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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

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

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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Executive summary

Ambient air pollution is recognised as the single biggest environmental threat to human health (WHO, 2021). Ambient air pollution is a principal source of morbidity and mortality, and it is estimated that it causes 4.9 million premature deaths worldwide every year due to health risks such as stroke, heart disease, and lung cancer (WHO, 2021).

As part of the European Green Deal, the Commission adopted the EU Action Plan "Pathway to a Healthy Planet for All: EU Action Plan: 'Towards Zero Pollution for Air, Water and Soil'" on 12 May 2021. The Plan aims to reduce air, water and soil pollution levels so that they are no longer considered harmful to health and natural ecosystems by 2050. As part of this, the EU is revising the Ambient Air Quality Directives (AAQ Directives), to align air quality standards more closely with the recommendations of the World Health Organisation (WHO) (WHO, 2021). The revision also aims to build on the lessons learnt from the 2019 evaluation ('fitness check') of the AAQ Directives (European Commission, 2019), including that the Directives have been partially effective in improving air quality, but not fully effective, particularly where there is a remaining gap to achieve air quality standards in certain cases. The Fitness Check outlined several lessons learnt to inform policy making. The purpose of this study is to support the European Commission with the revision of the AAQ Directives and its accompanying impact assessment.

Four problem areas have been defined to frame the planned revision to the AAQ Directives. These are: 1) environment and health shortcomings, 2) enforcement and governance shortcomings, 3) monitoring and assessment shortcomings, and 4) information and communication shortcomings. This study identified, developed and assessed policy options and interventions contained therein to address these problems. Three general, and five specific objectives that the options and interventions should achieve were identified and summarised in the table below.

Category of objectives	Description
General	• to avoid, prevent or reduce the harmful effects of air pollution on human health and the environment, in line with the European Green Deal and the Zero Pollution Action Plan; • to further enhance the effectiveness of EU air quality legislation; • to improve the efficiency of the legislation taking into account the lessons learnt from the fitness check, making it easier to meet a given level of effectiveness.
Specific	• Improve ambient air quality to the extent possible taking into account the latest scientific advice, feasibility, costs, and benefits – and ensure legislation can respond in an appropriate and effective manner to future changes in underlying evidence base. • Assure air quality plans are an effective means of identifying, planning and mitigating an exceedance situation (by taking relevant, effective and proportionate measures) – and include clearer provisions on stakeholder participation, access to justice, penalties and compensation linked to clean air in EU legislation. • Further improve monitoring as an effective and reliable tool which is consistently applied to identify exceedance areas – and harvest opportunities offered by air quality models to underpin the development of plans and monitor exceedances.

Category of objectives	Description
	• Provide information to citizens around health impacts of air pollution issues (targeting the concerns of citizens) – and ensure that the public in all Member States receive the same high quality and timely information about their air quality. • Simplify existing provisions where feasible to improve the effectiveness and efficiency of air quality management – and decrease associated administrative burden if and where possible.

The assessment is structured according to the three key areas:

- Policy Area 1: a closer alignment of the EU air quality standards with scientific knowledge including the latest recommendations of the World Health Organization (WHO).
- Policy Area 2: improving the air quality legislative framework, including provisions on penalties and public information, in order to enhance effectiveness, efficiency and coherence.
- Policy Area 3: strengthening of air quality monitoring, modelling and plans.

In total, 69 interventions were identified and considered as part of the Impact Assessment study: 22 in Policy Area 1 (further assessed in groups of 7 scenarios), 27 in Policy Area 2 and 20 in Policy Area 3.

Each intervention has a number of associated impacts, with the exact impact, size and significance depending on the individual intervention. To assess the impacts, the study has followed a methodology designed to meet the requirements of the Better Regulation Guidelines (European Commission, 2021) and to provide the European Commission with timely evidence collection, stakeholder engagement and analysis of information gathered.

Based on the Better Regulation Guidelines, interventions should be compared on the basis of how they address the objectives considering their effectiveness, efficiency and coherence. All interventions were screened for their likely key economic, environmental, and social impacts across the core stakeholders affected – competent authorities, other public authorities, industry (large and smaller businesses), citizens and workers. Twelve indicators have been defined to capture and present the key economic, environmental, and social impacts associated with the interventions being considered. All interventions across the three Policy Areas were appraised against this set of indicators, to ensure consistency in the analysis and presentation of results. Across each of these specific indicators, available evidence on the effectiveness, efficiency and coherence of the Policy Packages was collated, assessed and, where possible, quantified in comparison to the baseline. To support the assessment of impacts, evidence gathering has comprised of three main activities: Quantitative modelling, in particular focusing on the impacts of different air quality standards under Policy Area 1 - this has been carried out using an integrated assessment framework which has been extensively deployed to explore projections of air pollution and the impacts of mitigation strategies at EU-level under similar studies; detailed literature review and extensive stakeholder engagement.

Following the assessment, the interventions have then been grouped into illustrative policy packages, combining interventions across Intervention and Policy Areas. These packages are combined and assessed in order to explore the interactions, linkages and dependencies between interventions in different Intervention and Policy areas.

Assessing air quality, addressing exceedances of standards, providing timely information to the public and ensuring all stakeholders play their part to establish clean air for all, are complex processes with many interlinkages between these activities. Overall, each of these activities have substantial importance and each should be addressed for a successful improvement to the delivery of clean air across Europe. In reaching such policy decisions it is important to recognise the synergies between the various policy options and all of the policy sub-options.

The cost-benefit analysis conducted suggests there are significant benefits to be gained from setting more ambitious air quality standards, and that the benefits gained are likely to significantly outweigh the costs. In setting revised objectives for pollutants of concern, consideration should be given not only to the value to gained for human health and the environment, but also to how such objectives could be met and at what cost, how revisions in monitoring and assessment may impact on these and how such information can be readily communicated to the public. Furthermore, even if objectives for pollutants are not revised, should changes be made to aspects of monitoring and assessment, then this may impact on the pollution burden. For example, should the use of more monitoring, such as indicative monitoring and/or modelling be encouraged through policy sub-options, then the understanding of pollutant levels across a wider spatial area may increase and impact on where action should be taken.

The improvement of air quality plans is seen as a key success factor of a revised Directive. This is required to bring transparency to the measures Member States are to implement in cases of non-compliance. Improvement is needed on the effectiveness and efficiency of air quality plans. For any revised air quality objectives set for pollutants it is important that a pathway to compliance can be set out within an updated air quality planning process. Key milestones on this pathway to compliance should be transparent and policy sub-options to address the governance and enforcement of the directive should be considered crucial to achieve revised air quality objectives in the near term.

Some policy sub-options proposed consider the longer term air quality across Europe. While air quality modelling of pollutants to 2030 and 2050 have been presented to support this impact assessment, other longer term issues such as the importance of pollutants of emerging concern have also been considered. In addition, the consideration of a regular review of EU air quality standards is also proposed. Gathering data and information on current levels of such emerging pollutants to support research will be key to inform how we should deal with such pollutants over the longer term as the scientific evidence increases.

All 69 interventions have been assessed against 12 indicators which cover environmental, societal, economic and cost consequences/impacts and all offer benefits to the improvement of air quality for human health and the environment. While these have been amalgamated into policy options to address the identified shortcomings of the AAQ Directive, some of the interventions offer lower benefits when assessed in isolation. However, many of these are likely to bring more benefits when assessed synergistically with other interventions. For example, many interventions under the policy option for monitoring and assessment are a prerequisite to determine levels of pollution and how these compare to any revised air quality standards. These interlinkages between and within policy options are therefore an important aspect of bringing these together into an integrated policy package for further consideration by decision makers to deliver a clear pathway for cleaner air for all.

1 Introduction

1.1 Introduction to the report

This is the Final Report for the "Study to support the impact assessment for a revision of the EU Ambient Air Quality Directives", which is Service Request 28 under framework contract ENV.F.1/FRA/2019/0001. The specific contract commenced on 29 April 2021 and runs until 29 October 2022 (i.e. 18 months). This report has been submitted by Ricardo, the lead consultants appointed to conduct this study in partnership with Trinomics, VITO, Norwegian Meteorological Institute and IIASA.

This report is structured as follows:

- Section 2 presents an overview of the political and legal context;
- Section 3 discusses the problems and drivers under consideration in this impact assessment study;
- Section 4 outlines the rationale for EU action;
- Section 5 sets out the objectives for the interventions;
- Section 6 presents a summary of the approach to evidence gathering and analysis;
- Section 7 outlines the baseline and options to achieve the objectives;
- Section 8 presents the results of the quantitative modelling assessment around air quality standards;
- Section 9 presents the analysis of the interventions;
- Section 10 presents analysis of the illustrative policy packages;
- Section **Error! Reference source not found.** summarises the analysis of policy options;
- Section **Error! Reference source not found.** sets out a framework for monitoring and evaluation of the impacts.

The main body of the report is supported by several detailed appendices, which include the stakeholder consultation synopsis (Appendix 2), a more detailed description of the methodologies and approaches adopted to appraise the impacts (Appendices 3 – 8), and the results of the analysis for individual interventions (Appendix 10).

1.2 Objectives of the study

Assuring the best possible air quality, minimising population exposure to harmful levels of air pollutants and reducing their deposition to ecosystems have been on the agenda of the EU for several decades. Policies aimed at reducing emissions have brought a continuous decline in the levels of most air pollutants in the EU in recent decades. However, air pollution continues to be a significant problem (Section 3.1).

The EU's strategy to improve air quality rests on three pillars:

1. Ambient air quality standards set out in the Ambient Air Quality Directives (AAQ Directives). Member States which exceed the limit values are required to develop and adopt air quality plans;
2. The national emission reduction obligations set by the National Emission reduction Commitments Directive (NEC Directive) for the most important transboundary air pollutants;

3. Emission limits and efficiency standards for key sources of air pollution. These standards are set out at EU level in dedicated legislation.

The main objectives of the AAQ Directives are to: define common methods to monitor and assess air quality; ensure that information on air quality is made public, maintain good air quality and improve it where it is not good, and establish standards of air quality to achieve across the EU. The AAQ Directives set out standards for 12 pollutants: Fine particulate matter ($PM_{2.5}$), Particulate matter (PM_{10}), Sulphur dioxide (SO_2), Nitrogen dioxide (NO_2, including Nitrogen oxide, NO_x), Lead (Pb), Carbon monoxide (CO), Benzene ($C_6 H_6$), Ground-level ozone (O_3), Arsenic (As), Cadmium (Cd), Nickel (Ni) and Benzo(a)pyrene (BaP).

As part of the European Green Deal, the Commission adopted the EU Action Plan "Pathway to a Healthy Planet for All: EU Action Plan: 'Towards Zero Pollution for Air, Water and Soil'" on 12 May 2021. The Plan aims to reduce air, water and soil pollution levels so that they are no longer considered harmful to health and natural ecosystems by 2050. As part of this, the EU is revising the AAQ Directives, to align air quality standards more closely with the recommendations of the World Health Organisation (WHO) (WHO, 2021). It is important to recognise that the WHO guideline values do not consider the technical feasibility or the economic, political and social aspects of the achievement of the guideline levels; thus, assessing the full impacts of the differing guideline values is important.

The revision also aims to improve overall EU legislation for clean air, building on the lessons learnt from the 2019 evaluation ('fitness check') of the AAQ Directives (European Commission, 2019). Namely that the Directives have been partially effective in improving air quality, but not fully effective, particularly where there is a remaining gap to achieve air quality standards in certain cases. The Fitness Check outlined several lessons learnt to inform policy making.

The purpose of this study is to support the European Commission with the revision of the AAQ Directives. This assessment focusses on revisions that aim to ensure that future legislation takes the latest scientific evidence for the protection of human health and the environment into account. It is accompanied by consideration of options to strengthen the basis for effective action, including via better air quality monitoring, modelling and air quality plans. The assessment is structured according to the three key areas established by the Inception Impact Assessment (European Commission, 2021):

- Policy Area 1: a closer alignment of the EU air quality standards with scientific knowledge including the latest recommendations of the World Health Organization (WHO).
- Policy Area 2: improving the air quality legislative framework, including provisions on penalties and public information, in order to enhance effectiveness, efficiency and coherence.
- Policy Area 3: strengthening of air quality monitoring, modelling and plans.

Alongside this impact assessment support study, a separate but related study ran in parallel, exploring non-legislative solutions to the shortcomings considered in this study: "Strengthening of air quality monitoring, modelling and plans under the Ambient Air Quality Directives" (Conlan et al., 2022). This study complements the evidence gathered under the present impact assessment support study, and is referred to throughout.

2 Political and legal context

2.1 The issue of air quality: general overview on why legislation is relevant

Air pollution and poor air quality is one of the biggest current global environmental and health challenges (see Section 3.1). To manage the negative effects on human health and the environment, since the early 1970s the EU has aimed, through a series of instruments, standards, and legislative packages to achieve healthy levels of air quality.

2.2 European level

2.2.1 *Legislation targeting directly the improvement of air quality*

The first major legislative instrument concerning air quality to be introduced by the EU was the Air Quality Framework Directive 96/62/EC and its daughter Directives, which established air quality standards for a range of pollutants including ozone, particulate matter (PM_{10}) and nitrogen dioxide (NO_2), in the period up to 2004. There are two current Ambient Air Quality Directives (or "AAQ Directives"): 2008/50/EC and 2004/107/EC. Directive 2008/50/EC on ambient air quality and cleaner air for Europe[1] establishes ambient air quality objectives to reduce harmful effects on human health and the environment. It sets out the methods of assessing ambient air quality in Member States, sets limit and targets values for key pollutants (SO_2, NO_2, PM_{10} and $PM_{2.5}$, Pb, CO, C_6 H_6) and promotes transparency and cooperation between Member States. Directive 2008/50/EC merged previously existing EU air quality legislation[2,3,4] into a single directive, with the exception of Directive 2004/107/EC relating to As, Cd, Hg, Ni, and polycyclic aromatic hydrocarbons (PAH) in ambient air[5] (Fourth Daughter Directive), which continued to be a stand-alone directive. Directive 2004/107/EC sets target values for these pollutants to reduce their effects on human health and the environment. Hereafter these Directives (2008/50/EC and 2004/107/EC) are referred to jointly as "AAQ Directives".

In 2013, the Clean Air Policy Package was adopted based on a review of EU policy to date. This policy package included a Clean Air Programme for Europe (European Commission, 2013) – setting objectives for 2020 and 2030 - as well as a proposal for Directives on the reduction of national emissions of certain atmospheric pollutants (the NEC Directive) and on the limitation of emissions of certain pollutants into the air from medium combustion plants (the MCP Directive[6]). This was followed, in 2018, by the adoption of a Communication: "A Europe that protects: Clean air for all" that provided national, regional and local actors with practical help to improve air quality in Europe.

