.
(2) Further align the data coverage (time coverage and data capture) requirements for all air pollutants.
(3) For ozone, align data coverage requirements for both for the full calendar year and for the period of April to September, as well as for the AOT40 indicator.
(4) For indicative measurements, set separate data coverage requirements for annual mean values and for short-term mean values.
(5) For calibration and validation of air quality modelling, introduce specific data quality requirements for sampling points / measurements (that are less strict than those used for air quality assessments)

Purpose/operational objective: To improve data quality requirements for sampling points which is likely to increase robustness of data and may supplement evidence for trend analysis and modelling

Who would be impacted and how:
Direct: Competent authorities responsible for monitoring networks and data management. In addition, modellers could benefit from potential additional monitoring datasets should data quality requirements for model validation be implemented in the Directive.
Indirect: Academics, researchers and NGOs, who scrutinise air quality data, would benefit if the outcome of this intervention is higher quality pollution data.

Risks for implementation:

- Increase in resource/administration burden risk should revisions result in changing to data management processes, although this is expected to be a one-off increase.

Indicators											
1. Air Quality	2. Impacts on Health	3. Impacts on Ecosystem	4. Climate change links	5. Costs to Society	6. Mitigation costs	7. Impacts on Competitiveness	8. Impacts on Sensitive Groups	9. Societal benefits and burden sharing	10. Impacts on Employment	11.Zpolicy Synergies	12. Administrative Burden

(+)	(+)	(+)	0	0	0	0	0	0	0	0	-

Assessment

Effectiveness:

Clarification on the specific metrics and methods to calculate data coverage is essential, and detailed considerations from expert groups of AQUILA and FAIRMODE have been sought. Specific data quality objectives for measurement used for model calibration & validation is an important proposal, to allow for use of other types of measurements where there is a lack of available fixed or indicative measurement data. However, it is vital that measurements be of good enough quality that they do not compromise the quality of model data.

These proposals may lead to indirect improvements in air quality, health and ecosystem which may indirectly reduce costs to society as clarity is provided over the use of data. This may lead to larger datasets that are considered valid. [Air quality, Health and Ecosystems (+)]

Overall, response from stakeholders was generally supportive and reference was made to separate proposals made by AQUILA for technical changes to data quality objectives which should be adopted.

Efficiency:

No significant impact on administrative costs are expected from these proposals. However, for indicative measurements this could depend on how ambitious the separate data coverage requirements are and how indicative measurements are to be applied in the new directive (i.e. whether they are mandatory or not). Allowing measurements with lower data quality requirements for model calibration and validation could lower administrative costs, as they would likely cost less than having additional fixed and indicative measurements to ensure enough data for model calibration and validation. [Administrative burden -]

Coherence:

There are no foreseen impacts on policy synergies or climate change links [Climate and Policy 0]

Links to other interventions: [synergies / misalignment]

K3: *Introduce a standardized 'modelling quality objective' as a quality control mechanism to assess whether a modelling-based assessment is fit-for-purpose*. Measurement data quality is important for calibrating models [Synergy]

Benefit Cost Ratio:

Medium: The costs for this are low or may even be a cost saving in as administrative burden may reduce as modelling is likely to cost less than additional fixed or indicative measurements. Benefits gained are clarity over validity of measurement data which may lead to larger datasets. Enhancing air quality knowledge from further data may indirectly lead to air quality improvements.

Summary:

Clarity over data quality parameters has been proposed to increase harmonization of air quality data. However, to make the full use of available data a protocol/guidance specifying appropriate methods for assessing compliance and estimating statistical parameters to account for low data coverage or significant data losses should be published.

K2

Intervention Area K: Which requirements on data quality are needed to assess and report air quality?

Intervention (K2) Make it mandatory to provide up-to-date information on the pollutant concentration for certain air pollutants for a minimum number of sampling points per air quality zone.

The problem: Air quality Monitoring and assessment shortcomings.

(Drivers: Flexibilities may sometimes impact the comparability of data;
Monitoring rules offering flexibility are ‘stretched’ in instances; Modelling ability has improved, allows for much more detail.)

Description: There exists some ambiguity around the provision of up-to-date information from air quality assessment. Access to up-to-date air quality information is important for public communication on air quality. However, it is not clear what `up-to-date’ means nor is it is not possible to produce real time information with the reference method for particulate matter. Guidelines could be provided for how to produce this type of data when using the reference method for particulate matter.

Purpose/operational objective: This intervention would allow for increased transparency of up-to-date pollutant information to inform the public. Moreover it would allow for increased information for pollution forecasters

Who would be impacted and how:
Direct: Competent Authorities responsible for monitoring networks and data management. In addition, modellers could benefit from potential additional monitoring datasets should data quality requirements for model validation be implemented in the Directive.
Indirect: The general public may be indirectly impacted if data quality is improved.

Risks for implementation:

- Monitoring sampler or IT system failure would inhibit publication of air quality data in real-time.
- Increased resources may be needed for some Member States to ensure immediate data quality.

Indicators

1. Air quality	2. Impact on Health	3. Impacts on Ecosystem	4. Climate change links	5. Costs to society	6. Mitigation costs	7. Competitiveness	8. Impacts on Sensitive Groups	9. Societal benefits and burden sharing	10. Impacsts on Employment	11.Policy synergies	12. Administrative Burden
0	(+)	0	0	0	0	0	0	0	0	0	--

Assessment

Effectiveness:

Many Member States already provide up to date information from the majority of their fixed monitoring stations, therefore this intervention is not expected to bring significant changes. However, some data providers who do not have a systematic approach to the reporting of provisional data may be required to update their reporting, particularly for pollutants/measurement types that cannot provide real-time data. More real time data reporting would bring health benefits, particularly for short averaging periods and would better support air quality forecasting [health (+)]

Efficiency:

Administrative burden is expected to be low for most Member States but for some not currently reporting real-time data a small increase is likely [Administrative burden --].

However, access to more up to date information on air quality may indirectly improve health, especially during pollution episodic events where more health warnings could be issued. This may indirectly improve costs to society [Heath and Society (+)]

Coherence:

There are no foreseen impacts on policy synergies or climate change links [Climate and Policy 0]

Links to other interventions: [synergies / misalignment]

F1. *Introduce more specific requirements to ensure regular reporting of up-to-date data / information (instead of allowing Member States to report data as available).* [Synergy/misalignment dependent on the specifics of the interventions]

F3. *Mandate specific communication channels with citizens including user-friendly tools for public access to air quality and health risks information and monitoring to use (for example, smartphone apps and/or social media dedicated pages).* Clarity would be required on the publication route for air quality data under Intervention K2 [Synergy]

K1: *Further define the data quality requirements for sampling points / measurements used for air quality assessments.* Clarity is required if published data under intervention K2 is as provisional data, which would not have had time for full quality checks as required under intervention K1 [potential Misalignment]

Benefit Cost Ratio:

Low: This intervention would address the current ambiguity within the Directive on the precise requirements on the provision of up-to-date information on air quality. However, as most Member States are already providing real-time information for at least some of their monitoring stations it is not expected to bring significant change. Where Member States are not already reporting up to date data this intervention will bring an improvement to air quality forecasters and to those informing the public of episodic events of high pollution.

Summary:

This intervention would increase the harmonisation of the reporting of real-time air quality information, which during pollution episodic events, and for forecasters brings benefit to the public. Costs are low and those Member States already publishing real time data are unlikely to be impacted.

K3

Intervention area K: Which requirements on data quality are needed to assess and report air quality?

Intervention K3 - Introduce a standardized ‘modelling quality objective’ as a quality control mechanism to assess whether a modelling based assessment is fit-for-purpose.

The problem:
Air quality Monitoring and assessment shortcomings.
Drivers:
Flexibilities may sometimes impact the comparability of data;
Monitoring rules offering flexibility are ‘stretched’ in instances;
Modelling ability has improved, allows for much more details.

Description:
Any modelling application used in support of the implementation of the AAQ Directives should be of sufficient quality and be fit-for-purpose. This intervention is introducing a standardized Modelling Quality Objective (MQO) that should be met in the validation and QA/QC processes of modelling systems. FAIRMODE has proposed such a MQO which is currently under evaluation for becoming a CEN standard.

Purpose/operational objective:
This intervention allows for an increase in quality of assessment evidence and contribute to a harmonized QA/QC process of the European modelling framework.

Who would be impacted and how:
Direct:
Model developers in universities, research institutes or consultancy companies have to make sure that the modelling system is fit-for-purpose and is able to pass the MQO. Model users in the Competent Authorities have to make sure that modelling applications fulfil the MQO before the system is used in support of the AAQ Directives implementation. This might increase the administrative burden and comes with additional costs if the modelling capacity is not of sufficient quality.

Indirect:
Citizens across Europe will be indirectly impacted as the quality of modelling impacts the confidence of the general public in air quality information to support their personal decision-making.

Risks for implementation:

- Not all modelling systems currently used for policy support will meet the MQO and consequently will require upgrades to meet the quality standard.
- A complete and comprehensive definition of fitness-for-purpose under various AAQ Directives applications is still missing. Compliance with a MQO is a necessary condition but not sufficient to be fit-for-purpose.

Indicators

1. Air Quality	2. Impact on Health	3. Impacts on Ecosystems	4. Climate change links	5. Costs to society	6. Mitigation costs	7. Impacts on Competitiveness	8. Impacts on Sensitive Groups	9. Societal benefits and burden sharing	10. Impacts on Employment	11. Policy synergies	12. Administrative Burden
(+)	(+)	(+)	0	0	0	0	0	0	0	0	--

Assessment

Effectiveness:

High quality modelling applications will contribute to better air quality assessment and planning process. This results in high quality information for the public at large, better source allocation and source identification and eventually better air quality planning [Air Quality: (+)]. This will indirectly contribute to a reduced impact on health and ecosystems [Impact on Health: (+), Impacts on Ecosystems: (+)]. The impact of this intervention on the other indicators is expected to be low.

More than 60% of the stakeholder respondents indicate that this intervention will address the shortcoming fully or to a large extent. This is mostly supported by authorities and academic, NGO's and industry are more sceptical with respect to modelling. Only 2% of the respondents has no confidence in this intervention.

Various stakeholders refer to the ongoing work of FAIRMODE and CEN WG43 in the design of a consolidated MQO and stress the importance of proper reference of an MQO in the AAQ Directives.

Efficiency:

Obviously, a request for a standardized MQO will increase administrative burden since some of the modelling systems will have to be upgraded to meet the quality standards. Assuming modelling systems are already in place, aggregated medium one-off costs are expected to be incurred by Member States to update them, as there are already many systems running. Further to this, Member States would incur in low recurring costs to ensure continuous checks that objectives are still being met.

Coherence:

There are no foreseen impacts on policy synergies or climate change links [Climate and Policy 0]

Links to other interventions: [synergies / misalignment]

- **G2:** *Make the use of air quality modelling mandatory as part of air quality assessment (in some circumstances):* When the use of modelling systems becomes mandatory, a MQO is indispensable to guarantee overall quality of the modelling applications. [Synergy]
- **J3:** *Introduce the concept of a spatial representative area which should be estimated (and reported) for each sampling point (irrespective of exceedances being measured or not):* Higher Tier methods require fit-for-purpose modelling systems. An MQO plays a crucial role in this evaluation. [Synergy]

Benefit to Cost ratio:

High: fit-for-purpose and high-quality modelling systems can provide valuable support in a wide variety of application domains under the AAQD. Building modelling capacity comes with a significant cost, but the benefits (both direct and indirect) are expected to be much larger.

Summary:

A scientifically sound and standardized Modelling Quality Objective is essential to bring modelling applications to a maturity level that is needed in support of the AAQ Directives implementation. FAIRMODE has paved the way and build a large consensus for such an MQO in the modelling community. The benefit to cost ration of this intervention is expected to be high.

K4

Intervention Area K: Which requirements on data quality are needed to assess and report air quality?

Intervention (K4) Modify the definition of measurement uncertainty by defining it in absolute values and not in percentage values (or a combination of both).

The problem:
Air quality Monitoring and assessment shortcomings.
Drivers:
Flexibilities may sometimes impact the comparability of data;
Monitoring rules offering flexibility are 'stretched' in instances;
Modelling ability has improved, allows for much more details.

Description: Clarification in the definition of measurement uncertainty and changes to threshold levels to be achieved.

Purpose/operational objective: Harmonised quality/ reduced monitoring uncertainty. For lower limit values uncertainty is better defined in absolute terms ensuring data quality.

Who would be impacted and how:
Direct: Competent Authorities responsible for monitoring networks and data management. In addition, modellers could benefit from potential additional monitoring datasets should data quality requirements for model validation be implemented in the Directive.
Indirect: The general public may be indirectly impacted if data quality is improved.

Risks for implementation:

- Changes in the calculation for uncertainty risks existing long-established monitoring datasets should the new estimate not comply with uncertainty standards. This would negatively impact data quality and overall assessment of pollutant levels for those in non-compliance.

Indicators

1. Air quality	2. Imapcts on Health	3. Impacts on Ecosystem	4. Climate change links	5. Costs to society	6. Mitigation costs	7. Impacts on Competitiveness	8. Impacts on Sensitive Groups	9. Societal benefits and burden sharing	10. Impacts on Employment	11.Policy synergies	12. Administrative Burden
(+)	(+)	(+)	0	0	0	0	0	0	0	0	-

Assessment
Effectiveness:
Views from stakeholders is a preference to incorporate measurement uncertainty as both a percentage and absolute value which was reported as important particularly when air quality standards are low. Revised monitoring uncertainty could improve the quality of measurement data leading to overall improved air quality and reducing health and ecosystem impacts. Many stakeholders referred to considerations put forward by AQUILA which should be taken on board [Air quality, Health, Ecosystem (+)].

Efficiency:

The changes should have a very limited impact on administrative costs in practice [Administrative burden 0]

Coherence:

There are no foreseen impacts on policy synergies or climate change links [Climate and Policy 0]

Links to other interventions: [synergies / misalignment]

K1: *Further define the data quality requirements for sampling points / measurements used for air quality assessments.*

Benefit Cost Ratio:

Medium: This intervention would clarify the expected measurement uncertainty and is not expected to impact administrative burden.

Summary: Measurement uncertainty is essential parameter in assessing air quality particularly when air quality standards are low. Overall, stakeholders saw benefit in combining uncertainty in both absolute and percentage terms. While it is unlikley to bring significant benefits to air quality management it is an important aspect to clarify.

L1

Intervention Area L: Which additional air pollutants should be measured and to what extent should monitoring requirements be expanded?
Intervention (L1) Require monitoring stations that measure continuously certain emerging air pollutants (e.g. called "supersites" across the Member States).
The problem: Air quality Monitoring and assessment shortcomings. **Drivers:** Flexibilities may sometimes impact the comparability of data; Monitoring rules offering flexibility are 'stretched' in instances; Modelling ability has improved, allows for much more details.
Description: Specify a minimum number of monitoring stations that should monitor emerging pollutants (supersites) together with site type. Possibilities for what specific considerations should guide the establishment of such "supersites" include: (1) Establishment of the number of supersites should be guided by potential exposure (2) Supersites should be located at which locations, urban, rural etc
Purpose/operational objective: Increase data provision for research purposes including interactions between pollutants and measurement for emerging issues.
Who would be impacted and how: ***Direct:*** Competent Authorities responsible for monitoring networks and data management. In addition, modellers could benefit from potential additional monitoring datasets should data quality requirements for model validation be implemented in the Directive. ***Indirect:*** Academic researchers and agencies investigating air pollution, assessing trends and gathering evidence on environmental impacts.
Risks for implementation: • Costs for new analysers to measure emerging pollutants • Additional resources may be needed to service and maintain sites and manage and report data.

Indicators											
1. Air Qualtiy	2. Impacts on Health	3. Impacts on Ecosystem	4. Climate change links	5. Costs to society	6. Mitigation costs	7. Impacts on competitiveness	8. Impacts on Sensitive Groups	9. Societal benefit and burden sharing	10. Impacts on Employment	11. Policy synergies	12. Administrative Burden
(+)	(+)	(+)	0	(+)	0	0	0	0	0	0	---

Assessment

Effectiveness:

The use of `supersites' which include monitoring for a long suite of pollutants together with emerging pollutants to advance scientific understanding and support epidemiological studies has been established in many countries for decades. It brings much benefit to the academic community to support research of air quality and helps policy makers drive action where appropriate. Undoubtedly, in our expert view, further establishement of supersites across Europe, particularly for observing emerging pollutant trends would bring large benefit for their future assessment and control. Most benefit would be gained if these sites were established at both urban and rural locations.

Many stakeholders thought that while priority should be given to urban sites (where potential exposure is higher), however in our expert view it is important to have both urban and rural sites to be able to assess background levels. The majority agree 1 supersite per 5 m inhabitants was the preferred site density though a large group was in favour for 1 supersite per 10 m inhabitants. This intervention is expected to lead to indirect benefits to air quality and the related impacts [Air quality, Health, Ecosystems and Society (+)]

Efficiency:

Monitoring is very costly and many Public Authorities report this as their key concern. It will increase administrative burden, for capital and maintenance costs but may also entail requirement for more staff and training [Administrative burden ---]

Coherence:

There are no foreseen impacts on policy synergies or climate change links [Climate and Policy 0]

Links to other interventions: [synergies / misalignment]

L2: *Require monitoring of additional air pollutants at a minimum number of sampling points and with relevant data quality requirements*

L3: *Require monitoring of additional air pollutants at a minimum number of sampling points and with relevant data quality requirements*

Benefit Cost Ratio:

Medium: Additional pollutants would be costly to monitor at supersites but the research/knowledge to be potentially gained could indirectly improve air quality/health/ecosystems and have societal benefits

Summary:

Supersites provide important data on many pollutants which is important for furthering research and understanding of the interactions and trends of air pollutants and underpinning epidemiological studies. While monitoring costs are high some Member States e.g. Finland already have a supersite network in operation.

L2

Intervention Area L: Which additional air pollutants should be measured and to what extent should monitoring requirements be expanded?

Intervention (L2) Require monitoring of additional air pollutants at a minimum number of sampling points and with relevant data quality requirements.

The problem:

Air quality Monitoring and assessment shortcomings.

Drivers:

Flexibilities may sometimes impact the comparability of data;
Monitoring rules offering flexibility are ‘stretched’ in instances;
Modelling ability has improved, allows for much more details.

Description: Requirements for the monitoring of additional pollutants, possibilities for which additional air pollutants should be monitored, and where include:

(1) Ultrafine particles
(2) Ammonia
(3) Fine combustion particles
(4) Oxidative potential
(5) Additional heavy metals
(6) Hydrogen sulphide (H2S) and other reduced sulphur compounds (TRS)
(7) Nitro-PAHs
(8) Pesticides

Purpose/operational objective: This intervention will increase our understanding of current levels of any additional pollutants and will support research into the impact assessment of air pollution on health and ecosytesms.

Who would be impacted and how:

Direct: Competent Authorities responsible for monitoring networks and data management. In addition, modellers could benefit from potential additional monitoring datasets should data quality requirements for model validation be implemented in the Directive.

Indirect: Academic researchers and agencies investigating air pollution, assessing trends and gathering evidence on environmental impacts.

Risks for implementation:

- Costs for new analysers to measure emerging pollutants
- Additional resources may be needed to service and maintain sites and manage and report data.

Indicators

1. Air Quality	2. Impacts on Health	3. Impacts on Ecosystem	4. Climate change links	5. Costs to society	6. Mitigation costs	7.Impacts on Competitiveness	8. Impact son Sensitive Groups	9. Societal benefits and burden sharing	10. Impacts on Employment	11.Policy synergies	12. Administrative Burden
(+)	(+)	(+)	(+)	(+)	0	0	0	0	0	0	---

Assessment

Effectiveness:

Monitoring of emerging pollutants is essential to advance our understanding of current pollution loads, but also assess source apportionment and underpin modelling to assess future projected levels. As most interest in the assessment of these pollutants will be to researchers and policy makers, setting these sampler points at established supersites (or to be established) will facilitate pollutant interaction analysis.

In their recent publication the WHO states that black carbon and ultrafine particles are pollutants of concern and their concentrations should be kept under review. The additional evidence on chemical composition and particle number is valuable for future epidemiological studies on the health effects of black carbon and ultrafine particles and for distinguishing these effects from the effects of other pollutants. Our expert view is that these pollutants are the minimum for further monitoring. In addition, monitoring of ammonia is viewed as important for the impact assessment on ecosystems as critical levels of ammonia and nitrogen critical loads are widespreadly exceeded.

This intervention would facilitate research on these emerging pollutants [Air quality (+)] and support epidemiological studies of pollutants of most concern to health [Health (+)] e.g. ultrafine particles and ecosytems e.g. ammonia [Ecosytems (+)].

The majority of stakeholders suggested new pollutants should be located at supersites to facilitate research on pollutant interactions and trends. There was general support to monitor ultrafine particles, ammonia, oxidative potential and fine combustion particles but less generalised support for additional heavy metals, hydrogen sulphide, nitro-PAHs and pesticides monitoring.

Efficiency:

Monitoring of air pollution is costly, and even more so for pollutants which are not widely monitored. Adminitrative burden would be high, and likely to include capacity building to train site operators. Specifically, estimated costs to include BC and UFP at an existing station per year are € 10 000 – € 15 000 for BC and € 20 000 - € 25 000 for UFP. A high one-off cost is expected to be incurred for Member States setting up new samplers for additional pollutants. For recurring costs, this is expected to be medium to low depending on the number of additional monitoring stations that are required within each Member State. [Administrative burden ---].

However, with increased research to improve public health protection from these emerging pollutants there is likely to be a cost saving to society [Society (+)]

Coherence:

The intervention is also expected to contribute to climate changes policies as monitoring of BC will indirectly lead to measures to reduce these emissions [Climate change links: (+)].

Links to other interventions: [synergies / misalignment] **L1:** *Require monitoring stations that measure continuously certain emerging air pollutants (e.g. called “supersites” across the Member States*) [Synergy]. **H1:** *Change the minimum number of sampling points that are required per air quality zone*. The minimum number of sampling points for each new pollutant requires clarification) [Synergy]. **K1:** *Further define the data quality requirements for sampling points / measurements used for air quality assessments*) [Synergy].
Benefit Cost Ratio: **High**: Additional pollutants would be costly to monitor but the research/knowledge to be potentially gained could indirectly improve air quality/health/ecosystems and have societal benefits
Summary: Research into the impacts of new pollutants has to be supported by evidence on air pollutant concentrations and trends. This is important to further develop policy in the future. There is general support for monitoring requirements for ultrafine particles, ammonia, oxidative potential and fine combustion particles. While administrative burden is high the benefit for future research is also high.

L3

Intervention Area L: Which additional air pollutants should be measured and to what extent should monitoring requirements be expanded?

Intervention (L3) Expand the list of required and/or recommended volatile organic compounds (VOCs) to measure.

The problem:
Air quality Monitoring and assessment shortcomings.
Drivers:
Flexibilities may sometimes impact the comparability of data;
Monitoring rules offering flexibility are 'stretched' in instances;
Modelling ability has improved, allows for much more details.

Description: Additional VOCs to be monitored should be specified together with monitoring methods, data quality objectives and minimum number and siting requirements and reporting of data

Purpose/operational objective: This intervention will increase our understanding of current levels of VOCs

Who would be impacted and how:
Direct: Competent Authorities responsible for monitoring networks and data management. In addition, modellers could benefit from potential additional monitoring datasets for model validation.
Indirect: Academic researchers and agencies investigating air pollution, assessing trends and gathering evidence on environmental impacts.

Risks for implementation:

- Costs for new analysers to measure more VOCs
- Additional resources may be needed to service and maintain sites and manage and report data.

Indicators

1. Air qualitiy	2. Impacts on Health	3. Impacts on Ecosystem	4. Climate change links	5. Costs to society	6. Mitigation costs	7. Impacts on Competitiveness	8. Impacts on Sensitive Groups	9. Societal benefit and burden sharing	10. Impacts on Employment	11. Policy synergies	12. Administrative Burden
(+)	(+)	(+)	0	0	0	0	0	0	0	0	---

Assessment

Effectiveness:

VOCs are key pollutants, with established health and environmental impacts. An AQUILA working group has proposed a revision of the list of VOCs with a classification based on their physicochemical properties (e.g. volatility), their photochemical ozone formation potential, and their origin (biogenic/anthropogenic/both) as tracers of specific sources. Further monitoring will provide evidence to reduce these impacts [Air quality, Health, Ecosystems (+)].

There was strong support amongst all stakeholders that VOCs should be monitored based on latest scientific knowledge, especially for their health impacts, but also for their oxidative potential and their role as ozone precursors, as well as their role as PM precursors. However, there was no consensus on an expansion of the list of VOCs or any suggested new compounds to monitor.

Efficiency:

The cost of continuous VOC measurements are high and any further monitoring should be accompanied by data quality and siting specifications with appropriate guidance. However, data from a VOC monitoring network is valuable to the scientific understanding of these pollutants to drive emission control [Administrative burden --]

Coherence:

There are no foreseen impacts on policy synergies or climate change links [Climate and Policy 0]

Links to other interventions: [synergies / misalignment]

H1: *Change the minimum number of sampling points that are required per air quality zone.* An increase in the minimum number of sampling points, together with more VOC species to monitor could largely increase administrative burden [potential misalignment]

I2: *Include the requirement to monitor long-term trends if fixed monitoring stations are discontinued (by assessing air quality via indicative measurements or air quality modelling).* Member States should be prepared to monitor any additional VOCs for a long time period [Synergy]

J3: *Introduce the concept of a spatial representative area which should be estimated (and reported) for each sampling point (irrespective of exceedances being measured or not).* The spatial representativeness for current VOC analyser sites should be assessed prior to the introduceion onf new species for monitoring [Synergy]

K1: *Further define the data quality requirements for sampling points / measurements used for air quality assessments.* Data quality requirements should be specified for any new VOC species to be monitored [Synergy]

Benefit Cost Ratio:

Low: Further elaboration of VOC monitoring is necessary to develop scientific knowledge to support emission control. However, there are a large number of VOCs that could be monitored and the merits of each should be considered over and above those already being monitored. Costs for such monitoring are significantly high. As such, and as the additional benefit derived from this intervention are unclear BCR is low.

Summary: The expansion of VOCs monitoring is important to align with the evolution of scientific knowledge (health impacts, oxidative potential, ozone precursors and secondary organic aerosols). However, the health benefits of monitoring more (or other) VOCs remains unclear, although it is noted the increase in scienific understanding this brings. In addition costs of such additional monitoring will be high particularly as the potential number of species to be monitored is large. Overall the BCR is therefore low.

N1

Intervention area N: Which minimum information should be included in an air quality plan?

Intervention N1 - Refine the minimum information to be included in an air quality plan.

The problem:

AQ Implementation shortcomings:

Exceedances are not always addressed sufficiently and/or timely

AQ Governance shortcomings:

Air quality plans do not always address all sources effectively

Exceedances above health guidelines and negative health impacts persist

Air quality plans and measures have often proven ineffective

Some measures may seem disproportionate, ineffective

Description:

This intervention refines the minimum information that is requested in an air quality plan. In the current AAQ Directives (2008/50/EC) Annex XV details the information that has to be provide but it turns out that this information is not appropriate to evaluate the overall quality and eventual impact, effectiveness and efficiency of the air quality plan.

Purpose/operational objective:

Refining the minimum information that needs to be included in air quality pans would increase their transparency. The intervention would increase the harmonization of the air quality planning process and foster exchange of best practices.

Variants:

Possibilities for specific interventions to address the above identified shortcomings include:

(1) Require a quantification of emission reduction in t/a for air quality measures.

(2) Require estimates of concentration reduction of planned air quality measures in µg/m^3 at all sampling points in exceedance.

(3) Require an assessment of health impacts of the status-quo and after the implementation of air quality measures.

(4) Require an emission source apportionment of all relevant sectors that contribute to the exceedance (in line with the existing National Air Pollution Control Programmes).

(5) Require that an assessment of emissions and the responsible actors for those emissions should be carried out (e.g. city level, regional level, national level, and transboundary contributions).

Who would be impacted and how:

Direct: Competent Authorities responsible for the design and development of the air quality plan and in charge of the e-Reporting of the Annex XV information.

Indirect: Better air quality planning will result in lower air pollution concentrations and reduced impact on health and sensitive ecosystems.

Risks for implementation:

- Stakeholders involved in air quality planning could be requested to derive and develop new data sets, indicators and results currently not produced by the air quality planning tools. This could increase the administrative burden and results in extra costs.
- Broadening the information included in the AQPs itself does not ensure that the quality of the AQPs is improved. It is mainly necessary to further develop a common and harmonized approach on for AQPs process.

Indicators

1. Air Quality	2. Impact on Health	3. Impacts on Ecosystems	4. Climate change links	5. Costs to society	6. Mitigation costs	7. Impacts on Competitiveness	8. Impacts on Sensitive Groups	9. Societal benefits and burden sharing	10. Impacts on Employment	11. Policy synergies	12. Administrative Burden
++	+	+	(+)	(+)	-	0	(+)	0	0	+	--

Assessment

Effectiveness:

It is expected that this intervention will provide an improved framework for air quality planning which gives rise to better air quality plans and eventually an improved air quality [Air Quality: ++]. This will result in a reduced impact on health and ecosystems [Impact on health: +, Impact on Ecosystems: +]. With better air quality planning sensitive groups will benefit from reduced exposure to high concentration levels [Impact on Sensitive Groups: (+)].

66% of the stakeholder respondents support the implementation of this intervention and believe that it will address the shortcoming fully or at least to a large extent. Most of the variant receive a similar response. On average 60% or more of the respondents indicate that the intervention addresses the shortcoming fully or to a large extent. It should be notes that some stakeholders indicate that the variants of the intervention should be implemented all together.

Stakeholders indicate that a proper understanding of the exceedance situation and the major sources responsible for the exceedances is key in the development of an effective air quality plan. This aspect should receive sufficient attention in the preparation phase. Some stakeholders also stress the need to have health impact as an important end point in the planning process. The effectiveness of the air quality plan should be evaluated on the basis of these health indicators. Such a health outcome might also contribute to the social and political acceptability of the air quality plan.

Efficiency:

This intervention will increase administrative burden [Administrative Burden: ---] since the setup of a comprehensive and adequate air quality plan requires more resources for more in-depth analysis and more governance amongst various stakeholders involved in the planning process. A high one-off cost is expected to be incurred by Member States as it would involve the process of setting up the air quality plan, including costly and time-consuming activities, namely, stakeholder engagement, health impact assessment, proposing and evaluation measures, etc.