The European Commission completed a Fitness Check in 2019 (European Commission, 2019) of the AAQ Directives to examine whether they had been successful in meeting their objectives between 2008 to 2018 through public consultations and stakeholder workshops. It evaluated the relevance, effectiveness, efficiency, coherence, and EU added value of these Directives. The Fitness Check concluded that these Directives have been partially effective in improving air quality and achieving air quality standards but that not all their objectives had been met.

1 https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX%3A32008L0050
2 https://eur-lex.europa.eu/legal-content/en/ALL/?uri=CELEX%3A31996L0062
3 https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A31999L0030
4 https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32000L0069
5 https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32004L0107
6 https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32015L2193

The Fitness Check of the AAQ Directives found that although provisions on air quality standards (i.e. limit and target values) were seen as successful in incentivising action across Member States leading to a general lowering of air pollutant concentrations, current air quality standards for several pollutants, including $PM_{2.5}$, are not as ambitious as recent scientific advice suggests is appropriate for the protection of public health.

The Fitness Check also found that the AAQ Directives have given flexibility to competent national authorities to ensure air quality monitoring and air quality measures optimally fit local circumstances (in line with the subsidiarity principle). However, additional guidance or implementing acts could help to further harmonise the approaches applied to monitoring, information provisions, and air quality plans and measures. Air quality plans were identified as one of the most fundamental elements of the AAQ Directives in terms of incentivising remedial action by EU Member States. Nonetheless, compliance verification was found to be hampered through the lack of clear requirements for Member States to report on the implementation of air quality plans or update them with additional measures when progress is insufficient. Coordination and consistency in the actions of authorities within and across Member States was also deemed insufficient. In addition, the flexibility offered to Member States' competent authorities with regards to their monitoring network was argued by some to give too much leeway, reducing confidence in the comparability of monitored air quality. However, the Fitness Check concluded that this does not appear to amount to a systemic shortcoming in the EU-wide monitoring network: overall, the monitoring network ensures that reliable and representative air quality data is available.

Finally, the Fitness Check found that the successful establishment of an EU-wide e-reporting system based on machine-readable formats encourages up-to-date reporting of air quality data and supports further use of air quality modelling which is increasingly reported but would benefit from further guidance. Further elaboration of the problems identified in relation to the AAQ Directives are presented in Section 3.

In addition, the European Green Deal, approved in 2020, introduced a set of policy initiatives with the overarching aim of making the EU climate neutral by 2050. This included initiatives to further enhance the EU air quality legislation to avoid, prevent or reduce the harmful effects of air pollution on human health and the environment. As set out in the introduction to this study, the EU has adopted a Zero Pollution Action Plan as part of the Green Deal which (among other things) sets out the ambition to revise EU pollution standards to align them more closely with the latest WHO Air Quality Guidelines (WHO, 2021).

In July 2021, as part of the EU Recovery Plan (in place to tackle the socio-economic consequences of the COVID-19 pandemic), EU leaders agreed on a comprehensive package of €1 824.3 billion which combines the €1 074.3 billion multiannual financial framework (MFF) and an extraordinary €750 billion recovery effort, Next Generation EU to help transform the EU through its major policies, particularly the European Green Deal, the digital revolution and resilience. It was also agreed that 30% of the total expenditure from the MFF and Next Generation EU would target climate-related projects. The Plan also presents an opportunity to prioritise clean air, as it flags an urgent need to boost residential and public building renovations to kick-start the EU economy and reduce emissions.

2.2.2 *Other relevant pieces of EU legislation regarding air quality*

In addition to these key pieces of legislation and overreaching policy packages to improve air quality in the EU, the Commission has set regulations around the main sources, and main pollutants, within the Union. This includes the following:

- Road transport: emissions of PM, NO_x, unburnt hydrocarbons (HC) and CO are regulated within the EU framework for the type approval of cars, vans trucks, buses and coaches – commonly known as "Euro" standards for light-duty vehicles (cars and vans)[7] and heavy-duty vehicles (trucks, buses and coaches)[8].
- Non-Road Mobile Machinery (NRMM): since 2017, emissions from these engines are regulated by the 'NRMM Regulation': Regulation (EU) 2016/1628[9] on requirements relating to gaseous and particulate pollutant emission limits and type-approval for internal combustion engines for non-road mobile machinery.
- Maritime transport: SO_2 emissions from shipping in the EU are regulated in Directive (EU) 2016/802[10]. Since 2020, ships in all EU waters (except SO_x-ECAs) are required to use fuels with a sulphur content of no more than 0.5%.
- Agriculture: ammonia (NH_3) emissions reductions measures are included in Annex III part 2 of the NEC Directive[11].
- Energy and industrial sources: Emissions from these sources have been reduced thanks to a series of regulations including: the Energy Efficiency Directive[12], the Industrial Emissions Directive[13] and the Directive on the Sulphur Content of Certain Liquid Fuels[14].
- Paint: Emissions of volatile organic compounds due to the use of organic solvents in paints are regulated by Directive 2004/42/EC ("the Paints Directive")[15].
- Domestic heating: Commission Implementing Regulations under the Ecodesign Directive (2009/125/EC)[16] set emission limit values for solid fuel local space heaters ((EU) 2015/1185)[17] and for solid fuel boilers ((EU) 2015/1189)[18]. Emission limit values are complemented by energy labelling provisions adopted via the Energy Labelling Directive (2010/30/EU)[19] for energy labelling of local space heaters (Commission Delegated Regulation (EU) 2015/1186)[20] and for solid fuel boilers (Commission Delegated Regulation (EU) 2015/1187)[21].

2.2.3 *Main international EU commitments regarding air quality*

In the international context, the EU has participated and shaped the discussion around air quality through its commitments to, and participation in, a series of Conventions, among which the following stand out:

- Participation in the UNECE Convention on Long-Range Transboundary Air Pollution (the Air Convention), adopted in 1979. This Convention has been extended by 8 Protocols, of which the EU is part of seven. The original Gothenburg protocol (adopted in 1999), formed the basis for the original NEC Directive 2001/81/EC[22]. The protocol was revised in 2012 and the reduction

[7] https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX:32007R0715
[8] https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX%3A32009R0595
[9] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex:32016R1628
[10] https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX%3A32016L0802
[11] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv%3AOJ.L_.2016.344.01.0001.01.ENG
[12] https://eur-lex.europa.eu/eli/dir/2012/27/oj
[13] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32010L0075
[14] https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX%3A32016L0802
[15] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32004L0042
[16] https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=celex%3A32009L0125
[17] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv%3AOJ.L_.2015.193.01.0001.01.ENG
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[19] https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX%3A32010L0030
[20] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32015R1186
[21] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv%3AOJ.L_.2015.193.01.0043.01.ENG
[22] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32001L0081

commitments established for 2020 for the EU and its Member States have been transposed into EU law by the new Directive on National Emission Reductions (Directive 2016/2284/EU[23]). The amended protocol was ratified by Council Decision (EU) 2017/1757[24] in follow-up to the Commission Clean Air Policy Package.

- Participation in the UN Environmental Programme, Stockholm Convention on Persistent Organic Pollutants, adopted on 22 May 2001.
- Participation in the work on UN Environmental Assembly resolution UNEP/EA.3/Res.8 (UNEP, 2017) (December 2017) on Preventing and reducing air pollution to improve air quality globally.
- Commitment to the UN Sustainable Development Goals, several of which are directly or indirectly linked to improvements in air quality.
- Adoption of the 2015 World Health Assembly Resolution which emphasised the need to redouble the efforts of Member States and WHO to protect populations from the health risks posed by air pollution.
- Participation in the WHO ministerial conferences on environment and health.
- Commitment to the WHO guidelines on air quality, which are used as the scientific basis for legislation for the EU Directives.

2.3 International level

In 1958, the WHO released its first publication in the WHO Technical Report Series on air pollution and health – known as *Air pollution* (WHO, 1958). The report was concise, mainly providing an overview of air pollution science, the sources of air pollutants, factors affecting ambient concentrations, methods of measuring concentrations of pollutants and effects on health. This was the first time that the introduction of air quality guidelines (AQGs) was considered. In 1964, the WHO published a new report - *Atmospheric pollutants* (WHO, 1964) – which called for international guides to air quality. This eventually led to the development of the first edition of the WHO AQGs.

The first edition of the WHO AQGs was published in 1987, known as *Air quality guidelines for Europe* (WHO, 1987). It provides recommendations in the form of numerical values/ranges or unit risk factors for a total of 28 air pollutants (including Cd, CO, Pb, O_3, NO_2, SO_2, among others). The second edition of these guidelines was published in 2000. In it, the WHO set out guideline values for many individual substances (updating and consolidating earlier recommendations on air pollution) with the intention of providing instruction on how to avoid the adverse health implications linked to air pollution (WHO, 2000). The document provided recommendations in the form of numerical values/ranges and unit risk factors for the pollutants included in the previous edition, in addition to butadiene, polychlorinated biphenyls, dibenzodioxins and dibenzofurans, fluoride and platinum. A separate section for indoor air pollutants was also provided.

The guidelines on reducing the effects on health of air pollution for PM, O_3, NO_2, and SO_2 were updated, in a new WHO publication, in 2005 (WHO, 2005). This was the first time that interim targets were proposed for PM, O_3 and SO_2.

The guidelines for these pollutants were subsequently reviewed and updated in 2021 (WHO, 2021). The key outcomes of this publication are new air quality guideline exposure levels and interim targets for

[23] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv%3AOJ.L_.2016.344.01.0001.01.ENG
[24] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv:OJ.L_.2017.248.01.0003.01.ENG

$PM_{2.5}$, PM_{10}, O_3, NO_2, SO_2 and CO. In addition to the guideline exposure levels, the WHO has also outlined a series of less stringent interim targets for $PM_{2.5}$, PM_{10}, SO_2 and O_3, which, if met, would still be expected to lead to a significant decline in health conditions and diseases as a result of air pollution. The WHO also provides guidance for policymakers when considering air quality management opportunities and summarises information on air pollution sources, population exposure, quantifying the health burden of air pollution, and developing air quality standards.

2.4 National level

For the purposes of air quality assessment and management, the AAQ Directives oblige Member States to divide their territories in zones and agglomerations, each of which has to be classified in relation to the assessment thresholds for ambient concentrations of each pollutant. The Directives, require Member States to ensure compliance with the limit and target values; therefore, air quality plans – to reduce concentration of air pollutants - are required in polluted zones and agglomerations where there are exceedances.

The Fitness Check of the AAQ Directives included an analysis of the monitoring and assessment regimes for all the Member States in 2015, as well as case studies on the implementation of the air quality legislation in Bulgaria, Germany, Ireland, Italy, Slovakia, Spain, and Sweden.[25] In the analysis the number and type of nitrogen dioxide and particulate matter sampling points reported by the Member States to the Commission for the year 2015, compared to their minimum required number, without considering the use of other methods such as modelling or indicative measurement was reviewed and gaps identified. Overall, it was concluded that the Directives were partially effective in improving air quality and achieving air quality standards in the EU; that the remaining gap to achieve the agreed standards is too wide in certain cases; and that action taken by Member States to meet air quality standards and keep exceedances as short as possible was insufficient.

While the AAQ Directives set a series of standards on pollutant concentrations in ambient air for all Member States to comply with, the NEC Directive sets national reduction commitments for the emissions of five pollutants (SO_2, NO_x, volatile organic compounds (VOCs), NH_3 and $PM_{2.5}$). National air quality strategies and plans should set out the nation's air quality objectives and recognise that action at different scales may be required to meet the air quality guidelines at national, regional, and local levels. Each Member State also has the option of setting more strict standards for air pollutants in their national legislation. Therefore, national legislation of air quality standards, as well as measures implemented to reduce the effects of poor air quality, vary between Member States.

For example, in Sweden, air quality standards imposed by the AAQ Directives are relevant, but the Swedish legislation goes beyond the values imposed in the AAQ Directives, for example setting a daily limit value for $PM_{2.5}$ and for NO_2 (which is not contemplated in the Directives), as well as lower hourly limit values for SO_2 (while it is set at 350µg/m^3 in the Directives, Swedish standards set it at 200µg/m^3). In Ireland, there are additional complementary laws regarding residential solid fuel use (primary source of fine particulate matter air pollution in the country) for which there is no EU legislation. Further examples on how legislation and policy measures to control and reduce pollutants emission and

25 https://circabc.europa.eu/ui/group/cd69a4b9-1a68-4d6c-9c48-77c0399f225d/library/b5d2b8f5-a6c4-4610-b1ed-fad52af779f1?p=1&n=10&sort=modified_DESC

concentrations align or go beyond the standards set by the AAQ Directives are detailed in the Fitness Check case studies of Bulgaria, Germany, Spain, Slovakia (European Commission, 2019).

3 What is the problem and why?

3.1 The problem of air pollution

Ambient air pollution is recognised as the single biggest environmental threat to human health (WHO, 2021). Ambient air pollution is a principal source of morbidity and mortality, and it is estimated that it causes 4.9 million premature deaths worldwide every year due to health risks such as stroke, heart disease, and lung cancer (WHO, 2021).

Over the past decade, public awareness surrounding the global challenge of air pollution and its health implications has grown. Governments are being increasingly pressurised by NGOs, public health communities, and citizens who are demanding legislative changes to manage local, national, and global air quality. Additionally, the economic burden due to poor health and diseases caused by air pollution increases the pressure on governments to improve air quality. Some NGOs and citizen stakeholders have initiated court cases against local authorities and governments for poor air quality that does not meet legal standards. Such cases have been won by NGOs in courts in EU jurisdictions. Recent judgements passed include:

- Against France (October 2019)[26], Federal Republic of Germany (June 2021)[27] and the UK (March 2021)[28] for systematic exceedance of NO_2 limit values in certain zones and failure to keep the exceedance period as short as possible.
- Against the Italian Republic (November 2020)[29] and Romania (April 2020)[30] for systematic and persistent exceedance of PM_{10} and failure to keep the exceedance period as short as possible (November 2020).

In total, the European Commission has ongoing air quality infringement cases against 13 Member States for NO_2, 14 Members States for $PM_{2.5}$/PM_{10} and 1 Member State for SO_2[31]. In addition, there are breaches of the EU Ambient Air Quality Directives' limit values and parameters for air quality monitoring (European Commission, 2022).

The EU aims to improve overall EU legislation for clean air, in particular, where the implementation and operation of the EU legislation could be improved to more effectively and efficiently deliver its objectives, as identified by the Fitness Check. Findings from the Fitness Check show that:

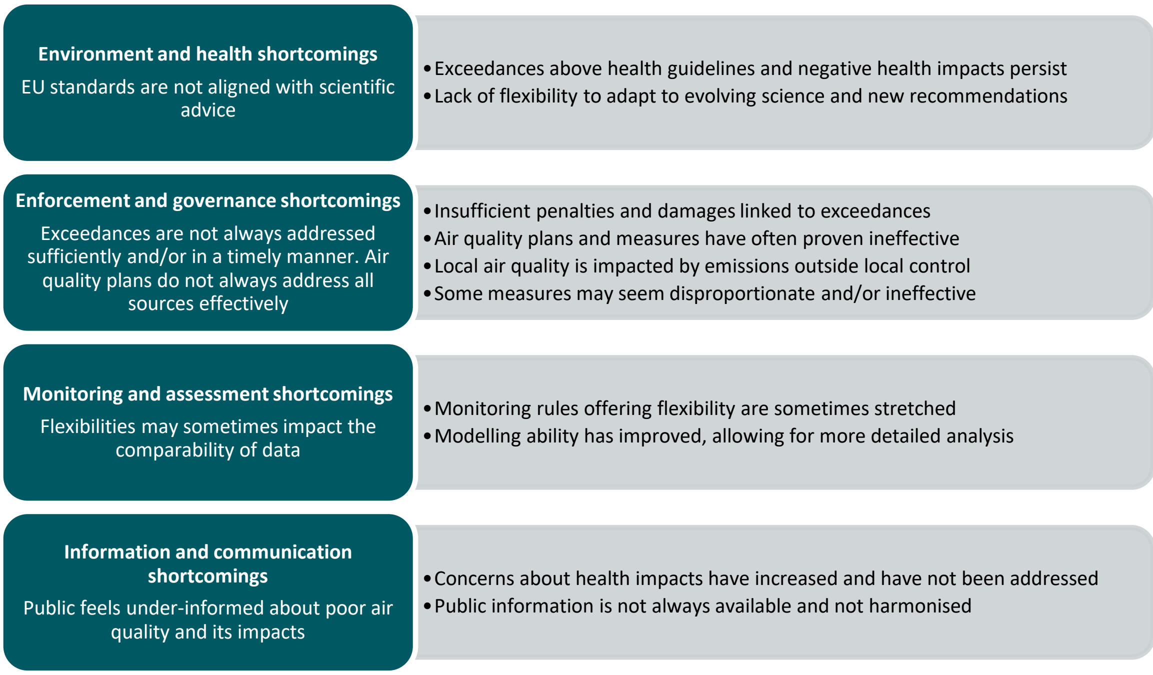
- There are ongoing health and environmental challenges in the EU caused by poor air quality and exposure to harmful air pollutants;
- Existing standards exceed the current health guidelines based on scientific evidence. There is no legal flexibility to amend the standards in accordance with evolving technologies and science;
- While air quality standards contribute to improved air quality, limit values are more effective than target values, and provisions are not designed to minimise short term exposure;
- Ongoing exceedances are indicative of the fact that existing penalties are failing as a deterrent, while legal enforcement action is an effective tool;

[26] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A62018CJ0636&qid=1653906483310
[27] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A62018CJ0635&qid=1653906057988
[28] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A62018CJ0664&qid=1653906483310
[29] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A62018CJ0644&qid=1653906483310
[30] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A62018CJ0638&qid=1653906483310
[31] Communication with European Commission, May 2022

- Inconsistencies between Member States regarding air quality plans, monitoring, modelling and information reduce the effectiveness of air quality standards:
  - Exceedances are occurring despite the measures set in air quality plans;
  - Measures can be considered disproportionate to the exceedance;
  - Local air quality is affected by emissions outside the local area. Air quality plans do not always facilitate planning with stakeholders responsible for emission sources (a problem where local air quality is impacted by emissions outside the air quality zone);
  - Flexibilities provided by the AAQ Directives have led to disparate approaches to monitoring and modelling that make it difficult to assess and report air quality in a comparable way.
- Reporting on air quality can be made more accessible (as regards monitoring and modelling data, and air quality information more generally). Despite public interest, information on air quality is not always made publicly available.

Four problem areas have been defined by the European Commission in its Intervention Logic to frame the planned revision to the AAQ Directives. These are: 1) environment and health shortcomings, 2) enforcement and governance shortcomings, 3) monitoring and assessment shortcomings, and 4) information and communication shortcomings. Figure 1 presents an overview of the problems and their drivers. In keeping with this structure, this section covers the problems to be addressed, the drivers of these problems and how these may evolve without any further policy intervention.

Figure 1 Overview of problems (left) and their drivers (right)

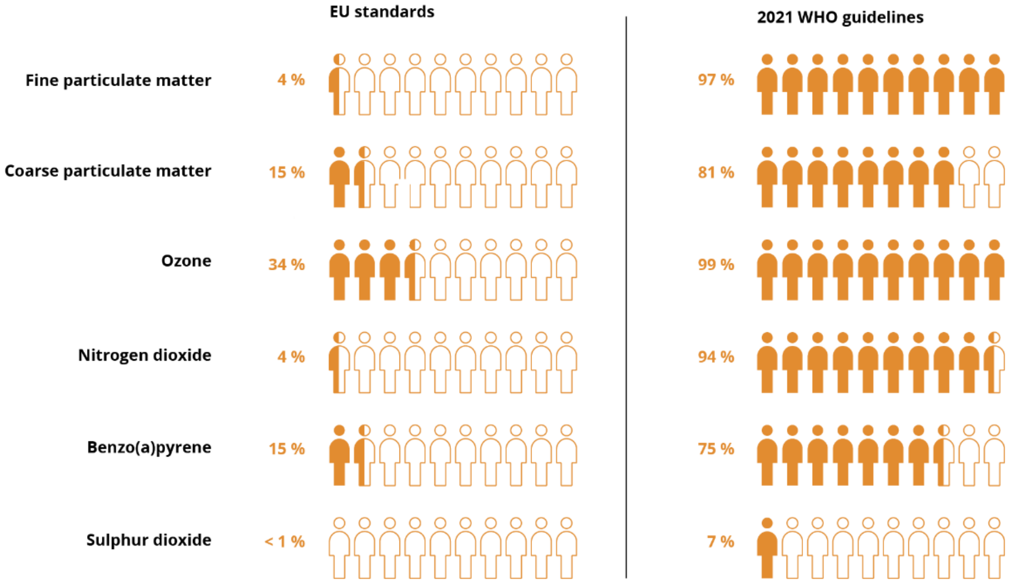


3.2 Problems and drivers

3.2.1 *Environment and health shortcomings*

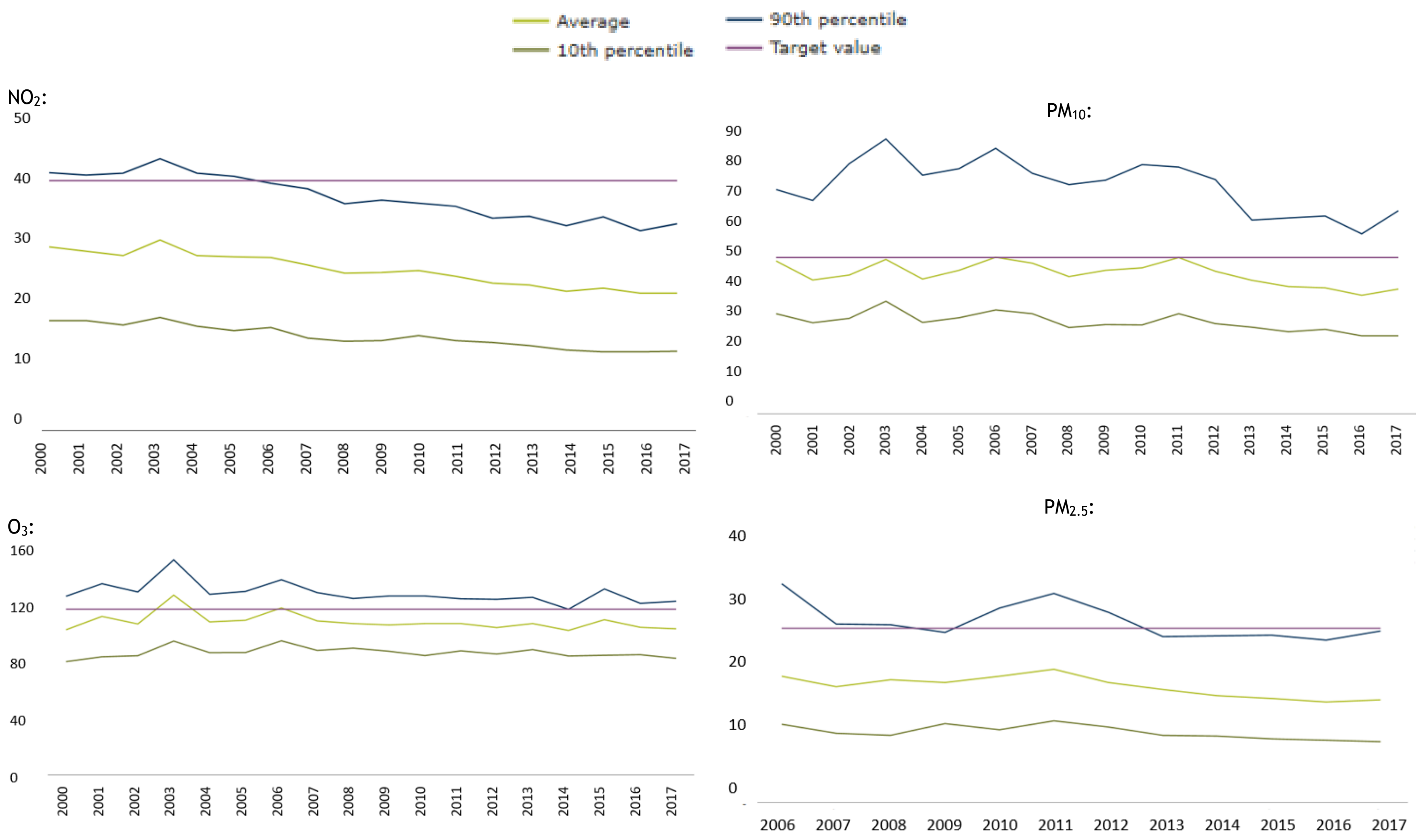
The figure below shows that in 2019 many EU residents remained exposed to ambient air pollutant concentrations above EU standards and those recommended by WHO (Figure 2). This is despite ongoing improvements to air quality (Figure 3).

Figure 2 Share of EU urban population exposed to air pollutant concentrations above EU standards and WHO guidelines (based on 2019 pollutant levels)



Source: (EEA, 2021)

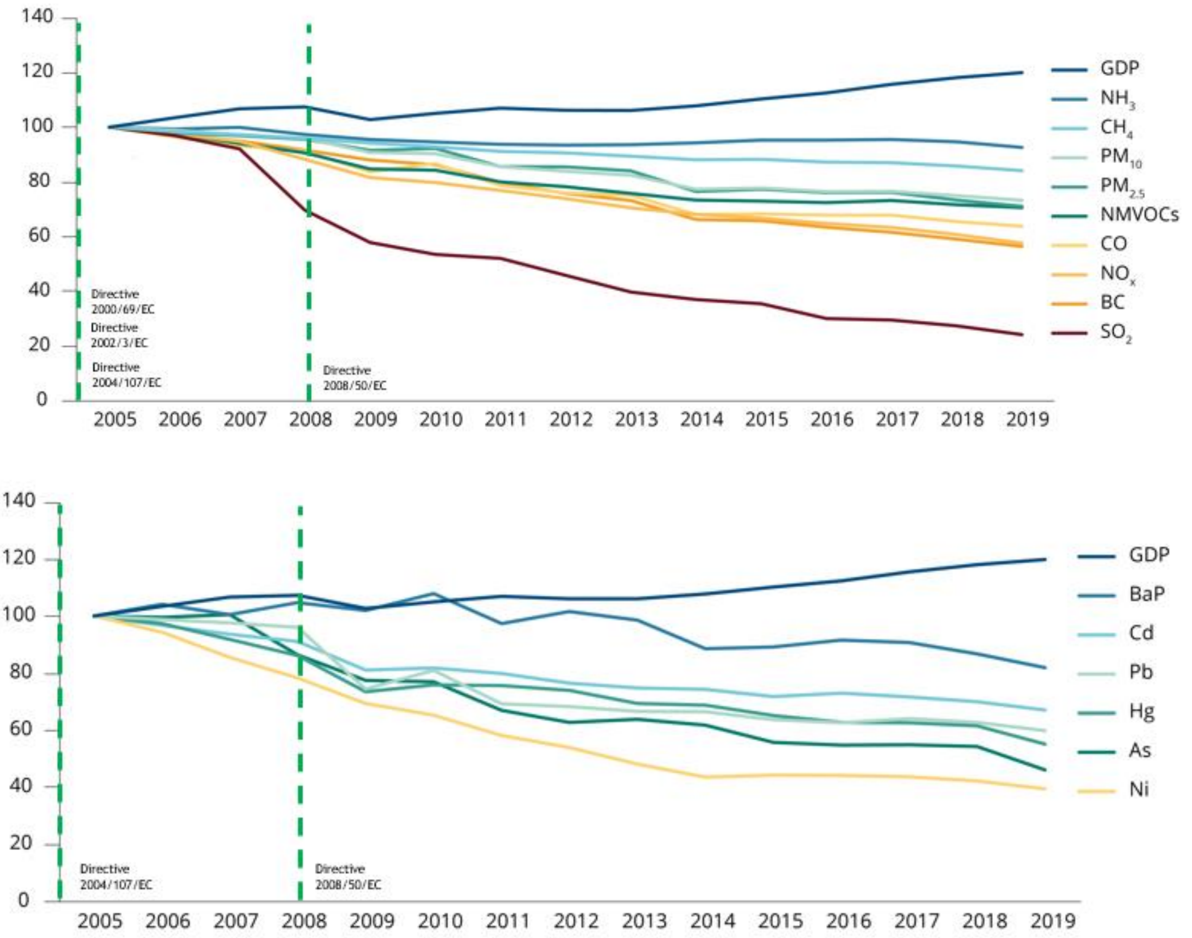
Figure 3 Annual mean concentrations for NO_2, PM_{10}, O_3, and $PM_{2.5}$, observed at (sub)urban background stations (2000 - 2017)*



Source: (EEA, 2019)

In addition to improvements to air quality, emissions of pollutants have decreased. SO_2, $PM_{2.5}$, PM_{10}, O_3 and NO_2, as well as As, Cd, Ni, Pb, Hg and BaP emissions have decreased between 2000 and 2018. While NH_3 emissions have also decreased in this timeframe, the reductions are comparatively small. Figure 4 also shows GDP, illustrating that reductions in emissions over this timeframe are decoupled from GDP growth (i.e. the emissions have gone down despite an increase in GDP).