Stakeholders indicate that there is a need to review the reporting requirements. They are currently far too prescriptive and represent a large administrative burden which is difficult to justify given the usefulness of some of the information required and the lack of clear guidelines on how the information is to be produced and used. The reporting of AQ plans needs to be streamlined to ensure that it includes the most important and useful information required to evaluate the fitness-for-purpose of an AQ plan. The risk should be reduced that unnecessary administrative burden for reporting uses up time and important resources that can be better used implementing AQ plans.

The implementation of the measures obviously come with a cost [Mitigation costs: -]. However, it is generally recognized and demonstrated that solid are quality planning and targeting the right sources can result in improved air quality giving rise to a positive benefit to cost ratio (see further).

Coherence:

By nature, air pollution is a multi-pollutant, multi-sector and multi-scale phenomenon. As a consequence air quality policies can have multiple synergies with other domains such as climate change, sustainable energy, sustainable transport, urban planning… [Climate change links: (+), Policy synergies: +].

Links to other interventions: [synergies / misalignment]

- **G2:** *Make the use of air quality modelling mandatory as part of air quality assessment (in some circumstances):* Modelling systems are a crucial tool in the design of air quality plans. [Synergy]
- **K3:** *Introduce a standardized 'modelling quality objective' as a quality control mechanism to assess whether a modelling-based assessment is fit-for-purpose:* High quality modelling tools are essential for proper air quality planning. [Synergy]

Benefit to Cost ratio:

High: development of a solid air quality plan comes with a significant cost. However, when properly implemented a solid air quality can result in even higher benefits for society giving rise to a high benefit to cost ratio.

Summary:

Almost all stakeholders agree that the design of an effective air quality plan is a centre-part in the implementation of the AAQ Directives. Reporting should facilitate and support the planning process and contribute to a further harmonisation the air quality plans. This will also support the comparability and exchange of best practices. Care should be taken that the administrative burden is not increased by unnecessary reporting which does not support the planning process itself or the evaluation of the fitness-for-purpose of the plan.

Assessment of interventions - Policy Area 1

O1

Intervention area O: EU air quality standards for particulate matter ($PM_{2.5}$)

Intervention (O1) Revise long-term (annual) air quality standards

The problem: ***Health Outcome Shortcoming:*** EU standards are not fully aligned with scientific advice.
Driver: Exceedances of air pollutant concentrations above health guidelines and negative health impacts persist.

Description: The current EU AAQ Directives standards for annual $PM_{2.5}$ sets an annual average limit value of 25 µg/m^3. The WHO guideline is set at 5 µg/m^3, alongside higher interim targets. Intervention explores the alignment of the EU long-term standard limit values for $PM_{2.5}$ with the WHO's 2021 Global Air Quality Guidelines (AQGs) updated limit values.

Variants of the intervention consider different levels at which the standard can be set below the existing EU standard. A sample of variants has been selected for the modelling in distinct 5 ug steps, but technically any numerical standard could be selected. Variants can also change the timeframe over which a standard should be achieved.

Purpose/operational objective: More closely aligns EU air quality standards with latest scientific knowledge and recommendations of WHO. This would reduce exposure to air pollution, therefore reducing negative health impacts.

Who would be impacted and how:

Direct: Should a lower standard be implemented, this will lead to an increase in the number of sites and zones in exceedance. As such, ***public authorities*** will be required to develop and implement new (and revise existing) AQ Plans in order to put in place a strategy to meet these new requirements. These plans will also require ongoing review and management.

Indirect: The AQ Plans will identify suitable strategies to bring air pollutant concentrations in line with standards. These strategies may imply costs for ***households, businesses and industry*** in order to change behavior to abate air pollutant emissions or influence concentrations. These costs may also have a knock-on impact to the wider economy in terms of employment or on business activity through supply chains.

Households, and indirectly businesses will benefit from the reduction in negative health impacts associated with higher levels of air pollution.

Risks for implementation:

$PM_{2.5}$ has a range of sources, both anthropogenic and natural. Natural sources are much more complex and difficult to control. In cases where natural sources contribute close to, or even more than, the levels of pollution set in the standard, it may be extremely challenging or unfeasible for public authorities to achieve such standards.

A further challenge is transboundary sources, and the ability for single public authorities to again control this as a source (link to M2).

Stakeholders (Workshop 1) have also highlighted that there are challenges monitoring $PM_{2.5}$ at very low concentration levels with sufficient accuracy and robustness.

The analysis also does not fully explore the feasibility of meeting more stringent standards in the short-term: i.e. it takes time to identify exceedances, put AQ plans in place and roll out mitigation techniques to achieve emissions and concentration reductions, and the size of the challenge will likely increase with ambition.

Setting standards on the basis of a single value to be achieved everywhere will not drive continual improvement where such standards are already met. Furthermore, this may also drive action in areas of lower priority, where the population are not exposed (links to O3 and B3 which consider average exposure targets).

Stakeholders (MS EG) also noted that having many different types of standards for a single pollutant (link to O2 and O3) increases the complexity for policy makers in terms of designing a response, and also communicating these standards to stakeholders (link to Intervention Area F).

	Indicators											
	1. Air Quality	2. Impact on Health	3. Impacts on Ecosystems	4. Climate change links	5. Costs to society	6. Mitigation costs	7. Impacts on Competitiveness	8. Impacts on Sensitive Groups	9. Societal benefits and burden	10. Impacts on Employment	11. Policy synergies	12. Administrative Burden
20 / 15 ug/m^3	+	+	+	+	+	-	+	+	+ / -	+	+	-
10 ug/m^3	++	++	++	++	++	--	+	++	+ / -	+	++	--
5 ug/m^3	+++	+++	+++	+++	+++	---	+	+++	+ / -	+	+++	---

Assessment

Effectiveness:

The impacts and effectiveness of the intervention to resolve the problem will scale with the ambition of the standard.

As of 2019[78], 7 reporting countries (of which 4 were EU Member States) registered concentrations above the existing EU annual limit value of 25 µg/m^3. All reporting countries, except Estonia, registered concentrations above the long-term WHO AQG of 5 µg/m^3. 4% of the EU urban population are exposed to air pollutant concentrations above the existing EU standard, relative to 97% above the WHO AQG, whilst 2% of monitoring stations registered concentrations above EU annual limit value, relative to 95% above the WHO AQG. The highest concentrations were found in central and eastern Europe and northern Italy. The use of solid fuels for combustion is the main reason for the situation in central and eastern Europe, together with an older vehicle fleet. In northern Italy, the high concentrations are due to the combination of a high density of anthropogenic emissions and meteorological conditions that favour the accumulation of air pollutants in the atmosphere.

In the modelling baseline, a further decline of emissions is expected associated with a reduced reliance on fossil fuels in many combustion related sectors (power and industry, residential, transport). In particular, the residential sector observes a decline in coal and biomass use as well as transition to cleaner technologies, whilst transport is depicted by a further reduction of exhaust emissions but non-exhaust component dominates. This reduces the EU population living in areas exceeding the existing EU standard to 0.02m in 2030, and effectively 0 in 2050. However, a large population will still reside in areas exceeding the WHO AQGs: around 330m people in 2030 and 210m in 2050. Hence although the baseline will achieve further reductions in the levels of air pollution the population is exposed to, achieving compliance with existing EU standards effectively by 2030, significant further effort would be required to achieve the WHO AQGs.

The modelled scenarios achieve further improvements in air quality. In the baseline there are very few residents living in areas exceeding 20µg/m^3 and even 15 µg/m^3 (around 0.74m in 2030). Under the modelled OPT20 and OPT15 scenarios, this number reduces further (to around 0.4m in 2030 OPT15), but full compliance

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is not achieved. That said, through the actions taken, further concentrations reductions are also achieved at lower levels of concentration: e.g. those exposed to 5-10 μg/m^3 reduces from 307m in the baseline in 2030 to 252m. Hence small reductions in the standard will achieve smaller improvements in Air Quality [+]. Furthermore, in practice such a standard will also help safeguard that and in itself provides a reduction of exposure compared to now.

More ambitious standards can achieve greater improvements in air quality: under OPT10, those living in areas above 5 μg/m^3 reduces to 243m in 2030 and 121m in 2050 [Air Quality ++], and under OPT5 to 225m in 2030 and 108m in 2050 [Air Quality +++]. However, with more ambitious targets, an increasing number of people continue to live in areas in exceedance of the revised targets: under OPT10 around 11m in 2030 and 8m in 2050 continue to live in areas above 10μg/m^3, and under OPT5 225m in 2030 and 108m in 2050. Indeed, even under the MTFR a sizeable number of the population remain exposed to concentration levels above the WHO AQGs (similar order of magnitude to OPT5). This suggests that to achieve full compliance with much more ambitious standards will at least require additional action, either in the form of non-technical measures which are not captured in GAINS (e.g. fuel-switch or dietary change), or at a very local level. The impacts (and costs) of such measures are not captured in the modelling and are hence uncertain, but such measures could imply a much greater level of change either at a national or local level, and the feasibility of such change would be more challenging in a shorter period of time. That said, even with such measures, it is uncertain that the WHO AQGs would be achievable in all places given the contribution of natural sources, and as such there is a risk of setting a standard which is unachievable for a selection of sites.

In terms of stakeholder opinion, there was a strong majority response to the OPC that stakeholders are concerned about the levels of air pollution to which they are exposed, and favour an ambitious change in air quality standards. This result was driven by EU citizens who were the main respondent type to the OPC (66%) and NGOs. However, other stakeholder types were more cautious in terms of ambition, as shown through the TSS. From the TSS it was clear that stakeholders see value in having this standard, and that it should apply as a limit value to all territories, but the response was more mixed around an appropriate level. For 2030, the majority favoured some reduction from the current standard (most selecting 15 or 10μg/m^3) – this was the case for public authorities, with NGOs being slightly more ambitious (split 10 and 5μg/m^3), with the majority of industry proposing to remain at the existing standard. To 2050, a small overall majority favoured moving in line with the WHO AQG, driven by the majority of NGOs and research that responded in this way. Public authorities were slightly less optimistic (mixed between 10 and 5 μg/m^3) with industry favouring a less ambitious reduction (15 μg/m^3 in 2050).

The health effects across the variants will scale with the level of ambition [Impact on health / Costs to society: +, ++, +++]. The MTFR scenario is estimated to achieve a reduction of 32,000 premature deaths associated with exposure to $PM_{2.5}$ in 2030 (56% reduction), and 14,000 in 2050 (50% reduction). Health effects associated with air pollution exposure are most typically associated with $PM_{2.5}$, which typically has the highest effect – as such this intervention and its variants score more highly relative to other pollutant standards (although this is also partially an artefact of the way in which the underlying epidemiological evidence base associates health impacts with air pollution). In addition, stakeholders (Workshop 2) highlighted that recent evidence from the ELAPSE study adds additional weight to the potential for non-linear at low levels of concentrations.

Ecosystem effects are associated more so with other pollutants. However, to achieve ambitious levels of $PM_{2.5}$ concentrations, ambitious reductions in NO_2, SO_2, NH_3 emissions and also VOC are also required. Hence ecosystem effects will scale with ambition [Impacts on ecosystems: +, ++, +++], and this intervention will also have the largest potential ecosystems benefits as acidification, eutrophication, and ozone improves.

Higher levels of $PM_{2.5}$ tend to be found in areas with a greater proportion of some vulnerable groups (e.g. lower income, lower educational attainment)[79]. As such, further reductions in $PM_{2.5}$ concentrations are anticipated to have a greater positive effect for more disadvantaged groups, scaling with the overall level of ambition [Impacts on Sensitive Groups: +, ++, +++]. However, the measures taken to mitigate emissions will carry costs. The distribution of such costs will critically depend on the national or local delivery mechanism. But there is a risk that costs may disproportionately fall on some more vulnerable groups given their contribution to emissions [Societal benefits and burden sharing: +/-].

Efficiency:

There is broad compliance in the baseline with existing EU standards by 2030 and 2050, and indeed broad compliance with a 20 or 15 µg/m^3 standard. As such, the additional costs of the OP20 and OPT15 scenarios is fairly small: e.g. around EUR 3.5bn for OPT15 in 2030, and negligible costs in 2050. Abatement costs increase with ambition. Hence the modelled costs of the OPT10 and OPT5 scenario increase, and with an exponential trend. The annualised mitigation costs of the OPT10 scenario around EUR 5.5bn in 2030 and EUR 4.5bn in 2050, with the annualised costs of OPT5 higher at EUR around 7bn and EUR 6bn in 2030 and 2050 respectively [Mitigation costs: -, --, ---]. However, it is worth noting that these are the costs of achieving a certain level, not full, compliance with the modelled standards. As noted above, around 8.5m people remain in areas exceeding 10µg/m^3 in 2050 under OPT10, and 109m in areas exceeding 5 µg/m^3 under OPT5. To achieve compliance will require the adoption of additional non-technical or local measures which are not captured in GAINS. As such the costs of such action are uncertain but these could imply significant change in behaviour at local or national level.

Admin burden will also scale with ambition. The more ambitious the standard, the more new zones or sites will be identified as in exceedance. Public authorities will need to develop new, or amend existing, AQ Plans to define and implement a strategy to handle each new exceedance. Given the costs of an AQ Plan, even a small number of exceedances will deliver a high burden [Administrative burden: -, --, ---].

Both the costs of mitigation measures, and the health benefits, could have a broader knock-on impact for the EU economy as costs (and benefits) filter through supply chains and into business decision making. The initial macro-economic suggested that overall (and across all sectors but agriculture), the net effect of more ambitious standards would be a positive gain in terms of GDP [Impacts on competitiveness, impacts on employment: +,++,+++].

Coherence:

Many of the measures taken to abate $PM_{2.5}$ will also have a complementary impact on GHG and black carbon emissions. These effects will scale with the level of ambition set [Climate change links: +,++,+++]. With a lower standard, larger co-benefit reductions in GHG emissions will provide additional synergies with wider EU climate change legislation and targets.

In addition, greater ambition will also lead to greater synergies with the EU's ZPAP as human and ecosystem health effects associated with exposure to air pollution will be reduced, indoor air pollution (for which outdoor air pollution is the greatest contributor) will also likely improve [Policy synergies: +,++,+++].

Links to other interventions: [synergies / misalignment]

- O2/O3 - achieving one standard for $PM_{2.5}$ will inherently somewhat work towards achieving other standards (if introduced in the case of O2).
- Links to B1 and B3 in terms of how standards will be defined, and also Intervention area F in terms of the complexity of having multiple standards for a single pollutant.

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[79] EEA report – unequal effects

- Link to M2 are transboundary sources will become increasingly important at low concentration levels.
- P1/P2/P3/Q1/Q2/Q3 /S1/S2 - achieving standards for $PM_{2.5}$ will rely on action to tackle other pollutants (PM_{10}, NO_2 and SO_2), in particular to achieve very low standards.

Benefit to cost ratio:

Benefit to cost ratio will vary with ambition. As the level of ambition increases, the cost of mitigation measures will increase on a non-linear basis. 20 and 15µg/m^3 standards appear to imply only limited additional effort over the baseline, and BCR is likely ***High***. To achieve compliance with 10 and (more so) 5 µg/m^3, modelled costs increase, but additional, non-technical action would be needed on a national or local level, the costs of which are uncertain. The BCR of these scenarios would necessarily be lower, but at which point the benefits and costs balance is uncertain.

Summary:

Stakeholders firmly recognise the value of an annual-average standard for $PM_{2.5}$, which applies as a limit value to all territory, but opinion varies on what level of ambition is appropriate by when. The modelling shows large improvements will be delivered in the baseline, but large numbers of population will remain in exceedance of the WHO AQGs. The modelling shows that additional mitigation measures under the scenarios can deliver large improvements in air quality, and associated benefits. Broad compliance with a 15µg/m^3 target should be feasible by 2030. However, the modelling also shows that achieving full compliance with a 10 and (more so) a 5 µg/m^3 standard is not possible without further non-technical or local measures, the costs of which are uncertain but most likely very high. Where more significant action and behavioural change is required, this would be more challenging to achieve in the short term. Furthermore, the importance of natural sources will challenge the feasibility of achieving the WHO AQG at multiple sites, and the imprecision of monitoring low concentrations will challenge the ability to measure compliance with WHO AQG in the short term.

O2

Intervention area O: EU air quality standards for particulate matter ($PM_{2.5}$)

Intervention (O2) Introduce short-term air quality standards and/or alert/information thresholds

The problem: *Health Outcome Shortcoming:* EU standards are not fully aligned with scientific advice. Driver: Exceedances of air pollutant concentrations above health guidelines and negative health impacts persist.

Description: The current EU AAQ Directives ***does not contain*** a short-term standard for $PM_{2.5}$. The WHO Guidelines set a recommended limit of 15 µg/m^3 over a 24-hour period (99th percentile, 3-4 exceedance days per year), alongside higher interim targets. This intervention explores the value of introducing a new EU short-term limit values for $PM_{2.5}$ in line with the WHO's 2021 Global Air Quality Guidelines (AQGs). Variants of the intervention consider different levels at which the standard can be set below the existing EU standard. Variants can also change the timeframe over which a standard should be achieved.

Purpose/operational objective: More closely aligns EU air quality standards with latest scientific knowledge and recommendations of WHO. This would reduce exposure to air pollution, therefore reducing negative health impacts.

Who would be impacted and how:

Direct: Should a lower standard be implemented, this will lead to an increase in the number of sites and zones in exceedance. As such, ***public authorities*** will be required to develop and implement new AQ Plans in order to put in place a strategy to meet these new requirements. These plans will also require ongoing review and management.

Indirect: The AQ Plans will identify suitable strategies to bring air pollutant concentrations in line with standards. These strategies may imply costs for ***households, businesses and industry*** in order to change behavior to abate air pollutant emissions or influence concentrations. These costs may also have a knock-on impact to the wider economy in terms of employment or on business activity through supply chains. ***Households, and indirectly businesses*** will benefit from the reduction in negative health impacts associated with higher levels of air pollution.

Risks for implementation:

$PM_{2.5}$ has a range of sources, both anthropogenic and natural. Natural sources are much more complex and difficult to control. In cases where natural sources contribute close to, or even more than, the levels of pollution set in the standard, it may be extremely challenging or unfeasible for public authorities to achieve such standards.

A further challenge is transboundary sources, and the ability for single public authorities to again control this as a source (link to M2).

Setting standards on the basis of a single value to be achieved everywhere will not drive continual improvement where such standards are already met. Furthermore, this may also drive action in areas of lower priority, where the population are not exposed – e.g. rural areas (links to O3 and B3 which consider average exposure targets).

Stakeholders (MS EG) also noted that having many different types of standards for a single pollutant (link to O2 and O3) increases the complexity for policy makers in terms of designing a response, and also communicating these standards to stakeholders (link to Intervention Area F).

Indicators

1. Air Quality	2. Impact on Health	3. Impacts on Ecosystems	4. Climate change links	5. Costs to society	6. Mitigation costs	7. Impacts on Competitiveness	8. Impacts on Sensitive Groups	9. Societal benefits and burden sharing	10. Impacts on Employment	11. Policy synergies	12. Administrative Burden
0 to +++	0 to +++	0 to +++	0 to +++	0 to +	0 to ---	+ / -	0 to ++	+ / -	0	0 to +++	0 to ---

Assessment

Effectiveness:

The impacts and effectiveness of the intervention to resolve the problem will scale with the ambition of the standard.

Reporting data is available for $PM_{2.5}$ over a 24-hourly average period. The existing level of compliance with any new standard will depend on the number of exceedance days allowed per annum. The WHO AQG is defined on the basis of the 99th percentile, whereas the existing EU 24-hour standard for PM_{10} for example is defined on the 90.4th percentile. For illustration:

- Based on the 99th percentile: across 1,256 monitoring sites in the EU27, 98% exceeded the WHO AQG in 2019 (and 84% exceeded a higher 25 µg/m^3 standard)
- Based on the 50th percentile: across 1,256 monitoring sites in the EU27, 9% exceeded the WHO AQG in 2019 (and 0% exceeded a higher 25 µg/m^3 standard).

Hence it appears there is currently broad exceedance of the WHO AQG. Furthermore, even where a larger number of exceedance days are allowed, comparing the distribution of results between $PM_{2.5}$ and PM_{10}, it appears that there are likely to be more exceedances of $PM_{2.5}$ relative to a 90.4th percentile relative to PM_{10}. Indeed continuing exceedances against the PM_{10} 24-hour limit value is currently an issue, in particular for a number Member States in eastern Europe and in northern Italy (Po valley). As such this intervention has the potential to have a large effect on Air Quality [0 to +++].

The detailed modelling only produces outputs in terms of annual average pollutant concentrations, as such no conclusions can be directly drawn from the analysis regarding compliance in the baseline going forward, nor under the abatement scenarios. That said, the significant, additional emissions reductions observed under the baseline will also drive an improvement in performance relative to a 24-hour standard, likewise the additional abatement taken up under the mitigation scenarios at additional cost. Assuming that the statistical relationship between long and short- term metrics holds going forward, a multiplier can be applied to annual average standards to suggest a complementary daily standard. The multiplier will vary depending on the percentile chosen: the multiplier for $PM_{2.5}$ (99th percentile) is close to 4.

Stakeholders generally see value in having a standard to manage $PM_{2.5}$ peaks. In response to the TSS, 65% stakeholders (majority of all groups except industry) responded that there was a need for EU standards to regulate peak concentrations. In addition, when asked, more respondents opted to select a standard than not, and suggested this should apply as a limit value to all territory (except for industry that noted it should apply only in selected locations). But there was a mixed response as to the appropriate level. The majority of public authorities, NGOs and research considered a 25 µg/m^3 level appropriate for 2030 (industry opting in the majority for no standard) and aligning with the WHO AQG in 2050 (with the same pattern across stakeholder types as 2030).

The most significant health effects (in particular in health impact analysis) associated with exposure to air pollution are typically associated with chronic exposure, rather than acute levels. However, health effects are also associated with short-term exposure but typically not quantified due to concerns around overlaps with more significant chronic effects[80]. Indeed, the WHO AQGs define a separate standard for $PM_{2.5}$ peaks, although in its 2021 publication it also revised down the relative risk co-efficient for all-cause mortality (relative to its previous HRAPIE publication). The WHO also noted in its 2021 publication evidence of sublinear health effects at higher concentration levels, so that the excess mortality will be overestimated by using a linear function. [Health impacts, value of benefits: 0 to +++].

For ecosystems: PM does not have a large, direct impact and short-term peaks will have even less of an effect. That said, again to achieve a PM standard will also require reducing other emissions (NO_2, SO_2, NH_3) for which a direct effect on ecosystems has been more clearly established [Ecosystem impact: 0 to +++].

Higher levels of $PM_{2.5}$ tend to be found in areas with a greater proportion of some vulnerable groups (e.g. lower income, lower educational attainment)[81]. As such, further reductions in $PM_{2.5}$ concentrations are anticipated to have a greater positive effect for more disadvantaged groups, scaling with the overall level of ambition, albeit the aggregate effect is likely to be less than for O1 [Impacts on Sensitive Groups: 0 to ++]. However, the measures taken to mitigate emissions will carry costs. The distribution of such costs will critically depend on the national or local delivery mechanism. But there is a risk that costs may disproportionately fall on some more vulnerable groups given their contribution to emissions [Societal benefits and burden sharing: +/-].

Efficiency:

The mitigation costs will increase with the level of ambition and will depend on the action taken. Short-term standards have not been modelled, as such the costs of such actions are more uncertain. Expert judgement suggests that some measures to limit short-term concentrations might carry more significant costs and subsequent macroeconomic effects - e.g. where vehicle movements are limited or fossil fuel burning restricted at short notice. However, if the standards are set based on a correlation to annual average concentrations, the costs and competitiveness impacts of measures to meet short term limits could be similar. In response to the TSS, the majority of stakeholders suggested that the introduction of a 24-hour standard for $PM_{2.5}$ would carry high compliance costs. The costs will scale with the number of exceedances [Mitigation costs: 0 to ---; Competitiveness + / -]. However, given the short-term nature of such actions, expert judgement suggests any long-term impact on employment is likely to be negligible [Employment: 0].

Administrative burden will also scale with ambition. The more ambitious the standard, the more new zones or sites will be identified as in exceedance. Public authorities will need to develop new, or amend existing, AQ Plans to define and implement a strategy to handle each new exceedance. In response to the TSS, the majority of stakeholders suggested that the introduction of a 24-hour standard for $PM_{2.5}$ would carry high administrative burden. However, given the costs of AQ Plans, even low ambition could deliver high administrative burden (relative to all interventions) [Administrative burden: 0 to ---].

Coherence:

The co-benefit for GHG emissions will depend on the type of the measures taken in response, with the significance of impact scaling with ambition. The nature of some short-term measures to reduce peak concentrations (e.g. vehicle limits at short notice or working at home order) could impact on GHG emissions (also assuming that there is no rebound in activity on non-peak days) [Climate change links: 0 to +++].

Given the intervention has the potential to have a positive impact on human and environmental health, it can provide positive synergies with the EU's ZPAP [Policy synergies: 0 to +++].

Links to other interventions: [synergies / misalignment]

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[80] WHO HRAPIE

[81] EEA report – unequal effects

- O1/O3 - achieving one standard for $PM_{2.5}$ will inherently somewhat work towards achieving other standards. In particular, to achieve a given annual standard, concentration levels can only inherently exceed the annual standard a certain number of days a year for the annual standard to still be achievable.
- P1/P2/P3/Q1/Q2/Q3 - achieving standards for $PM_{2.5}$, will also somewhat help to contribute to achieving standards for other air pollutants, in particular PM_{10} and NO_2.
- Links to B1 and B3 in terms of how standards will be defined, and also Intervention area F in terms of the complexity of having multiple standards for a single pollutant.
- Link to M2 are transboundary sources will become increasingly important at low concentration levels

Benefit to cost ratio:

Benefit to cost ratio will vary with ambition. Short-term standards are not modelled explicitly, and hence judgements regarding the balance of costs and benefits is more uncertain. Where there is a risk of exceedance, public authorities will need to put new plans in place to manage these risks. In addition, short-term compliance measures to tackle peak concentrations specifically may be more disruptive in nature (albeit for a short-time) and carry a higher cost, which is underlined by the perception of stakeholders. With respect to benefits, greater health effects are typically associated with chronic exposure (in assessment), but where the risk of peaks is quite high and considering this intervention in isolation, the benefits would be much more significant. **High.**

Summary:

The intervention considers the introduction of a new standard. In isolation, there is a strong case for a standard managing $PM_{2.5}$ peak concentrations. In the context of other interventions around PM (O1, O3 and P1-3), a more crucial question is what additional value a peak standard for $PM_{2.5}$ would deliver, in particular given the risk of additional complexity for public authorities and citizens.

It appears that there is merit in having a standard to manage peak alongside annual average concentrations – this is underlined by stakeholders and the advice of the WHO, who explore that even a small number of extreme peaks could have a significant impact. However, the effectiveness of a peak concentration as a safety net (and indeed its additional value over an annual standard) decreases with the number of allowed exceedance days per year.

In addition, there is a question as to whether a peak standard for $PM_{2.5}$ would offer additional value alongside a peak standard for PM_{10}. Both are likely to share similar sources, and hence control strategies. Hence the additional value would increase to the extent that peaks in each are not correlated, and any unique sources driving peaks in $PM_{2.5}$ can be controlled (i.e. are not from natural sources).

Where a standard is put in place, the benefit-to-cost ratio will vary with the level of ambition. Short-term standards have not been considered in the modelling, so it is challenging to fully assess the impacts with any certainty. In 2019, there is a significant level of exceedance with both the WHO AQG or even a higher 25 $\mu g/m^3$ standard, although this does not account for further anticipated reductions in $PM_{2.5}$ emissions in the baseline to 2030 and 2050. Such an intervention would carry potentially high costs and administrative burden where exceedances occur, but where the risk of peaks is high, the benefits could be much more significant.

The indicators present a range as the significance of impacts will depend on the level of standard set. It is challenging to precisely define the level at which the indicator score would change. That said, based on the modelling and wider evidence gathering, expert judgement suggests that: low (non-zero) impacts could be associated with a 60 ug/m^3 standard (99th percentile), moderate impacts with a 40 ug/m^3 standard (99th percentile), and the highest scoring associated with a 15 ug/m^3 standard (99th percentile) – note these standards would be different where a different percentile (i.e. number of permitted exceedances per year) was considered.

O3

Intervention Area: EU air quality standards for particulate matter ($PM_{2.5}$)

Intervention (O3) Revise average exposure obligations and reduction targets

The problem: Health outcome shortcomings: Exceedances above health guidelines and negative health impacts persist

Description: Revise exposure reduction targets for $PM_{2.5}$, in terms of the initial concentration values and the percentage reduction target. Variants for this intervention are based on different initial concentrations (µg/m^3) and look at whether the reduction targets should be based on annual or daily exposure, and whether they should be set at a regional or national level. The following mechanisms are under review:

- ECO Exposure concentration obligation – i.e. 'an average level determined on the basis of measurements at urban background locations, reflects population exposure – and to be attained over a given period';
- (N)ERT (National) exposure reduction target – i.e. 'a percentage reduction of the average exposure to be attained where possible over a given period'.

The WHO air quality guidelines include targets for $PM_{2.5}$ based on concentration values rather than exposure reduction targets.

The AAQ Directives includes average exposure obligations among the current provisions to regulate $PM_{2.5}$ concentrations. This is to complement the emission limit value for $PM_{2.5}$ by targeting areas with higher concentration values.

Accordingly, the AAQ Directives sets a national $PM_{2.5}$ exposure reduction target to protect human health (Article 15). The reduction target is a percentage reduction based on the initial concentration. To determine the initial concentration, an average exposure indicator is used (an average level determined on the basis of measurements at urban background locations throughout the territory of a Member State and which reflects population exposure).

Purpose/operational objective: To reduce exposure to harmful levels of air pollution, with reference to best-practice guidance regarding safe levels of exposure. This would reduce exposure to air pollution, therefore reducing negative health impacts.