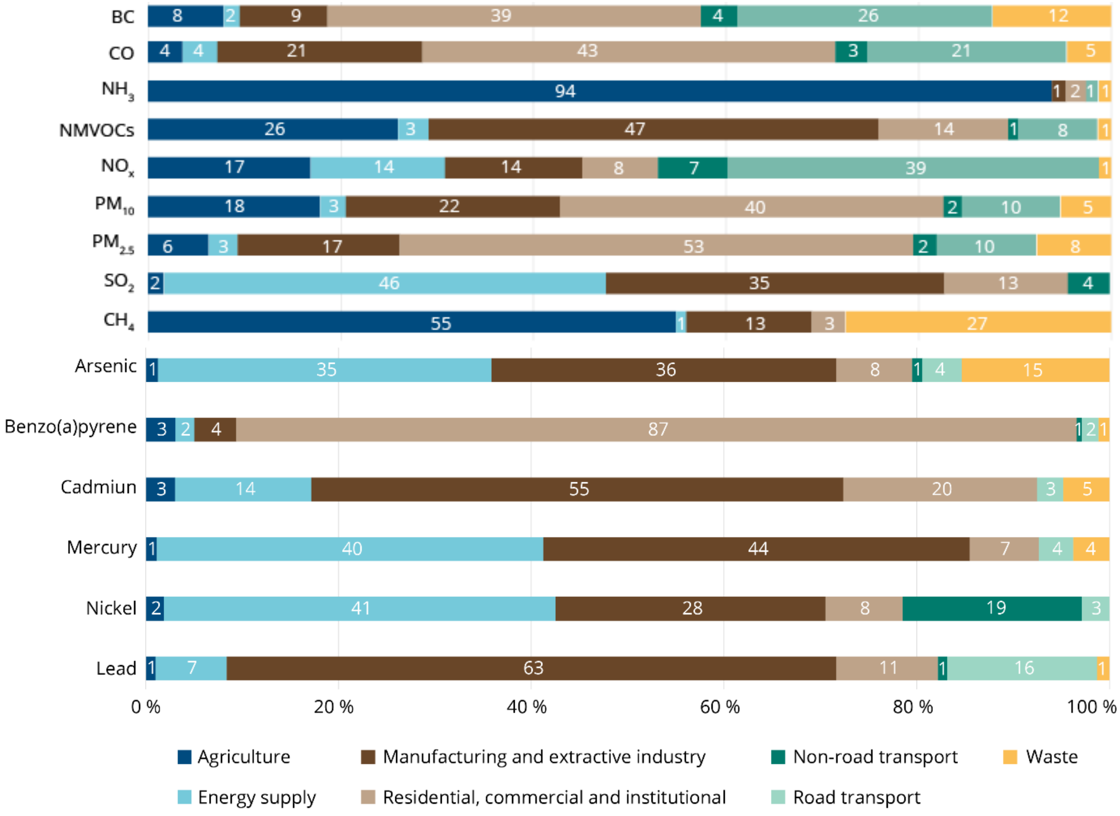
Figure 4 Emissions in EU by air pollutant, 2000-2018: (a) SO_2, NO_X, NH_3, PM_{10}, $PM_{2.5}$, NMVOCs, CO, CH_4 and BC; (b) As, Cd, Ni, Pb, Hg and BaP (index 2005 = 100). EU28 GDP (2010, % of 2000 level)



Source: (EEA, 2021)

Figure 5 presents the share of emissions by sector, showing that key sources in the EU include agriculture (namely of NH_3, NMVOCs and CH_4), industry (namely of SO_2, NMVOCs and select heavy metals), energy supply (namely of SO_2 and select heavy metals) and the residential, commercial and institutional sector (energy use for heating).

Figure 5 Emissions in EU by main sectors, 2000-2018 (SO_x, NO_x, NH_3, PM_{10}, $PM_{2.5}$, NMVOCs, CO, CH_4 and BC (% 2000 levels) compared with sectoral activity (% 2000 levels, except waste (kg per capita))



Source: (EEA, 2021)

Despite improvements in air quality in the EU, evidence shows that poor air quality continues to impact the health of citizens in the EU, especially in cities. In 2019, air pollution is still a major cause of health impacts – both in terms of mortality and morbidity. Estimates of the number of premature deaths attributed to key air pollutants in the 27 EU Member States for the year 2019 are as follows: 307,000 premature deaths were attributed to chronic exposure to fine particulate matter; 40,400 premature deaths were attributed to chronic nitrogen dioxide exposure; 16,800 premature deaths were attributed to acute ozone exposure (EEA, 2021). There are two dimensions to this problem: 1) ongoing exceedances of EU air quality standards, and 2) EU standards are not aligned with scientific advice.

The Fitness Check concluded that while air quality standards contribute to improved air quality, limit values are more effective than target values, with the mandatory nature of the former serving as an important success factor. Thus, where used, the extent to which target values are an effective mechanism to limit exceedances above EU air quality standards is under review.

Focussing on health aspects, the WHO guidelines are based on a growing scientific evidence base demonstrating the harmful impact of air quality pollutants on human health and the environment. As set out in Table 1, the WHO guidelines include guideline values with lower concentration levels than the EU air quality standards (including for $PM_{2.5}$, PM_{10} and SO_2). Comparing the WHO guidelines with EU standards, it is apparent that the two are not aligned and that this is a driving factor for persistent exceedances above health guidelines. Moreover, there is no mechanism in place to trigger regular review of air quality standards (based on scientific evidence). Thus, the current legal framework lacks flexibility to adapt to evolving science and new recommendations.

Table 1 Comparison of standards contained in EU AAQ Directives and WHO guidelines

Pollutant	*Averaging period*	*AAQ DIRECTIVES standards (concentration)*	*AAQ DIRECTIVES standards (number of exceedances permitted)*	*WHO Guidelines*** (concentration)*
Fine particulate matter ($PM_{2.5}$)	24 hours	n/a	-	15 µg/m³ **
	1 year	25 µg/m³ (LV)	-	5 µg/m³ **
Particulate matter (PM_{10})	24 hours	50 µg/m³ (LV)	*35 days / year*	45 µg/m³ **
	1 year	40 µg/m³ (LV)	-	15 µg/m³ **
Sulphur dioxide (SO_2)	10 minute	n/a	-	500 µg/m³ **
	1 hour	350 µg/m³ (LV)	*24 hours / year*	n/a **
	24 hours	125 µg/m³ (LV)	*3 days / year*	40 µg/m³ **
Nitrogen dioxide (NO_2)	1 hour	200 µg/m³ (LV)	*18 hours / year*	200 µg/m³ **
	24 hour	n/a	-	25 µg/m³ **
	1 year	40 µg/m³ (LV)	-	10 µg/m³ **
Lead (Pb)	1 year	0.5 µg/m³ (LV)	-	0.5 µg/m³ *
Carbon monoxide (CO)	Max. daily 8 hour mean	10 mg/m³ (LV)	-	10 mg/m³ **
Benzene (C_6H_6)	1 year	5 µg/m³ (LV)	-	1.7 µg/m³ *
Ground-level ozone (O_3)	Max. daily 8 hour mean	120 µg/m³ (TV)	*25 days avg. over 3 years*	100 µg/m³ **
Arsenic (As)	1 year	6 ng/m³ (TV)	-	6.6 ng/m³ *
Cadmium (Cd)	1 year	5 ng/m³ (TV)	-	5 ng/m³ *
Nickel (Ni)	1 year	20 ng/m³ (TV)	-	25 ng/m³ *
Benzo(a)pyrene (BaP)	1 year	1 ng/m³ (TV)	-	0.12 ng/m³ *

Notes: (LV) = limit value; (TV) = target value; *Taken from WHO (2000) Air Quality Guidelines for Europe (Second Edition) ** WHO (2021) WHO global air quality guidelines *** Note this does not include all WHO guidelines for all air pollutants or averaging periods. WHO guidelines also include interim guideline values, not presented here.

In addition, the Fitness Check refers to mounting evidence that exposure (short-term (24 hours) and long-term (annual)) to air pollutants, which is currently outside the scope of the AAQ Directives, has an impact on human health (i.e. black carbon, ultrafine particles and ammonia). Moreover, for $PM_{2.5}$, there is a greater understanding of short-term exposure occurring from peak periods of air pollution (which is currently not regulated by the AAQ Directives).

The WHO guideline values do not consider the technical feasibility or the economic, political and social aspects of the achievement of the guideline levels. These impacts are assessed as part of this study to the extent that this is possible.

3.2.2 *Enforcement and governance shortcomings*

Enforcement and governance shortcomings have together led to ongoing instances of exceedances of air quality standards and high exposure of some of Europe's urban population to air pollution above the standards established by the AAQ Directives. While the number of zones reporting exceedances of the limit or target values decreased between 2008 and 2017 for all air pollutants except $PM_{2.5}$ (4 in 2008 and 8 in 2017), the Fitness Check concluded that in 2017 there remained a number of zones that exceeded the respective limit values. This is an ongoing challenge. For example, in 2020, limit values for annual averages were exceeded in 31 zones for NO_2, 10 for PM_{10} and 13 for $PM_{2.5}$ (EEA, 2020).

Although the frequency, extent and magnitude of exceedances have decreased since 2008, the Fitness Check concludes that, where exceedances occur, enforcement action at the EU level is not always adequate with the result that exceedances are not always addressed sufficiently and/ or in a timely manner.

Directive 2008/50/EC states only that penalties must be effective, proportionate and dissuasive. This has led to different approaches to enforcement between Member States and a limited use of penalties in Member States with little impact on air pollution reduction. The extent to which enforcement action is effective, proportionate and dissuasive is unclear from the evidence included in the Fitness Check. The Fitness Check did however highlight the effectiveness of enforcement action by the European Commission and civil society by way of proceedings in court (both before the Court of Justice of the EU and before national courts), which has led to actionable rulings to accelerate air quality improvements to achieve air quality standards.

The European Commission has increased its enforcement action against Member States for systematic and persistent exceedances of limit values. These have resulted in multiple infringement cases related to the breach of pollutant limit values (a total of 14 cases for PM_{10} and/or $PM_{2.5}$, 14 for NO_2 and 1 for SO_2). 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.

As summarised in the Fitness Check, court proceedings from cases before national courts and from cases before the Court of Justice of the EU show that the claimants often maintain that air quality plans were not adequate and/ or sufficient measures were not adopted to address air pollution problems. While the defences maintain that challenges in meeting EU standards arise because of external factors (including socio-economic conditions, cost and administrative difficulties, natural sources, meteorological conditions, and emissions occurring from outside the local areas), the fact remains that certain air quality plans currently adopted by national authorities and the measures contained therein do not always facilitate planning to adequately address the air quality challenge.

Linked to enforcement, an overarching issue for governance shortcomings is that air quality plans do not always effectively address all sources of pollution affecting air quality. Reasons for this identified in the Fitness Check include:

- The AAQ Directives do not require Member States to report on the implementation of air quality plans, or to update them when new measures are adopted or when progress is insufficient – only to update plans at the end of the plan's period (European Commission, 2019). This makes it difficult to verify compliance with the air quality plan provisions of the AAQ Directives. However, it was also found in a targeted survey conducted as part of the "Strengthening of air quality monitoring, modelling and plans under the Ambient Air Quality Directives" study (Conlan et al., 2022), that of the representatives of 14 Member States, 10 reported that their air quality plans had been updated over the past 5 years with many of the current air quality plans being published between 2018-2020, and these were an update of previous plans dated in the range 2011-2016. These plan updates may have been driven by infringement proceedings brought by the European Commission for failure to meet certain limit values.
- There are a lack of national plans for measuring ambient air policy effectiveness and an absence of performance indicators.

- Air quality plans are not viewed as an emergency tool to address serious hazards to public health, as such urgency is not always evident in the planning process.
- Methods used for forecasting the evolution of air quality, and the underlying assumptions and uncertainties, vary between and within Member States. There is limited information available on the approaches taken. As such, the projected impacts included in air quality plans are often lacking rigour and cannot be compared with one another.
- Evidence of public participation during the adoption of air quality plans is not always apparent. It is often unclear which aspects of this planning process have been open to public consultation and what this involved.
- There is a lack of awareness of air quality across the institutions responsible for sectoral emission control. This has led to short-term thinking and delayed national action on improving air quality policy.
- Not all air pollutant precursors are directly attributable to emission sources, for example, O_3 concentrations are highly influenced by meteorological conditions. Measures can therefore seem disproportionate to sectors.
- The extent of devolution to local level authorities has been found to have both positive and negative implications for efficiency. Sometimes, devolution to local level authorities has led to unclear direction (compared to action led by national authorities) and weak communication across different tiers of government. Competences and the division of responsibilities to implement the measures are not always suitably defined. Coordination between different levels of governance (national, regional, local) is a key challenge.
- As regards funding, the Fitness Check refers to instances where EU funds are used to support projects that may have adverse effects on air quality. The example used relates to biomass investments (in the 2014-2020 multi-annual financial framework period, EUR 1.6 billion was allocated to biomass under the cohesion policy's objective of supporting the shift to a low-carbon economy). The actual impact of these investments on air quality is dependent on the specific projects and contexts.

An additional problem occurs as a result of transboundary air pollution. The 2021 EMEP Status Report for transboundary particulate matter, photo-oxidants, acidifying and eutrophying components shows the extent of transboundary pollution in Europe and the way in which external factors such as the weather contribute to further challenges (EMEP, 2021). Member States face both intra-EU and extra-EU transboundary air pollution. While transboundary air pollution is primarily addressed by the NEC Directive (Directive 2016/2284/EU), the Convention on Long-range Transboundary Air Pollution (the Air Convention) and the Gothenburg Protocol, the AAQ Directives include provisions to facilitate Member State's planning in this regard (a mechanism for joint cooperation between Member States on joint or coordinated air quality plans in case of transboundary air pollution, Article 25 of Directive 2008/50/EC). However, the Fitness Check findings show that this provision is rarely complied with. Reasons for low compliance include: "lack of resources at local authority level to solve issues with air pollution in neighbouring Member States close to common borders, lack of guidance on how Article 25 should be implemented in practice given different legislative settings across Member States, or perceptions that Article 25(2) should only be called upon when Member States were not able to solve a dispute by themselves". 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.

3.2.3 *Monitoring and assessment shortcomings*

Findings from the Fitness Check show that there are uncertainties regarding the current monitoring rules. Uncertainties arise from flexibilities (provisions intended to facilitate Member States), instances where the problem of air quality has evolved, and lack of clarity in the current provisions. These flexibilities and uncertainties are key drivers which have led to monitoring and assessment shortcomings where diverging approaches have sometimes impacted the comparability of data.

First, the **assessment of exposure and exceedance of air quality is not always representative**. Air quality management and assessment is carried out by air quality zone or agglomeration. Therefore, the definition of air quality zones and agglomerations in Member States is the basis for reporting air quality information under Directive 2008/50/EC. In most Member States the definition of the air quality zones have not changed over the last 10 years (Conlan et al., 2022). However, Member States differ in their methods of establishing air quality zones, with many relying on existing administrative units and their boundaries as well as on the population density over these existing administrative units. Others, however, also take into account available information on air quality levels, involving pre-existing monitoring data as well as modelling and emission information.

These differences in approach have led to further inconsistencies, such as how to determine the area where the measured exceedances apply. In principle, this relates to the area of representativeness of a specific sampling point, so that the area with exceedance of limit values should be the same as the area of representativeness of the sampling points measuring the exceedances. The consequence of this is a lack of consistency for the calculation of exposure and exceedance indicators which Member States should report, which means data for indicators of air quality are either not reported because they are difficult to calculate (among the findings for the study “Strengthening of air quality monitoring, modelling and plans under the Ambient Air Quality Directives”), or where the data are reported, they are not comparable. Very few Member States report these indicators on an annual basis (see Table 2 for those who reported in 2020).

Table 2 Number of Member States reporting exceedance/exposure indicators in 2020

Indicator	Number of Member States reporting
Ecosystem Areas Exposed	6
Population Exposed	15
Road Length in exceedance	6
Surface Area in exceedance	16

Source: (EEA, 2021)

Another issue is **that siting criteria for sampling points lacks clarity for a full assessment of air quality**. Annex III to Directive 2008/50/EC provides criteria for siting monitoring stations for all air pollutants except ozone (O_3), whilst Annex VIII describes the siting criteria for ozone. Siting criteria are given on two different scales: a) a macroscale siting criterion that defines the general position of monitoring stations within a zone; and b) a microscale siting criterion that addresses the immediate vicinity of the monitoring station.

According to responses to a survey undertaken for (Conlan et al., 2022), the majority of Member States find it difficult to determine the best location for monitoring sites but in addition once a site is established it is difficult to know what spatial area it represents. This is important as it impacts the spatial coverage of the monitoring network to ensure the maximum pollution concentrations are included. It also impacts the assessment of the size of population exposed to poor air quality. Therefore, the full assessment of air quality has shortcomings which are unlikely to change without further clarity.

In addition, the given definition of sampling point types and classification lacked clarity particularly around the role of industrial sampling points and whether they should be linked to specific industrial plant. This has resulted in industrial sampling points not necessarily being located in the best position to assess population exposure or there can be too few sampling points to do this comprehensively. This has resulted in incomplete information to assess the impact of emissions from industrial sites.

A related issue is that the **minimum number of sampling points are not always adequate to fully assess air quality**. The Fitness Check concluded that most zones in the Member States have the required minimum number of sampling points. However, the extent to which there are sufficient sampling points in the right locations was brought into question. Findings from a survey undertaken for (Conlan et al., 2022) show that among Member States there is a generalised view in that the monitoring of ozone outside cities does not necessarily require revision, while the monitoring of complex mixtures of pollution in urban areas, such as for particulate matter, requires an increased number of fixed measurements.

Annexes III, V, VIII and IX to Directive 2008/50/EC define the number and type of sampling points required for the assessment of air pollution. However, when Member States do not increase their sampling points above the minimum number, they do not always have the capability of identifying areas of maximum concentration levels in urban areas based on a limited number of fixed measurements alone. Therefore, this can lead to unidentified pollution hotspots, where public health could be negatively impacted.

The **use of indicative measurements to assess air quality is unclear**. Under Directive 2008/50/EC, Member States can rely on supplementary air quality assessment methods including indicative measurements. Some Member States are now including these in their reporting (primarily passive NO_2 diffusion tubes results, used in Belgium, France and Germany). It is not always clear how these methods have to be implemented and what data quality is sufficient to apply the methods in a formal assessment process. This has led to uncertainty in data quality and how much weight can be put on this data to assess air quality.

Low-cost sensor technology is rapidly emerging in Europe, often driven by citizen science, academic or commercial initiatives. Many Member States are facing local initiatives where low- cost sensor technology is used (with or without expert knowledge) in the air quality debate. Given the large variety of sensor technologies currently available on the market and the lack of a general application framework for sensor networks, it is hard to identify sensor uncertainty in a generic way and assess the quality of the extracted information.

Alongside problems relating to monitoring, there have been substantial developments as regards the use of modelling techniques since the AAQ Directives entered into force. Modelling is increasingly used by Member States to assess air quality, driven by improved modelling ability (through FAIRMODE[32]) (see Table 6-5 of the accompanying evaluation to the Fitness Check summarising Member State use of modelling to assess air quality).

Modelling can be helpful for various air quality management practices. Findings from a targeted survey undertaken (Conlan et al., 2022) of experts involved in monitoring, modelling and development of plans showed that 61% of respondents (n=79) reported that they used complex modelling to assess air quality. Of these, most used modelling for the development of air quality plans (75%) and source apportionment (70%) and less for the assessment of exceedances (62%), health impact (51%) or for now casting (44%).

For those using models for air quality plans only 26% of respondents to the survey used complex modelling to estimate future projections with and without measures to determine when compliance is likely. To show if exceedance periods are kept as short as possible, as required by the provisions in the AAQ Directives, this model application is required, and therefore many Member States are unable to present such evidence.

There are a wide range of modelling approaches in use across Europe, which leads to low comparability between modelling results between Member States. Models can be used over a wide range of spatial scales from many kilometres down to one metre. A key issue is the lack of a harmonised approach on how to use modelling as a supplementary assessment method. Current practice lacks consistency as, for example, results of a regional scale model with a resolution of a few kilometres cannot be compared to the results of a street scale model.

For the estimation of exceedance situation indicators, street scale models are generally used. This is a sound choice because many exceedances have a local character and require modelling tools with sufficient spatial resolution to be captured. Modelling tools are regularly used for the detection of new hot spots, but only a small fraction of these modelling results are actually reported under the e-Reporting framework. Most of the modelling exercises on hot spot detection are used to inform the public. Consequently, as not all modelling data are reported, there is confusion as to what is official data and what is informal data, and there is a low level of confidence associated with these various datasets.

The quality of modelling is fundamental to its usefulness in air quality assessment but in practice, the **quality of modelling sometimes is not robust.** A basic component of robustness is model validation, where the outputs from the model are statistically compared to monitoring data available within the model domain. This informs the level of confidence that can be applied to the model results.

Findings from a survey by (Conlan et al., 2022), showed that the majority (75%) of modelling applications used in the context of the AAQ Directives are validated. This could be considered as a significant fraction. However, this also means that many (25%) of the modelling applications are still not validated which could be seen as a serious concern to the overall quality of the modelling. FAIRMODE have proposed a Modelling Quality Objective (MQO) and in slightly more than half of the

[32] FAIRMODE or the Forum for Air quality Modelling was launched in 2007 as a joint response initiative of the European Environment Agency (EEA) and the European Commission Joint Research Centre (JRC). The forum is currently chaired by the Joint Research Centre. Its aim is to bring together air quality modelers and users in order to promote and support the harmonized use of models by EU Member States, with emphasis on model application under the European Air Quality Directives. For further information see: https://fairmode.jrc.ec.europa.eu/

cases where modelling is validated, the harmonised FAIRMODE MQO (Janssen & Thunis, 2020) is already used as the QA/QC framework.

In addition, there is some confusion over how many monitoring stations are required to validate a model and in particular what process should be followed when there are only a limited number of stations available in the modelling domain. Adding to this, **definitions are not included in the AAQ Directive for the type of monitoring station** (traffic, industrial or background) and **the area classification** (urban, suburban or rural), resulting in inconsistencies between Member States and within Member States. It is also challenging to verify compliance with the minimum requirements between traffic and background stations.

To summarise, the legislation does not support wide use of modelling, which makes it more difficult to compare data. Issues affecting comparability of air quality data have arisen from inconsistencies in the use of indicative measurements, and the selection of monitoring station types (traffic, background). In addition, emission inventories are not referenced in the AAQ Directives but provide input to modelling (among other things). The AAQ Directives are not sufficiently clear about the use of modelling and the need to report modelling results. This in turn impacts the comparability of modelled data to assess air quality in the EU.

3.2.4 *Information and communication shortcomings*

There is a growing body of evidence and a rapidly evolving communication technology, information on air quality, associated health impacts and measures to address exceedances. This information is not always readily available to the public or in an accessible format that the general public can understand. These factors are contributing to a general feeling among the public of being under informed. A 2019 Eurobarometer survey found that more than half of Europeans (54%) say they are not informed about air quality problems (European Commission, 2019).

The availability of public and comparable information on air quality in Member States enables the public to identify where air pollution levels are particularly high and better understand the risks to health. While there is a wealth of information concerning air quality, information is not always publicly available or accessible. The Fitness Check established that air quality is of importance to EU citizens and that many are of the opinion that air quality has deteriorated in the EU. The fact that air quality has in fact improved is indicative of the fact that information is not readily available and/ or clear.

Findings from the Fitness Check show that air quality data is available at EU level (via Air Quality e-Reporting database, the EEA's EIONET Reporting Obligation Database and the EEA's on-line information services and European Air Quality Index). Overall, the Fitness Check concluded that the AAQ Directives have facilitated the availability and accessibility of reliable and comparable air quality data across the EU, with a clear EU added value. However, further harmonisation of the way air quality information is presented would be both possible and desirable, and help ensure even higher comparability.

Information concerning impacts of air quality is not consistently available at Member State level. As a result, public concerns about health impacts continue and there is a feeling of being under-informed. Findings from the Fitness Check include:

- Relevant air quality information was accessible for 11 out of 28 Member States (at the time of the Fitness Check) and only 12 Member States were found to publish annual reports with information on exceedances and their effects;
- Directive 2008/50/EC requires Member States to set information and alert thresholds for O_3, NO_2 and SO_2 that, in case of exceedance trigger the provision on informing the public (Article 19 of the Directive) and in case of risk of exceedance trigger the provision on the development of short-term action plans (Article 24 of the Directive). However, approaches between Member States vary in relation to the collection, assessment and reporting of information. Moreover, the provision does not extend to PM (only 13 Member States have set information and alert thresholds for PM_{10} and only 2 for $PM_{2.5}$). Overall, the levels of thresholds can vary considerably between Member States and within them.
- Member State authorities do not always use available media platforms and technology, such as social media and smartphone apps, to disseminate information.

3.2.5 *Obsolete provisions*

The Fitness Check highlights that the AAQ Directives include provisions that have become redundant:

- Five-year timeframe allowing for postponement of attainment deadlines and the exemption from the obligation to apply certain limit values until June 2011 (Article 22 of Directive 2008/50/EC and Annex XV, Section B on the information to be provided under this provision);
- 2013 European Commission review of the provisions related to $PM_{2.5}$ and, as appropriate, other pollutants (Article 32 of Directive 2008/50/EC);
- 2010 European Commission review of the Directive 2004/107/EC (Article 8 of Directive 2004/107/EC).
- The references in Directive 2008/50/EC to margins of tolerance that were applicable until a certain date (e.g.: until 1 January 2020 for NO_2)

3.3 Who is affected by the problems?

Table 3 shows an overview of stakeholders affected by the problems set out in Section 3.2.

Table 3 Overview of stakeholders affected

Stakeholder	Related problems	Impact on stakeholder group
Citizens	Environment and health shortcomings - EU standards are not aligned with scientific advice. Information and communication shortcomings - Public feels under informed about poor air quality and its impacts.	Citizens are exposed to poor air quality. Citizens residing in hot spots are particularly vulnerable as a result of high exposure to air pollution. Citizens with existing medical conditions and citizens in vulnerable groups (such as children, pregnant women and the elderly) may be at higher risk from exposure. Likely to have increased concerns with the knowledge that they are particularly vulnerable to poor air quality. Due to current dissemination of information, citizens do not have equal access to relevant information allowing them to make informed

Stakeholder	Related problems	Impact on stakeholder group
		decisions that may help reduce their exposure to poor air quality, or even how they may contribute to improving air quality in their local area.
Business association/ business organisation	Environment and health shortcomings - EU standards are not aligned with scientific advice. Enforcement and governance shortcomings - Air quality plans do not always address all sources effectively Monitoring and assessment shortcomings - Flexibilities may sometimes impact the comparability of data	Businesses may be affected by productivity impacts of poor air quality (e.g. reduced workforce, lower agricultural yields, etc.) The lack of flexibility to amend standards in accordance with evolving technologies and science may hinder businesses from investing in new technologies that could improve air quality. There is a risk of contributing to an uneven playing field between businesses operating in different Member States if standards are made more stringent by some and not others (e.g. to align with WHO guidelines).
Regional and local competent authorities	Enforcement and governance shortcomings - Air quality plans do not always address all sources effectively Monitoring and assessment shortcomings - Flexibilities may sometimes impact the comparability of data	The need to address poor air quality in hot spots requires urgent and costly action at local level. Efficiency opportunities are missed where the approach to assist communication and planning between authorities is not standardised. Exceedances will continue to be adversely affected by transboundary emission sources with limited support to address the issue at source. Uncertainty over competences and responsibilities between local, regional and national authorities.
National competent authorities	Enforcement and governance shortcomings - Air quality plans do not always address all sources effectively Monitoring and assessment shortcomings - Flexibilities may sometimes impact the comparability of data	Risk of inefficiencies when planning and implementing measures in air quality plans. Reduced capacity to learn from other Member States owing to disparities in monitoring and modelling. Lack of a level playing field where exceedances may be reported using disparate monitoring and modelling methods. Uncertainty over competences and responsibilities between local, regional and national authorities. May act as a deterrent for authorities to act as needed to address air quality issue. There is also a risk of facing enforcement actions by the European Commission in case of persistent exceedances.

Stakeholder	Related problems	Impact on stakeholder group
Environmental organisations and Non-governmental organisations	Enforcement and governance shortcomings - Exceedances are not always addressed sufficiently and/ or timely	Non-governmental organisations are investing resources to identify areas with air quality standard exceedances, investigate the causes and find remedies (i.e. taking authorities to court where air quality plans are failing to deliver air quality improvements).
Academic/research institution	Monitoring and assessment shortcomings - Flexibilities may sometimes impact the comparability of data	Disparities between monitoring and modelling will affect access to comparable data at EU level.

4 Why should the EU act?

4.1 Legal basis

The legal basis for the EU to act on air quality lies in Articles 191 and 192 of the Treaty on the functioning of the European Union (TFEU). In accordance with Article 191(1) of the TFEU, EU policy on the environment shall contribute to pursuit of the following objectives: “preserving, protecting and improving the quality of the environment; protecting human health; prudent and rational utilisation of natural resources; promoting measures at international level to deal with regional or worldwide environmental problems, and in particular combating climate change.”. This is the same legal basis that underpins the current Ambient Air Quality Directives.

4.2 Subsidiarity

In accordance with Article 4(2), point (e) of the TFEU, environment is an area of shared competence between the EU and the Member States, which means that EU action must respect the principle of subsidiarity. Under this principle, the EU can only act if the proposed action cannot be sufficiently achieved at Member States’ level (necessity of EU action) and can be better achieved at EU level (added value of EU action).

Having regard to the subsidiarity principle and to what is set out in Articles 191, 192 and 193 of the TFEU:

- EU air quality standards are needed to assure an equal degree of protection for EU citizens.
- Transboundary air pollution contributing to poor air quality requires EU intervention.
- EU intervention shall respect the flexibility needed to account for the environmental conditions in the various regions of the EU – particularly to account for transboundary air pollution and meteorological conditions that affect air quality;
- The effectiveness of the current EU air quality standards demonstrates the benefit of EU action.
- In view of the risks to disparate impacts relating to economic and social development between regions, EU intervention is appropriate to ensure a fair playing field.