Who would be impacted and how:

Direct: It is understood that reducing exposure will lead to health benefits in a shorter timeframe than would be achieved with limit values alone. Thus citizens currently exposed to poor air quality would benefit from this intervention. In particular, citizens residing in urban areas exposed to high concentration values of $PM_{2.5}$. Citizens with existing medical conditions and citizens in vulnerable groups (such as babies, children, the elderly) are at higher risk to exposure and therefore health benefits are expected to be greater for vulnerable groups as a result. Administrative and monitoring costs would fall on competent authorities and are expected to be marginal (for monitoring, it is assumed that no new monitoring stations would be required). Measures to attain the reduction targets are likely to address emissions from domestic heating, thus compliance costs are expected to impact citizens rather than businesses.

Indirect: Where reduced exposure leads to health benefits indirect benefits can be expected for businesses and productivity impacts relating to workforce where poor air quality can have a negative effect (reduced workforce).

Risks for implementation:

Implementation will require amending the legal provisions currently set out in Annex XIV of 2008/50/EC.

Indicators											
1. Air Quality	2. Impact on Health	3. Impacts on Ecosystems	4. Climate change links	5. Costs to society	6. Mitigation costs	7. Impacts on Competitiveness	8. Impacts on Sensitive Groups	9. Societal benefits and burden sharing	10. Impacts on Employment	11. Policy synergies	12. Administrative Burden
0 to ++	0 to ++	0 to ++	0 to ++	0 to ++	0 to --	0 to +	0 to +++	+ / -	0 to +	0 to ++	0 to --

Assessment

Effectiveness:

Recognising the variants for this intervention, it is understood that the potential effectiveness would scale with the level of ambition. In general terms, revisions to average exposure obligations are expected to improve air quality by reducing concentrations of $PM_{2.5}$ in targeted areas (regardless of the level of ambition) [Air Quality and Health impacts: 0 to ++]. The main benefit of setting average exposure targets is that it can complement limit values, particularly in cases of non-compliance with limit values as average exposure targets facilitate targeted action mitigate negative health impacts in a shorter timeframe.

Stakeholder responses gathered from the TSS highlight that reduction targets are believed not to be the most effective mechanism (compared to limit values); however, as a complementary mechanism to limit values they are viewed as effective.

Notably, reduction targets can target air quality in specific areas and facilitate achieving more stringent limit values over a longer timeframe (and particularly useful for areas where there is a significant compliance gap). In the context of stakeholder responses to setting more stringent limit values which are aligned with WHO guidelines, many stakeholders expressed concern that the WHO guideline values would be challenging (owing to the transboundary nature of $PM_{2.5}$, the given timeframe and available abatement technologies, among others). In this way, the average exposure indicator may be an effective mechanism to protect human health by facilitating a more targeted approach, particularly if made legally binding.

By facilitating a targeted response to areas with high concentrations of $PM_{2.5}$, this mechanism is expected to contribute to the protection of human health in such areas, including citizens with existing medical conditions and citizens in vulnerable groups (such as babies, children, the elderly) [Sensitive groups: 0 to +++].

Stakeholder responses gathered from the TSS show that most stakeholders prefer local or regional level intervention, rather than national – and indeed, there is emphasis on local (including by air quality zone or agglomeration) rather than regional among responses received.

Reduced concentrations of $PM_{2.5}$ will not directly benefit ecosystems, however, the measures to attain the revised average exposure obligations have co-benefits of reducing NO_2, SO_2, NH_3 and VOC, thus mitigating acidification and eutrophication [Ecosystem impacts: 0 to ++].

The costs of attaining the reduction targets may fall on vulnerable people (those living in poorer areas with lower education), where measures to attain the reduction targets are likely to address emissions from domestic heating although the balance of impacts very much depends on implementation [Societal: + / -].

Stakeholders have noted that the criteria for setting a reduction target will be particularly important for ensuring such a mechanism is effective (in terms of identifying which areas are subject to reduction targets). One suggestion repeated by a few stakeholders is to establish a weighting based on population density combined with modelling (thus moving away from determining the average exposure indicators based on monitoring data at a few sites).

It is also noted that exposure reduction targets can overemphasise air quality in urban areas over rural areas and that this is not always effective for Member States with high population densities as it offers limited health benefits. To address this, one stakeholder proposes that the average exposure indicator should be based on all monitoring stations, excluding rural background stations only if it is more than 5 km from a residential area.

Exposure time is also noted as a key factor that should be considered when setting reduction targets as is the initial baseline concentration against which the targets are set.

Efficiency:

Recognising the variants for this intervention, it is understood that the potential efficiency would scale with the level of ambition.

Revisions to average exposure obligations can deliver significant benefits in terms of protection of human health (depending on the level of ambition). [Costs to society: 0 to ++]

Mitigation costs will be incurred from measures to attain the reduction targets and while costs are dependent on implementation, they will be significant [Mitigation costs: 0 to --]. Measures to attain the reduction targets are likely to address emissions from domestic heating. Stakeholders generally did not provide responses on the scale of costs, however, where an opinion was provided, there is a split between “high compliance costs” and “low compliance costs”.

The administrative burden is dependent on the number of additional areas of exceedance that require air quality plans as a result of the average exposure indicator. In addition, a cost associated with monitoring is expected (and potentially a modelling cost depending on the criteria adopted to determine the average exposure indicator). Neither the cost of monitoring nor modelling is expected to be great as it will make use of existing systems. Stakeholder responses gathered from the TSS show that most stakeholders do not hold a single, shared opinion on the administrative burden [Administrative burden: 0 to --]. There is potential to reduce the administrative burden by taking more coordinated and centralised action in each Member State in response to exposure targets. For example, only one air quality plan may be needed, rather than multiple at regional or local level.

A small positive impact on employment [0 to +] and competitiveness [0 to +] is expected as a result of the abatement measures adopted to attain the targets (in line with O1).

Coherence:

Revisions to the average exposure obligations would facilitate the improvement of air quality by reducing concentrations of $PM_{2.5}$. This is aligned with wider policy objectives to achieve zero pollution [Policy Synergies: ++]. The intervention is also expected to contribute to climate changes policies as measures to abate PM will also reduce GHG emissions, and BC [Climate change links: 0 to ++].

Links to other interventions: [synergies / misalignment]

- O1/O2 - achieving one standard for $PM_{2.5}$ will contribute towards achieving other standards. Note that stakeholders repeatedly commented that exposure reduction targets are only effective as a complementary mechanism to limit values.
- P1/P2/P3/Q1/Q2/Q3 - achieving standards for $PM_{2.5}$, will contribute to achieving standards for other air pollutants, in particular PM_{10} and NO_2.
- Links to B3 and type of exposure indicator.

Benefit-to-cost ratio: The benefit-to-cost ratio would be **high**:

- The revised reduction obligations is expected to deliver health benefits particularly benefitting sensitive groups. The extent to which it contributes to air quality improvements is dependent on the level of ambition. A benefit of setting average exposure targets is that it can complement limit values, particularly in cases of non-compliance with limit values as average exposure targets facilitate targeted action mitigate negative health impacts in a shorter timeframe. Benefits to ecosystems will occur as a co-benefit of the measures implemented to attain the reduction targets.

- Costs are significant, arising primarily from measures to attain the reduction targets and administrative burden. There is potential to reduce the administrative burden by taking more coordinated and centralised action.

Summary: Stakeholders do not have strong opinions regarding revisions to average exposure targets. The impact on air quality will vary with ambition; however, regardless of the level of ambition, revisions to average exposure targets are expected to facilitate targeted reductions of $PM_{2.5}$ and attaining the revised reduction obligations is expected to deliver health benefits and particularly benefit sensitive groups. Compliance costs have the potential to be significant although the measures to attain the reduction targets (and their associated costs) are generally accepted by stakeholders. Administrative burden will vary with ambition (with more air quality plans required in cases of the high ambition variant to account for the greater number of exceedances – with scope to reduce this burden through coordinated action).

P1

Intervention area P: EU air quality standards for particulate matter (PM_{10})

Intervention (P1) Revise long-term (annual) air quality standards

The problem: *Health Outcome Shortcoming:* EU standards are not fully aligned with scientific advice.

Driver: Exceedances of air pollutant concentrations above health guidelines and negative health impacts persist.

Description: The current EU AAQ Directives standards for annual PM_{10} sets an annual average limit value of 40 µg/m^3. The WHO guideline is set at 15 µg/m^3, alongside higher interim targets. Intervention explores the alignment of the EU long-term standard limit values for PM_{10} with the WHO's 2021 Global Air Quality Guidelines (AQGs) updated limit values.

Variants of the intervention consider different levels at which the standard can be set below the existing EU standard: any numerical standard could be selected. Variants can also change the timeframe over which a standard should be achieved.

Purpose/operational objective: More closely aligns EU air quality standards with latest scientific knowledge and recommendations of WHO. This would reduce exposure to air pollution, therefore reducing negative health impacts.

Who would be impacted and how:

Direct: Should a lower standard be implemented, this will lead to an increase in the number of sites and zones in exceedance. As such, ***public authorities*** will be required to develop and implement new (and revise existing) AQ Plans in order to put in place a strategy to meet these new requirements. These plans will also require ongoing review and management.

Indirect: The AQ Plans will identify suitable strategies to bring air pollutant concentrations in line with standards. These strategies may imply costs for ***households, businesses and industry*** in order to change behavior to abate air pollutant emissions or influence concentrations. These costs may also have a knock-on impact to the wider economy in terms of employment or on business activity through supply chains.

Households, and indirectly businesses will benefit from the reduction in negative health impacts associated with higher levels of air pollution.

Risks for implementation:

PM_{10} (as $PM_{2.5}$) has a range of sources, both anthropogenic and natural. Natural sources are much more complex and difficult to control. In cases where natural sources present a significant contribution, it will be more challenging for public authorities to achieve such standards.

A further challenge is transboundary sources, and the ability for single public authorities to again control this as a source (link to M2).

There are delivery risks around meeting more stringent standards in the short-term: i.e. it takes time to identify exceedances, put AQ plans in place and roll out mitigation techniques to achieve emissions and concentration reductions, and the size of the challenge will likely increase with ambition.

Setting standards on the basis of a single value to be achieved everywhere will not drive continual improvement where such standards are already met. Furthermore, this may also drive action in areas of lower priority, where the population are not exposed (links to P3 and B3 which consider average exposure targets).

Stakeholders (MS EG) also noted that having many different types of standards for a single pollutant (link to P2 and P3) increases the complexity for policy makers in terms of designing a response, and also communicating these standards to stakeholders (link to Intervention Area F).

Indicators

1. Air Quality	2. Impact on Health	3. Impacts on Ecosystems	4. Climate change links	5. Costs to society	6. Mitigation costs	7. Impacts on Competitiveness	8. Impacts on Sensitive Groups	9. Societal benefits and burden sharing	10. Impacts on Employment	11. Policy synergies	12. Administrative Burden
0 to +++	0 to +++	0 to +++	0 to +++	0 to +	0 to ---	0 to +	0 to +++	+ / -	0 to +	0 to +++	0 to --

Assessment

Effectiveness:

The impacts and effectiveness of the intervention to resolve the problem will scale with the ambition of the standard.

As of 2019[82], 11 reporting countries, of which 7 were EU Member States, registered concentrations above the EU annual limit value of 40 µg/m^3. All the reporting countries registered concentrations above the stricter WHO guideline of 15 µg/m^3. 15% of EU urban population exposed to air pollutant concentrations above EU standard; 81% above WHO standard. The highest concentrations were found in central and eastern Europe and northern Italy. The use of solid fuels such as coal are widely used for heating households and in some industrial facilities and power plants. The Po Valley, in northern Italy, is a densely populated and industrialised area with specific meteorological conditions that favour the accumulation of air pollutants in the atmosphere.

In the modelling baseline, a further decline of emissions is expected associated with a reduced reliance on fossil fuels in many combustion related sectors (power and industry, residential, transport). In particular, the residential sector observes a decline in coal and biomass use as well as transition to cleaner technologies, whilst transport is depicted by a further reduction of exhaust emissions but non-exhaust component dominates. This leads to a reduction in EU population living in areas exceeding the existing EU standard, from around 0.45m in 2020, to 0.11m in 2030, and 0.11m in 2050. However, some people will reside in areas exceeding the WHO AQGs: around 17.6m people in 2030 and 15.9m in 2050. Hence this intervention could have a significant impact on Air Quality [0 to +++].

The modelling scenarios offer some, but little further impact: by 2030, there will be broad compliance with a 30 µg/m3 target – only around 13,000 people will remain living in areas of exceedance in OPT15. Under OPT10, around 2.7 million people remain living in areas exceeding 20 µg/m3, implying a moderate level of effort would be needed at local level to meet this ambition. Under OPT5, 13.7 million remain in areas exceeding the WHO AQG 15 µg/m3. To 2050, a fairly similar pattern of results holds: with 0.15m, 2.85m and 13.5m people living in areas exceeding 30 µg/m3 (OPT15), 20 µg/m3 (OPT10) and 15 µg/m3 (OPT5) respectively. Hence in order to achieve compliance with the WHO AQGs, in particular by 2030, would require national, non-technical or local scale measures which are not captured by GAINS.

In terms of stakeholder opinion, there was a strong majority response to the OPC that stakeholders are concerned about the levels of air pollution to which they are exposed, and favour an ambitious change in air quality standards. This result was driven by EU citizens who were the main respondent type to the OPC (66%) and NGOs. However, other stakeholder types were more cautious in terms of ambition, as shown through the TSS. From the TSS it was clear that stakeholders see value in having this standard, and that it should apply as a limit value to all territories, but the response was more mixed around an appropriate level. For 2030, the majority favoured some reduction from the current standard (most selecting 30 or 20µg/m^3) – this was the case for public authorities, with NGOs being slightly more ambitious (split 10 and 5µg/m^3), with the majority of

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industry selecting a small reduction to 30µg/m^3 as most appropriate. To 2050, a large overall majority favoured moving in line with the WHO AQG, driven by the majority of NGOs, public authorities and research that responded in this way, with industry favouring a less ambitious reduction (30 µg/m^3 in 2050).

The health effects across the variants will scale with the level of ambition. But health effects are more closely associated with exposure to finer particles $PM_{2.5}$. Indeed the health impact modelling conducted has not appraised effects associated directly with PM_{10}. As such there would likely be some overlap in the benefits achieved by standards for PM_{10} and $PM_{2.5}$ when implemented together (Link to O1, O2 and O3), hence this intervention is scored lower than O1 [Impact on health: 0 to +++; Costs to society: 0 to +].

As for $PM_{2.5}$, ecosystem effects are associated more so with other pollutants. However, to achieve ambitious levels of PM_{10} concentrations, ambitious reductions in NO_2, SO_2, NH_3 emissions and also VOC are also required. Hence ecosystem effects will scale with ambition [Impacts on ecosystems: 0 to +++].

As with $PM_{2.5}$, higher levels of PM_{10} tend to be found in areas with a greater proportion of some vulnerable groups (e.g. lower income, lower educational attainment)[83]. As such, further reductions in PM_{10} concentrations are anticipated to have a greater positive effect for more disadvantaged groups, scaling with the overall level of ambition [Impacts on Sensitive Groups: 0 to +++]. However, the measures taken to mitigate emissions will carry costs. The distribution of such costs will critically depend on the national or local delivery mechanism. But there is a risk that costs may disproportionately fall on more vulnerable groups given their contribution to emissions [Societal benefits and burden sharing: +/-].

Efficiency:

The mitigation costs of lower standards for PM_{10} has not been modelled directly. Some insights can be gained from the modelling optimising around $PM_{2.5}$: many of the measures which mitigate $PM_{2.5}$ would also mitigate PM_{10} emissions, hence in some way the measures and costs would be similar [Mitigation costs: 0 to ---]. As such, the costs of mitigation action will scale with ambition, and somewhat exponentially, but a certain level of compliance could be achieved for a fairly low cost.

Further insight is provided by stakeholders: the majority of respondents to the TSS suggested the WHO PM_{10} AQGs 'could be achieved with only significant effort', whilst the majority noted the WHO $PM_{2.5}$ AQGs are 'not feasible for the foreseeable future'. This suggests the costs for achieving $PM_{2.5}$ standards could be an upper bound for PM_{10}.

Administrative burden will also scale with ambition. The more ambitious the standard, the more new zones or sites will be identified as in exceedance. Public authorities will need to develop new, or amend existing, AQ Plans to define and implement a strategy to handle each new exceedance. However, given the costs of AQ Plans, even low ambition could deliver high administrative burden (relative to all interventions) [Administrative burden: 0 to --].

Both the costs of mitigation measures, and the health benefits, could have a broader knock-on impact for the EU economy as costs (and benefits) filter through supply chains and into business decision making. No modelling has been undertaken focusing on the achievement of PM_{10} standards directly. Given mitigation costs would be at most similar to $PM_{2.5}$, but the benefits would also be lower, it is more uncertain that a small net positive impact would also accrue for PM_{10} as modelled for $PM_{2.5}$ [Impacts on competitiveness, impacts on employment: 0 to +].

Coherence:

Many of the measures taken to abate PM_{10} will also have a complementary impact on GHG and black carbon emissions. These effects will scale with the level of ambition set [Climate change links: 0 to +++]. With a lower

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standard, larger co-benefit reductions in GHG emissions will provide additional synergies with wider EU climate change legislation and targets.

In addition, greater ambition will also lead to greater synergies with the EU's ZPAP as human and ecosystem health effects associated with exposure to air pollution will be reduced, indoor air pollution (for which outdoor air pollution is the greatest contributor) will also likely improve. Given the overlap in health benefits with $PM_{2.5}$ standards, the potential benefit for PM_{10} standards has been scored as O1 [Policy synergies: 0 to +++].

Links to other interventions: [synergies / misalignment]

- P2/P3 - achieving one standard for PM_{10} will inherently somewhat work towards achieving other standards (if introduced in the case of P3).
- Links to B1 and B3 in terms of how standards will be defined, and also Intervention area F in terms of the complexity of having multiple standards for a single pollutant.
- Link to M2 are transboundary sources will become increasingly important at low concentration levels.
- O1/O2/O3 /Q1/Q2/Q3 /S1/S2 - achieving standards for PM_{10} will interact with action to tackle other pollutants ($PM_{2.5}$, NO_2 and SO_2)

Benefit to cost ratio:

Benefit to cost ratio will vary with ambition. As the level of ambition increases, the cost of mitigation measures will increase on a non-linear basis. The mitigation costs of lower standards for PM_{10} has not been modelled directly, as such contrasting benefits and costs is more uncertain. The insights provided by the modelling and stakeholders suggest the costs of lower standards and the WHO AQGs may be less than those for $PM_{2.5}$, but the associated benefits associated with a PM_{10} standard specifically would also be lower given overlap with $PM_{2.5}$. As shown in the modelling, a certain level of cost can achieve a certain level, but not full compliance – to achieve full compliance will require the uptake of local or non-technical measures not captured by GAINS. Overall, expert judgement assumes that the pattern of benefit-to-cost ratio could follow that for $PM_{2.5}$: namely smaller improvements in the standard are likely to imply only limited additional effort over the baseline with a ***high*** BCR. To achieve more ambitious standards, costs will increase – given these are not modelled costs are uncertain. The BCR of these scenarios would necessarily be lower, and at which point the benefits and costs balance is uncertain. **High.**

Summary:

Stakeholders firmly recognise the value of an annual-average standard for PM_{10}, which applies as a limit value to all territory. Furthermore, stakeholders also affirm the additional value of a standard for PM_{10} alongside $PM_{2.5}$ and show a general appetite for some improvement. But opinion varies on what level of ambition is appropriate by when. As PM_{10} standards have not been modelled explicitly makes it more difficult to make a judgement as to the balance of costs and benefits: costs will increase with ambition, alongside the benefits, and both are judged to be less extreme than for $PM_{2.5}$. For small improvements in ambition, the BCR is likely to be high, but the balance becomes more uncertain for more ambitious change, The majority of stakeholders feel alignment with the WHO AQGs would not be appropriate by 2030, but most feel a target in the range from 20-30 $\mu g/m^3$ would be achievable. Should a revised target be set for 2030 (or the short-term), the ability to deliver the necessary mitigation in that timeframe is a key consideration.

The indicators present a range as the significance of impacts will depend on the level of standard set. It is challenging to precisely define the level at which the indicator score would change. That said, based on the modelling and wider evidence gathering, expert judgement suggests that: low (non-zero) impacts could be associated with a 30 ug/m^3 standard, moderate impacts with a 20 ug/m^3 standard, and the highest scoring associated with a 15 ug/m^3 standard.

P2

Intervention area P: EU air quality standards for particulate matter (PM_{10})

Intervention (P2) Revise short-term air quality standards and/or alert/information thresholds

The problem: ***Health Outcome Shortcoming:*** EU standards are not fully aligned with scientific advice.
Driver: Exceedances of air pollutant concentrations above health guidelines and negative health impacts persist.

Description: The current EU AAQ Directives standards for 24-hour PM_{10} sets a limit value of 50 µg/m^3. The WHO guideline is set at 45 µg/m^3, alongside higher interim targets. This intervention explores the alignment of the EU 24-hour limit values for PM_{10} with the WHO's 2021 Global Air Quality Guidelines (AQGs) updated limit values. Variants of the intervention consider different levels at which the standard can be set below the existing EU standard: any numerical standard could be selected. Variants can also change the timeframe over which a standard should be achieved.

Purpose/operational objective: More closely aligns EU air quality standards with latest scientific knowledge and recommendations of WHO. This would reduce exposure to air pollution, therefore reducing negative health impacts.

Who would be impacted and how:
Direct: Should a lower standard be implemented, this will lead to an increase in the number of sites and zones in exceedance. As such, ***public authorities*** will be required to develop and implement new (and revise existing) AQ Plans in order to put in place a strategy to meet these new requirements. These plans will also require ongoing review and management.
Indirect: The AQ Plans will identify suitable strategies to bring air pollutant concentrations in line with standards. These strategies may imply costs for ***households, businesses and industry*** in order to change behavior to abate air pollutant emissions or influence concentrations. These costs may also have a knock-on impact to the wider economy in terms of employment or on business activity through supply chains.
Households, and indirectly businesses will benefit from the reduction in negative health impacts associated with higher levels of air pollution.

Risks for implementation:
PM_{10} (as $PM_{2.5}$) has a range of sources, both anthropogenic and natural. Natural sources are much more complex and difficult to control. In cases where natural sources present a significant contribution, it will be more challenging for public authorities to achieve such standards.
A further challenge is transboundary sources, and the ability for single public authorities to again control this as a source (link to M2).
There are delivery risks around meeting more stringent standards in the short-term: i.e. it takes time to identify exceedances, put AQ plans in place and roll out mitigation techniques to achieve emissions and concentration reductions, and the size of the challenge will likely increase with ambition.
Setting standards on the basis of a single value to be achieved everywhere will not drive continual improvement where such standards are already met. Furthermore, this may also drive action in areas of lower priority, where the population are not exposed (links to P3 and B3 which consider average exposure targets).
Stakeholders (MS EG) also noted that having many different types of standards for a single pollutant (link to P1 and P3) increases the complexity for policy makers in terms of designing a response, and also communicating these standards to stakeholders (link to Intervention Area F).

Indicators

1. Air Quality	2. Impact on Health	3. Impacts on Ecosystems	4. Climate change links	5. Costs to society	6. Mitigation costs	7. Impacts on Competitiveness	8. Impacts on Sensitive Groups	9. Societal benefits and burden sharing	10. Impacts on Employment	11. Policy synergies	12. Administrative Burden
0 to +++	0 to +++	0 to +	0 to +	0 to +	0 to ---	+ / -	0 to ++	+ / -	0	0 to +++	0 to --

Assessment

Effectiveness:

The impacts and effectiveness of the intervention to resolve the problem will scale with the ambition of the standard.

Reporting data is available for PM_{10} over a 24-hourly average period. The WHO AQG is defined on the basis of the 99th percentile, whereas the existing EU 24-hour standard for PM_{10} is defined on the 90.4th percentile:

- Based on the 90.4th percentile: across 2,635 monitoring sites in the EU27, 10% exceed the existing EU 24-hour standard (and 16% exceeded the WHO AQG level) in 2019.
- Based on the 99th percentile: across 2,635 monitoring sites in the EU27, 55% exceed the existing EU 24-hour standard (and 69% exceeded the WHO AQG level) in 2019.

Hence there is currently continuing exceedances against the PM_{10} 24-hour limit value, in particular for a number Member States in eastern Europe and in northern Italy (Po valley). Aligning with the WHO in terms of numerical standard would pose a challenge for a relatively small number of sites, but full alignment (i.e. on the basis of 99th percentile) would pose a challenge for a much greater number of sites. As such this intervention has the potential to have a large effect on Air Quality [0 to +++].

The detailed modelling only produces outputs in terms of annual average pollutant concentrations, as such no conclusions can be directly drawn from the analysis regarding compliance in the baseline going forward, nor under the abatement scenarios. That said, the significant, additional emissions reductions observed under the baseline will also drive an improvement in performance relative to a 24-hour standard, likewise the additional abatement taken up under the mitigation scenarios at additional cost. Assuming that the statistical relationship between long- and short-term metrics holds going forward, a multiplier of around 3.5 (99th percentile) relative to the long-term standard could apply.

Stakeholders generally see value in this intervention. In response to the TSS, 71% of stakeholders (majority of all groups) believed there was a need for EU standards to regulate peak PM_{10} concentrations. In addition, when asked, more respondents opted to select a numerical standard than not and suggested this should apply as a limit value to all territory (except for industry that noted it should apply only in selected locations). But there was a mixed response as to the appropriate level. The majority of all stakeholder types except research and academics considered the existing 50 $\mu g/m^3$ level appropriate for 2030, but a sizeable minority of all groups and the majority of researchers felt 45 $\mu g/m^3$ was appropriate for 2030. A significant majority of all groups (except industry) opted for alignment with the WHO AQG in 2050.

The most significant health effects (in particular in health impact analysis) associated with exposure to air pollution are typically associated with chronic exposure to $PM_{2.5}$, rather than acute levels and to PM_{10}. As such this intervention is scored lower than O1 [Health impacts: 0 to ++; costs to society: 0 to +]. However, health effects are also associated with short-term exposure and with PM_{10} (of which $PM_{2.5}$ is a subset) but typically not quantified due to concerns around overlaps with more significant chronic effects[84]. Indeed, the WHO AQGs define a separate standard for PM_{10} peak concentrations.

For ecosystems, PM does not have a large, direct impact and short-term peaks will have even less of an effect. That said, again to achieve a PM standard could also require reducing other emissions (NO_2, SO_2, NH_3) for which a direct effect on ecosystems has been more clearly established, thus there is the potential for small effects [Ecosystem impact: 0 to +].

Higher levels of PM_{10} tend to be found in areas with a greater proportion of some vulnerable groups (e.g. lower income, lower educational attainment)[85]. As such, further reductions in PM_{10} concentrations are anticipated to have a greater positive effect for more disadvantaged groups, scaling with the overall level of ambition. Albeit given this focuses on pollution peaks, the aggregate effect is likely to be less than for P1 [Impacts on Sensitive Groups: 0 to ++]. However, the measures taken to mitigate emissions will carry costs. The distribution of such costs will critically depend on the national or local delivery mechanism. But there is a risk that costs may disproportionately fall on more vulnerable groups given their contribution to emissions [Societal benefits and burden sharing: +/-].

Efficiency:

The mitigation costs will increase with the level of ambition and will depend on the action taken. Short-term standards have not been modelled, as such the costs of mitigation actions are more uncertain. Expert judgement suggests many of the actions taken to mitigate peak concentrations will be the same as those to tackle annual average concentrations – so the costs will at least be the same. In addition, some measures to specifically limit short-term concentrations might carry more significant costs and subsequent macroeconomic effects - e.g. where vehicle movements are limited or fossil fuel burning restricted at short notice [Mitigation costs: 0 to ---; Competitiveness + /-]. However, given the short-term nature of such actions, expert judgement suggests any long-term impact on employment is likely to be negligible [Employment: 0].

Administrative burden will also scale with ambition. The more ambitious the standard, the more new zones or sites will be identified as in exceedance. Public authorities will need to develop new, or amend existing, AQ Plans to define and implement a strategy to handle each new exceedance. However, given the costs of AQ Plans, even low ambition could deliver high administrative burden (relative to all interventions) [Administrative burden: 0 to --].

Coherence:

The co-benefit for GHG emissions will depend on the type of the measures taken in response, with the significance of impact scaling with ambition. The nature of some short-term measures to reduce peak concentrations (e.g. vehicle limits at short notice or working at home order) could impact on GHG emissions (also assuming that there is no rebound in activity on non-peak days) [Climate change links: 0 to +].

Given the intervention has the potential to have a positive impact on human and environmental health, it can provide positive synergies with the EU's ZPAP [Policy synergies: 0 to +++].

Links to other interventions: [synergies / misalignment]

- P1/P3 - achieving one standard for PM_{10} will inherently somewhat work towards achieving other standards. In particular, to achieve a given annual standard, concentration levels can only inherently exceed the annual standard a certain number of days a year for the annual standard to still be achievable.
- O1/O2/O3/Q1/Q2/Q3 - achieving standards for PM_{10}, will also somewhat help to contribute to achieving standards for other air pollutants, in particular $PM_{2.5}$ and NO_2.

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- Links to B1 and B3 in terms of how standards will be defined, and also Intervention area F in terms of the complexity of having multiple standards for a single pollutant.
- Link to M2 are transboundary sources will become increasingly important at low concentration levels

Benefit to cost ratio:

Benefit to cost ratio will vary with ambition. Short-term standards are not modelled explicitly, and hence judgements regarding the balance of costs and benefits is more uncertain. Where there is a risk of exceedance, public authorities will need to put new plans in place to manage these risks. In addition, short-term compliance measures to tackle peak concentrations specifically may be more disruptive in nature (albeit for a short-time). With respect to benefits, greater health effects are typically associated with chronic exposure and $PM_{2.5}$ (in assessment), but where the risk of peaks is quite high and considering this intervention in isolation, the benefits would be much more significant. **High.**

Summary:

The intervention considers the revision of the existing standard. In isolation, there is a strong case for a standard managing PM_{10} peak concentrations. In the context of other interventions around PM (O1-3, P1 and P3), a more crucial question is what additional value a peak standard for PM_{10} would deliver, in particular given the risk of complexity for public authorities and citizens. It appears that there is merit in having a standard to manage peak alongside annual average concentrations – this is underlined by stakeholders and the advice of the WHO, who explore that even a small number of extreme peaks could have a significant impact. However, the effectiveness of a peak concentration as a safety net (and indeed its additional value over an annual standard) decreases with the number of allowed exceedance days per year.