5 What should be achieved?

5.1 Objectives of intervention

General objectives for the impact assessment were defined in the Inception Impact Assessment (European Commission, 2021):

- to avoid, prevent or reduce the harmful effects of air pollution on human health and the environment, in line with the European Green Deal and the Zero Pollution Action Plan;
- to further enhance the effectiveness of EU air quality legislation;
- to improve the efficiency of the legislation taking into account the lessons learnt from the fitness check, making it easier to meet a given level of effectiveness.

This is complemented by a suite of specific objectives, as presented in Figure 6.

5.2 Intervention logic

Figure 7 presents the intervention logic summarising:

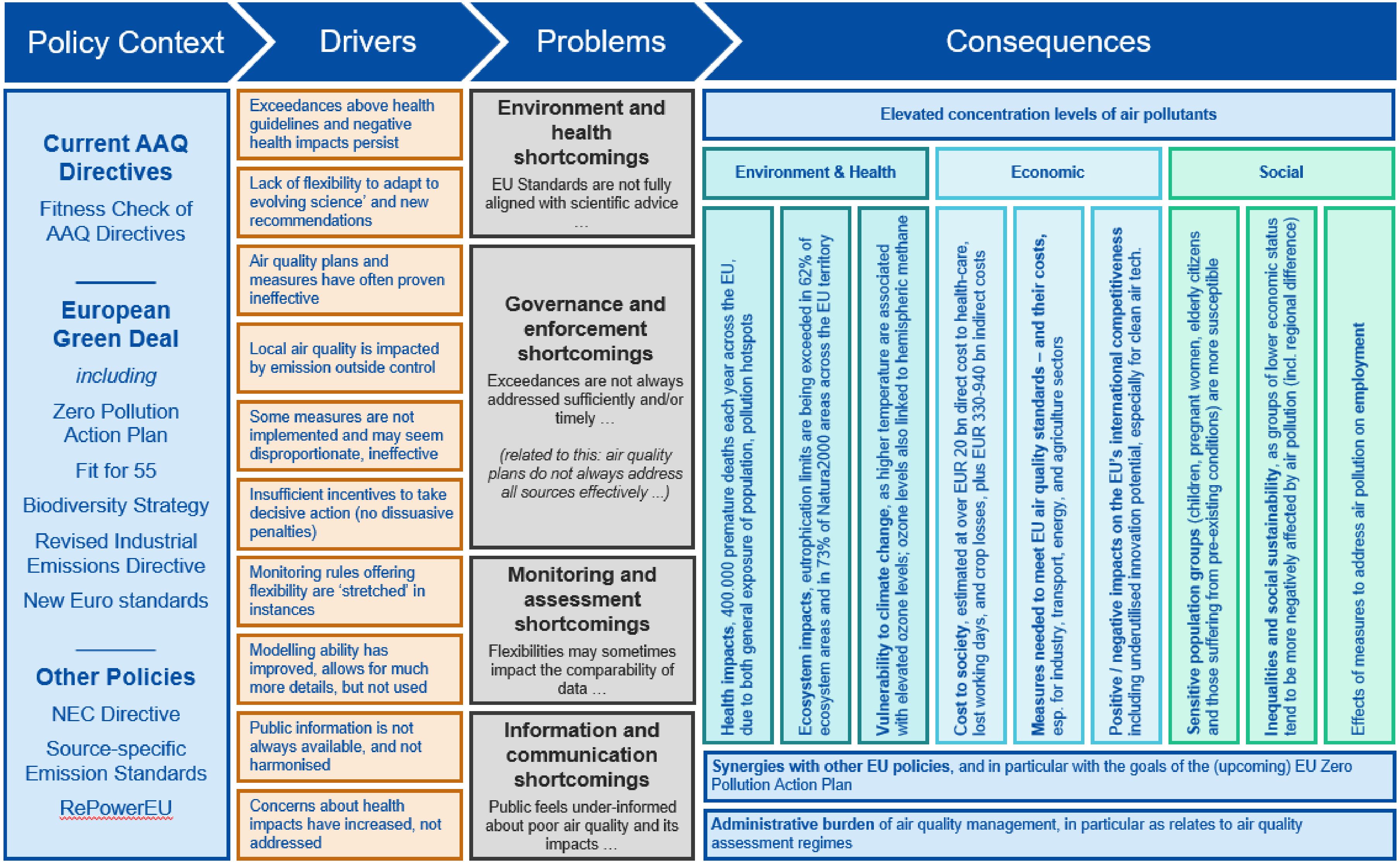
- The shortcomings, their drivers and the consequences of inaction;
- External factors;
- Focus areas for further and/ or improved EU intervention.

Figure 6 - Objectives for the intervention

Shortcoming	Drivers	Intervention needs	Specific objectives
Environment and health shortcomings	Exceedances above health guidelines and negative health impacts persist	• Reduce exposure to harmful levels of air pollution, with reference to best-practice guidance regarding safe levels of exposure	Specific objective 1: Improve ambient air quality to the extent possible taking into account the latest scientific advice, feasibility, costs, and benefits - and ensure legislation can respond in an appropriate and effective manner to future changes in underlying evidence base.
	Lack of flexibility to adapt to evolving science and new recommendations	• Ensure legislation can appropriately and effectively respond to future changes in underlying evidence base	
Enforcement and governance shortcomings	Insufficient penalties and damages linked to exceedances	• Penalties should be proportionate and sufficiently dissuasive to underpin effective enforcement • Ensure citizens' rights to compensation are effectively enshrined and supported by the Directive	Specific objective 2: Assure air quality plans are an effective means of identifying, planning and mitigating an exceedance situation (by taking relevant, effective and proportionate measures) - and include clearer provisions on stakeholder participation, access to justice, penalties and compensation linked to clean air in EU legislation.
	Air quality plans and measures have often proven ineffective or may seem disproportionate	• Minimise the risk that limit values are exceeded • Air quality plans should be an effective means of identifying, planning and mitigating an exceedance issue • Measures proposed should be relevant, effective and proportionate to the problem	
	Local air quality is impacted by emission outside control	• Resolution of exceedance issues should effectively involve all relevant stakeholders and sources	
Monitoring and assessment shortcomings	Monitoring rules offering flexibility are 'stretched' in instances	• Monitoring should be an effective tool which is consistently applied to identify exceedance areas	Specific objective 3: Further improve monitoring as an effective and reliable tool which is consistently applied to identify exceedance areas - and harvest

Shortcoming	Drivers	Intervention needs	Specific objectives
	Modelling ability has improved, allows for much more detail	• Ensure that modelling is used consistently to underpin the development of plans and monitor exceedances	opportunities offered by air quality models to underpin the development of plans and monitor exceedances.
Information and communication shortcomings	Concerns about health impacts have increased, not addressed	• Information provided to citizens around air pollution issues should be sufficient, and relevant (targeting the concerns of citizens)	Specific objective 4: Provide information to citizens around health impacts of air pollution issues (targeting the concerns of citizens) – and ensure that the public in all Member States receive the same high quality and timely information about their air quality.
	Public information is not always available, and not harmonised	• Public information is available and harmonised. Information should be clear and coherent, based on a robust evidence base, and be consistent across Member States	
Relevant to all shortcomings	*n/a*	• *Horizontal need for simplification*	*Specific objective 5: Simplify existing provisions where feasible to improve the effectiveness and efficiency of air quality management – and decrease associated administrative burden if and where possible.*

Figure 7 - Intervention Logic (DG ENV)



6 Approach to the analysis

6.1 Overview of approach to the analysis

A range of interventions have been defined to revise various elements of the AAQ Directives under the three Policy Areas. Each intervention has a number of associated impacts, with the exact impacts, their size and significance depending on the individual intervention. To assess the impacts, the study has followed a methodology designed to meet the requirements of the Better Regulation Guidelines (European Commission, 2021) and to provide the European Commission with timely evidence collection, stakeholder engagement and analysis of information gathered.

Based on the Better Regulation Guidelines, interventions should be compared on the basis of how they address the objectives considering their effectiveness, efficiency and coherence. All interventions were screened for their likely key economic, environmental, and social impacts across the core stakeholders – competent authorities, other public authorities, industry (large and smaller businesses), citizens and workers. Twelve indicators have been defined to capture and present the key economic, environmental, and social impacts associated with the interventions being considered. All interventions across the three Policy Areas will be appraised against this set of indicators, to ensure consistency in the analysis and presentation of results. The twelve indicators are defined in Table 4.

Across each of these specific indicators, available evidence on the effectiveness, efficiency and coherence of the Policy Packages was collated, assessed and, where possible, quantified in comparison to the baseline. To support the assessment of impacts, evidence gathering has comprised of three main activities: Quantitative modelling, in particular focusing on the impacts of different air quality standards under Policy Area 1 - this has been carried out using an established mature integrated assessment framework, as described in Section 6.2 (further information in Appendix 3); detailed literature review (see Section 6.3) and extensive stakeholder engagement (see Section 6.4).

Where possible the study has sought to quantitatively assess the impacts, but this has not been possible in all cases. Where quantification was not possible, impacts were assessed in a qualitative way, clearly indicating the type of most important impacts and their likely magnitude. For interventions considered under Policy Areas 2 and 3, quantitative assessment of impacts is much more challenging. The effects of these options on key indicators (e.g. levels of air pollution) are more indirect, uncertain and therefore difficult to isolate, attribute and measure. In these cases, the analysis is predominantly qualitative, based on evidence gathered from the literature (not least the preceding Fitness Check of the Ambient Air Quality Directives and the parallel study on “Strengthening of air quality monitoring, modelling and plans under the Ambient Air Quality Directives” (see chapter 2.1.1.)), feedback from stakeholder engagement and stakeholder engagement. As such, the overall assessment combines both quantified and non-quantified effects.

Across all interventions, the effects have consistently been mapped to the twelve indicators for consistency, assigning a ‘score’ based on an underlying framework. 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, relative to the baseline (see Table 5).

Table 4 : Twelve indicators used as the basis for the in-depth assessment

Broad impact category	Indicator	Indicator #
Environmental impacts	Concentration levels of air pollutants, at (a) background locations, and (b) 'hot-spot' (incl. both traffic and industry-related) locations, and their development over time;	1
	Health impacts of air pollution, for example the health impacts resulting from exposure to particulate matter ($PM_{2.5}$ and/or PM_{10}), nitrogen dioxide and ozone;	2
	Ecosystem impacts of air pollution, including acidification, eutrophication, ozone damage to vegetation and agricultural yields;	3
	Links between air pollution and climate change, including increased ozone levels due to global warming, and co-benefits or trade-offs between climate and air pollution abatement measures;	4
	Synergies with other goals of the (upcoming) EU Zero Pollution Action Plan on air, water and soil. This includes premature death reduction (indicator 2) and ecosystem impact (indicator 3) goals. It additionally reflects the synergistic role of indoor pollution (notably in terms of exposure and health impacts) or co-benefits in reducing noise pollution.	11
Economic impacts	Cost to society due to air pollution, including health and healthcare impacts and costs, lost working days, crop and animal value loss, losses to other assets and other costs avoided by taking action to reduce air pollution;	5
	Measures needed to meet EU air quality standards - and their costs, including costs for key economic sectors, and regional differences across the EU of the costs and benefits of the air pollution abatement measures;	6
	Positive and negative impacts on the EU's international competitiveness, including tapping into innovation potential for clean air technologies;	7
	Administrative burden of air quality management, in particular as relates to air quality assessment regimes (including monitoring, modelling, and reporting of related data) (Indicator #12)	12
Social impacts	Effects of air pollution on sensitive population groups, including children, pregnant women, elderly citizens and those suffering from pre-existing conditions;	8
	Societal impacts of air pollution and societal impacts of air pollution abatement measures, including resulting inequalities (i.e. who is most affected, who bears the costs);	9
	Effects of measures to address impacts of air pollution on employment;	10

Table 5: Coding used to present expected impacts

+++	Very significant direct positive impact (e.g. Indicator 1 – Air Quality: full alignment WHO AQG for $PM_{2.5}$*)
++	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. Indicator 6 – Mitigation Costs: costs of maximum feasible technical potential (MTFR or MFR) and more*)

*Examples included in the table are illustrative and relate to specific indicators. The range for each indicator has been set to define the maximum positive and negative effect for that indicator specifically (hence as such, for Indicator 1 describing Air Quality effects, the maximum positive effect will be associated with full alignment with the WHO AQG for $PM_{2.5}$). All interventions across all Policy Areas 1, 2 and 3 have been assessed using a consistent scale for each indicator, to ensure consistency and comparability in the assessment across Policy Areas. As such, the scoring inherently captures a comparative, relative assessment across indicators.

6.2 Quantitative modelling

Quantitative modelling 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 models were used to estimate air pollutants' emissions, ambient concentrations, ecosystem impacts, and to assess the feasibility of attaining particular air quality targets as well as respective measures and their costs.

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 ($PM_{2.5}$) and ground level ozone (O_3), vegetation damage caused by ground level ozone, the acidification of terrestrial and aquatic ecosystems and excess nitrogen deposition on soils. GAINS brings together data and projections of the economic development and structure, emission control potential and costs of mitigation measures, the formation and dispersion in the atmosphere of - as well as the inter-relations between - pollutants such as sulphur dioxide (SO_2), nitrogen-oxides (NO_x), particulate matter (PM), non-methane volatile organic compounds (NMVOCs) and ammonia (NH_3). GAINS assesses more than 1,000 emission control measures for all emission sources in the EU and key air pollutants, computes the atmospheric dispersion of pollutants and analyses the costs and environmental impacts of pollution control strategies. The emission characteristics of sources and measures, their current application rates as well as their costs are updated regularly drawing on the work of international task forces[33] and working groups as well as occasional consultations with Member States[34], industrial stakeholders, and peer reviewed studies. The last update of the data and assumptions was done during the study supporting the development of the second Clean Air Outlook while preliminary assumptions about Euro 7 were introduced only during this study using CLOVE consortium proposal. The assumptions, as used in

[33] For example, UNECE Task Force on Techno-Economic Issues (TFTEI), Task Force on Emission Inventories and Projections (TFEIP) and respective updates to the EMEP/EEE guidebook, Task Force on Reactive Nitrogen (TFRN)
[34] The last formal consultations with the MS were done during the thematic Strategy work, but currently a new round of consultations takes place within the ongoing support for the third Clean Air Outlook

the 2nd Clean Air Outlook, are available in the online GAINS model application (GAINS, 2022). More details on the atmospheric calculations in the GAINS model, and a discussion on the consistency with the EMEP CTM model, are given in Appendix 3.

In its optimisation mode, GAINS identifies the cost-effective emission control strategies that can be used to inform policy processes and international negotiations on mitigation of atmospheric air pollutants to achieve proposed concentration or emission reduction targets. The GAINS cost-effectiveness analysis proceeds in two broad steps. First, starting from the baseline, the lowest technically feasible emission level is established by minimizing the total emissions, while ignoring the costs. The model then chooses the most effective portfolio of emission reduction technologies for each country and each pollutant, while respecting the relevant technological constraints, such as maximum application rates, capital vintage structure and limitations in the scheduling of new technologies. The result is what is called the maximum (technically) feasible scenario (MTFR or MFR), which, together with the baseline scenario defines the space of feasible scenarios: the emissions of any cost-effective reduction scenario will lie between the baseline and MTFR levels. Note: The GAINS model only contains technical measures for which unit costs can be robustly quantified. The values for unit costs of non-technical measures, i.e. those that involve behavioural changes such as a shift in diet, depend on the exact methodology that is used to quantify them, and hence it is more challenging to estimate costs with certainty. Therefore, the benefits of packages comprising of such measures are best estimated on a scenario basis without reference to cost-effectiveness vis-a-vis alternative measures.

In a second step, a specific target is set in the model, and the optimisation routine identifies that portfolio of emission reduction technologies which reaches the given target at lowest costs. Such a target can be formulated, e.g., as a concentration target at the grid level in GAINS, or as a population-weighted concentration target at the country level, or an emission target.

Here we have deployed the optimization to identify cost-effective solutions to predefined concentration targets at the grid-cell level. In particular, targets are set for 15 $\mu g/m^3$, 10 $\mu g/m^3$ and 5 $\mu g/m^3$ for the years 2030 and 2050 (also 20 $\mu g/m^3$ for the year 2030). In some locations some of these targets cannot be reached, i.e., even at the lowest technically feasible concentration level (i.e., in the MTFR scenario) the concentration level in these grid-cells exceeds the target level. This happens in heavily polluted areas and would, if the target values are taken strictly literally, mean that such a target cannot be achieved everywhere in Europe, and thus render the target setting infeasible. In Section 8.1.1 more details are given on how targets are set in such situations.

The ***EMEP CTM*** is a state of the art atmospheric chemistry transport model, and includes a recently developed novel, but well documented (see Denby et al., 2020; EMEP report 2020) uEMEP (urban EMEP) downscaling module that allows the estimation of ambient air pollution concentrations down to a grid resolution of approximately 250x250 m^2 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, aviation, non-mobile sources and residential heating. All other sectors are modelled using the EMEP model at a resolution of 0.1°. Gridded EMEP emissions are redistributed using the emission proxies and high resolution concentrations are calculated, providing consistency between scales. Downscaling is carried out only on primary emissions, with the exception of NO_2 that is calculated based on a simplified NOX – OX chemistry scheme. For this application annual mean concentrations are calculated with the EMEP model under different policy scenarios for the following pollutants: SO_2, NO_2 and NOx, PM10, PM2.5, NMVOC, O_3, NH_3, BaP, benzene and carbon monoxide (CO). Downscaling of annual mean concentrations is applied to a selection of these pollutants, namely PM2.5, PM10, NO_2, BaP, Benzene and CO. More details concerning the methodology is provided in Appendix 3.

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.

The GAINS and EMEP models provide analysis of many of the impacts in the scope of this study. That said, some further calculations and post-processing was required to bring out further impacts associated with the interventions. This was the case for the assessment of health, social cost, and impacts on vulnerable groups.

We have developed a tiered approach to quantify the ***health impacts of air pollution***. The first Tier quantifies the premature mortality caused by the long-term exposure to particulate matter and the peak exposure to ozone using the concentration response functions (CRF) recommended by the recent systematic reviews of the WHO (Chen & Hoek, 2020; Huangfu & Atkinson, 2020). The second Tier focuses on health outcomes considered in the HRAPIE recommendations (WHO, 2013). This Tier includes health outcomes caused by the short-term (cardiovascular hospital admissions, respiratory hospital admissions, restricted activity days and lost working-days) and long-term exposure (chronic bronchitis in adults, bronchitis symptoms in children, infant mortality) to air pollution. We consider these outcomes as the second Tier of the approach, as they have been put forward by the WHO, and have undergone a greater degree of review (relative to pathways and CRFs which were not included in the HRAPIE study). 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 morbidity effects beyond HRAPIE. This third Tier is 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 pathways beyond HRAPIE for which there is convincing evidence for inclusion 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 analysis (COPD, Diabetes Mellitus Type 2 and myocardial infarction). Details on the methodology for the three Tiers are provided in Appendix 5.

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. This approach has been adopted given that:

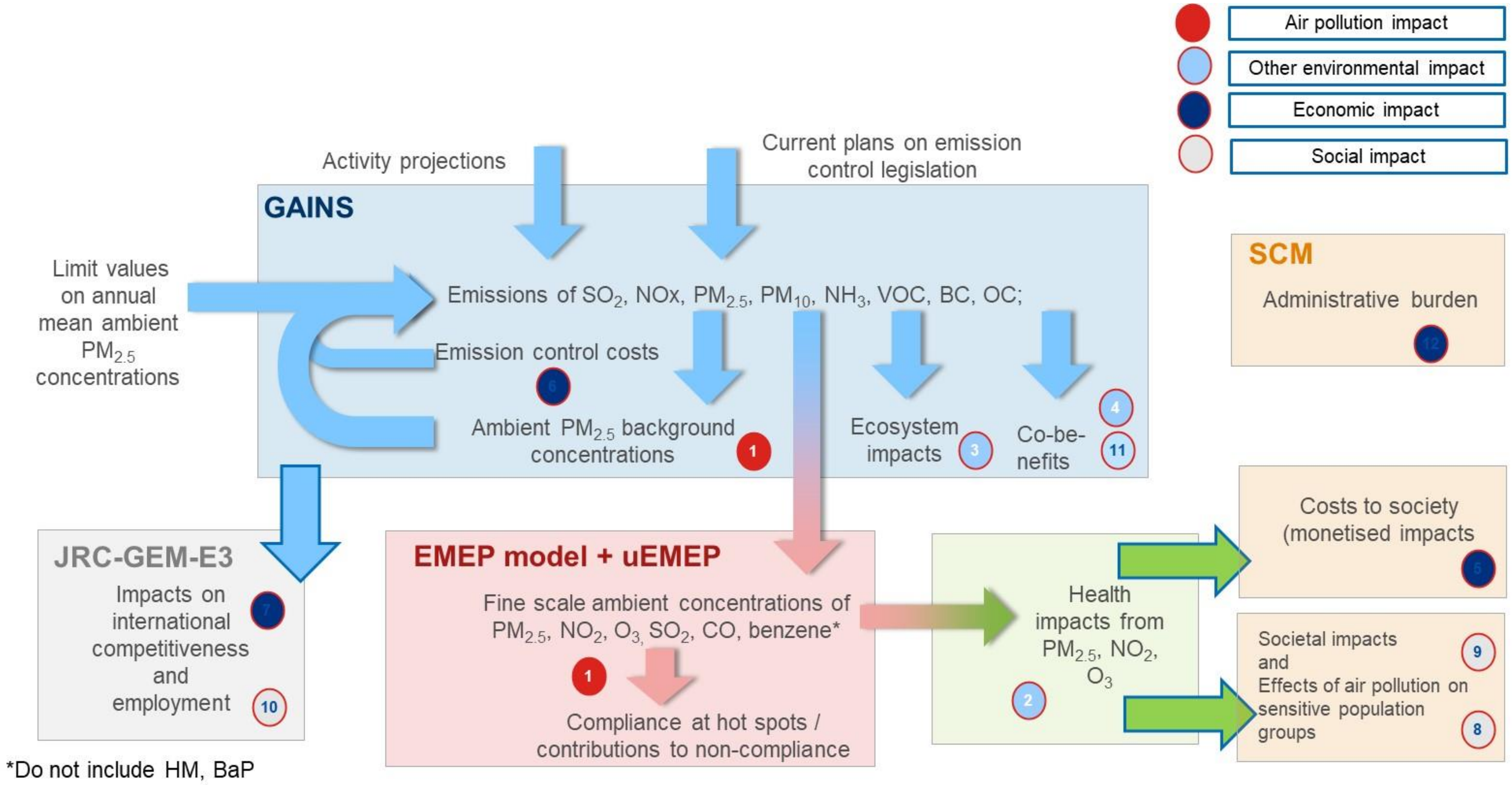
- The guideline exposure levels have been subject to extensive review work from WHO and represent an up to date overview of scientific knowledge on the subject, including on levels above which the health impacts are well documented.
- There is added uncertainty in the applicability of concentration response functions below the guideline exposure levels suggested by the WHO.

It is acknowledged, however, that this approach likely underestimates the total impact of air pollution on health, and thus also underestimates the likely benefits of action to improve air quality. For this reason, further quantification of the assumptions have been carried out in sensitivity runs, in which it is assumed that health impacts also occur below the WHO Air Quality Guidelines.

Health impacts are quantified for all years and scenarios under consideration, at NUTS2 resolution for mortality and country resolution for morbidity. As the uncertainty around the results will increase when the spatial resolution is increased, the main report focuses on results up to NUTS1 for mortality, and up to country level for morbidity. Higher resolution data will be provided in separate datasets. Only countries in the EU-27 are considered. The methodology builds on the results of Indicator #1, starting from the uEMEP annual mean concentrations for NO_2 and $PM_{2.5}$ and the EMEP SOMO35 indicator (defined as the yearly sum of the daily maximum of 8-hour running average over 35 ppb) for O_3. The main analysis uses the standard modelling results, including anthropogenic and natural sources of pollution, and omitting the bias adjustment, because sensitivity tests in the annex indicate that the impact of the bias adjustment on the relative health impact of the scenarios is limited. The methodology is aligned as much as feasible with previous European air pollution cost-benefit analyses (including Clean Air Outlook I and II), and with the yearly assessment reports provided by the European Environmental Agency (EEA).

Alongside the detrimental welfare effect of air pollution on health outcomes, exposure to air pollution also results in related healthcare expenditures, crop yield losses due to ozone, absence from work due to illness (including of dependent children) and lower productivity at work can imply a drag on the economy. Improving air quality can therefore bring economic gains. However, air pollution control comes at a gross cost, as it requires costly investments and purchases of abatement equipment. A priori, it is unclear whether air pollution control policies therefore lead to net economic gains or losses, and how these are distributed across stakeholders. To shed some light on these ***macro-economic*** trade-offs, we conducted analysis by linking the GAINS model with the JRC-GEM-E3 model. GEM-E3 (European Commission, 2022) is an applied general equilibrium model that covers the interactions between the Economy, the Energy system and the Environment. It represents the whole economy and the interactions between key actors: firms, households and governments in the EU and in the rest of the world. Linking between GAINS, EMEP and JRC-GEM-E3 has been done in previous work, such as the 1st and 2nd Clean Air Outlook (European Commission, 2022), and both models feature in a broader modelling toolbox e.g. in the assessment of the EU long-term climate strategy (Weitzel et al. 2019). The overall quantitative modelling flow is summarised in the following figure.

Figure 8 – Modelling framework



Notes: '(I1)' refers to the 12 separate indicators, defined in the TOR for this study, against which the different interventions are to be assessed.

6.2.1 *Limitations of the approach*

The strength of an impact assessment is linked to the robustness of the evidence that has been gathered. Information on robustness of evidence and uncertainty and caveats around each analysis step are included throughout this document (and accompanying appendices) under each relevant section.

Upfront it is important to note the following general limitations around the modelling specifically:

- **Pollutant modelling:** Calculations of emissions made with the GAINS model for several scenarios are provided to MET Norway for use in the EMEP/uEMEP models. Both GAINS and EMEP/uEMEP also use information provided by the Member States as part of their reporting of the national emissions; GAINS model emission estimates for past years have been compared and documented in the Second Clean Air Outlook (Amann, 2018) report and further updated to align to the possible extent with the 2021 national reporting within the NECD obligations. Beyond uncertainties in the data and methods available to estimate emissions, the ***quality of these submitted national emissions may vary from Member State to Member State***.

  GAINS uses linear transfer coefficients to calculate ambient $PM_{2.5}$ concentration levels at 7 km resolution, which are in this study only used in the GAINS optimization for achieving different ambient $PM_{2.5}$ targets. Since the transfer coefficients are based on perturbation simulations of the EMEP CTM, GAINS and EMEP models are roughly consistent but there are differences related to various factors like EMEP model version, meteorological years, spatial emission distribution used. Typically, these lead to slightly higher ambient $PM_{2.5}$ concentrations in GAINS, or in other words the EMEP/uEMEP model is somewhat more optimistic about ambient concentrations for a given emission scenario, in particular under strong mitigation cases. More discussion is provided in Appendix 3.

  In general, for all pollutants modelled with the EMEP/uEMEP models, except BaP, we see a negative bias in the results, indicating missing emission sources or underestimation of submitted emissions. This is particularly evident with the CO and Benzene calculations with a substantial negative bias of around 50%. Validation of the model calculations for all compounds is provided in the Appendix (see Appendix 3 – validation of concentration modelling). Negative bias of < 20% is calculated for NO_2, $PM_{2.5}$, O_3 and BaP for these preparatory calculations. The pollutants NO_2 and PM2.5 have less negative bias, ~ -20%, and O_3 and BaP have a slightly positive bias. Validation of the model calculations for all compounds is provided in Appendix 3 (see Section Validation of concentration modelling). As part of the uncertainty analysis of the concentration and exposure modelling a bias adjustment has been applied to assess the importance of the biases on the results.

  It is not possible to realise highly accurate emission distributions for all of Europe at 250 or 25 m resolution. At station sites, for instance, there will be significant additional noise due to errors in the redistribution proxies. However, on a statistical level, when sufficient stations are available then we expect the methodology to provide good general estimates of the concentrations and their frequency distributions. This is important to be aware of when scenarios are predicting just a handful of stations in exceedance. This will depend entirely on the very local modelled emissions in close vicinity to the stations.

- **Health impacts:** We only consider 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. In addition, we only consider morbidity related to long-term exposure to PM. Other pollutants and morbidity due to short-term exposure are not considered. We focus on a limited number of 'health endpoints' (i.e. diseases) for which a causal relationship between exposure to air pollution and the occurrence of the disease exists. These limitations mean that health impacts are likely to be somewhat **under-estimated** by the modelling framework.

Following assessment of impacts of the policy options against the above impact indicators, we have identified which assumptions and/or data points result in the largest uncertainty in the results. Sensitivity analysis has been conducted around these key assumptions. The results of this analysis are presented alongside the central results, in Sections 7 and 8 of this document and in the relevant Appendix.

6.3 Literature review

The literature review formed a critical part of the data collection and formation of the evidence base underpinning the study. The literature review included materials from a wide range of stakeholders, including industry, local and national governmental authorities, researchers, and non-governmental organisations (NGOs). Key data sources included existing policy reports from the European Commission and other public bodies (including existing evaluations, impact assessments, studies, audits, information on infringements, complaints, court rulings), academic papers, techno-scientific publications, databases, in particular data from EUROSTAT to support the quantitative assessment; and other grey literature, such as position papers, proceedings of conferences, symposia and meetings.

The literature review started with the identification of 'information and data' needs for the overall project along with the identification of relevant data sources. The identified literature was subject to a preliminary screening that determined the availability and reliability of information. A final list of relevant references was then identified, allowing a critical assessment of the information gathered. The detailed review of the literature allowed the identification of potential gaps, contradictory statements, and additional questions that were then discussed during the consultation activities. A bibliography of the sources on which the study has drawn is included in Appendix 1.