In addition, there is a question as to whether a peak standard for PM_{10} would offer additional value alongside a peak standard for $PM_{2.5}$. Both are likely to share similar sources, and hence control strategies. Hence the additional value would increase to the extent that peaks in each are not correlated, and any unique sources driving peaks in PM_{10} can be controlled (i.e. are not from natural sources).

Where a standard is put in place, the benefit-to-cost ratio will vary with the level of ambition. Short-term standards have not been considered in the modelling, so it is challenging to fully assess the impacts with any certainty. In 2019, there are exceedances of the existing EU standard, but a much higher number of sites exceed the WHO AQG, although this does not account for further anticipated reductions in $PM_{2.5}$ emissions in the baseline to 2030 and 2050. Such an intervention would carry potentially high costs and administrative burden where exceedances occur, but where the risk of peaks is high, the benefits would be much more significant.

That said, stakeholders voted positively that they see additional value in a standard to manage peak concentrations of PM_{10}.

The indicators present a range as the significance of impacts will depend on the level of standard set. It is challenging to precisely define the level at which the indicator score would change. That said, based on the modelling and wider evidence gathering, expert judgement suggests that: moderate impacts with a 50-45 ug/m^3 standard, and the highest scoring associated with a 45 ug/m^3 standard.

P3

Intervention area P: EU air quality standards for particulate matter (PM_{10})

Intervention (P3) Introduce average exposure obligations and reduction targets

The problem: Health outcome shortcomings: Exceedances above health guidelines and negative health impacts persist

Description: Introduce average exposure concentration obligations and reduction targets for PM_{10}. Variants for this intervention are based on different initial concentrations (µg/m^3) and look at whether the reduction targets should be based on annual or daily exposure, and whether they should be set at a regional or national level. In particular, the following mechanisms are under review:

- ECO Exposure concentration obligation – i.e. ‘based an average level determined on the basis of measurements at urban background locations, reflects population exposure – and to be attained over a given period’;
- (N)ERT (National) exposure reduction target – i.e. ‘a percentage reduction of the average exposure to be attained where possible over a given period’.

The WHO air quality guidelines include targets for PM_{10} based on concentration values rather than exposure reduction targets. Current provisions in the AAQ Directives do not set average exposure obligations or reduction targets for PM_{10}.

Purpose/operational objective: To reduce exposure to harmful levels of air pollution, with reference to best-practice guidance regarding safe levels of exposure. This would reduce exposure to air pollution, therefore reducing negative health impacts.

Who would be impacted and how:

Direct: It is understood that reducing exposure will lead to health benefits in a shorter timeframe than would be achieved with limit values alone. Thus, citizens currently exposed to poor air quality would benefit from this intervention. In particular, citizens residing in urban areas exposed to high concentration values of PM_{10} (primarily from road transport but also from domestic heating). Citizens with existing medical conditions and citizens in vulnerable groups (such as babies, children, the elderly) are at higher risk to exposure and therefore health benefits are expected to be greater for vulnerable groups as a result. Administrative and monitoring costs would fall on competent authorities and are expected to be marginal (for monitoring, it is assumed that no new monitoring stations would be required). Measures to attain the reduction targets are likely to address emissions from road transport and domestic heating, thus compliance costs are expected to impact citizens and businesses manufacturing vehicles. One stakeholder response from a trade association representing vehicle manufacturers refer to evidence showing that further emission reductions of PM from road transport is not feasible based on available technologies (ACEA, 2022).

Indirect: Households, and indirectly businesses will benefit from the reduction in negative health impacts associated with higher levels of air pollution. Road transport abatement measures may have an indirect impact on poorer households if they own older vehicles (abatement measures will likely involve replacing old vehicles with improved models. The impact on vehicle manufacturers will likely result in higher prices of road vehicles which may have an indirect impact on poorer households which are unable to afford the new models.

Risks for implementation:

Implementation will require introducing new legal provisions to those currently in 2008/50/EC.

While the WHO Guideline values do not include exposure reduction targets (meaning there is no scientific reference point on which to base a standard), it is understood that reducing exposure will lead to health benefits.

Indicators											
1. Air Quality	2. Impact on Health	3. Impacts on Ecosystems	4. Climate change links	5. Costs to society	6. Mitigation costs	7. Impacts on Competitiveness	8. Impacts on Sensitive Groups	9. Societal benefits and burden sharing	10. Impacts on Employment	11. Policy synergies	12. Administrative Burden
0 to ++	0 to ++	0 to ++	0 to ++	0 to +	0 to --	0 to +	0 to ++	+ / -	0 to +	0 to ++	0 to --

Assessment

Effectiveness:

Revisions to average exposure obligations will contribute to air quality improvements [Air Quality: 0 to ++], although the extent of improvement will vary according to the level of ambition. The benefit of setting average exposure targets is that it can complement limit values, particularly in cases of non-compliance with limit values as average exposure targets facilitate targeted action mitigate negative health impacts in a shorter timeframe.

Stakeholder responses gathered from the TSS are mixed as regards regional level intervention or national, particularly for annual obligations. Although based on the open text responses, stakeholders have stated a clear preference for local or regional level intervention, rather than national – and indeed, there is emphasis on local (including by air quality zone or agglomeration) rather than regional among responses received.

Introducing average exposure obligations for PM_{10} will facilitate a targeted response to areas with high concentrations of PM_{10} and contribute to the protection of human health in such areas, including citizens with existing medical conditions and citizens in vulnerable groups (such as babies, children, the elderly) [Sensitive groups: 0 to ++]. Given $PM_{2.5}$ is a component of PM_{10}, the health impacts of a stand-alone average exposure indicator for PM_{10} could be similar to that for $PM_{2.5}$, although in practice the additional impact would be lower given an average exposure standard for $PM_{2.5}$ is already in place [Impacts on health: 0 to ++].

There is a question as to whether an average exposure standard for PM_{10} would offer additional value alongside the similar existing standard for $PM_{2.5}$. Both are likely to share similar sources, and hence control strategies. Hence the additional value would increase to the extent that peaks in each are not correlated, and any unique sources driving peaks in PM_{10} can be controlled (i.e. are not from natural sources).

Reduced concentrations of PM_{10} will not directly benefit ecosystems, however, the measures to attain the revised average exposure obligations have co-benefits of reducing NO_2, SO_2, NH_3 and VOC, thus mitigating acidification and eutrophication [Ecosystem impacts: 0 to ++].

Measures to attain the reduction targets are likely to address emissions from road transport and domestic heating, thus the costs are likely to fall on citizens, however the balance of impacts very much depends on implementation [Societal: + / -].

Stakeholder responses gathered from the TSS highlight that reduction targets are not the most effective mechanism (compared to limit values); however, as a complementary mechanism to limit values they are viewed as effective.

In general terms, stakeholders have noted that the criteria for setting a reduction target will be particularly important for ensuring such a mechanism is effective (in terms of identifying which areas are subject to reduction targets). One suggestion repeated by a few stakeholders is to establish a weighting based on population density combined with modelling (thus moving away from determining the average exposure indicators based on monitoring data at a few sites). It is also noted that exposure reduction targets can overemphasise air quality in urban areas over rural areas and that this is not always effective for Member States with high population densities as it offers limited health benefits. To address this, one stakeholder proposes that the average exposure indicator should be based on all monitoring stations, excluding rural background stations only if it is more than 5 km from a residential area. Exposure time is also noted as a key factor that should be considered when setting reduction targets as is the initial baseline concentration against which the targets are set.

Efficiency:

Recognising the variants for this intervention, it is understood that the potential efficiency would scale with level of ambition.

While revisions to average exposure obligations can deliver benefits in terms of protection of human health, the value of benefits is limited (in accordance with the effects of PM_{10} on human health) [Costs to society: 0 to +].

Mitigation costs will be incurred from measures to attain the reduction targets and while costs are dependent on implementation, they will be significant [Mitigation costs: 0 to --]. Measures to attain the reduction targets are likely to address emissions from road transport and domestic heating. Stakeholders generally did not provide responses on the scale of costs, however, where an opinion was provided, there is a split between “high compliance costs” and “low compliance costs”.

The administrative burden is dependent on the number of additional areas of exceedance that require air quality plans as a result of the average exposure indicator. Stakeholder responses gathered from the TSS show that most stakeholders do not hold an opinion on the administrative burden [Administrative burden: 0 to --]. There is potential to reduce the administrative burden by taking more coordinated and centralised action in each Member State in response to exposure targets. For example, only one air quality plan may be needed, rather than multiple at regional or local level.

A small positive impact on employment [0 to +] and competitiveness [0 to +] is expected as a result of the abatement measures adopted to attain the targets.

Coherence:

Revisions to the average exposure obligations would facilitate the improvement of air quality by reducing concentrations of PM_{10}. This is aligned with wider policy objectives to achieve zero pollution [Policy synergies: 0 to ++]. The intervention is also expected to contribute to climate changes policies as measures to abate PM will also reduce GHG emissions, and BC [Climate change links: 0 to ++].

Links to other interventions: [synergies / misalignment]

- P1/P2 - achieving one standard for PM_{10} will contribute towards achieving other standards.
- O1/O2/O3/Q1/Q2/Q3 - achieving standards for PM_{10}, will contribute to achieving standards for other air pollutants, in particular $PM_{2.5}$ and NO_2.
- Links to B3 and if exposure indicator introduced and type.

Benefit-to-cost ratio: The benefit-to-cost ratio would be medium-low:

- The revised reduction obligations is expected to deliver health benefits particularly benefitting sensitive groups. The extent to which it contributes to air quality improvements is dependent on the level of ambition. A benefit of setting average exposure targets is that it can complement limit values, particularly in cases of non-compliance with limit values as average exposure targets

facilitate targeted action mitigate negative health impacts in a shorter timeframe. Benefits to ecosystems will occur as a co-benefit of the measures implemented to attain the reduction targets.
- Costs are significant, arising primarily from measures to attain the reduction targets and administrative burden. There is potential to reduce the administrative burden by taking more coordinated and centralised action.

Summary: The impact on air quality will vary with ambition and benefits only become significant with medium to high levels of ambition. Stakeholder responses gathered from the TSS highlight that reduction targets alone are not the most effective mechanism (compared to limit values), however, as a complementary mechanism to limit values they are viewed as effective.

While the introduction of reduction obligations is expected to deliver health benefits particularly benefit sensitive groups, the significance of the health benefits is limited compared to $PM_{2.5}$ based on baseline health impacts associated with PM_{10}. Compliance costs have the potential to be significant although the measures to attain the reduction targets (and their associated costs) are generally accepted by stakeholders.

As with O2, given this intervention involves introducing a new standard, there is a question as to whether an average exposure standard for PM_{10} would offer additional value alongside the similar existing standard for $PM_{2.5}$. Both are likely to share similar sources, and hence control strategies. Hence the additional value would increase to the extent that peaks in each are not correlated, and any unique sources driving peaks in PM_{10} can be controlled (i.e. are not from natural sources).

Q1

Intervention area Q: EU air quality standards for nitrogen dioxide (NO_2)

Intervention (Q1) Revise long-term (annual) air quality standards

The problem: ***Health Outcome Shortcoming:*** EU standards are not fully aligned with scientific advice.
Driver: Exceedances of air pollutant concentrations above health guidelines and negative health impacts persist.

Description: The current EU AAQ Directives standards for annual NO_2 sets an annual average limit value of 40 $\mu g/m^3$. The WHO guideline is set at 10 $\mu g/m^3$, alongside higher interim targets. This intervention explores the alignment of the EU long-term standard limit values for NO_2 with the WHO's 2021 Global Air Quality Guidelines (AQGs) updated limit values.

Variants of the intervention consider different levels at which the standard can be set below the existing EU standard: any numerical standard could be selected. Variants can also change the timeframe over which a standard should be achieved.

Purpose/operational objective: More closely aligns EU air quality standards with latest scientific knowledge and recommendations of WHO. This would reduce exposure to air pollution, therefore reducing negative health impacts.

Who would be impacted and how:

Direct: Should a lower standard be implemented, this will lead to an increase in the number of sites and zones in exceedance. As such, ***public authorities*** will be required to develop and implement new (and revise existing) AQ Plans in order to put in place a strategy to meet these new requirements. These plans will also require ongoing review and management.

Indirect: The AQ Plans will identify suitable strategies to bring air pollutant concentrations in line with standards. These strategies may imply costs for ***households, businesses and industry*** in order to change behavior to abate air pollutant emissions or influence concentrations. These costs may also have a knock-on impact to the wider economy in terms of employment or on business activity through supply chains. ***Households, and indirectly businesses*** will benefit from the reduction in negative health impacts associated with higher levels of air pollution.

Risks for implementation:

There are delivery risks around meeting more stringent standards in the short-term: i.e. it takes time to identify exceedances, put AQ plans in place and roll out mitigation techniques to achieve emissions and concentration reductions, and the size of the challenge will likely increase with ambition.

Setting standards on the basis of a single value to be achieved everywhere will not drive continual improvement where such standards are already met (links to Q3 and B3 which consider average exposure targets).

Stakeholders (MS EG) also noted that having many different types of standards for a single pollutant (link to Q2 and Q3) increases the complexity for policy makers in terms of designing a response, and also communicating these standards to stakeholders (link to Intervention Area F).

Indicators

1. Air Quality	2. Impact on Health	3. Impacts on Ecosystems	4. Climate change links	5. Costs to society	6. Mitigation costs	7. Impacts on Competitiveness	8. Impacts on Sensitive Groups	9. Societal benefits and burden sharing	10. Impacts on Employment	11. Policy synergies	12. Administrative Burden
0 to +++	0 to ++	0 to +++	0 to +	0 to ++	0 to --	0 to +	0 to +	+ / -	0 to +	0 to ++	0 to ---

Assessment

Effectiveness:

The impacts and effectiveness of the intervention to resolve the problem will scale with the ambition of the standard.

As of 2019[86], 22 reporting countries, of which 18 were EU Member States, registered concentrations above the EU annual limit value of 40 µg/m³. All the reporting countries registered concentrations above the WHO AGQ of 10 µg/m³. 4% of the EU urban population are exposed to air pollutant concentrations above the existing EU standard, relative to 94% above the WHO AQG, whilst 6% of monitoring stations registered concentrations above EU annual limit value, relative to 79% above the WHO AQG. In contrast to particulates, these issues are not concentrated in specific geographic region, but spread across Europe.

In the modelling baseline, further large declines of emissions are expected going forward. In particular, transport (the most important source of NOx) continues to see a reduction in emissions due to the electrification of the fleet and the assumption that deNOx technology works and is enforced. Meanwhile, the relevance of soil NOx emissions increases. This translates into further reductions in the EU population living in areas exceeding the existing EU standard, reducing from around 1.03m in 2020 to 0.11m in 2030, and 0.03m in 2050. However, some people will reside in areas exceeding the WHO AQGs: around 52m people in 2030 and 6m in 2050. Persistent exceedances in 2030 and 2050 are at sites near Mediterranean ports. Hence although the baseline will achieve further reductions in the levels of air pollution the population is exposed to, further effort would be required to achieve the WHO AQGs. Hence this intervention could have a significant impact on Air Quality [0 to +++].

The modelling scenarios did not address meeting NO_2 targets directly. The modelling scenarios offer little further impact: e.g. in 2030, the MTFR scenario would increase the number of people living in areas below the WHO AQG by 14m in 2030, and in 2050 by only 1.4m. Hence in order to achieve compliance with the WHO AQGs, in particular by 2030, would require national, non-technical or local scale measures which are not captured by GAINS.

In terms of stakeholder opinion, there was a strong majority response to the OPC that stakeholders are concerned about the levels of air pollution to which they are exposed, and favour an ambitious change in air quality standards. This result was driven by EU citizens who were the main respondent type to the OPC (66%) and NGOs. However, other stakeholder types were more cautious in terms of ambition, as shown through the TSS. From the TSS it was clear that stakeholders see value in having this standard, and that it should apply as a limit value to all territories, but the response was more mixed around an appropriate level. For 2030, the majority favoured some reduction from the current standard (most selecting 30µg/m³) – this was the case for public authorities, industry and research, with NGOs being slightly more ambitious (split 20 and 10µg/m³). To 2050, a strong overall majority favoured moving in line with the WHO AQG, driven by the majority of NGOs, public authorities and research that responded in this way. Industry remained favouring a less ambitious reduction (30 µg/m³ in 2050).

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[86] EEA AQ report

The health effects across the variants will scale with the level of ambition. The MTFR scenario is estimated to achieve a reduction of 1,300 premature deaths associated with exposure to NO_2 in 2030 (29% reduction), and 100 in 2050 (16% reduction). Health effects associated with air pollution exposure are more typically associated with $PM_{2.5}$ (although this is also partially an artefact of the way in which the underlying epidemiological evidence base associates health impacts with air pollution). As such this intervention could still deliver important health benefits but is scored lower than O1 [Impact on health / Costs to society: 0 to ++].

Ecosystem effects are directly associated with NOx emissions. Hence this intervention will have an important benefit for ecosystems, the significance of which will scale with ambition [Impacts on ecosystems: 0 to +++].

Higher levels of NO_2 tend to be found in areas with a greater proportion of higher income households[87]. As such, further reductions in NO_2 concentrations are anticipated to have a disproportionately positive effect for more advantaged groups, scaling with the overall level of ambition – that said, sensitive groups will still benefit (albeit less so than less disadvantaged groups [Impacts on Sensitive Groups: 0 to +]. In addition, the measures taken to mitigate emissions will carry costs. The distribution of such costs will critically depend on the national or local delivery mechanism. But there is a risk that costs may disproportionately fall on more vulnerable groups where Member States do not mitigate. Again vulnerable groups will benefit from Air Quality improvements, but disproportionately less than less disadvantaged groups [Societal benefits: +/-]

Efficiency:

Costs of mitigation will scale with ambition. It is difficult to extract those costs from the model that are directly associated with the reduction of NOx emissions. Even so, the modelling shows a significant improvement in the baseline as many mitigation options are taken up (e.g. moving to more recent Euro standards for vehicles, and subsequently electrification). Hence these costs of a more ambitious standards to a point will be very small (if not negligible). However, the modelling also shows that the potential for going further based on the mitigation options in GAINS is limited (the MTFR scenario offers limited improvement over the baseline). As such to achieve (more complete) compliance with more ambitious standards will require non-technical, or local measures not contained in GAINS. The costs of which are uncertain. Expert judgement suggests that relatively more disruptive measures taken at a local level may carry a higher cost for resolving an individual exceedance, but the overall cost will also depend on the number of remaining exceedances, which appear fewer than for $PM_{2.5}$ hence this intervention is scored lower than O1 [Mitigation costs: 0 to --].

Administrative burden will also scale with ambition. The more ambitious the standard, the more new zones or sites will be identified as in exceedance. Public authorities will need to develop new, or amend existing, AQ Plans to define and implement a strategy to handle each new exceedance. It appears fewer areas remain in exceedance, hence this intervention scores lower than O1. However, given the costs of AQ Plans, even low ambition could deliver high administrative burden (relative to all interventions) [Administrative burden: 0 to ---].

Both the costs of mitigation measures, and the health benefits, could have a broader knock-on impact for the EU economy as costs (and benefits) filter through supply chains and into business decision making. No modelling has been undertaken focusing on the achievement of NO_2 standards directly. Both mitigation costs and health benefits are both likely to be lower than O1, but expert judgement assumes that a small net positive impact could also accrue for NO_2 as modelled for $PM_{2.5}$ [Impacts on competitiveness, impacts on employment: 0 to +].

Coherence:

Some of the measures taken to abate NO_2 will also have a complementary impact on GHG emissions, but less so than for particulates as some measures can directly target NOx only (e.g. end-of-pipe techniques in industry).

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[87] EEA report – unequal effects

These effects will scale with the level of ambition set, but this Intervention is scored lower than O1 [Climate change links: 0 to +]. With a lower standard, larger co-benefit reductions in GHG emissions will provide additional synergies with wider EU climate change legislation and targets.

In addition, greater ambition will also lead to greater synergies with the EU's ZPAP. Although the link with human health and indoor air pollution is less strong relative to that for particulates, this intervention will have important synergies for ecosystem effects [Policy synergies: 0 to ++].

Links to other interventions: [synergies / misalignment]

- Q2/Q3 - achieving one standard for NO$_2$ will inherently somewhat work towards achieving other standards (if introduced in the case of Q3).
- Links to B1 and B3 in terms of how standards will be defined, and also Intervention area F in terms of the complexity of having multiple standards for a single pollutant.
- O1/O2/O3 / P1/P2/P3 - achieving standards for NO$_2$ will interact with action to tackle other pollutants (PM$_{2.5}$, and PM$_{10}$).

Benefit to cost ratio:

Benefit to cost ratio will vary with ambition. The mitigation costs of lower standards for NO$_2$ has not been modelled directly, as such contrasting benefits and costs is more uncertain. The baseline will achieve broad compliance with more stringent targets in 2030 and 2050 – hence the additional costs and benefits of these options are both negligible (although in practice a reduction in standard will help reinforce this delivery). Increasing ambition above the baseline will require the uptake of measures not captured in GAINS, and hence for which the costs are uncertain. However, expert judgement would suggest that costs of localised activity may be more disruptive and imply a higher cost (albeit at a local level). In addition, the health benefits of action targeting NO$_2$ concentrations may be smaller (assuming there are no co-benefits by way of particulate or GHG emission reductions). **High.**

Summary:

Stakeholders firmly recognise the value of an annual-average standard for NO$_2$, applying as a limit value to all territory. Furthermore, stakeholders also show a general appetite for some improvement, but opinion varies on what level of ambition is appropriate by when. The majority of stakeholders feel alignment with the WHO AQGs would not be appropriate by 2030, but most feel a target in the range from 20-30 µg/m^3 would be achievable, with full alignment to 2050. As optimisation for NO$_2$ standards have not been modelled explicitly makes it more difficult to make a judgement as to the balance of costs and benefits. That said, the modelling does show that there should be broad alignment with a 20 µg/m^3 standard by 2030, and with the WHO AQG by 2050, with only a small number of people which remain exposed to concentrations above these levels (around 4m and 6m respectively). To achieve full compliance (and indeed to go beyond these levels in 2030) will require the uptake of local measures outside the scope of GAINS, the costs of which are uncertain and could be higher at a local level.

The indicators present a range as the significance of impacts will depend on the level of standard set. It is challenging to precisely define the level at which the indicator score would change. That said, based on the modelling and wider evidence gathering, expert judgement suggests that: low (non-zero) impacts could be associated with a 30 ug/m^3 standard, moderate impacts with a 20 ug/m^3 standard, and the highest scoring associated with a 10 ug/m^3 standard.

Q2

Intervention area Q: EU air quality standards for nitrogen dioxide (NO_2)

Intervention (Q2) Revise/introduce short-term air quality standards and/or alert/information thresholds

The problem: ***Health Outcome Shortcoming:*** EU standards are not fully aligned with scientific advice.

Driver: Exceedances of air pollutant concentrations above health guidelines and negative health impacts persist.

Description: This intervention explores the alignment of the EU short-term limit values for NO_2 with the WHO's 2021 Global Air Quality Guidelines (AQGs) updated limit values.

The current EU AAQ Directives sets a standard for 1-hour NO_2 at a limit value of 200 µg/m^3. The 2021 WHO AQG publication did not include a 1-hour limit for NO_2, although its 2000 Guidelines[88] included a 1-hour Guideline which is consistent with the EU standard.

The WHO AQGs set a standard for 24-hour NO_2 at a limit value of 25 µg/m^3, alongside higher interim targets. No current EU standard for the 24-hour period exists.

Variants of the intervention consider different levels at which the standard can be set below the existing EU standard: any numerical standard could be selected. Variants can also change the timeframe over which a standard should be achieved.

Purpose/operational objective: More closely aligns EU air quality standards with latest scientific knowledge and recommendations of WHO. This would reduce exposure to air pollution, therefore reducing negative health impacts.

Who would be impacted and how:

Direct: Should a lower standard be implemented, this will lead to an increase in the number of sites and zones in exceedance. As such, ***public authorities*** will be required to develop and implement new (and revise existing) AQ Plans in order to put in place a strategy to meet these new requirements. These plans will also require ongoing review and management.

Indirect: The AQ Plans will identify suitable strategies to bring air pollutant concentrations in line with standards. These strategies may imply costs for ***households, businesses and industry*** in order to change behavior to abate air pollutant emissions or influence concentrations. These costs may also have a knock-on impact to the wider economy in terms of employment or on business activity through supply chains.

Households, and indirectly businesses will benefit from the reduction in negative health impacts associated with higher levels of air pollution.

Risks for implementation:

There are delivery risks around meeting more stringent standards in the short-term: i.e. it takes time to identify exceedances, put AQ plans in place and roll out mitigation techniques to achieve emissions and concentration reductions, and the size of the challenge will likely increase with ambition.

Setting standards on the basis of a single value to be achieved everywhere will not drive continual improvement where such standards are already met (links to Q3 and B3 which consider average exposure targets).

Stakeholders (MS EG) also noted that having many different types of standards for a single pollutant (link to Q1 and Q3) increases the complexity for policy makers in terms of designing a response, and also communicating these standards to stakeholders (link to Intervention Area F).

Indicators

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[88] https://www.euro.who.int/__data/assets/pdf_file/0013/123052/AQG2ndEd_3summary.pdf

1. Air Quality	2. Impact on Health	3. Impacts on Ecosystems	4. Climate change links	5. Costs to society	6. Mitigation costs	7. Impacts on Competitiveness	8. Impacts on Sensitive Groups	9. Societal benefits and burden sharing	10. Impacts on Employment	11. Policy synergies	12. Administrative Burden
0 to +++	0 to +	0 to ++	0 to +	0 to +	0 to ---	+ / -	0 to +	+ / -	0	0 to ++	0 to ---

Assessment

Effectiveness:

The impacts and effectiveness of the intervention to resolve the problem will scale with the ambition of the standard.

Reporting data is available for NO_2 over a ***1-hourly average period***. The EU standard for NO_2 can be exceeded 18 times a year. Based on the maximum 19th value:

- Across 2,641 monitoring sites in the EU27, 0% exceed the existing EU 1-hour standard (and 9% exceeded a lower 120 µg/m^3 level) in 2019.

Hence it appears there is current broad compliance with the existing EU 1-hour standard, but more effort would be required should the standard be reduced.

Reporting data is available for NO_2 over a ***24-hourly average period***. The level of compliance with any new standard will depend on the number of exceeance days allowed per annum. The WHO AQG is defined on the basis of the 99th percentile, whereas the existing EU 24-hour standard for PM_{10} for example is defined on the 90.4th percentile. For illustration:

- Based on the 99th percentile: across 2,941 monitoring sites in the EU27, 83% exceeded the WHO AQG in 2019 (and 37% exceeded a higher 50 µg/m^3 standard)
- Based on the 50th percentile: across 2,941 monitoring sites in the EU27, 26% exceeded the WHO AQG in 2019 (and 1% exceeded a higher 50 µg/m^3 standard).

Hence it appears there is currently broad exceedance of the WHO AQG. Furthermore, even where a larger number of exceedance days are allowed, comparing the distribution of results between NO_2 and PM_{10}, it appears that there are likely to be more exceedances of NO_2 relative to a 90.4th percentile relative to PM_{10}. Hence a standard could deliver significant improvements in Air Quality [0 to +++].

The detailed modelling only produces outputs in terms of annual average pollutant concentrations, as such no conclusions can be directly drawn from the analysis regarding compliance with short-term standards in the baseline going forward, nor under the abatement scenarios. That said, the significant, additional emissions reductions observed under the baseline will also drive an improvement in performance relative to a short-term standards, likewise the additional abatement taken up under the mitigation scenarios at additional cost. Assuming the statistical relationship between annual and daily concentrations holds, this suggests a daily limit 3x above the annual (99th percentile).

Stakeholders generally see value in this intervention. In response to the TSS, 67% of stakeholders (majority of all groups except industry) believed there was a need for EU standards to regulate peak NO_2 concentrations.

For a ***1-hour standard***, when asked, more respondents opted to select a numerical standard than not, and suggested this should apply as a limit value to all territory (except for industry that noted it should apply only in selected locations). There was also some alignment regarding the appropriate level for 2030: The majority of all stakeholder types considered remaining at the existing 200 µg/m^3 level appropriate. For 2050, the response was more mixed, with stakeholders fairly evenly split between remaining at the existing 200 µg/m^3 limit or increasing ambition (in the case of the survey to 120 µg/m^3).

For a ***24-hour standard***, opition was more mixed as to whether a standard is required (potentially due to the existence of the existing 1-hour standard). When asked, only half of respondents selected a numerical value, but only 13% selected directly that no standard is required (with the remaining offering no opinion or no reply). For those that selected a standard, the majority considered this should be a limit value applying to all terriroty (With the exception of industry who felt this should apply only at selected locations). In terms of the level, the majority of public authorities and reserach opted for 50 µg/m^3 as the appropriate level for 2030, with NGO's split between 50µg/m^3 and alignment with the WHO AQGs (majoirty of industry selected 'no standard'). To 2050, a greater number of respondents selected a standard, with the majority of public authorities, Ngos and research opting for full alignment with the WHO AQGs (industry selected 120 µg/m^3).

The most significant health effects are typically associated with chronic exposure to $PM_{2.5}$, rather than acute expsoure to NO_2. As such this intervention is scored lower than O1 [Health impacts, value of benefits: 0 to +]. However, health effects are also associated with short-term exposure to NO_2 but typically not quantified due to concerns around overlaps with more significant chronic effects[89]. Indeed, the HRAPIE study identified a mortality RR for short-term exposure to NO_2, and the WHO AQGs define a separate standard for NO_2 peak concentrations.

In its 2021 AQGs, the 24-hour AQG level of 25 µg/m^3 was introduced as a new standard. The 2005 1-hour AQG level of 200 µg/m^3 was not re-evaluated but was reaffirmed as remaining valid. The WHO also points out that in most practical circumstances, the 24-hour AQG level is more stringent than the 2005 1-hour AQG level, and in its Guidance equates the 1-hour 200 µg/m^3 Guideline with the 24-hour 120 µg/m^3 interim target.

Ecosystem effects are directly associated with NOx emissions. Hence this intervention will have an important benefit for ecossytems, the significance of which will scale with ambition. But the effect of a peak target (in particular in addition to an annual average standard) is anticipated to be lower than Q1 [Impacts on ecosystems: 0 to ++].

Higher levels of NO_2 tend to be found in areas with a greater proportion of higher income households[90]. As such, further reductions in NO_2 concentrations are anticipated to have a disproportionately positive effect for more advantaged groups, scaling with the overall level of ambition – that said, sensitive groups will still benefit (albeit less so than less disadvantaged groups [Impacts on Sensitive Groups: 0 to +]. In addition, the measures taken to mitigate emissions will carry costs. The distribution of such costs will critically depend on the national or local delivery mechanism. But there is a risk that costs may disproportionately fall on more vulnerable groups where Member States do not mitigate. Again vulnerable groups will benefit from Air Quality improvements, but disproportionately less than less disadvantaged groups [Societal benefits: +/-]

Efficiency:

The mitigation costs will increase with the level of ambition, and will depend on the action taken. Short-term standards have not been modelled, as such the costs of mitigation actions are more uncertain. Expert judgement suggests many of the actions taken to mitigate peak concentrations will be the same as those to tackle annual average concentrations – so the costs will at least be the same. In addition, some measures to specifically limit short-term concentrations might carry more significant costs and subsequent macroeconomic effects - e.g. where vehicle movements are limited or fossil fuel burning restricted at short notice – however, if short term standards are set on the basis of correlation with annual average standards, the costs and competitiveness effects are likely to be similar [Mitigation costs: 0 to ---; Competitiveness + / -]. However, given the short-term nature of such actions, expert judgement suggests any long-term impact on employment is likely to be negligible [Employment: 0].

Administrative burden will also scale with ambition. The more ambitious the standard, the more new zones or sites will be identified as in exceedance. Public authorities will need to develop new, or amend existing, AQ Plans

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[89] WHO HRAPIE

[90] EEA report – unequal effects

to define and implement a strategy to handle each new exceedance. However, given the costs of AQ Plans, even low ambition could deliver high administrative burden (relative to all interventions) [Administrative burden: 0 to ---].

For a ***24-hour standard,*** the majority of stakeholders (TSS) agreed that a new standard would carry both a high compliance and administrative cost.

Coherence:

With a lower standard, larger co-benefit reductions in GHG emissions will provide additional synergies with wider EU climate change legislation and targets. Some of the measures taken to abate NO_2 will also have a complementary impact on GHG emissions, but less so than for particulates as some measures can directly target NOx only (e.g. end-of-pipe techniques in industry). These effects will scale with the level of ambition set, but this Intervention is scored lower than O1 [Climate change links: 0 to +].

In addition, greater ambition will also lead to greater synergies with the EU's ZPAP. Although the link with human health and indoor air pollution is less strong relative to that for particulates, this intervention will have important synergies for ecosystem effects [Policy synergies: 0 to ++].

Links to other interventions: [synergies / misalignment]

- Q1/Q3 - achieving one standard for NO_2 will inherently somewhat work towards achieving other standards (if introduced in the case of Q3).
- Links to B1 and B3 in terms of how standards will be defined, and also Intervention area F in terms of the complexity of having multiple standards for a single pollutant.
- O1/O2/O3 / P1/P2/P3 - achieving standards for NO_2 will interact with action to tackle other pollutants ($PM_{2.5}$, and PM_{10}).

Benefit to cost ratio:

Benefit to cost ratio will vary with ambition. Short-term standards are not modelled explicitly, and hence judgements regarding the balance of costs and benefits is more uncertain. Where there is a risk of exceedance, public authorities will need to put new plans in place to manage these risks. In addition, short-term compliance measures to tackle peak concentrations specifically may be more disruptive in nature (albeit for a short-time). With respect to benefits, greater health effects are typically associated with chronic exposure and $PM_{2.5}$ (in HIA), but where the risk of peaks is high and considering this intervention in isolation, the benefits would be much more significant. **High.**

Summary:

The intervention considers both the revision of an existing standard (1-hour) and the potential introduction of a new (24-hour) standard. In isolation, there is a strong case for a standard managing NO_2 peak concentrations.

In the context of other interventions around NO_2 (Q1 and Q3), a more crucial question is what additional value one or more peak standards for NO_2 would deliver, in particular given the risk of complexity for public authorities and citizens. It appears that there is merit in having a standard to manage peak alongside annual average concentrations – this is underlined by stakeholders and the advice of the WHO, who explore that even a small number of extreme peaks could have a significant impact. However, the effectiveness of a peak concentration as a safety net (and indeed its additional value over an annual standard) decreases with the number of allowed exceedance days per year.

In addition, there is a question as to whether a 1-hour or 24-hour peak standard, or both together, would offer the most effective solution. Both are likely to share similar sources, and hence control strategies. Although the WHO note their 1-hour Guideline from 2000 remains valid, in 2021 the WHO introduced the new 24-hour AQG and conflated the existing 1-hour Guideline with a higher, interim 24-hour target. In addition stakeholders were less positive about introducing a new 24-hour EU standard, in the context of an existing 1-hour standard. However, the additional burden of a further standard is low given no new monitoring is required. In addition, the WHO noted their 1-hour Guideline from 2000 remains valid whilst introducing the new 24-hour AQG. Indeed, the WHO conflated the existing 1-hour Guideline with a higher, interim 24-hour target, and as such, the additional gradated steps offered by the 24-hour interim targets and guideline provide the opportunity to increase ambition.

The benefit-to-cost ratio of either standard will vary with the level of ambition. Short-term standards have not been considered in the modelling, so it is challenging to fully assess the impacts with any certainty. In 2019, there is broad compliance with the existing 1-hour EU standard, but broad exceedance of the WHO 24-hour AQG, although this does not account for further anticipated reductions in emissions in the baseline to 2030 and 2050. Such an intervention would carry potentially high costs and administrative burden where exceedances occur, but where the risk of peaks is high, the benefits would be much more significant.

The indicators present a range as the significance of impacts will depend on the level of standard set. It is challenging to precisely define the level at which the indicator score would change. That said, based on the modelling and wider evidence gathering, expert judgement suggests that: moderate impacts with an hourly 40 ug/m^3 standard, and the highest scoring associated with an hourly 25 ug/m^3 standard.

Q3

Intervention area Q: EU air quality standards for nitrogen dioxide (NO_2)

Intervention (Q3) Introduce average exposure obligations and reduction targets

The problem: Health outcome shortcomings: Exceedances above health guidelines and negative health impacts persist

Description: Introduce average exposure concentration obligations and reduction targets for NO_2. Variants for this intervention are based on different initial concentrations (µg/m^3) and look at whether the reduction targets should be based on annual or daily exposure, and whether they should be set at a regional or national level. In particular, the following mechanisms are under review:

- ECO Exposure concentration obligation – i.e. 'based an average level determined on the basis of measurements at urban background locations, reflects population exposure – and to be attained over a given period';
- (N)ERT (National) exposure reduction target – i.e. 'a percentage reduction of the average exposure to be attained where possible over a given period'.

The WHO air quality guidelines include targets for NO_2 based on concentration values rather than exposure reduction targets. Current provisions in the AAQ Directives do not set average exposure obligations or reduction targets for NO_2.

Purpose/operational objective: To reduce exposure to harmful levels of air pollution, with reference to best-practice guidance regarding safe levels of exposure. This would reduce exposure to air pollution, therefore reducing negative health impacts.

Who would be impacted and how:

Direct: It is understood that reducing exposure will lead to health benefits in a shorter timeframe than would be achieved with limit values alone. Thus citizens currently exposed to poor air quality would benefit from this intervention. In particular, citizens residing in urban areas exposed to high concentration values of NO_2 (from road transport). Administrative and monitoring costs would fall on competent authorities and are expected to be marginal (for monitoring, it is assumed that no new monitoring stations would be required). Measures to attain the reduction targets are likely to address emissions from road transport, thus compliance costs are expected to impact businesses manufacturing vehicles. Stakeholder responses from trade associations representing vehicle manufacturers refer to evidence to showing that further emission reductions from road transport is not feasible based on available technologies.

Indirect: Households, and indirectly businesses will benefit from the reduction in negative health impacts associated with higher levels of air pollution.

Risks for implementation: Implementation will require introducing new legal provisions to those currently in 2008/50/EC. While the WHO Guideline values do not include exposure reduction targets (meaning there is no scientific reference point on which to base a standard), it is understood that reducing exposure will lead to health benefits.

Indicators

1. Air Quality	2. Impact on Health	3. Impacts on Ecosystems	4. Climate change links	5. Costs to society	6. Mitigation costs	7. Impacts on Competitiveness	8. Impacts on Sensitive Groups	9. Societal benefits and burden sharing	10. Impacts on Employment	11. Policy synergies	12. Administrative Burden
0 to ++	0 to +	0 to ++	0 to +	0 to +	0 to --	0 to +	0 to +	+ / -	0 to +	0 to +	0 to --

Assessment

Effectiveness:

Revisions to average exposure obligations will contribute to air quality improvements [Air Quality: 0 to ++], although the extent of improvement will vary according to the level of ambition. The effectiveness of this intervention should reflect the additional value it can add over and above existing standards. Given NO_2 is less so a 'regional' pollutant than PM, and is more concentrated at hotspots, this reduces the additional value that Q3 could deliver over and above a limit value applying everything (Q1).

Reduced concentrations of NO_2 will directly benefit ecosystems, thus mitigating acidification and eutrophication [Ecosystem impacts: 0 to ++]. The significance of the health benefits is limited compared to $PM_{2.5}$ based on baseline health impacts associated with NO_2 [Health impacts: 0 to +].

Higher levels of NO_2 tend to be found in areas with a greater proportion of higher income households[91]. As such, further reductions in NO_2 concentrations are anticipated to have a disproportionately positive effect for more advantaged groups, scaling with the overall level of ambition – that said, sensitive groups will still benefit (albeit less so than less disadvantaged groups [Impacts on Sensitive Groups: 0 to +]. In addition, the measures taken to mitigate emissions will carry costs. The distribution of such costs will critically depend on the national or local delivery mechanism. But there is a risk that costs may disproportionately fall on more vulnerable groups where Member States do not mitigate. Again vulnerable groups will benefit from Air Quality improvements, but disproportionately less than less disadvantaged groups [Societal benefits: +/-]. There is an important link here between this average exposure measure and limit values for NO_2 (interventions Q1 and Q2) – given the average inverse correlation between size of benefits and disadvantage across different groups (i.e. more advantaged groups tend to benefit more), where an average exposure indicator for NO_2 is not combined with limit values which apply everywhere, this may emphasize the risk that the greatest benefits will indeed accrue to the most advantaged groups. I.e. should an average indicator be put in place, limit values are more critical for NO_2 to ensure that reductions occur at all hotspots.

Stakeholder responses gathered from the TSS highlight that reduction targets are not the most effective mechanism (compared to limit values); however, as a complementary mechanism to limit values they are viewed as effective.

In general terms, stakeholders have noted that the criteria for setting a reduction target will be particularly important for ensuring such a mechanism is effective (in terms of identifying which areas are subject to reduction targets). One suggestion repeated by a few stakeholders is to establish a weighting based on population density combined with modelling (thus moving away from determining the average exposure indicators based on monitoring data at a few sites). It is also noted that exposure reduction targets can overemphasise air quality in urban areas over rural areas and that this is not always effective for Member States with high population densities as it offers limited health benefits. To address this, one stakeholder proposes that the average exposure indicator should be based on all monitoring stations, excluding rural background stations only if it is more than 5 km from a residential area. Exposure time is also noted as a key

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[91] EEA report – unequal effects

factor that should be considered when setting reduction targets as is the initial baseline concentration against which the targets are set.

Efficiency:

Recognising the variants for this intervention, it is understood that the potential efficiency would scale with level of ambition.

While revisions to average exposure obligations can deliver benefits in terms of protection of human health, the significance of the health benefits is limited compared to $PM_{2.5}$ based on baseline health impacts associated with NO_2 [Costs to society: 0 to +].

Mitigation costs will be incurred from measures to attain the reduction targets and while costs are dependent on implementation, they will be significant [Mitigation costs: 0 to --]. Measures to attain the reduction targets are likely to address emissions from road transport. Stakeholders generally did not provide responses on the scale of costs, however, where an opinion was provided, there is a split between “high compliance costs” and “low compliance costs”.

The administrative burden is dependent on the number of additional areas of exceedance that require air quality plans as a result of the average exposure indicator [Administrative burden: 0 to --], while stakeholder responses gathered from the TSS show that most stakeholders do not hold an opinion on the administrative burden. There is potential to reduce the administrative burden by taking more coordinated and centralised action in each Member State in response to exposure targets. For example, only one air quality plan may be needed, rather than multiple at regional or local level.

A small positive impact on employment [0 to +] and competitiveness [0 to +] is expected as a result of the abatement measures adopted to attain the targets.

Coherence:

Revisions to the average exposure obligations would facilitate the improvement of air quality by reducing concentrations of NO_2. This is aligned with wider policy objectives to achieve zero pollution [Policy synergies: 0 to +]. The intervention is also expected to contribute to climate changes policies as measures to abate NO_2 from road transport will also reduce GHG emissions (although less so than abatement measures for PM) [Climate change links: 0 to +].

Links to other interventions: [synergies / misalignment]

- Q1/Q2- achieving one standard for NO_2 will inherently somewhat work towards achieving other standards.
- P1/P2/P3/ O1/O2/O3 - achieving standards for NO_2, will also somewhat help to contribute to achieving standards for other air pollutants, in particular $PM_{2.5}$ and PM_{10}. There is an interaction with intervention O3 (and P3) where NO2 is a precursor or PM2.5 , thus to a certain extent O3 is expected to drive similar action to reduce NO2 concentrations in a step-wise fashion.
- Links to B3 and if exposure indicator introduced and type.

Benefit-to-cost ratio: The benefit-to-cost ratio would be medium:

- The extent to which it contribute to air quality improvements and ecosystems are dependent on the level of ambition. Given NO_2 is less so a ‘regional’ pollutant than PM, and is more concentrated at hotspots, this reduces the additional value that Q3 could deliver over and above a limit value applying everything (Q1).
- Costs are significant, arising primarily from measures to attain the reduction targets and administrative burden. There is potential to reduce the administrative burden by taking more coordinated and centralised action.

Summary: The impact on air quality and ecosystems will vary with ambition and benefits only become significant with medium to high levels of ambition. Stakeholder responses gathered from the TSS highlight that reduction targets are not the most effective mechanism (compared to limit values); however, as a complementary mechanism to limit values they are viewed as effective.

As for P3, given this intervention considers the introduction of a new standard, a key question is what additional value this will add over and above existing standards. As for P3, given NO_2 is a precursor or $PM_{2.5}$, to a certain extent O3 will also drive similar action to reduce NO_2 concentrations in a step-wise fashion. Furthermore, given NO_2 is less so a 'regional' pollutant than PM, and is more concentrated at hotspots, this reduces the additional value that Q3 could deliver over and above a limit value applying everything (Q1).

This question is particularly pertinent given compliance costs and administrative burdens have the potential to be significant.

R1

Intervention area R: EU air quality standards for ozone (O_3)

Intervention (R1) Revise long-term (peak-season) air quality standards

The problem: *Health Outcome Shortcoming:* EU standards are not fully aligned with scientific advice.

Driver: Exceedances of air pollutant concentrations above health guidelines and negative health impacts persist.

Description: This intervention explores the revision of the EU long-term standard for O_3.

The current EU AAQ Directives has a long-term ozone standard aimed at the protection of vegetation. This target value is defined in terms as of AOT40 (calculated from 1 hour values), over a May to July averaging period, at 18,000 µg/m^3 over 5-year average. These is no current EU standard for long-term ozone targeting protection of human health.

The WHO AQG sets a peak season recommendation for average daily maximum 8-hour mean O_3 concentrations of 60 µg/m^3, in the six consecutive months with the highest six-month running-average O_3 concentration.

Variants of the intervention consider different levels at which the standard can be set below the existing EU standard: any numerical standard could be selected. Variants can also change the timeframe over which a standard should be achieved, and the type of standard to be set.

Purpose/operational objective: More closely aligns EU air quality standards with latest scientific knowledge. This would reduce exposure to air pollution, therefore reducing negative health impacts.

Who would be impacted and how:

Direct: Should a lower standard be implemented, this will lead to an increase in the number of sites and zones in exceedance. As such, ***public authorities*** will be required to develop and implement new (and revise existing) AQ Plans in order to put in place a strategy to meet these new requirements. These plans will also require ongoing review and management.

Indirect: The AQ Plans will identify suitable strategies to bring air pollutant concentrations in line with standards. These strategies may imply costs for ***households and businesses*** in order to change behavior to abate air pollutant emissions or influence concentrations. These costs may also have a knock-on impact to the wider economy in terms of employment or on business activity through supply chains.

Households, and indirectly businesses will benefit from the reduction in negative health impacts associated with higher levels of air pollution.

Risks for implementation:

Delivery risks around meeting more stringent standards in the short-term: i.e. it takes time to identify exceedances, put AQ plans in place and roll out mitigation techniques.

Setting single value standards will not incentivise continual improvement where such standards are already met.

Furthermore, this may also drive action in areas of lower priority, where the population are not exposed.

Complexity risk of having many different standards for a single pollutant (Stakeholders (MS EG)).

Indicators

1. Air Quality	2. Impact on Health	3. Impacts on Ecosystems	4. Climate change links	5. Costs to society	6. Mitigation costs	7. Impacts on Competitiveness	8. Impacts on Sensitive Groups	9. Societal benefits and burden sharing	10. Impacts on Employment	11. Policy synergies	12. Administrative Burden
0 to +++	0 to +	0 to +++	0 to +	0 to +	0 to ---	0 to -	0 to +	+ / -	0	0 to +	0 to ---

Assessment

Effectiveness:

Ground-level (tropospheric) ozone is not directly emitted into the atmosphere. Instead, it forms in the atmosphere from a chain of chemical reactions following emissions of certain precursor gases: NOX, carbon monoxide (CO) and NMVOCs and methane (CH4)[92]. Emissions of these gases are anthropogenic and, in the case of VOCs, also biogenic. Ozone also enters Europe from other parts of the northern hemisphere and from the upper atmosphere. Meteorology plays an important role in the formation and interannual variation of air pollutant concentrations, and this effect is especially significant for ozone. The highest concentrations were found in southern parts of Europe during spring and summer, when the meteorological conditions favour ozone formation.

The effectiveness of the intervention will scale with ambition.

Monitoring data for 2019 across the EU27 reports that:

- Of 1516 sites, 50% exceeded the EU standard target value for protection of vegetation. This coincides with EEA reporting that in 2019, the fraction of land exposed to levels of ozone exceeding the threshold decreased by about 8 percentage points, compared with 2018, to 37%, amounting to a total area of 870 million km2 being exposed to levels above the air quality threshold. Ozone exposure values in 2019 were lower in northern countries and in central Europe than they were in 2018[93].
- Of 1768 sites, 99% exceeded the WHO AQG for peak season ozone. 25% exceeded the highest Interim Target (100 µg/m^3).

Given high levels of existing exceedance, the Air Quality benefit of this measure is strongly positive [0 to +++].

Through the TSS, stakeholders highlighted the need for this intervention, with the majority of respondents agreeing that there is a need for an air quality standard to regulate annual/seasonal ozone concentrations. However, there was a mix of views as to what an appropriate standard should be. Respondents were asked to provide views on a seasonal standard in line with the WHO AQG and there was no clear response that such a standard would deliver additional value, in particular over and above the existing long-term standard for protection of vegetation.

To 2030, only a (large) minority of respondents selected a numerical value – the number selecting ‘no standard’ was almost as great as that selecting any individual numerical value, and overall the majority of respondents selected either ‘no standard’, ‘no opinion’ or ‘no reply’. Where a standard does exist, the majority of stakeholders suggested such a standard should apply to all territory (with the exception of industry respondents who suggested this should only apply at selected locations). However there was disagreement regarding the type of standard and its level. A small majority favored a limit value standard, but the majority of authorities and research respondents believe a target value is more appropriate.

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[92] https://www.eea.europa.eu/themes/air/air-pollution-sources-1

[93] https://www.eea.europa.eu/ims/exposure-of-europes-ecosystems-to-ozone

Regarding the level, a small majority selected the highest WHO Interim target (100 µg/m^3), but likewise a large minority selected alignment with the WHO AQG.

To 2050, again the majority of stakeholders believed a target should apply to all territory (again with the exception of industry). Again there was a mixed response to the type of standard, in this case a small majority opted for target value as most appropriate. With respect to level, to 2050 a majority opted for alignment with the WHO AQG.

The main health effects associated with chronic air pollutant exposure are linked to $PM_{2.5}$, not O_3. Hence the human health benefits are positive but small [Health impact, costs to society: 0 to +]. But the potential ecosystem effects have the potential to be much more significant [Impacts on ecosystems: 0 to +++] – in 2019, the AAQ Directives long-term objective for the protection of vegetation was met for only about 14% of the total agricultural area of the EEA countries, and the percentage of forests exposed to ozone below the critical level defined in the UNECE CLRTAP (1979) (10,000 µg/m^3.hour) decreased in 2018 to its lowest value (13%) since 2007.

Distributional analysis has not been conducted for concentrations of O_3. As with $PM_{2.5}$, higher levels of O_3 tend to be found in areas with a greater proportion of some vulnerable groups (e.g. lower income, lower educational attainment)[94]. As such, further reductions in O_3 concentrations are anticipated to have a greater positive effect for more disadvantaged groups, scaling with the overall level of ambition, but these effects are less pronounced than for PM [Impacts on Sensitive Groups: 0 to +]. However, the measures taken to mitigate emissions will carry costs. The distribution of such costs will critically depend on the national or local delivery mechanism. But there is a risk that costs may disproportionately fall on more vulnerable groups given their employment in low wage sectors (e.g. agriculture) [Societal benefits and burden sharing: +/-].

Efficiency:

The cost of achieving different standards for O_3 have not been modelled directly so costs are uncertain. Costs will increase with the level of ambition. There was some uncertainty regarding the costs amongst stakeholders (TSS): a small majority noted there could be high additional compliance costs, but a sizeable minority considered there would be no additional cost, but the overwhelming majority gave no opinion or no reply. Reducing ozone concentrations is challenging as it relies on the control of precursors. Given this, and the fact that there are still broad exceedances of the EU and WHO AQG standards suggests the costs of compliance would be high [Mitigation costs 0 to ---].

The administrative burden associated with a new standard would be inherently higher, as this may require new monitoring and plans where exceedances are identified. Again burden would scale with ambition. There is mixed opinion amongst stakeholders (TSS), with broadly equal numbers reporting that such a standard could have no, low or even high additional burdens, although the overwhelming majority gave no opinion or no reply. However, given the costs of AQ Plans, even low ambition could deliver high administrative burden (relative to all interventions) [Administrative burden: 0 to ---].

The macroeconomic effects are uncertain as these have not been modelled directly, but effects on Competitiveness may be small and negative if limited health benefits are limited and the majority of the mitigation costs fall on businesses (e.g. industry and agriculture sectors) [0 to -]. Effects on employment are anticipated to be negligible [0].

Coherence:

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[94] EEA report – unequal effects

Some measures to mitigate O_3 may also influence GHG emissions, for example where these affect methane emissions from agriculture. This, in addition to the potential health benefits, suggest that both Climate Change and Policy Synergy effects are anticipated to be positive, but small [0 to +].

Links to other interventions: [synergies / misalignment]

- R2/R3 – there will be interaction between different ozone standards.
- Q1/ Q2 /Q3 /T1 – there will be interactions with standards that govern ozone's precursors.

Benefit-to-cost ratio:

Given the size of existing levels of exceedance, and the challenges in controlling ozone concentrations, the costs of increasing ambition or switching to a limit value might be significant. Human health benefits tend to be more linked with exposure to other pollutants and hence can be small. Likewise, ecosystem effects typically comprise a lower proportion of the overall benefit of air quality action, relative to human health effects (albeit this is based on an evidence base which has predominantly focused on the valuation of human health effects, for which by extension is more well explored and understood). **High*** (*Controlling ozone concentrations is complex and challenging, as such it is questionable whether very ambitious standards for ozone would be feasible in all locations).

Summary:

There remains a clear need for a standard to regulate seasonal concentrations of ozone. However, it is not clear that an additional ozone standard targeting human health effects of seasonal exposure would deliver additional value over and above the existing target. In particular as there are similarities in the way in which the current EU standard for the protection of vegetation and the WHO AQG for the protection of human health are defined (e.g. they both look at excess concentrations in peak season) and as such would be somewhat correlated.

Controlling ozone concentrations is complex and challenging, and is driven in part by control of precursors but also by the meteorological conditions. As such it is questionable whether very ambitious standards for ozone would be feasible in all locations. This is perhaps underlined by the different of opinion amongst stakeholders as to whether limit or target values would be most appropriate. Furthermore, there is currently broad exceedances of both the existing EU target value and the WHO AQG, as such substantial effort would be required to meet an even stricter target, whereas the benefits of such action (at least in economic impact assessment) often rank below action taken around other pollutants.

R2

Intervention area R: EU air quality standards for ozone (O_3)
Intervention (R2) Revise short-term air quality standards and/or alert/information thresholds
The problem: ***Health Outcome Shortcoming:*** EU standards are not fully aligned with scientific advice. Driver: Exceedances of air pollutant concentrations above health guidelines and negative health impacts persist.
Description: This intervention explores the revision of the EU short-term standard for O_3. The current EU AAQ Directives has a target value for the maximum 8-hour daily mean for ozone of 120 µg/m^3 (with 25 permitted exceedances allowed per annum averaged over 3 years). The WHO AQGs set a recommendation for average daily maximum 8-hour mean O_3 concentrations of 100 µg/m^3 (defined as the 99th percentile). Variants of the intervention consider different levels at which the standard can be set below the existing EU standard: any numerical standard could be selected. Variants can also change the timeframe over which a standard should be achieved, and the type of standard to be set.
Purpose/operational objective: More closely aligns EU air quality standards with latest scientific knowledge. This would reduce exposure to air pollution, therefore reducing negative health impacts.
Who would be impacted and how: ***Direct:*** Should a lower standard be implemented, this will lead to an increase in the number of sites and zones in exceedance. As such, ***public authorities*** will be required to develop and implement new (and revise existing) AQ Plans in order to put in place a strategy to meet these new requirements. These plans will also require ongoing review and management. ***Indirect:*** The AQ Plans will identify suitable strategies to bring air pollutant concentrations in line with standards. These strategies may imply costs for ***households and businesses*** in order to change behavior to abate air pollutant emissions or influence concentrations. These costs may also have a knock-on impact to the wider economy in terms of employment or on business activity through supply chains. ***Households, and indirectly businesses*** will benefit from the reduction in negative health impacts associated with higher levels of air pollution.
Risks for implementation: Delivery risks around meeting more stringent standards in the short-term: i.e. it takes time to identify exceedances, put AQ plans in place and roll out mitigation techniques. Setting single value standards will not incentivise continual improvement where such standards are already met. Furthermore, this may also drive action in areas of lower priority, where the population are not exposed. Complexity risk of having many different standards for a single pollutant (Stakeholders (MS EG)).

Indicators

1. Air Quality	2. Impact on Health	3. Impacts on Ecosystems	4. Climate change links	5. Costs to society	6. Mitigation costs	7. Impacts on Competitiveness	8. Impacts on Sensitive Groups	9. Societal benefits and burden sharing	10. Impacts on Employment	11. Policy synergies	12. Administrative Burden

0 to +++	0 to +	0 to ++	0 to +	0 to +	0 to ---	0 to -	0 to +	+ / -	0	0 to +	0 to ---

Assessment

Effectiveness:

The effectiveness of the intervention will scale with ambition.

Monitoring data for 2019 across the EU27 reports that:

- Of 1826 sites, 31% exceeded the EU standard target value (based on 93.15 percentile).
- Of 1826 sites, 95% exceeded the WHO AQG (based on the 99th percentile).

Given high levels of existing exceedance, the Air Quality benefit of this measure is strongly positive [0 to +++].

The modelling data however suggests that there will be broad compliance with the EU standard by 2030, but still substantial non-compliance with the WHO AQG both under the baseline (585/1778 sites) and MTFR (348/1778 sites).

Through the TSS, stakeholders highlighted the need for this intervention, with the majority of respondents agreeing that there is a need for an air quality standard to regulate peak ozone concentrations. Furthermore, when asked, the majority also selected a numerical standard (rather than 'no standard'). However, there was a mix of views as to what an appropriate standard should be. To 2030, the majority of stakeholders suggested such a standard should apply to all territory (with the exception of industry respondents who suggested this should only apply at selected locations). However there was disagreement regarding the type of standard and its level. A small majority favored a limit value standard, but the majority of authorities and research respondents believe a target value would be more appropriate. Regarding the level, a small majority opted to remain at the existing EU standard, but a large minority believed the WHO AQG would be appropriate (indeed the majority of respondents suggested moving to the WHO AQG would be feasible with 'no significant additional effort'). To 2050, again the majority of stakeholders believed a target should apply to all territory (again with the exception of industry). Again there was a mixed response to the type of standard, in this case a small majority opted for target value as most appropriate. With respect to level, to 2050 a majority opted for alignment with the WHO AQG.

The main health effects associated with chronic air pollutant exposure are linked to $PM_{2.5}$, not O_3. Hence the human health benefits are positive but small [Health impact, costs to society: 0 to +]. But the potential ecosystem effects have the potential to be much more significant, but less so relative to the peak season intervention (R1) which better captures cumulative exposure over the season [Impacts on ecosystems: 0 to ++].

Distributional analysis has not been conducted for concentrations of O_3. As with $PM_{2.5}$, higher levels of O_3 tend to be found in areas with a greater proportion of some vulnerable groups (e.g. lower income, lower educational attainment)[95]. As such, further reductions in O_3 concentrations are anticipated to have a greater positive effect for more disadvantaged groups, scaling with the overall level of ambition, but these effects are less pronounced than for PM [Impacts on Sensitive Groups: 0 to +]. However, the measures taken to mitigate emissions will carry costs. The distribution of such costs will critically depend on the national or local delivery mechanism. But there is a risk that costs may disproportionately fall on more vulnerable groups given their employment in low wage sectors (e.g. agriculture) [Societal benefits and burden sharing: +/-].

Efficiency:

The cost of achieving different standards for O_3 have not been modelled directly so costs are uncertain. Costs will increase with the level of ambition. Reducing ozone concentrations is challenging as it relies on the

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[95] EEA report – unequal effects

control of precursors. Given this, and the fact that there are still broad exceedances of the EU and WHO AQG standards suggests the costs of compliance would be high [Mitigation costs 0 to ---].

Administrative burden will also scale with ambition. The more ambitious the standard, the more new zones or sites will be identified as in exceedance. Public authorities will need to develop new, or amend existing, AQ Plans to define and implement a strategy to handle each new exceedance. However, given the costs of AQ Plans, even low ambition could deliver high administrative burden (relative to all interventions) [Administrative burden: 0 to ---].

The macroeconomic effects are uncertain as these have not been modelled directly, but effects on Competitiveness may be small and negative if limited health benefits are limited and the majority of the mitigation costs fall on businesses (e.g. industry and agriculture sectors) [0 to -]. Impacts on employment are anticipated to be negligible given the potential short-term nature of some actions [0].

Coherence:

Some measures to mitigate O_3 may also influence GHG emissions, for example where these affect methane emissions from agriculture. This, in addition to the potential health benefits, suggest that both Climate Change and Policy Synergy effects are anticipated to be positive, but small [0 to +].

Links to other interventions: [synergies / misalignment]

- R1/R3 – there will be interaction between different ozone standards.
- Q1/ Q2 /Q3 /T1 – there will be interactions with standards that govern ozone’s precursors.

Benefit-to-cost ratio:

Given the size of existing levels of exceedance, and the challenges in controlling ozone concentrations, the costs of increasing ambition or switching to a limit value might be significant. Human health benefits tend to be more linked with exposure to other pollutants and hence can be small. Likewise, ecosystem effects typically comprise a lower proportion of the overall benefit of air quality action, relative to human health effects (albeit this is based on an evidence base which has predominantly focused on the valuation of human health effects, for which by extension is more well explored and understood). **High*** (*Controlling ozone concentrations is complex and challenging, as such it is questionable whether very ambitious standards for ozone would be feasible in all locations)

Summary:

There remains a clear need for a standard to regulate peak concentrations of ozone. However, controlling ozone concentrations is complex and challenging, and is driven in part by control of precursors but also by the meteorological conditions. As such it is questionable whether very ambitious standards for ozone would be feasible in all locations. This is perhaps underlined by the different of opinion amongst stakeholders as to whether limit or target values would be most appropriate. Furthermore, there is currently broad exceedances of both the existing EU target value and the WHO AQG, as such substantial effort would be required to meet an even stricter target, whereas the benefits of such action (at least in economic impact assessment) often rank below action taken around other pollutants.

The indicators present a range as the significance of impacts will depend on the level of standard set. It is challenging to precisely define the level at which the indicator score would change. That said, based on the modelling and wider evidence gathering, expert judgement suggests that: moderate impacts would be associated with a 120-100 ug/m^3 standard, and the highest scoring associated with a 100 ug/m^3 standard.

R3

Intervention area R: EU air quality standards for ozone (O_3)
Intervention (R3) Introduce average exposure obligations and reduction targets
The problem: Health outcome shortcomings: Exceedances above health guidelines and negative health impacts persist
Description: Introduce average exposure concentration obligations and reduction targets for O_3. Variants for this intervention are based on different initial concentrations (µg/m^3) and look at whether the reduction targets should be based on annual or daily exposure, and whether they should be set at a regional or national level. In particular, the following mechanisms are under review: • ECO Exposure concentration obligation – i.e. 'based an average level determined on the basis of measurements at urban background locations, reflects population exposure – and to be attained over a given period'; • (N)ERT (National) exposure reduction target – i.e. 'a percentage reduction of the average exposure to be attained where possible over a given period'. The WHO air quality guidelines include targets for O_3 based on concentration values rather than exposure reduction targets. Current provisions in the AAQ Directives do not set average exposure obligations or reduction targets for O_3.
Purpose/operational objective: To reduce exposure to harmful levels of air pollution, with reference to best-practice guidance regarding safe levels of exposure. This would reduce exposure to air pollution, therefore reducing negative health impacts.
Who would be impacted and how: ***Direct:*** It is understood that reducing exposure will lead to health benefits in a shorter timeframe than would be achieved with target values alone. Administrative and monitoring costs would fall on competent authorities and are expected to be marginal (for monitoring, it is assumed that no new monitoring stations would be required). Measures to attain the reduction targets are likely to address emissions from industry manufacturing, thus compliance costs are expected to impact businesses. ***Indirect:*** Households, and indirectly businesses will benefit from the reduction in negative health impacts associated with higher levels of air pollution.
Risks for implementation: Implementation will require introducing new legal provisions to those currently in 2008/50/EC. While the WHO Guideline values do not include exposure reduction targets (meaning there is no scientific reference point on which to base a standard), it is understood that reducing exposure will lead to health benefits.

Indicators											
1. Air Quality	2. Impact on Health	3. Impacts on Ecosystems	4. Climate change links	5. Costs to society	6. Mitigation costs	7. Impacts on Competitiveness	8. Impacts on Sensitive Groups	9. Societal benefits and burden sharing	10. Impacts on Employment	11. Policy synergies	12. Administrative Burden

0 to ++	0 to +	0 to ++	0 to +	0 to +	0 to --	0 to -	0 to +	+ / -	0	0 to +	0 to --

Assessment

Effectiveness:

Recognising the variants for this intervention, it is understood that the potential effectiveness would scale with level of ambition. The effectiveness of setting average exposure targets relates to the way in which it can complement target values, particularly in cases of non-compliance with limit values as average exposure targets facilitate targeted action mitigate negative ecosystem impacts in a shorter timeframe.

Revisions to average exposure obligations will contribute to air quality improvements [Air Quality: 0 to ++], although the extent of improvement will vary according to the level of ambition. Reduced concentrations of O_3 will directly benefit ecosystems, thus mitigating acidification and eutrophication [Ecosystem impacts: 0 to ++]. The significance of the health benefits is limited [Health impacts: 0 to +]. One paper submitted in the TSS as part of evidence reviews the impact of exposure to O_3 on PAH, showing an effect for benzo [a]pyrene, perylene and benz [a]anthracene; thus there are indirect health impacts to consider (Balducci, C. et al, 2017).

Most stakeholders expressed no opinion on the type of air quality standards that would be appropriate for the EU in the short to medium term based on the calculation of an average exposure indicator. Other than that, there was a significant number of answers pointing towards ECO at a more regional level, as focusing on the local situation seemed more reasonable for these stakeholders. Only a few pointing towards ECO at national level or (N)ERT. This was the same case when asked about the type of air quality standards appropriate for the EU in the long term.

Measures to attain the reduction targets are likely to address emissions from industry and they are likely to bear the costs. The cost on industry will likely be transferred to consumers which may fall more so on poorer households (driving older vehicles, industrial workers, etc.) [Societal benefits: +/-].

Stakeholder responses gathered from the TSS highlight that reduction targets are not the most effective mechanism (compared to target values); however, as a complementary mechanism to target values they are viewed as effective. Whereas stakeholder responses highlight concerns that the more stringent WHO guideline values are not feasible, there is general consensus that regional targeting of O_3 is feasible, as well as being relevant to the protection of human health.

In general terms, stakeholders have noted that the criteria for setting a reduction target will be particularly important for ensuring such a mechanism is effective (in terms of identifying which areas are subject to reduction targets). One suggestion repeated by a few stakeholders is to establish a weighting based on population density combined with modelling (thus moving away from determining the average exposure indicators based on monitoring data at a few sites). It is also noted that exposure reduction targets can overemphasise air quality in urban areas over rural areas and that this is not always effective for Member States with high population densities as it offers limited health benefits. To address this, one stakeholder proposes that the average exposure indicator should be based on all monitoring stations, excluding rural background stations only if it is more than 5 km from a residential area. Exposure time is also noted as a key factor that should be considered when setting reduction targets as is the initial baseline concentration against which the targets are set.

Efficiency:

Recognising the variants for this intervention, it is understood that the potential efficiency would scale with level of ambition.

While revisions to average exposure obligations can deliver benefits in terms of protection of human health [Costs to society: 0 to +].

Mitigation costs will be incurred from measures to attain the reduction targets and while costs are dependent on implementation, they will be significant [Mitigation costs: 0 to --]. Measures to attain the reduction targets are likely to be significant as EU still far away from complying with existing TVs and mitigation is challenging.

The administrative burden is dependent on the number of additional areas of exceedance that require air quality plans as a result of the average exposure indicator. Regarding the costs of achieving compliance with the Directives after the introduction of an additional Average Exposure Indicator, the majority of stakeholder had no opinion. The rest were more or less evenly divided between "high compliance costs" and "low compliance costs". On the administrative burden of achieving compliance with the Directives, most stakeholder also held no opinion, and those who did, mostly indicated there would be low additional administrative burden [Administrative burden: 0 to --]. There is potential to reduce the administrative burden by taking more coordinated and centralised action in each Member State in response to exposure targets. For example, only one air quality plan may be needed, rather than multiple at regional or local level.

The macroeconomic effects are uncertain as these have not been modelled directly, but effects on Competitiveness may be small and negative if limited health benefits are limited and the majority of the mitigation costs fall on businesses (e.g. industry and agriculture sectors) [0 to -]. Impacts on employment are anticipated to be negligible given the potential short-term nature of some actions [0].

Coherence:

Revisions to the average exposure obligations would facilitate the improvement of air quality by reducing concentrations of O_3. This is aligned with wider policy objectives to achieve zero pollution [Policy synergies: 0 to +]. The intervention is also expected to contribute to climate changes policies as measures to abate O3 will target precursors (e.g. targeting methane), thus contributing to GHG emissions mitigation [Climate change links: 0 to +].

Links to other interventions: [synergies / misalignment]

- R1/R2 – there will be interaction between different ozone standards.
- Q1/ Q2 /Q3 /T1 – there will be interactions with standards that govern ozone's precursors
- B3 and choice around type of standard implemented

Benefit-to-cost ratio: The benefit-to-cost ratio would be medium-low:

- The extent to which it contribute to air quality improvements and ecosystems are dependent on the level of ambition. A benefit of setting average exposure targets is that it can complement target values, particularly in cases of non-compliance with limit values as average exposure targets facilitate targeted action mitigate negative ecosystem impacts in a shorter timeframe.
- Costs are significant, arising primarily from measures to attain the reduction targets and administrative burden. There is potential to reduce the administrative burden by taking more coordinated and centralised action.

Summary: The impact on air quality and ecosystems will vary with ambition and benefits only become significant with medium to high levels of ambition. Stakeholder responses gathered from the TSS highlight that reduction targets are not the most effective mechanism (compared to target values); however, as a complementary mechanism to target values they are viewed as effective. Compliance costs have the potential to be significant although the measures to attain the reduction targets (and their associated costs) are generally accepted by stakeholders. Administrative burden will vary with ambition (with more air quality plans required in cases of the high ambition variant to account for the greater number of exceedances – with scope to reduce this burden through coordinated action).

S1

Intervention area S: EU air quality standards for sulphur dioxide (SO_2)

Intervention (S1) Revise long-term (annual) air quality standards

The problem: *Health Outcome Shortcoming:* EU standards are not fully aligned with scientific advice.

Driver: Exceedances of air pollutant concentrations above health guidelines and negative health impacts persist.

Description: This intervention explores the revision of the EU long-term limit standard for SO_2.

The current EU AAQ Directives sets a critical level for the protection of vegetation over the calendar year and winter (1 October to 31 March) of 20 µg/m^3, with no margin of tolerance. There is no existing, long-term EU standard for SO_2 aimed at the protection of human health. Furthermore, the WHO did not make an AQG recommendation around long-term exposure to SO_2.

Variants of the intervention consider different levels at which the standard can be set below the existing EU standard: any numerical standard could be selected. Variants can also change the timeframe over which a standard should be achieved.

Purpose/operational objective: More closely aligns EU air quality standards with latest scientific knowledge. This would reduce exposure to air pollution, therefore reducing negative health impacts.

Who would be impacted and how:

Direct: Should a lower standard be implemented, this will lead to an increase in the number of sites and zones in exceedance. As such, ***public authorities*** will be required to develop and implement new (and revise existing) AQ Plans in order to put in place a strategy to meet these new requirements. These plans will also require ongoing review and management.

Indirect: The AQ Plans will identify suitable strategies to bring air pollutant concentrations in line with standards. These strategies may imply costs for ***households and businesses*** in order to change behavior to abate air pollutant emissions or influence concentrations. These costs may also have a knock-on impact to the wider economy in terms of employment or on business activity through supply chains.

Households, and indirectly businesses will benefit from the reduction in negative health impacts associated with higher levels of air pollution.

Risks for implementation:

Delivery risks around meeting more stringent standards in the short-term: i.e. it takes time to identify exceedances, put AQ plans in place and roll out mitigation techniques.

Setting single value standards will not incentivise continual improvement where such standards are already met.

Furthermore, this may also drive action in areas of lower priority, where the population are not exposed.

Complexity risk of having many different standards for a single pollutant (Stakeholders (MS EG).

Indicators

1. Air Quality	2. Impact on Health	3. Impacts on Ecosystems	4. Climate change links	5. Costs to society	6. Mitigation costs	7. Impacts on Competitiveness	8. Impacts on Sensitive Groups	9. Societal benefits and burden sharing	10. Impacts on Employment	11. Policy synergies	12. Administrative Burden
0 to +	0 to +	0 to +	0 to +	0 to +	0 to -	0	0	0	0	0 to +	0 to -

Assessment

Effectiveness:

Sulphur dioxide is formed and emitted by combustion of fossil fuels (mainly coal and oil) primarily for electricity generation. The highest concentrations of SO_2 have been recorded in the vicinity of large industrial facilities. SO_2 emissions are an important environmental issue because they are a major precursor to ambient $PM_{2.5}$ concentrations[96].

The effectiveness of the intervention will scale with ambition.

Monitoring data for annual average concentrations in 2019 suggests that across 1307 stations in the EU27, only 4 sites were in exceedance of the current EU standard. Given the low existing level of exceedance, the Air Quality benefit of this measure is positive but less so relative to other interventions [0 to +]. No monitoring data was available for the winter period specifically.

Emissions and concentrations of SO_2 have been modelled directly. To 2030, the baseline shows broad achievement of very low concentrations, with only 4 and 23 (out of 1269 sites) exceeding either 10ug/m3 or 5 ug/m3 respectively. To 2050, even further progress is made, with only 5 sites remaining above 5 ug/m3.

Through the TSS, stakeholders somewhat re-affirmed the need for this intervention, with the majority of respondents agreeing that there is still a need for an air quality standard to regulate annual/seasonal SO_2 concentrations. However, the majority highlighting this need was significantly less than that for other pollutants (with the exception of CO).

The main health effects associated with chronic air pollutant exposure are linked to $PM_{2.5}$, not SO_2. This is underlined somewhat but the WHO's reviews, which focus on defining AQGs for short-term standards. This, in addition to the limited number of exceedances, suggests the health benefits are small to negligible [Health impact, costs to society: 0 to +]. Ecosystem effects are linked with SO_2 emissions hence the potential impact is also anticipated to be positive, but small [Impacts on ecosystems: 0 to +].

The pattern of distributional impacts are uncertain as these are not modelled, but the overall size of effects suggests these also would be negligible relative to other pollutant standards [Impacts on Sensitive Groups, Societal benefits and burden sharing: 0].

Efficiency:

The cost of achieving different standards for SO_2 have not been modelled directly so costs are uncertain. Costs will increase with the level of ambition. Expert judgement suggests that given the overall level of exceedances, aggregate costs are likely to be small [Mitigation costs, administrative burden: 0 to -]. As such, it is also anticipated that macro-economic, Competitiveness and Employment effects will be negligible [0].

Coherence:

Some measures to mitigate SO_2 may also influence GHG emissions, for example where these affect transport fuel consumption. This, in addition to the potential health benefits, suggest that both Climate Change and Policy Synergy effects are anticipated to be positive, but small [0 to +].

Links to other interventions: [synergies / misalignment]

- S2 – measures targeting short-term levels will also impact on longer-term standards
- O1/O2/O3 / P1/P2/P3 – action to abate PM will also impact on SO_2 emissions.

Benefit-to-cost ratio:

The intervention has not been modelled directly so the balance of costs and benefits is more uncertain. Furthermore, stakeholders only offered very limited insights through engagement activity. There has been substantial progress around SO_2 emissions and concentrations historically. This may also suggest that a

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[96] https://www.eea.europa.eu/themes/air/air-pollution-sources-1

majority of the low-cost actions may have already been captured. Furthermore, the benefits per tonne of pollutant abated are smaller than for other pollutants (e.g. $PM_{2.5}$). Hence benefits may be small, but costs could be even smaller. **Medium.**
Summary: A summary judgement around this standard is challenging given limitations in the underlying evidence – revisions to this standard were not modelled directly, and stakeholders only provided limited comment. Given only limited focus has been placed on this by stakeholders, one could infer revisions to this critical limit are not high priority amongst stakeholders. Furthermore, without a specific direction from the WHO there is no consistent body of peer reviewed evidence with which an EU standard targeting human health could align. The indicators present a range as the significance of impacts will depend on the level of standard set. It is challenging to precisely define the level at which the indicator score would change. That said, based on the modelling and wider evidence gathering, expert judgement suggests that: low (non-zero) impacts would be associated with a 20 ug/m^3 standard.

S2

Intervention area S: EU air quality standards for sulphur dioxide (SO2)

Intervention (S2) Revise short-term air quality standards and/or alert/information thresholds

The problem: *Health Outcome Shortcoming:* EU standards are not fully aligned with scientific advice.

Driver: Exceedances of air pollutant concentrations above health guidelines and negative health impacts persist.

Description: This intervention explores the alignment of the EU short-term limit values for SO_2 with the WHO's 2021 Global Air Quality Guidelines (AQGs) updated limit values.

The current EU AAQ Directives sets a two standards:

- A ***24-hour*** limit value of 125µg/m^3 (can be exceeded up to 3 times per year), which is above the WHO 2021 AQG of 40 µg/m^3 (based on 99th percentile)
- A 1-***hour*** limit value of 350µg/m^3 (can be exceeded up to 24 times per year). The WHO do not make a recommendation of exposure over a 1-hour averaging period.

The WHO AQGs also sets a short-term standard for a ***10-minute*** averaging period, for which an EU standard does not exist: 500 µg/m^3.

The intervention also considers the revision of existing and/or introduction of short-term standards, either alongside or instead of the existing standard.

Variants of the intervention consider different levels at which the standard can be set below the existing EU standard: any numerical standard could be selected. Variants can also change the timeframe over which a standard should be achieved.

Purpose/operational objective: More closely aligns EU air quality standards with latest scientific knowledge and recommendations of WHO. This would reduce exposure to air pollution, therefore reducing negative health impacts.

Who would be impacted and how:

Direct: Should a lower standard be implemented, this will lead to an increase in the number of sites and zones in exceedance. As such, ***public authorities*** will be required to develop and implement new (and revise existing) AQ Plans in order to put in place a strategy to meet these new requirements. These plans will also require ongoing review and management.

Indirect: The AQ Plans will identify suitable strategies to bring air pollutant concentrations in line with standards. These strategies may imply costs for ***households and businesses*** in order to change behavior to abate air pollutant emissions or influence concentrations. These costs may also have a knock-on impact to the wider economy in terms of employment or on business activity through supply chains.

Households, and indirectly businesses will benefit from the reduction in negative health impacts associated with higher levels of air pollution.

Risks for implementation:

Delivery risks around meeting more stringent standards in the short-term: i.e. it takes time to identify exceedances, put AQ plans in place and roll out mitigation techniques.

Setting single value standards will not incentivise continual improvement where such standards are already met.

Furthermore, this may also drive action in areas of lower priority, where the population are not exposed.

Complexity risk of having many different standards for a single pollutant (Stakeholders (MS EG).

Indicators

1. Air Quality	2. Impact on Health	3. Impacts on Ecosystems	4. Climate change links	5. Costs to society	6. Mitigation costs	7. Impacts on Competitiveness	8. Impacts on Sensitive Groups	9. Societal benefits and burden sharing	10. Impacts on Employment	11. Policy synergies	12. Administrative Burden
0 to +	0 to +	0 to +	0 to +	0 to +	0 to -	0	0	0	0	0 to +	0 to -

Assessment

Effectiveness:

The impacts and effectiveness of the intervention will scale with the ambition of the standards.

Reporting data is available for SO_2 over a ***24-hour average period***:

- Across 1314 monitoring sites in the EU27, 0% (2 sites) exceeded the existing EU 24-hour standard in 2019.
- But 3.7% (49) sites exceeded the WHO AQG

Reporting data is available for SO_2 over a ***1-hour average period***:

- Across 1278 monitoring sites in the EU27, 0% (1 site) exceeded the existing EU 1-hour standard in 2019. For illustration:
  - 1% (7 sites) exceeded a 200 µg/m^3 1-hour average
  - 4% (45 sites) exceeded a 100 µg/m^3 1-hour average
  - 12% (147 sites) exceeded a 50 µg/m^3 1-hour average.

Hence it appears there is current broad compliance with the existing EU standard, but more effort would be required should the standard be reduced. No reporting data is available over a 10-minute averaging period. Hence the intervention could have a positive, but small, benefit for Air Quality [0 to +].

Emissions of SO_2 have been modelled directly, but short-term concentrations have not. Assuming a constant statistical relationship between annual and daily averages of around 4.5, given there is broad achievement of a 10 ug/m3 annual average in 2030, this provides support that the WHO AQG is achievable.

Stakeholders generally see value in this intervention, although less so than other pollutants (perhaps given the high levels of existing compliance and historic progress in reducing emissions of SO_2 in the EU). In response to the TSS, 55% of stakeholders (majority of all groups except industry) believed there was a need for EU standards to regulate peak SO_2 concentrations, with the majority also believing WHO AQGs could be met 'without significant additional effort'.

Related to the existing ***24-hour standard***, when asked, slightly more respondents opted to select a numerical standard than not and suggested this should apply as a limit value to all territory (except for industry that noted it should apply only in selected locations). There was also some alignment regarding the appropriate level for 2030, with the majority of all stakeholder types who selected a numerical value suggesting that alignment with the WHO AQG would be appropriate (although the majority of all industry respondents opted to remain at the existing standard). The same overall response pattern was also observed for 2050, with the exception that the majority of industry replied, 'no opinion' or 'no reply'.

For a 1-***hour standard***, when asked, again slightly more respondents opted to select a numerical standard than not and suggested this should apply as a limit value to all territory (except for industry that noted it should apply only in selected locations). There was also some alignment regarding the appropriate level for 2030, with the majority of all stakeholder types who selected a numerical value suggesting that ambition could go further than the existing EU standard selecting 'less than 350' (although the majority of NGO and industry respondents opted to remain at the existing standard). The same overall response pattern was also observed for 2050, with the exception that the majority of all stakeholder types suggested going beyond the existing standard would be appropriate (although the majority of industry replied ‘no opinion’ or ‘no reply’).

For a ***10-minute standard***, when asked, the majority of respondents suggested that ‘no standard’ was needed – this was true for all stakeholder types except NGOs, the majority of which selected a numerical value in response. Should a standard be implemented, the majority of respondents suggested this should apply as a limit value to all territory (except for industry that noted it should apply only in selected locations). Those that selected a numerical value were fairly evenly split as to whether this should be set in line with the WHO AQG, or even below this level. The same overall response pattern was also observed for 2050, with the exception that the majority of all stakeholder types (where they selected a numerical value) suggested going beyond the existing standard would be appropriate.

The main health effects associated with chronic air pollutant exposure are linked to $PM_{2.5}$, not SO_2. This, in addition to the limited number of exceedances, suggests the health benefits are small to negligible [Health impact, costs to society: 0 to +]. Ecosystem effects are linked with SO_2 emissions hence the potential impact is also anticipated to be positive, but small [Impacts on ecosystems: 0 to +].

The pattern of distributional impacts are uncertain as these are not modelled, but the overall size of effects suggests these also would be negligible relative to other pollutant standards [Impacts on Sensitive Groups, Societal benefits and burden sharing: 0].

Efficiency:

The cost of achieving different short-term standards for SO_2 have not been modelled directly so costs are uncertain. Costs will increase with the level of ambition. The majority of stakeholders (TSS) believed that the WHO AQGs would be ‘feasible without significant additional effort’, suggesting that additional costs could be low. Stakeholders (TSS) were divided on the potential additional compliance costs of a new 10-minute standard, with fairly equal numbers suggesting this may have no, low or even high additional costs. The response for administrative burden was also split, but a slight majority suggested the additional burden would be ‘low’. Expert judgement suggests that given the overall level of exceedances, aggregate costs are likely to be small [Mitigation costs, administrative burden: 0 to -]. As such, it is also anticipated that macro-economic, Competitiveness and Employment effects will be negligible [0].

Coherence:

Some measures to mitigate SO_2 may also influence GHG emissions, for example where these affect transport fuel consumption. This, in addition to the potential health benefits, suggest that both Climate Change and Policy Synergy effects are anticipated to be positive, but small [0 to +].

Links to other interventions: [synergies / misalignment]

- S1 – measures targeting long-term levels will also impact on shorter-term standards
- O1/O2/O3 / P1/P2/P3 – action to abate PM will also impact on SO_2 emissions.

Benefit-to-cost ratio:

The intervention has not been modelled directly so the balance of costs and benefits is more uncertain. Furthermore, stakeholders only offered very limited insights through engagement activity. There has been substantial progress around SO_2 emissions and concentrations historically. This may also suggest that a majority of the low-cost actions may have already been captured. Furthermore, the benefits per tonne of pollutant abated are smaller than for other pollutants (e.g. $PM_{2.5}$). Hence benefits may be small, but costs could be even smaller. **Medium.**

Summary:

This intervention considers both: (a) changes to the existing EU limit values and (b) addition to or substitution of the existing EU standard with alternative short-term standards in the WHO Guideline.

Based on the monitoring data, there was broad compliance with the existing EU standards in 2019. The monitoring data also suggests high levels of compliance with lower standards. Given overlap in key sources, there is an important link to the interventions setting standards for PM, as action to achieve these targets will also drive progress towards this intervention. Stakeholders propose that the WHO AQG standards could be met with limited additional effort and there is some appetite to move beyond the existing 1-hour standard. Introducing a new 10-minute standard will introduce additional complexity and administrative burden for public authorities. The response to the TSS suggested that the value of an additional standard is uncertain. The WHO 2021 AQG introduced a new 24-hour AQG– it did not re-review its 10-minute Guideline but noted this remains valid. No monitoring data is available over a 10-minute period, which makes it challenging to draw a conclusions around the impact of and merit to introducing a new 10-minute standard alongside, or instead of, other short-term standards for SO_2.

The indicators present a range as the significance of impacts will depend on the level of standard set. It is challenging to precisely define the level at which the indicator score would change. That said, based on the modelling and wider evidence gathering, expert judgement suggests that: low (non-zero) impacts would be associated with a 40 ug/m^3 standard.

T1

Intervention area T: EU air quality standards for carbon monoxide (CO)
Intervention (T1) Revise short-term air quality standards
The problem: ***Health Outcome Shortcoming:*** EU standards are not fully aligned with scientific advice. Driver: Exceedances of air pollutant concentrations above health guidelines and negative health impacts persist.
Description: This intervention explores the alignment of the EU short-term limit values for CO with the WHO's 2021 Global Air Quality Guidelines (AQGs) updated limit values. The current EU AAQ Directives sets a max daily 8-hour mean limit value set at 10mg/m^3, which matches the WHO 2021 AQGs. This intervention considers going beyond the WHO AQG for this averaging period. The WHO AQGs also set several other short-term standards, for which an EU standard does not exist: - The recommended 24-hour AQG is set at 4 mg/m^3 (measured on the 99th percentile) - The recommended 1-hour AQG is set at 35 mg/m^3 - The recommended 15 minute AQG is set at 100 mg/m^3. The 24-hour target was introduced as a new Guideline by the WHO in 2021, with the other three Guidelines being confirmed as remaining valid. The intervention also considers the introduction of short-term standards over these averaging periods, either alongside or instead of the existing standard. Variants of the intervention consider different levels at which the standard can be set below the existing EU standard: any numerical standard could be selected. Variants can also change the timeframe over which a standard should be achieved.
Purpose/operational objective: More closely aligns EU air quality standards with latest scientific knowledge and recommendations of WHO. This would reduce exposure to air pollution, therefore reducing negative health impacts.
Who would be impacted and how: ***Direct:*** Should a lower standard be implemented, this will lead to an increase in the number of sites and zones in exceedance. As such, ***public authorities*** will be required to develop and implement new (and revise existing) AQ Plans in order to put in place a strategy to meet these new requirements. These plans will also require ongoing review and management. ***Indirect:*** The AQ Plans will identify suitable strategies to bring air pollutant concentrations in line with standards. These strategies may imply costs for ***households*** in order to change behavior to abate air pollutant emissions or influence concentrations. These costs may also have a knock-on impact to the wider economy in terms of employment or on business activity through supply chains. ***Households, and indirectly businesses*** will benefit from the reduction in negative health impacts associated with higher levels of air pollution.
Risks for implementation: Delivery risks around meeting more stringent standards in the short-term: i.e. it takes time to identify exceedances, put AQ plans in place and roll out mitigation techniques. Setting single value standards will not incentivise continual improvement where such standards are already met. Furthermore, this may also drive action in areas of lower priority, where the population are not exposed. Complexity risk of having many different standards for a single pollutant (Stakeholders (MS EG).
Indicators

1. Air Quality	2. Impact on Health	3. Impacts on Ecosystems	4. Climate change links	5. Costs to society	6. Mitigation costs	7. Impacts on Competitiveness	8. Impacts on Sensitive Groups	9. Societal benefits and burden sharing	10. Impacts on Employment	11. Policy synergies	12. Administrative Burden
0 to +	0 to +	0	0 to +	0	0 to -	0	0	0	0	0 to +	0 to -

Assessment

Effectiveness:

Carbon monoxide (CO) arises from incomplete fuel-combustion and is of concern mainly because of its effect on human health and its role in tropospheric ozone formation. It leads to a decreased uptake of oxygen by the lungs and can lead to a range of symptoms as the concentration increases. Since 2013, the most significant source of CO in the UK has been residential sector combustion[97]. Likewise in the US, the greatest sources of CO to outdoor air are cars, trucks and other vehicles or machinery that burn fossil fuels. A variety of items in the home such as unvented kerosene and gas space heaters, leaking chimneys and furnaces, and gas stoves also release CO and can affect air quality indoors[98].

The impacts and effectiveness of the intervention to resolve the problem will scale with the ambition of the standard.

Reporting data is available for CO over an 8-***hour maximum average period***:

- Across 792 monitoring sites in the EU27, 0% (1 site) exceeded the existing EU 8-hour maximum standard in 2019. In fact, only 1 site is recorded as exceeding a lower 7 mg/m^3 limit, and two sites exceeding a lower 4 mg/m^3 limit (only 6 sites registered non-zero concentrations).

Hence it appears there is current broad compliance with the existing EU standard, but more effort would be required should the standard be reduced.

Reporting data is available for CO over a ***24-hour and 1-hour averaging period***. The level of compliance with any new standard will depend on the number of exceedance days allowed per annum. The WHO AQG 24-hour is defined on the basis of the 99th percentile, whereas this is not specified for the 1-hour period. From the monitoring data:

- For a 24-hour averaging period, based on the 99th percentile: across 804 monitoring sites in the EU27, 0% (1 site) exceeded the WHO AQG in 2019 (the same site that also exceeded the existing 8-hour maximum standard). Many more sites recorded non-zero concentrations (relative to the 8-hour maximum)
    - Based on the maximum value, 5% (39 sites) exceeded the WHO AQG in 2019
- For a 1-hour averaging period, based on the maximum value: across 794 monitoring sites in the EU27, 0% (1 site) exceeded the WHO AQG in 2019 (the same site that also exceeded the existing 8-hour maximum standard). Many more sites recorded non-zero concentrations (relative to the 8-hour maximum)

No monitoring data is available for a 15-minute averaging period.

Hence it appears there is currently broad compliance with WHO AQGs for which data is available. It also appears that there is consistency between the standards in terms of the site identified as being high risk.

Stakeholders generally see value in this intervention, although less so than other pollutants (perhaps given the high levels of existing compliance and historic progress in reducing emissions of CO in the EU). In response to the

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[97] https://naei.beis.gov.uk/overview/pollutants?pollutant_id=4

[98] https://www.epa.gov/co-pollution/basic-information-about-carbon-monoxide-co-outdoor-air-pollution#:~:text=The%20greatest%20sources%20of%20CO,can%20affect%20air%20quality%20indoors.

TSS, 53% of stakeholders (majority of all groups except industry) believed there was a need for EU standards to regulate peak CO concentrations, with the majority also believing WHO AQGs could be met ‘without significant additional effort’.

Related to the existing ***average 8-hour maximum standard***, when asked, slightly more respondents opted to select a numerical standard than not and suggested this should apply as a limit value to all territory (except for industry that noted it should apply only in selected locations). There was also some alignment regarding the appropriate level for 2030, with the majority of all stakeholder types who selected a numerical value agreeing that remaining at the existing 10 mg/m^3 being most appropriate (although the majority of all industry respondents selected ‘no standard’). The same overall response pattern was also observed for 2050.

For a ***24-hour standard***, opinion was more mixed as to whether a standard is required (potentially due to the existence of the existing 8-hour maximum standard). When asked, less than half of respondents (43%) selected a numerical value, and 23% selected directly that no standard is required (with the remaining offering no opinion or no reply). For those that selected a standard, the majority considered this should be a limit value applying to all territory (with the exception of industry who felt this should apply only at selected locations). In terms of the level, the majority of public authorities and research opted for alignment with the WHO AQG in 2030, with NGO’s split between 7 mg/m^3 and alignment with the WHO AQGs (majority of industry selected ‘no standard’). To 2050, a greater number of respondents selected a standard, with the majority of public authorities, NGOs and research opting for full alignment with the WHO AQGs (majority of industry again selected ‘no standard’).

No questions were asked in the TSS regarding a potential 1-hour or 15-minute standard.

The main health effects associated with air pollutant exposure are linked to $PM_{2.5}$ and NO_2, not CO. No EEA damage cost has been estimated for CO. This in addition to the limited number of exceedances, suggests the health benefits are small to negligible [Health impact: 0 to +; costs to society: 0].

Significant ecosystem effects are not typically linked with CO emissions hence the potential impact is also anticipated to be negligible [Impacts on ecosystems: 0].

The pattern of distributional impacts are uncertain as these are not modelled, but the overall size of effects suggests these also would be negligible relative to other pollutant standards [Impacts on Sensitive Groups, Societal benefits and burden sharing: 0].

Efficiency:

The cost of achieving different standards for CO have not been modelled directly so costs are uncertain. Costs will increase with the level of ambition.

The majority of respondents to the TSS suggested that achieving the WHO AQGs would be feasible ‘without significant additional effort’, but the response was mixed with the majority of industry respondents (that did not select no opinion or no reply) selecting these could be achieved only with ‘significant additional effort’. The response was very mixed, but a slight majority of respondents suggested that the there would be ‘no additional’ compliance costs, bit ‘low’ additional administrative burden associated with a 24-hour standard (but majority of industry respondents suggests compliance costs and administrative burden would be ‘high’.

Expert judgement suggests that given the overall level of exceedances, aggregate costs are likely to be small [Mitigation costs, administrative burden: 0 to -]. As such, it is also anticipated that macro-economic, Competitiveness and Employment effects will be negligible [0].

Coherence:

Many of the measures taken to abate CO will also have a complementary impact on GHG emissions. These effects will scale with the level of ambition set [Climate change links: 0 to +].

In addition, greater ambition will also lead to greater synergies with the EU’s ZPAP as human health effects associated with exposure to outdoor and indoor air pollution will be reduced [Policy synergies: 0 to +].

Links to other interventions: [synergies / misalignment] - Interventions which target other pollutants (O1-3, P1-3, Q1-3) could also influence CO emissions, for example where they influence aggregate fuel consumption. But such synergies are anticipated to be small.
Benefit-cost ratio: The benefit-cost ratio is challenging to assess with certainty as the costs and benefits have not been modelled directly. The BCR will vary with the level of ambition. From the modelling, a certain level of improvement can be made through the national, technical measures included in the GAINS model for moderate cost. However, achieving further improvements going beyond the WHO AQGs will require the take up of non-technical or local measures not captured by the model, the costs of which are uncertain. Health benefits are more commonly associated with $PM_{2.5}$, as such the benefits per tonne of CO reduction are relatively lower. Hence benefits may be small, but costs could be even smaller. **Medium.**
Summary: This intervention considers both: (a) changes to the existing EU limit value and (b) addition to or substitution of the existing EU standard with alternative short-term standards in the WHO Guideline. Based on the monitoring data, there was broad compliance with the existing EU standards in 2019. The monitoring data also suggests high levels of compliance with lower standards, although a large 'zero' response in the site data reduces confidence in this assessment. Given overlap in key sources, there is an important link to the interventions setting standards for PM, as action to achieve these targets will also drive progress towards this intervention. Stakeholders propose that the existing EU standards can be met with limited additional effort and propose to remain at the existing standard. Introducing new standards will introduce additional complexity and administrative burden for public authorities. The response to the TSS suggested that the value of an additional standard is uncertain. The WHO 2021 AQG introduced the 24-hour Guideline as a new target – it did not re-review its other Guidelines for CO but noted these remain valid. Given the monitoring data highlights the same station at risk under an 8-hour maximum, 24 or 1-hour average, this suggests there would be some overlap in the effects of different standards. In addition, it is notable that a larger 'non-zero' data return is available for both the 24 and 1-hour standards, perhaps suggesting that these are simpler to monitor, report and understand. Expert judgement suggests that a 24-hour or 1-hour average would be simpler to understand for EU citizens. Given CO is harmful when inhaled in large amounts over a short space of time, expert judgement suggests that a 1-hour standard may better target risks of CO than a 24-hour standard.

U1

Intervention area U: EU air quality standards for benzene

Intervention (U1) Revise long-term (annual) air quality standards

The problem: ***Health Outcome Shortcoming:*** EU standards are not fully aligned with scientific advice.

Driver: Exceedances of air pollutant concentrations above health guidelines and negative health impacts persist.

Description: Intervention explores the alignment of the EU long-term standard limit values for benzene with the WHO's Global Air Quality Guidelines (AQGs), which for benzene were contained in the 2000 Guidelines. The current EU AAQ Directives sets an annual average limit value for benzene of 5 µg/m^3. The WHO guideline is set at 1.7 µg/m^3. Variants of the intervention consider different levels at which the standard can be set below the existing EU standard: any numerical standard could be selected. Variants can also change the timeframe over which a standard should be achieved.

Purpose/operational objective: More closely aligns EU air quality standards with latest scientific knowledge and recommendations of WHO. This would reduce exposure to air pollution, therefore reducing negative health impacts.

Who would be impacted and how:

Direct: Should a lower standard be implemented, this will lead to an increase in the number of sites and zones in exceedance. As such, ***public authorities*** will be required to develop and implement new (and revise existing) AQ Plans in order to put in place a strategy to meet these new requirements. These plans will also require ongoing review and management.

Indirect: The AQ Plans will identify suitable strategies to bring air pollutant concentrations in line with standards. These strategies may imply costs for ***households, businesses and industry*** in order to change behavior to abate air pollutant emissions or influence concentrations. These costs may also have a knock-on impact to the wider economy in terms of employment or on business activity through supply chains.

Households, and indirectly businesses will benefit from the reduction in negative health impacts associated with higher levels of air pollution.

Risks for implementation:

Delivery risks around meeting more stringent standards in the short-term: i.e. it takes time to identify exceedances, put AQ plans in place and roll out mitigation techniques.

Setting single value standards will not incentivise continual improvement where such standards are already met. Furthermore, this may also drive action in areas of lower priority, where the population are not exposed.

Indicators

1. Air Quality	2. Impact on Health	3. Impacts on Ecosystems	4. Climate change links	5. Costs to society	6. Mitigation costs	7. Impacts on Competitiveness	8. Impacts on Sensitive Groups	9. Societal benefits and burden sharing	10. Impacts on Employment	11. Policy synergies	12. Administrative Burden
0 to +	0 to +	0	0	0	0 to -	0	0	0	0	0	0 to -

Assessment

Effectiveness:

Benzene emissions to ambient air include cigarette smoke, combustion and evaporation of benzene-containing petrol, petrochemical industries, and combustion processes[99]. The IED BREF relating to petrochemical industries has driven significant improvement historically.

The effectiveness of the intervention will scale with ambition.

Monitoring data for annual average concentrations in 2019 suggests that across 591 stations in the EU27, only 1 site was in exceedance of the current EU standard and 11% were in exceedance of the WHO 2000 AQG. Given the low existing level of exceedance relative to the WHO AQG, the Air Quality benefit of this measure is positive but less so relative to other interventions [0 to +].

Through the TSS, stakeholders re-affirmed the need for this intervention, with the majority of respondents selecting a numerical standard when asked. The majority of stakeholders also agreed this should apply as a limit value and to all territory (with the exception of industry who volunteered that it should only apply at selected locations). There was some collaboration regarding ambition level across stakeholder types: the majority of public authorities, NGOs and research suggested that aligning with the WHO AQG by 2030 would be appropriate, with industry respondents suggesting keeping the existing EU standard (although the majority of industry respondents in fact offered no opinion or reply).

The main health effects associated with air pollutant exposure are linked to $PM_{2.5}$ and NO_2, not benzene. Indeed the damage cost per tonne of benzene emission is significantly lower than for other pollutants (around 0.36 EUR / tonne)[100]. This in addition to the limited number of exceedances, suggests the health benefits are small to negligible [Health impact: 0 to +; costs to society: 0]. Significant ecosystem effects are not typically linked with benzene emissions hence the potential impact is also anticipated to be negligible [Impacts on ecosystems: 0].

The pattern of distributional impacts are uncertain as these are not modelled, but the overall size of effects suggests these also would be negligible relative to other pollutant standards [Impacts on Sensitive Groups, Societal benefits and burden sharing: 0].

Efficiency:

The cost of achieving different standards for benzene have not been modelled directly so costs are uncertain. Costs will increase with the level of ambition. The majority of respondents to the TSS suggested that achieving the WHO AQGs would be feasible ‘with some additional effort’, but the response was mixed with the majority of industry respondents (that did not select no opinion or no reply) selecting these could be achieved only with ‘significant additional effort’. Expert judgement suggests that given the overall level of exceedances, aggregate costs are likely to be small [Mitigation costs, administrative burden: 0 to -]. As such, it is also anticipated that macro-economic, Competitiveness and Employment effects will be negligible [0].

Coherence:

Some measures to mitigate benzene may also influence GHG emissions, for example where these affect transport fuel consumption. But Climate Change and Policy Synergy effects are anticipated to be negligible [0].

Links to other interventions: [synergies / misalignment]

- Interventions which target other pollutants (O1-3, P1-3, Q1-3) could also influence benzene emissions, for example where they influence aggregate fuel consumption. But such synergies are anticipated to be small.

Benefit-to-cost ratio:

The intervention has not been modelled directly so the balance of costs and benefits is more uncertain. The majority of stakeholders propose that the WHO AQGs are feasible with limited additional effort (with the

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[99] EEA damage cost report

[100] EEA damage cost report

exception of industry). That said, the benefits of any action are also anticipated to be small. Several high benefit-low-cost actions may have already been captured by existing legislation (e.g. IED BREF). **Low/medium.**
Summary: The majority of stakeholders favour alignment with the WHO AQG in the short term and feel this can be achieved with limited additional effort (with the exception of industry). There is broad compliance with the existing standard in 2019 and low exceedances relative to the WHO AQG, not accounting for further improvements in the baseline. The BCR is uncertain, as costs have not been modelled directly and the value of benefits will be small. The indicators present a range as the significance of impacts will depend on the level of standard set. It is challenging to precisely define the level at which the indicator score would change. That said, based on the modelling and wider evidence gathering, expert judgement suggests that: low (non-zero) impacts could be associated with a 5 ug/m^3 standard, and moderate impacts with a 1.7 ug/m^3 standard.

V1

Intervention area V: EU air quality standards for benzo(a)pyrene (BaP)

Intervention (V1) Revise long-term (annual) air quality standards

The problem: ***Health Outcome Shortcoming:*** EU standards are not fully aligned with scientific advice.

Driver: Exceedances of air pollutant concentrations above health guidelines and negative health impacts persist.

Description: Intervention explores the possibility for the EU annual average target value for BaP to align with the WHO's Global Air Quality Guidelines (AQGs) contained in the 2000 Guidelines, and or changing the type of standard. The current EU AAQ Directives sets an annual average target value of 1 ng/m^3, relative to the WHO guideline of 0.12 ng/m^3. Variants of the intervention consider different levels at which the standard can be set below the existing EU standard: any numerical standard could be selected. Variants can also change the timeframe over which a standard should be achieved.

Purpose/operational objective: More closely aligns EU air quality standards with latest scientific knowledge and recommendations of WHO. This would reduce exposure to air pollution, therefore reducing negative health impacts.

Who would be impacted and how:

Direct: Should a lower standard be implemented, this will lead to an increase in the number of sites and zones in exceedance. As such, ***public authorities*** will be required to develop and implement new (and revise existing) AQ Plans in order to put in place a strategy to meet these new requirements. These plans will also require ongoing review and management.

Indirect: The AQ Plans will identify suitable strategies to bring air pollutant concentrations in line with standards. These strategies may imply costs for ***households, businesses and industry*** in order to change behavior to abate air pollutant emissions or influence concentrations. These costs may also have a knock-on impact to the wider economy in terms of employment or on business activity through supply chains.

Households, and indirectly businesses will benefit from the reduction in negative health impacts associated with higher levels of air pollution.

Risks for implementation:

Delivery risks around meeting more stringent standards in the short-term: i.e. it takes time to identify exceedances, put AQ plans in place and roll out mitigation techniques.

Setting single value standards will not incentivise continual improvement where such standards are already met.

Furthermore, this may also drive action in areas of lower priority, where the population are not exposed.

Indicators

1. Air Quality	2. Impact on Health	3. Impacts on Ecosystems	4. Climate change links	5. Costs to society	6. Mitigation costs	7. Impacts on Competitiveness	8. Impacts on Sensitive Groups	9. Societal benefits and burden sharing	10. Impacts on Employment	11. Policy synergies	12. Administrative Burden
0 to ++	0 to +	0	0 o +	0 to +	0 to --	+/-	0 to +	+/-	+/-	0 to +	0 to ---

Assessment

Effectiveness:

Polycyclic aromatic hydrocarbons is a group of chemicals produced during incomplete combustion of organic matter (e.g., from the burning of fossil fuels and biomass, and vehicle exhaust; tobacco smoke and food preparation are major contributors to PAH exposure)[101]. The residential, commercial and institutional sector is the principal source of lead emissions in the EU[102].

The effectiveness of the intervention will scale with ambition.

In 2019, from monitoring data across 401 sites in the EU27 there were:

- 149 exceedances of the EU limit value (37% sites)
- 338 exceedances of the WHO AQG (84% sites).

Emissions and concentrations of BaP have been modelled directly. Significant improvements are observed in the baseline, with the number of sites (for the modelling out of a total of 334) exceeding the existing EU target value reducing from 144 in 2020, to 62 in 2030 and 0 in 2050. Relative to the WHO AQG, this also shows a reduction over time, from 326 sites in 2020, to 286 in 2030 and 223 in 2050. Given a large number of sites are observed to remain above the WHO AQGs in the baseline, this intervention could deliver a positive Air Quality benefit but less so relative to other interventions [0 to ++].

Mitigation techniques can achieve additional improvements. Under the MTFR scenario in the modelling, the number of sites exceeding the EU standard in 2030 reduces from 62 under the baseline to 10. The number exceeding the WHO AQG in 2030 drops from 286 to 248, and in 2050 from 223 to 165. However, again there are a large number of sites that remain in exceedance, suggesting additional, non-technical or local measures would be required to achieve higher levels of compliance, which are not captured by the model.

Through the TSS, stakeholders re-affirmed the need for this intervention, with the majority of respondents selecting a numerical standard when asked. The majority of stakeholders also agreed this should apply to all territory (with the exception of industry who volunteered that it should only apply at selected locations) and should instead apply as a limit value (with the exception of industry who opted in majority for a target value). There were mixed views regarding the ambition level across stakeholder types: a slight majority favoured alignment with the WHO AQG (driven by the majority of NGOs and research and academics), but a sizeable majority also favoured retaining the existing EU standard (selected by the majority of industry), with the opinion of public authorities spread between the WHO AQG, existing EU standard and in between. The majority of respondents thought the WHO AQG could only be achieved with ‘significant additional effort’.

Where emissions and exposure occurs, the health impacts can be moderate: the damage cost per tonne of emission is moderate relative to many other pollutants (around 6,800 EUR / tonne)[103]. However, the limited number of exceedances limits the overall size of the achievable benefit [Health impact, costs to society: 0 to +]. BaP is not strongly associated with detrimental impacts for ecosystems [0].

Distributional impacts of the intervention are unclear as these have not been modelled directly, although it is anticipated some benefit will fall on more vulnerable groups [Impacts on Sensitive Groups: 0 to +]. Given residential is a key source, expert judgement suggests that where fossil fuels are used more so by lower income households for heating and cooking, there may be a small positive societal benefit. However these same households could bear the costs of mitigation [Societal benefits and burden sharing: +/-].

Efficiency:

The costs of mitigation action will scale with ambition. The mitigation costs of lower standards for BaP have not been modelled. Many of the measures which mitigate PM would also mitigate BaP emissions, hence in

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[101] EEA DC report

[102] https://www.eea.europa.eu/publications/air-quality-in-europe-2021/sources-and-emissions-of-air

[103] EEA damage cost

some way the measures and costs would be similar but would focus on a narrower subset of sectors and sources, so would not be as high as O1 [0 to --].

Given the number of sites which move into exceedance under lower standards is quite large, there may be moderate additional administrative burden. However, given the costs of AQ Plans, even low ambition could deliver high administrative burden (relative to all interventions) [0 to ---].

Both the costs of mitigation measures, and the health benefits, could have a broader knock-on impact for the EU economy as costs (and benefits) filter through supply chains and into business decision making. No modelling has been undertaken focusing on the achievement of BaP standards directly. The mitigation costs would fall on both residential and commercial sectors, but businesses would also benefit from the health improvements of the workforce [Impacts on competitiveness, impacts on employment: +/-].

Coherence:

Many of the measures taken to abate BaP will also have a complementary impact on GHG emissions. These effects will scale with the level of ambition set [Climate change links: 0 to +].

In addition, greater ambition will also lead to greater synergies with the EU's ZPAP as human health effects associated with exposure to outdoor and indoor air pollution will be reduced [Policy synergies: 0 to +].

Links to other interventions: [synergies / misalignment]

- O1/O2/O3 / P1/P2/P3 – action to abate PM will also impact on BaP emissions.
- L2 – requirement for monitoring of additional heavy metals could help improve evidence around sources of emissions.

Benefit-cost ratio:

The benefit-cost ratio is challenging to assess with certainty as the costs and benefits have not been modelled directly. The BCR will vary with the level of ambition. From the modelling, a certain level of improvement can be made through the national, technical measures included in the GAINS model for moderate cost. However, achieving further improvements and alignment with the WHO AQGs will require the take up of non-technical or local measures not captured by the model, the costs of which are uncertain. Health benefits are more commonly associated with $PM_{2.5}$, as such the benefits per tonne of BaP reduction are relatively lower. **Low-medium.**

Summary:

This intervention considers both: (a) changing from target to limit value and (b) aligning the standard with the WHO Guideline. Given overlap in key sources, there is an important link to the interventions setting standards for PM, as action to achieve these targets will also drive progress towards this intervention. Based on the modelling, there will be broad compliance with the existing EU standards by 2050, but a large number of sites will remain in exceedance in 2030. The adoption of significant additional mitigation actions (i.e. under the MTFR scenario) can achieve broader (but not complete) compliance by 2030 (10 of 334 sites remain). Hence achieving compliance with the existing EU standard as a limit value may entail substantial cost, relative to benefits which are not as substantial as other pollutants.

Likewise to comply with a lower standard would also require significant abatement action, both technical (as captured by GAINS) and non-technical or local measures (not captured by GAINS), the costs of which are uncertain.

The indicators present a range as the significance of impacts will depend on the level of standard set. It is challenging to precisely define the level at which the indicator score would change. That said, based on the modelling and wider evidence gathering, expert judgement suggests that: moderate impacts could be associated with a 0.7 ug/m^3 standard, high impacts with a 0.4 ug/m^3 standard, and the highest scoring associated with a 0.12 ug/m^3 standard.

W1

Intervention area W: EU air quality standards for lead (Pb)

Intervention (W1) Revise long-term (annual) air quality standards

The problem: ***Health Outcome Shortcoming:*** EU standards are not fully aligned with scientific advice.

Driver: Exceedances of air pollutant concentrations above health guidelines and negative health impacts persist.

Description: Intervention explores the possibility for the EU annual average limit value for lead to go beyond the WHO's Global Air Quality Guidelines (AQGs) contained in the 2000 Guidelines. The current EU AAQ Directives sets an annual average limit value of 0.5 µg/m^3, which is consistent with the WHO guideline. Variants of the intervention consider different levels at which the standard can be set below the existing EU standard: any numerical standard could be selected. Variants can also change the timeframe over which a standard should be achieved.

Purpose/operational objective: More closely aligns EU air quality standards with latest scientific knowledge and recommendations of WHO. This would reduce exposure to air pollution, therefore reducing negative health impacts.

Who would be impacted and how:

Direct: Should a lower standard be implemented, this will lead to an increase in the number of sites and zones in exceedance. As such, ***public authorities*** will be required to develop and implement new (and revise existing) AQ Plans in order to put in place a strategy to meet these new requirements. These plans will also require ongoing review and management.

Indirect: The AQ Plans will identify suitable strategies to bring air pollutant concentrations in line with standards. These strategies may imply costs for ***households, businesses and industry*** in order to change behavior to abate air pollutant emissions or influence concentrations. These costs may also have a knock-on impact to the wider economy in terms of employment or on business activity through supply chains.

Households, and indirectly businesses will benefit from the reduction in negative health impacts associated with higher levels of air pollution.

Risks for implementation:

Delivery risks around meeting more stringent standards in the short-term: i.e. it takes time to identify exceedances, put AQ plans in place and roll out mitigation techniques.

Setting single value standards will not incentivise continual improvement where such standards are already met. Furthermore, this may also drive action in areas of lower priority, where the population are not exposed.

Indicators

1. Air Quality	2. Impact on Health	3. Impacts on Ecosystems	4. Climate change links	5. Costs to society	6. Mitigation costs	7. Impacts on Competitiveness	8. Impacts on Sensitive Groups	9. Societal benefits and burden sharing	10. Impacts on Employment	11. Policy synergies	12. Administrative Burden
0 to +	0 to +	0 to +	0	0 to +	0 to -	0 to -	0	+ / -	0 to -	0 to +	0 to -

Assessment

Effectiveness:

The manufacturing and extractive industry sector is the principal source of lead emissions in the EU[104].

The effectiveness of the intervention will scale with ambition.

In 2019, from the monitoring data there were:

- No exceedances of the EU limit value across the EU27
- 8 exceedances above a lower limit of 0.15 µg/m^3 (3 with a data coverage of >85%)
- 26 exceedances above a lower limit of 0.05 µg/m^3 (13 with a data coverage of >85%).

Given the low existing level of exceedance relative to the WHO AQG and given this does not consider potential further improvements in the modelling baseline, the Air Quality benefit of this measure is positive but less so relative to other interventions [0 to +]. That said, key mitigation techniques are often similar to those used to abate PM emissions[105], and industry PM emissions are seen to stay broadly constant in the baseline to 2030 and 2050.

Through the TSS, stakeholders re-affirmed the need for this intervention, with the majority of respondents selecting a numerical standard when asked. The majority of stakeholders also agreed this should continue to apply as a limit value and to all territory (with the exception of industry who volunteered that it should only apply at selected locations). There was strong agreement regarding the ambition level across stakeholder types, with the majority of all groups opting to maintain the existing EU standard and WHO Guideline, and that this should be feasible ‘without additional effort’.

Where emissions and exposure occurs, the health and ecosystem impacts can be substantial: the damage cost per tonne of emission is significantly higher than many other pollutants (around 33,000 EUR / kg)[106]. However, the limited number of exceedances limits the overall size of the achievable benefit [Health impact, costs to society, ecosystem impacts: 0 to +].

Distributional impacts of the intervention are unclear as these have not been modelled directly. Given the site-specific nature of releases from industry, this would depend on where specific sites are located [Impacts on Sensitive Groups: 0]. Given heavy industry is the key source, which typically comprises lower wage jobs, expert judgement suggests that there may be a small positive societal benefit for lower income groups through a reduction in occupational exposure, however these same industries could bear the costs of mitigation which may also impact on employment, and in turn imply a small, indirect negative effects for these groups [Societal benefits and burden sharing: +/-; Employment: 0 to -].

Efficiency:

Costs associated with additional mitigation are uncertain and have not been modelled in detail. Top-down analysis to try and understand what is driving higher concentrations at particular sites has proven it is challenging to link high concentrations to specific sources with existing available data. This in turn makes it challenging to make a judgement on the level of cost or effort required to go further. One reason for this is that in some cases diffuse emissions will be important. Even where sources can be identified, the level of additional effort will also depend on existing processes and techniques deployed to mitigate emissions. Where the key contributor is an industrial source, it is likely that the site would also have to comply with the relevant BREF under the IED, which will mandate action that is ‘commercially-viable’ under the BATC (although depending on the applicable BREF, there may or may not be BATC specific to lead releases). Where this is the case, expert judgement could conclude that many low-cost measures have already been adopted. These broad arguments, coupled with the preference of stakeholders to remain at the existing standard perhaps suggests that the costs of going further could be more

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[104] https://www.eea.europa.eu/publications/air-quality-in-europe-2021/sources-and-emissions-of-air

[105] https://www3.epa.gov/ttnchie1/le/lead.pdf

[106] EEA damage cost

significant [Mitigation costs: 0 to -]. Given these costs will be faced by industry, there may be a knock-on, small negative impact on Competitiveness [0 to -].

Given the number of sites which move into exceedance under lower standards is small, any additional administrative burden is anticipated to be moderate - given the costs of AQ Plans, even low ambition could deliver administrative burden (relative to all interventions) [0 to -].

Coherence:

The nature of measures to abate lead emissions (e.g. end-of-pipe techniques) imply there is unlikely to be a significant Climate Change co-benefit [0]. However, even small benefits for health and ecosystems would deliver positive Policy Synergies [0 to +].

Links to other interventions: [synergies / misalignment]

- X1/Y1/Z1 – several sources of heavy metals are likely to be common, so abatement for one could impact on others.
- O1-3 and P1-3 – abatement for PM also often controls HM releases.
- L2 – requirement for monitoring of additional heavy metals could help improve evidence around sources of emissions.

Benefit-to-cost ratio:

The benefit-to-cost ratio is uncertain as lead standards have not been modelled directly. Where emissions and exceedances occur, the health and ecosystem benefits could be significant. Costs would strongly depend on the specific control measures deployed at an individual site to abate emissions. Given many sites will fall under the scope of a relevant IED BREF, many low-cost measures may already have been adopted. **Low/Medium.**

Summary:

The existing EU standard is equivalent to the current WHO AQG, and as such this intervention considers going further in lieu of further guidance from the WHO. Based on the monitoring data, only a very limited number of sites would fall into exceedance under a lower limit value. The benefits of reducing emissions would be significant on a per emission basis, but low overall (taking into account that this would affect only few sites). However, the costs of such action are highly uncertain given limitations in the underlying evidence. Furthermore, there is a strong preference amongst stakeholders for continued consistency with the WHO AQG (perhaps reflecting that without a revised AQG they see no strong mandate on health grounds to go further at this stage). There is an important link to interventions under Policy Area 3, and the need to enhance the evidence base around the source apportionment of sites with high lead concentrations.

X1

Intervention area X: EU air quality standards for arsenic (As)

Intervention (X1) Revise long-term (annual) air quality standards

The problem: ***Health Outcome Shortcoming:*** EU standards are not fully aligned with scientific advice. Driver: Exceedances of air pollutant concentrations above health guidelines and negative health impacts persist.

Description: Intervention explores the possibility for the EU annual average target value for As to go beyond the WHO's Global Air Quality Guidelines (AQGs) contained in the 2000 Guidelines, and or changing the type of standard. The current EU AAQ Directives sets an annual average target value of 6 ng/m^3, which is already slightly below the WHO guideline of 6.6 ng/m^3. Variants of the intervention consider different levels at which the standard can be set below the existing EU standard: any numerical standard could be selected. Variants can also change the timeframe over which a standard should be achieved.

Purpose/operational objective: More closely aligns EU air quality standards with latest scientific knowledge and recommendations of WHO. This would reduce exposure to air pollution, therefore reducing negative health impacts.

Who would be impacted and how:

Direct: Should a lower standard be implemented, this will lead to an increase in the number of sites and zones in exceedance. As such, ***public authorities*** will be required to develop and implement new (and revise existing) AQ Plans in order to put in place a strategy to meet these new requirements. These plans will also require ongoing review and management.

Indirect: The AQ Plans will identify suitable strategies to bring air pollutant concentrations in line with standards. These strategies may imply costs for ***households, businesses and industry*** in order to change behavior to abate air pollutant emissions or influence concentrations. These costs may also have a knock-on impact to the wider economy in terms of employment or on business activity through supply chains.

Households, and indirectly businesses will benefit from the reduction in negative health impacts associated with higher levels of air pollution.

Risks for implementation:

Delivery risks around meeting more stringent standards in the short-term: i.e. it takes time to identify exceedances, put AQ plans in place and roll out mitigation techniques.

Setting single value standards will not incentivise continual improvement where such standards are already met.

Furthermore, this may also drive action in areas of lower priority, where the population are not exposed.

Indicators

1. Air Quality	2. Impact on Health	3. Impacts on Ecosystems	4. Climate change links	5. Costs to society	6. Mitigation costs	7. Impacts on Competitiveness	8. Impacts on Sensitive	9. Societal benefits and burden sharing	10. Impacts on Employment	11. Policy synergies	12. Administrative Burden
0 to +	0 to +	0 to +	0	0 to +	0 to -	0 to -	0	+ / -	0 to -	0 to +	0 to -

Assessment

Effectiveness:

The manufacturing and extractive industry and energy supply sectors are the principal sources of arsenic emissions in the EU[107].

The effectiveness of the intervention will scale with ambition.

In 2019, from the monitoring data there were:

- 8 exceedances of the EU target value across the EU27 (6 exceedances relative to the slightly higher WHO AQG)
- 24 exceedances above a lower limit of 3 ng/m^3 (14 with a data coverage of >85%)
- 253 exceedances above a lower limit of 0.66 ng/m^3 (130 with a data coverage of >85%).

Given the low existing level of exceedance relative to the WHO AQG and given this does not consider potential further improvements in the modelling baseline, the Air Quality benefit of this measure is positive but less so relative to other interventions [0 to +].

Through the TSS, stakeholders re-affirmed the need for this intervention, with the majority of respondents selecting a numerical standard when asked. The majority of stakeholders also agreed this should apply to all territory (with the exception of industry who volunteered that it should only apply at selected locations) and should instead apply as a limit value (with the exception of industry who opted in majority for a target value). There was strong agreement regarding the ambition level across stakeholder types, with the majority of all groups opting to maintain the existing EU standard, and that this should be feasible 'without additional effort'.

Where emissions and exposure occurs, the health and ecosystem impacts can be substantial: the damage cost per tonne of emission is significantly higher than many other pollutants (around 11,000 EUR / kg)[108]. However, the limited number of exceedances limits the overall size of the achievable benefit [Health impact, costs to society, ecosystem impacts: 0 to +].

Distributional impacts of the intervention are unclear as these have not been modelled directly. Given the site-specific nature of releases from industry, this would depend on where specific sites are located [Impacts on Sensitive Groups: 0]. Given heavy industry is the key source, which typically comprises lower wage jobs, expert judgement suggests that there may be a small positive societal benefit for lower income groups through a reduction in occupational exposure, however these same industries could bear the costs of mitigation which may also impact on employment, and in turn imply a small, indirect negative effects for these groups [Societal benefits and burden sharing: +/-; Employment: 0 to -].

Efficiency:

Costs associated with additional mitigation are uncertain and have not been modelled in detail. Top-down analysis to try and understand what is driving higher concentrations at particular sites has proven it is challenging to link high concentrations to specific sources with existing available data. This in turn makes it challenging to make a judgement on the level of cost or effort required to go further. One reason for this is that in some cases diffuse emissions will be important. Even where sources can be identified, the level of additional effort will also depend on existing processes and techniques deployed to mitigate emissions. Where the key contributor is an industrial source, it is likely that the site would also have to comply with the relevant BREF under the IED, which will mandate action that is 'commercially-viable' under the BATC (although depending on the applicable BREF, there may or may not be BATC specific to As releases). Where this is the case, expert judgement could conclude that many low-cost measures have already been adopted. These broad arguments, coupled with the preference of stakeholders to remain at the existing standard perhaps

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[107] https://www.eea.europa.eu/publications/air-quality-in-europe-2021/sources-and-emissions-of-air

[108] EEA damage cost

suggests that the costs of going further could be more significant [Mitigation costs: 0 to -]. Given these costs will be faced by industry, there may be a knock-on, small negative impact on Competitiveness [0 to -]. Given the number of sites which move into exceedance under lower standards is small, any additional administrative burden is anticipated to be moderate - given the costs of AQ Plans, even low ambition could deliver administrative burden (relative to all interventions) [0 to -].

Coherence:

The nature of measures to abate As emissions (e.g. absorption techniques targeting As directly[109]) imply there is unlikely to be a significant Climate Change co-benefit [0]. However, even small benefits for health and ecosystems would deliver positive Policy Synergies [0 to +].

Links to other interventions: [synergies / misalignment]

- W1/Y1/Z1 – several sources of heavy metals are likely to be common, so abatement for one could impact on others.
- L2 – requirement for monitoring of additional heavy metals could help improve evidence around sources of emissions.

Benefit-to-cost ratio:

The benefit-to-cost ratio is uncertain as As standards have not been modelled directly. Where emissions and exceedances occur, the health and ecosystem benefits could be significant. Costs would strongly depend on the specific control measures deployed at an individual site to abate emissions. Given many sites will fall under the scope of a relevant IED BREF, many low-cost measures may already have been adopted. **Low/Medium.**

Summary:

The existing EU standard is already below the current WHO AQG, and as such this intervention considers both: (a) changing from target to limit value and (b) going further in lieu of further guidance from the WHO. Based on the monitoring data, only a very limited number of sites currently exceed the existing target value. As such the costs (and benefits) of implementing the standard as a limit value could be small, but this could help drive compliance of the few remaining sites (some of which have very high concentrations – max 21 ng/m^3 in 2019) and ensure continued performance at compliant sites.

In terms of going further, the benefits of reducing emissions would be significant on a per emission basis. The benefits would scale with the level of ambition and the number of sites where additional action would be required – as illustrated by the monitoring data, for large reductions (e.g. to 0.66 ng/m^3) this could bring a large number of sites into exceedance. However, the costs of such action are highly uncertain given limitations in the underlying evidence. Furthermore, there is a strong preference amongst stakeholders to remain at the existing EU standard (perhaps reflecting that in lieu of a revised AQG there is no strong mandate on health grounds to go further at this stage). There is an important link to interventions under Policy Area 3, and the need to enhance the evidence base around the source apportionment of sites with high As concentrations.

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[109] https://reader.elsevier.com/reader/sd/pii/S2666790821000756?token=1358868CFB9367A786880BB2C8ED54B77C39E1A6014D8206C5C9628B7DB6142E7C960CB6ED9EF6FD6F0DEC29D9AF0D20&originRegion=eu-west-1&originCreation=20220407193032

Y1

Intervention area Y: EU air quality standards for cadmium (Cd)

Intervention (Y1) Revise long-term (annual) air quality standards

The problem: ***Health Outcome Shortcoming:*** EU standards are not fully aligned with scientific advice.
Driver: Exceedances of air pollutant concentrations above health guidelines and negative health impacts persist.

Description: Intervention explores the possibility for the EU annual average target value for Cd to go beyond the WHO's Global Air Quality Guidelines (AQGs) contained in the 2000 Guidelines, and or changing the type of standard. The current EU AAQ Directives sets an annual average target value of 5 ng/m^3 which is equivalent to the WHO guideline. Variants of the intervention consider different levels at which the standard can be set below the existing EU standard: any numerical standard could be selected. Variants can also change the timeframe over which a standard should be achieved.

Purpose/operational objective: More closely aligns EU air quality standards with latest scientific knowledge and recommendations of WHO. This would reduce exposure to air pollution, therefore reducing negative health impacts.

Who would be impacted and how:

Direct: Should a lower standard be implemented, this will lead to an increase in the number of sites and zones in exceedance. As such, ***public authorities*** will be required to develop and implement new (and revise existing) AQ Plans in order to put in place a strategy to meet these new requirements. These plans will also require ongoing review and management.

Indirect: The AQ Plans will identify suitable strategies to bring air pollutant concentrations in line with standards. These strategies may imply costs for ***industry*** in order to change behavior to abate air pollutant emissions or influence concentrations. These costs may also have a knock-on impact to the wider economy in terms of employment or on business activity through supply chains. ***Households, and indirectly businesses*** will benefit from the reduction in negative health impacts associated with higher levels of air pollution.

Risks for implementation:

Delivery risks around meeting more stringent standards in the short-term: i.e. it takes time to identify exceedances, put AQ plans in place and roll out mitigation techniques.

Setting single value standards will not incentivise continual improvement where such standards are already met. Furthermore, this may also drive action in areas of lower priority, where the population are not exposed.

Indicators

1. Air Quality	2. Impact on Health	3. Impacts on Ecosystems	4. Climate change links	5. Costs to society	6. Mitigation costs	7. Impacts on Competitiveness	8. Impacts on Sensitive Groups	9. Societal benefits and burden sharing	10. Impacts on Employment	11. Policy synergies	12. Administrative Burden
0 to +	0 to +	0 to +	0	0 to +	0 to -	0 to -	0	+ / -	0 to -	0 to +	0 to -

Assessment

Effectiveness:

The manufacturing and extractive industry sector is the principal source of Cd emissions in the EU[110].
The effectiveness of the intervention will scale with ambition.
In 2019, from the monitoring data there were:

- 1 exceedances of the EU target value across the EU27
- 11 exceedances above a lower limit of 2.5 ng/m^3 (5 with a data coverage of >85%)
- 77 exceedances above a lower limit of 0.5 ng/m^3 (33 with a data coverage of >85%).

Given the low existing level of exceedance relative to the WHO AQG and given this does not consider potential further improvements in the modelling baseline, the Air Quality benefit of this measure is positive but less so relative to other interventions [0 to +]. That said, key mitigation techniques are often similar to those used to abate PM emissions, and industry PM emissions are seen to stay broadly constant in the baseline to 2030 and 2050.
Through the TSS, stakeholders re-affirmed the need for this intervention, with the majority of respondents selecting a numerical standard when asked. The majority of stakeholders also agreed this should apply to all territory (with the exception of industry who volunteered that it should only apply at selected locations) and should instead apply as a limit value (with the exception of industry who opted in majority for a target value). There was strong agreement regarding the ambition level across stakeholder types, with the majority of all groups opting to maintain the existing EU standard, and that this should be feasible ‘without additional effort’.
Where emissions and exposure occurs, the health and ecosystem impacts can be substantial: the damage cost per tonne of emission is significantly higher than many other pollutants (around 185,000 EUR / kg)[111]. However, the limited number of exceedances limits the overall size of the achievable benefit [Health impact, costs to society, ecosystem impacts: 0 to +].
Distributional impacts of the intervention are unclear as these have not been modelled directly. Given the site-specific nature of releases from industry, this would depend on where specific sites are located [Impacts on Sensitive Groups: 0]. Given heavy industry is the key source, which typically comprises lower wage jobs, expert judgement suggests that there may be a small positive societal benefit for lower income groups through a reduction in occupational exposure, however these same industries could bear the costs of mitigation which may also impact on employment, and in turn imply a small, indirect negative effects for these groups [Societal benefits and burden sharing: +/-; Employment: 0 to -].

Efficiency:
Costs associated with additional mitigation are uncertain and have not been modelled in detail. Top-down analysis to try and understand what is driving higher concentrations at particular sites has proven it is challenging to link high concentrations to specific sources with existing available data. This in turn makes it challenging to make a judgement on the level of cost or effort required to go further. One reason for this is that in some cases diffuse emissions will be important. Even where sources can be identified, the level of additional effort will also depend on existing processes and techniques deployed to mitigate emissions. Where the key contributor is an industrial source, it is likely that the site would also have to comply with the relevant BREF under the IED, which will mandate action that is ‘commercially-viable’ under the BATC (although depending on the applicable BREF, there may or may not be BATC specific to Cd releases). Where this is the case, expert judgement could conclude that many low-cost measures have already been adopted. These broad arguments, coupled with the preference of stakeholders to remain at the existing standard perhaps suggests that the costs of going further could be more significant [Mitigation costs: 0 to -]. Given these costs will be faced by industry, there may be a knock-on, small negative impact on Competitiveness [0 to -].

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[110] https://www.eea.europa.eu/publications/air-quality-in-europe-2021/sources-and-emissions-of-air
[111] EEA damage cost

Given the number of sites which move into exceedance under lower standards is small, any additional administrative burden is anticipated to be moderate - given the costs of AQ Plans, even low ambition could deliver administrative burden (relative to all interventions) [0 to -].

Coherence:

The nature of measures to abate Cd emissions[112] (e.g. dust filters) imply there is unlikely to be a significant Climate Change co-benefit [0]. However, even small benefits for health and ecosystems would deliver positive Policy Synergies [0 to +].

Links to other interventions: [synergies / misalignment]

- W1/X1/Z1 – several sources of heavy metals are likely to be common, so abatement for one could impact on others.
- O1-3 and P1-3 – abatement for PM also often controls Cd releases.
- L2 – requirement for monitoring of additional heavy metals could help improve evidence around sources of emissions.

Benefit-to-cost ratio:

The benefit-to-cost ratio is uncertain as Cd standards have not been modelled directly. Where emissions and exceedances occur, the health and ecosystem benefits could be significant. Costs would strongly depend on the specific control measures deployed at an individual site to abate emissions. Given many sites will fall under the scope of a relevant IED BREF, many low-cost measures may already have been adopted. **Low/Medium.**

Summary:

The existing EU standard is already consistent with the current WHO AQG, and as such this intervention considers both: (a) changing from target to limit value and (b) going further in lieu of further guidance from the WHO. Based on the monitoring data, only one site currently exceeds the existing target value. As such the costs (and benefits) of implementing the standard as a limit value could be small, but this could help drive compliance at the remaining site (concentrations of 5.7 ng/m^3 in 2019) and ensure continued performance at compliant sites.

In terms of going further, the benefits of reducing emissions would be significant on a per emission basis. The benefits would scale with the level of ambition and the number of sites where additional action would be required – as illustrated by the monitoring data, for large reductions (e.g. to 0.5 ng/m^3) this could bring a large number of sites into exceedance. However, the costs of such action are highly uncertain given limitations in the underlying evidence. Furthermore, there is a strong preference amongst stakeholders to remain at the existing EU standard (perhaps reflecting that in lieu of a revised AQG there is no strong mandate on health grounds to go further at this stage). There is an important link to interventions under Policy Area 3, and the need to enhance the evidence base around the source apportionment of sites with high Cd concentrations.

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[112] https://unece.org/fileadmin/DAM/env/documents/2011/eb/wg5/WGSR49/Informal%20docs/15_AnnexIII_notrackchanges.pdf

Z1

Intervention area Z: EU air quality standards for nickel (Ni)

Intervention (Z1) Revise long-term (annual) air quality standards

The problem: ***Health Outcome Shortcoming:*** EU standards are not fully aligned with scientific advice. Driver: Exceedances of air pollutant concentrations above health guidelines and negative health impacts persist.

Description: Intervention explores the possibility for the EU annual average target value for Ni to go beyond the WHO's Global Air Quality Guidelines (AQGs) contained in the 2000 Guidelines, and or changing the type of standard. The current EU AAQ Directives sets an annual average target value of 20 ng/m^3, which is already slightly below the WHO guideline of 25 ng/m^3. Variants of the intervention consider different levels at which the standard can be set below the existing EU standard: any numerical standard could be selected. Variants can also change the timeframe over which a standard should be achieved.

Purpose/operational objective: More closely aligns EU air quality standards with latest scientific knowledge and recommendations of WHO. This would reduce exposure to air pollution, therefore reducing negative health impacts.

Who would be impacted and how:

Direct: Should a lower standard be implemented, this will lead to an increase in the number of sites and zones in exceedance. As such, ***public authorities*** will be required to develop and implement new (and revise existing) AQ Plans in order to put in place a strategy to meet these new requirements. These plans will also require ongoing review and management.

Indirect: The AQ Plans will identify suitable strategies to bring air pollutant concentrations in line with standards. These strategies may imply costs for ***industry*** in order to change behavior to abate air pollutant emissions or influence concentrations. These costs may also have a knock-on impact to the wider economy in terms of employment or on business activity through supply chains. ***Households, and indirectly businesses*** will benefit from the reduction in negative health impacts associated with higher levels of air pollution.

Risks for implementation:

Delivery risks around meeting more stringent standards in the short-term: i.e. it takes time to identify exceedances, put AQ plans in place and roll out mitigation techniques.

Setting single value standards will not incentivise continual improvement where such standards are already met.

Furthermore, this may also drive action in areas of lower priority, where the population are not exposed.

Indicators

1. Air Quality	2. Impact on Health	3. Impacts on Ecosystems	4. Climate change links	5. Costs to society	6. Mitigation costs	7. Impacts on Competitiveness	8. Impacts on Sensitive Groups	9. Societal benefits and burden sharing	10. Impacts on Employment	11. Policy synergies	12. Administrative Burden
0 to +	0	0	0	0	0 to -	0 to -	0	+ / -	0 to -	0	0 to -

Assessment

Effectiveness:

The energy supply and manufacturing and extractive industries are the principal sources of Ni emissions in the EU[113].

The effectiveness of the intervention will scale with ambition.

In 2019, from the monitoring data there were:

- 3 exceedances of the EU target value across the EU27 (also 3 exceedances relative to the slightly higher WHO AQG)
- 12 exceedances above a lower limit of 10 ng/m^3 (6 with a data coverage of >85%)
- 201 exceedances above a lower limit of 2.5 ng/m^3 (77 with a data coverage of >85%).

Given the low existing level of exceedance relative to the WHO AQG and given this does not consider potential further improvements in the modelling baseline, the Air Quality benefit of this measure is positive but less so relative to other interventions [0 to +].

Through the TSS, stakeholders re-affirmed the need for this intervention, with the majority of respondents selecting a numerical standard when asked. The majority of stakeholders also agreed this should apply to all territory (with the exception of industry who volunteered that it should only apply at selected locations) and should instead apply as a limit value (with the exception of industry who opted in majority for a target value). There was strong agreement regarding the ambition level across stakeholder types, with the majority of all groups opting to maintain the existing EU standard, and that this should be feasible 'without additional effort'.

Where emissions and exposure occurs, the health and ecosystem impacts may be fairly small: the damage cost per tonne of emission is significantly lower than many other heavy metals (around 24 EUR / kg)[114]. This, together with the limited number of exceedances limits the overall size of the achievable benefit [Health impact, costs to society, ecosystem impacts: 0].

Distributional impacts of the intervention are unclear as these have not been modelled directly. Given the site-specific nature of releases from industry, this would depend on where specific sites are located [Impacts on Sensitive Groups: 0]. Given the energy supply industry is the key source, which typically comprises lower wage jobs, expert judgement suggests that there may be a small positive societal benefit for lower income groups through a reduction in occupational exposure, however these same industries could bear the costs of mitigation which may also impact on employment, and in turn imply a small, indirect negative effects for these groups [Societal benefits and burden sharing: +/-; Employment: 0 to -].

Efficiency:

Costs associated with additional mitigation are uncertain and have not been modelled in detail. Top-down analysis to try and understand what is driving higher concentrations at particular sites has proven it is challenging to link high concentrations to specific sources with existing available data. This in turn makes it challenging to make a judgement on the level of cost or effort required to go further. One reason for this is that in some cases diffuse emissions will be important. Even where sources can be identified, the level of additional effort will also depend on existing processes and techniques deployed to mitigate emissions. Where the key contributor is an industrial source, it is likely that the site would also have to comply with the relevant BREF under the IED, which will mandate action that is 'commercially-viable' under the BATC (although depending on the applicable BREF, there may or may not be BATC specific to Ni releases). Where this is the case, expert judgement could conclude that many low-cost measures have already been adopted. These broad arguments, coupled with the preference of stakeholders to remain at the existing standard perhaps

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[113] https://www.eea.europa.eu/publications/air-quality-in-europe-2021/sources-and-emissions-of-air

[114] EEA damage cost

suggests that the costs of going further could be more significant [Mitigation costs: 0 to -]. Given these costs will be faced by industry, there may be a knock-on, small negative impact on Competitiveness [0 to -]. Given the number of sites which move into exceedance under lower standards is small, any additional administrative burden is anticipated to be moderate - given the costs of AQ Plans, even low ambition could deliver administrative burden (relative to all interventions) [0 to -].

Coherence:

The nature of measures to abate Ni emissions imply there is unlikely to be a significant Climate Change co-benefit [0]. Given the limited benefits for health and ecosystems, there would also be only limited if any Policy Synergies [0].

Links to other interventions: [synergies / misalignment]

- W1/X1/Y1 – several sources of heavy metals are likely to be common, so abatement for one could impact on others.
- O1-3 and P1-3 – abatement for PM also often controls Ni releases.
- L2 – requirement for monitoring of additional heavy metals could help improve evidence around sources of emissions.

Benefit-to-cost ratio:

The benefit-to-cost ratio is uncertain as Ni standards have not been modelled directly. Where emissions and exceedances occur, the health and ecosystem benefits could be fairly small. Costs would strongly depend on the specific control measures deployed at an individual site to abate emissions. Given many sites will fall under the scope of a relevant IED BREF, many low-cost measures may already have been adopted. **Low.**

Summary:

The existing EU standard is already below the current WHO AQG, and as such this intervention considers both: (a) changing from target to limit value and (b) going further in lieu of further guidance from the WHO. Based on the monitoring data, only three sites currently exceed the existing target value. As such the costs (and benefits) of implementing the standard as a limit value could be small, but this could help drive compliance at the remaining sites (which can be substantial exceedances – maximum concentrations 77 ng/m^3 in 2019) and ensure continued performance at compliant sites.

In terms of going further, the benefits of reducing emissions would be significant on a per emission basis. The benefits would scale with the level of ambition and the number of sites where additional action would be required – as illustrated by the monitoring data, for large reductions (e.g. to 2.5 ng/m^3) this could bring a large number of sites into exceedance. However, the costs of such action are highly uncertain given limitations in the underlying evidence. Furthermore, there is a strong preference amongst stakeholders to remain at the existing EU standard (perhaps reflecting that in lieu of a revised AQG there is no strong mandate on health grounds to go further at this stage). There is an important link to interventions under Policy Area 3, and the need to enhance the evidence base around the source apportionment of sites with high Ni concentrations.

Ø1

Intervention area Ø: EU air quality standards for pollutants of emerging concern

Intervention (Ø1) Introduce air quality standards for additional pollutants

The problem: Health outcome shortcomings: Exceedances above health guidelines and negative health impacts persist

Description:

Introduce standards to the AAQ Directives for air pollutants for which there are no WHO guideline levels or reference levels (e.g. ammonia, black carbon (BC), ultra-fine particles (UFP), others). These could take the form of annual or peak standards, and could be expressed as limit, target values or otherwise.

WHO did not recommend introducing standards at this stage (except 'where appropriate for BC'). The focus of WHO recommendations is on action to enhance further research on risks and approaches for mitigation. WHO concluded that as yet, there is insufficient data on which to provide recommendations and interim target levels for BC, UFP and ammonia. Thus, setting standards would go beyond latest scientific advice and the extent to which they may reduce negative health impacts is uncertain.

Purpose/operational objective: To reduce exposure to harmful levels of air pollution, with reference to best-practice guidance regarding safe levels of exposure. This would reduce exposure to air pollution, therefore reducing negative health impacts.

Who would be impacted and how:

Direct: Citizens currently exposed to poor air quality would benefit from this intervention. In particular, citizens working in agriculture (ammonia) and citizens residing in urban areas likely to be exposed to high concentration values of BC and UFP. Citizens with existing medical conditions and citizens in vulnerable groups (such as babies, children, the elderly) are at higher risk to exposure and therefore health benefits are expected to be greater for vulnerable groups as a result.

Indirect: Households, and indirectly businesses will benefit from the reduction in negative health impacts associated with higher levels of air pollution.

Risks for implementation: Implementation will require introducing new legal provisions to those currently in 2008/50/EC. While the WHO Guideline values do not include specific recommendations (meaning there is no scientific reference point on which to base a standard), it is understood that reducing exposure will lead to health benefits. Thus, setting standards would go beyond latest scientific advice and the extent to which they may reduce negative health impacts is uncertain.

Indicators

1. Air Quality	2. Impact on Health	3. Impacts on Ecosystems	4. Climate change links	5. Costs to society	6. Mitigation costs	7. Impacts on Competitiveness	8. Impacts on Sensitive Groups	9. Societal benefits and burden sharing	10. Impacts on Employment	11. Policy synergies	12. Administrative Burden
0 to ++	0 to +	0 to +	0 to +	0 to +	0 to --	+/-	0 to +	+ / -	+/-	0 to +	0 to ---

Assessment

Effectiveness:

The effectiveness of this intervention in relation to the impact on air quality and ecosystems will vary with ambition and benefits only become significant with medium to high levels of ambition. Setting standards would go beyond latest scientific advice and the extent to which they may reduce negative health impacts is uncertain. This intervention in the form of target values could provide the first step towards setting limit values as it would require monitoring concentrations and this information could subsequently be used to set limit values – indeed this intervention could improve the effectiveness of linked monitoring interventions (L1 and L2).

Stakeholders (TSS) stated clearly that there is unease with current levels of pollution. In response to the TSS, of those that responded 'yes', 'not yet' and 'no', for ammonia and BC a slight majority selected 'yes', a standard is needed to regulate concentrations. For UFP, 'yes' was a significant minority response. However, the response was mixed with all answers receiving a significant minority. In addition, when including both 'no opinion' and 'no reply' responses, those that answered 'yes' were in the minority for all pollutants.

Furthermore, when reviewing the open-text responses for those that answered affirmatively, many noted that more monitoring and evidence is needed, both around existing pollution levels and health effects, to understand the scale of the problem before standards can be set. There was a clear preference amongst stakeholders that annual targets were favoured over peak targets for these pollutants.

Given stakeholder concern and that UFP, as part of the wider PM category, is part of the group of air pollutants with which the most significant health effects are associated, this intervention could have positive, moderately significant impacts [Air Quality: 0 to ++], although the extent of improvement will vary according to the level of ambition. The significance of the health benefits is uncertain as there is limited evidence of current levels of pollutants and associated health impacts [Health impacts: 0 to +].

Reduced concentrations of ammonia will directly benefit ecosystems, thus mitigating acidification and eutrophication [Ecosystem impacts: 0 to +].

Stakeholder responses gathered from the TSS are mixed as regards regional level intervention or national, particularly for annual obligations. Although based on the open text responses, stakeholders have stated a clear preference for local or regional level intervention, rather than national – and indeed, there is emphasis on local (including by air quality zone or agglomeration) rather than regional among responses received. Opinion was also mixed on whether standards were needed to manage pollution peak concentrations for these pollutants.

The costs of attaining the reduction targets may fall on vulnerable people (those living in poorer areas with lower education), where measures to attain the reduction targets are likely to address emissions from domestic heating although the balance of impacts very much depends on implementation [Societal benefits: + / -]. By facilitating a targeted response to areas with high concentrations of BC and UFP, this intervention is expected to contribute to the protection of human health for those living in poorer areas, including citizens with existing medical conditions and citizens in vulnerable groups (such as babies, children, the elderly) and agro-industrial workers [Sensitive groups: 0 to +].

Efficiency:

Recognising the variants for this intervention, it is understood that the potential efficiency would scale with level of ambition.

This intervention can contribute to the protection of human health but the evidence base is uncertain (for BC and UFP) [Costs to society: 0 to +].

Mitigation costs will be incurred from measures to attain the reduction targets and while costs are dependent on implementation, they will be significant [Mitigation costs: 0 to --]. Measures to attain the targets are likely to address emissions from domestic heating, road transport and agriculture.

The administrative burden is dependent on the number of additional areas of exceedance that require air quality plans as a result of the average exposure indicator – noting though that the scope of pollutants for this intervention are not currently regulated under the AAQ Directives and thus the administrative burden will be greater than if it was building on existing provisions [0 to ---].
The impact on employment and competitiveness [+/-] is unclear as it is dependent on implementation but may hold costs for key sectors (e.g. agriculture) but could also bring health benefits which in turn would benefit business.

Coherence:
Revisions to the average exposure obligations would facilitate the improvement of air quality by reducing concentrations of ammonia, black carbon and ultra-fine particles. This is aligned with wider policy objectives to achieve zero pollution and emission reductions under the NECD [Policy synergies: 0 to +]. The intervention is also expected to contribute to climate changes policies, particularly as measures to abate black carbon will also reduce GHG emissions [Climate change links: 0 to +].

Links to other interventions: [synergies / misalignment]*/

- L1 and L2 - without monitoring it would not be possible to enforce (and even set) standards. Indeed having a standard would drive the requirement for monitoring and increase the effectiveness of this measure.
- O/P/Q - action to tackle other air pollutants will also somewhat reduce emissions and concentrations of emerging pollutants

Benefit to Cost ratio: The benefit-to-cost ratio would be **low**:

- The extent to which it contributes to air quality improvements and ecosystems are dependent on the level of ambition. Setting standards would go beyond latest scientific advice and the extent to which they may reduce negative health impacts is uncertain. This intervention would provide the first step towards setting limit values as it would require monitoring concentrations and this information could subsequently be used to set limit values.
- Costs are significant, arising primarily from measures to attain the reduction targets and administrative burden. There is potential to reduce the administrative burden by taking more coordinated and centralised action; however, as none of the pollutants are currently in scope, the administrative burden of introducing this intervention would be significant (as well as the costs associated with additional monitoring required).

Summary The impact on air quality and ecosystems will vary with ambition and benefits only become significant with medium to high levels of ambition. Setting standards would go beyond latest scientific advice and the extent to which they may reduce negative health impacts is uncertain. This intervention in the form of target values could provide the first step towards setting limit values as it would require monitoring concentrations and this information could subsequently be used to set limit values – indeed this intervention could improve the effectiveness of linked monitoring interventions (L1 and L2). Administrative burden will vary with ambition (with more air quality plans required in cases of the high ambition variant to account for the greater number of exceedances – with scope to reduce this burden through coordinated action). There will be costs associated with additional monitoring required (link to L1 and L2).

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