This task built on the extensive evidence base collated and analysed as part of the Fitness Check of the EU Ambient Air Quality Directives (2019) (European Commission, 2019) (hereafter the Fitness Check) as well as on the ongoing study for the Commission on 'Strengthening air quality monitoring, modelling and plans under the Ambient Air Quality Directives', which looks at options to improve the implementation of air quality assessment beyond changes in the legislative framework (for example, via additional guidance or exchanges on good practice).

6.4 Consultation activities

This section provides an overview of the consultation activities undertaken as part of the study.

6.4.1 *Inception impact assessment*

An Inception Impact Assessment was published by the European Commission in December 2020 (European Commission, 2021). Inception Impact Assessments are useful to gather initial ideas regarding the problems the initiative aims to tackle, as well as to ask for relevant data (European Commission, n.d). As part of this exercise, stakeholders were able to upload written contributions in the form of position papers or other documents between 17 December 2020 and 14 January 2021, and 63 provided feedback. The contributions received as well as statistics on stakeholder type and country of origin are accessible on the "Have your say"- webpage (European Commission, 2021).

This initial feedback received from stakeholders was synthesised in an Excel file. From each feedback, we extracted the metadata (author, high level summary, etc.) as well as information of potential relevance to the impact assessment, including:

- Comments on the problem / objectives;
- Comments on the baseline / current status;
- Policy suggestions on limit values, legislative changes, and technical measures related to monitoring, modelling and air quality plans;
- Recommendations and policy ideas;
- Proposed factors for consideration and assessment criteria;
- Comments on the impacts of policy options (economic, social, environmental);
- References to further material.

This information formed part of the knowledge base used by the project team to create a long list of policy interventions.

6.4.2 *Online public consultation*

The online public consultation (OPC) was open for 12 weeks, from 23 September 2021 until 16 December 2021 (European Commission, 2021). The aim of this consultation was to collect the views of citizens and other stakeholders in order to inform the impact assessment, especially with regard to designing potential (regulatory and non-regulatory) measures to reduce air pollution, strengthen air quality monitoring, modelling and plans, and reduce the related impacts on environment and society.

The online public consultation had a total of 31 questions (excluding introductory questions about respondent profile) and was structured as follows:

- Part 1: Questions about the respondents' profile and why they are answering the questionnaire;
- Part 2: General questions section – on respondents' views on air quality issues;
- Part 3: Specialised questions section – on respondents' views on air quality measures and their impacts. This section focused on more technical aspects of the topics/measures considered by the Directives' revision, requiring some degree of knowledge on the topic;
- Part 4: Concluding questions & remarks – where respondents could share their thoughts on topics not covered by the questions and provide further information, including documents.

The questionnaire contained a mix of closed- and open-ended questions, the latter enabling respondents to either explain their replies to closed questions, or to provide other comments or information of relevance to the impact assessment. The online public consultation was shared via email with a variety of stakeholders from all EU Member States, including public authorities at local, regional or national level. In addition, it was advertised during the first workshop held on 23 September 2021 as well as on the European Commission's website. The objective of this dissemination was to ensure a high level of participation but also participation that was as representative as possible in terms of geographical spread and stakeholder type.

The methodology for the (ongoing) analysis of the OPC results can be summarised in a number of steps. Raw data was obtained from EUSurvey and was subsequently imported into an Excel template. The consultants checked whether there were any duplicate replies, and no campaigns were identified. The same template was used to create graphics summarising the closed questions, which can be reproduced for different purposes in the study and/or by the Commission without further references and/or difficulty. Regarding open-ended questions, the approach to their analysis depends on the nature of the open-ended question. For questions in which respondents could provide an answer not already included in the multiple-choice options and explain this answer, a quantitative analysis was undertaken using the software R to identify keywords and how often they were mentioned. For other open-ended questions (e.g., "please explain your answer, if you wish to"), a number of open replies was selected to analyse qualitatively, with the aim of ensuring a representative sample of replies in terms of opinions expressed (both rather positive and negative) as well as in terms of the respondent's background (country of origin and stakeholder type). Finally, any attachments, links or other materials submitted by stakeholders including position papers, were analysed and summarised separately.

A total of 934 responses were received, and 116 position papers were submitted. The targeted section received a total of 555 responses. On average, open questions received 124 individual responses, with a minimum of 11 and a maximum of 406 individual responses.

6.4.3 *Targeted survey*

The targeted survey was designed in two parts: the first part was published on 13 December 2021 containing questions about closer alignment of the EU air quality standards with the latest recommendations of the World Health Organization (i.e., Policy Area 1). The second part was published on 13 January 2022 and contained questions about improving the current air quality legislative framework, including provisions on penalties and public information (i.e., Policy Area 2) and questions on strengthening air quality monitoring, modelling and plans (i.e., Policy Area 3). Both parts of the targeted survey were open until 11 February 2022.

The objective of the targeted survey was to seek in-depth views of organisations with an interest in, and/or who are working with, EU rules on air quality regarding how specific provisions in the current air quality rules could be revised.

Part 1 of the targeted survey contained 26 main questions (excluding introductory questions, and further sub-divided in some instances). The questions focused on:

- How to address air pollutants covered by the latest World Health Organization (WHO) Air Quality Guidelines? (i.e. $PM_{2.5}$, PM_{10}, O_3, NO_2, SO_2, CO);
- How to address air pollutants covered by earlier editions of the WHO Air Quality Guidelines only? (i.e. arsenic, cadmium, nickel, lead, benzene, polycyclic aromatic hydrocarbons);
- How to address air pollutants for which there are no WHO guideline levels or reference levels? (i.e. black carbon, ultrafine particles, ammonia, others);

- What type of EU air quality standards should apply for different pollutants? (i.e. limit values, target values, long-term objectives, average exposure levels, alert thresholds, other);
- What are the likely costs and expected benefits from setting revised EU air quality standards? (i.e. societal cost, societal benefits, implementation and administrative costs, implementation barriers); and
- Concluding remarks, providing the opportunity to add comments and to upload relevant supporting evidence or materials.

Part 2 of the targeted survey included 78 questions (excluding introductory questions and further sub-questions). All questions asked for stakeholder inputs regarding the different intervention areas (A through N) being considered for Policy Areas 2 and 3 regarding:

- The baseline scenario;
- The extent to which individual interventions would address the identified shortcomings; and
- Administrative costs expected to result from the introduction of the individual intervention.

As for the OPC, the questionnaires for part 1 and 2 contained a mix of closed- and open-ended questions, the latter enabling respondents to either explain their replies to closed questions, or to provide other comments or information of relevance to the impact assessment.

Due to the level of expertise needed to answer, the targeted survey was specifically disseminated to targeted stakeholders including: public authorities (i.e., on local, regional and national level), industry & businesses, civil society & NGOs, and academia & research. The survey was sent via email to over 330 potential respondents from the 27 EU Member States.

Part 1 of the targeted stakeholder survey received in total 139 replies from 24 Member States. Part 2 of the survey received 93 replies from 22 Member States.

6.4.4 *Targeted interviews*

Targeted interviews were conducted to fill in information gaps that had not been filled by the literature review or the previous consultation activities. A total of four interviews were conducted in April 2022 (two public authorities, one NGO, and one academic organisation). In addition, one stakeholder declined to be interviewed and instead sent written answers (public authority). All the interviews focused on Policy Area 2, as the main remaining information gaps were in this Policy Area. A list of questions was sent to each interviewee prior to the meeting, which were then discussed during the calls.

These targeted interviews have allowed us to:

- Clarify any relevant issues that have emerged as a result of the previous stakeholder input;
- Address gaps in the online survey e.g. information / data on countries which were underrepresented and allow for territorial balance in our assessment;
- Complement results;
- Dive deeper into interesting issues raised in the online survey that the project team would like to have more information on;
- Validate findings from the survey.

6.4.5 *Stakeholder meetings*

Two stakeholder meetings have taken place in the context of the impact assessment study. The **first stakeholder meeting** took place on 23 September 2021. The meeting was a full day hybrid event and its purpose was to assist in identifying and confirming the issues for the impact assessment, and gather initial stakeholder views on the proposed interventions and their ambition levels for the revision of the Ambient Air Quality Directives, specifically in relation to each individual Policy Area.

The meeting was attended by 316[35] participants (with a total of 401 registered participants). Invitations were sent directly to a wide range of stakeholder groups, with the largest group represented at the meeting being public authorities. The outcomes of the first stakeholder meeting were used to further define and tailor the specific interventions for all Policy Areas.

Regarding stakeholder inputs on Policy Area 1, the discussion touched upon many different topics. For example, a number of stakeholders reflected on the need to fully align EU air quality standards with the WHO guideline exposure, ideally by 2030 or consideration of additional pollutants. Other pollutants, like PM_{10}, ozone, ammonia, ultrafine particles and black carbon were discussed. Regarding Policy Area 2, there was a general support for the proposed elements to be tackled and possible interventions to be introduced. However, stakeholder views differed as to the conditions for implementation and timing. For example, there was a consensus regarding the use of limit values, however divergences regarding their form (i.e. in terms of whether the limit values triggering should be defined at local and/or regional level, legal nature of limit values or even alternative technologies). Regarding feedback on Policy Area 3, stakeholders provided feedback on all proposed intervention areas. For example, regarding augmenting assessment regime rules the use of models to supplement assessment methods was welcomed, though it was noted this should not be at the expense of a reduced monitoring network.

The **second stakeholder meeting** took place on 4 April 2022. This meeting was also a hybrid event, and aimed at collecting feedback from stakeholders on the preliminary results of the study – notably on modelling and on the results from the OPC and targeted Stakeholder Survey - that would assist in verifying and complementing the results. The meeting was attended by 257[36] participants (with a total of 382 registered participants). Similarly to the first meeting, invitations were sent to a wide range of stakeholder groups, and public authorities were the most-represented group.

The main topics discussed were updates on the progress of the revision of the EU air quality rules and on the modelling analysis of air quality improvement potential. Furthermore, stakeholders were given the opportunity to comment on the outcomes of the OPC as well as the targeted Stakeholder Survey. On the OPC, stakeholders were for example curious whether similarities existed within responses of individual stakeholder groups, whether any campaigns had been identified or whether the focus of the analysis also included analysis split by Member State. The presentation of the updated results on the air quality improvement potential (i.e., on the modelling results on air pollutant concentration and exposure and on the health impacts of different pollutants) was commented on by a variety of stakeholders. For instance, public authorities highlighted the importance of all relevant studies being considered within the analysis and offered to provide additional inputs and civil society & NGOs as well as research & academia stakeholders discussed the suitability of applying the WHO Guidelines, which

[35] The consultants contributing to the study and the participants from the European Commission were not taken into account.
[36] The consultants contributing to the study and the participants from the European Commission were not taken into account.

are intended for global application, to Europe. Afterwards, the results of the targeted Stakeholder Survey were presented per Policy Area. Here again, a variety of stakeholders asked clarification questions and expressed their views on the results obtained.

7 What are the interventions to achieve the objectives?

7.1 The baseline and maximum feasible reduction scenarios

7.1.1 *Approach to building the baseline and a maximum (technically) feasible reduction (MTFR) scenario*

The baseline provides a critical reference point against which to assess changes and impacts of the formulated policy options. The baseline serves as the counterfactual for examining how the situation is expected to change in the case of no further changes to the AAQ Directives. The baseline provides an overview of the current situation, considering economic, social, and environmental aspects, and describes expected future trends based on the current situation and extrapolation of known trends (in the absence of further policy options).

The starting point is defined by the current status of implementation of different obligations under the existing EU Directives relevant for air pollutant releases as well as national legislation, if stricter than the EU law. This defines the existing political and legal context at the EU and at the national level. The current status of implementation is well defined in several existing studies, including the second Clean Air Outlook (CAO2) (European Commission, 2021). This baseline builds on the backdrop of existing measures and policies already committed (including some which might require introduction of further measures in the near term). In line with the Commission's Better Regulation guidelines, policy proposals (even though still subject to modifications in the course of policy making cycle) form part of the baseline assumptions. Policies and measures included in the baseline are considered to continue over the duration of the analysis period. A full list of the policies and programmes included in the baseline can be found in Appendix 3, section 'Legislation and policies included in the baseline'.

Key elements of the baseline that have been updated since CAO2 include:

- The broader policy environment and potential changes - including revised European Commission climate targets (*Fit for 55*) as reflected in the underlying energy and agricultural scenarios[37],
- Draft proposal for the Euro 7 emission standards and its timeline, as developed by the CLOVE Consortium,
- New knowledge about real-world emission factors and share of high emitting vehicles,
- Confirmed changes at Member State level (i.e. adopted policies and measures towards compliance with the EU and national legislation, as set out in Member States' NAPCPs),
- Sulphur Emissions Control Area (SECA) in the Mediterranean Sea from 2025 (EU Directive 2005/33/EC Sulphur content of marine fuel MARPOL Annex VI Air Pollution),
- Assumptions about the development in non-EU countries are of relevance owing to the impact of transboundary pollution. In particular, new data and projections (energy and agriculture) for the Western Balkans, Ukraine, Moldova, and Georgia are available from a recently completed EU funded project[38], and under the UNECE Long Range Transboundary Air Pollution (LRTAP) Convention on review of the Gothenburg Protocol new projections and updates of the

[37] https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=SWD:2021:0611:FIN:EN:PDF
[38] Extension of the EU Energy and Climate Modelling Capacity to include the Energy Community and its Nine Contracting Parties (ENER/2020/OP/0005)

policies for remaining EECCA countries are under development building on data from the World Energy Outlook 2021 (IEA, 2021),

- Updates of the GAINS model with data and information from the 2021 national inventory submissions within the NECD, these include: updated information about fuelwood use, structure of installations in residential sector and their trends (if reported in the Informative Inventory Reports) and new documented emission factors.

The baseline does not include data from the revision of the IED for agriculture that was published on the 5th April 2022. While the impact assessment study of revised IED[39] indicated the potential impact on emissions (reduction of about 115-185 kt NH_3 or 3-5% of the current total EU-27 NH_3 emissions), the detailed implementation in the GAINS model is still ongoing and will be completed within the work on the third Clean Air Outlook.

The baseline is defined for the period 2015 to 2050 with specific focus on 2030 and 2050, the period for which the analysis of interventions has been developed.

The baseline contains quantitative assessments where these are possible to define, and qualitative narrative where quantitative data is not available. The quantitative assessment captures emissions and concentrations of air pollutants, associated health and environmental impacts, control costs as well as costs to society. Qualitative assessment is predominantly applied to assess the more detailed elements of implementation (where information is lacking) and other aspects which do not lend themselves well to quantification (e.g. elements under Policy Areas 2 and 3). Both quantitative and qualitative elements of the baseline are subject to limitations, as described throughout the remainder of this section. It is worth recalling that the baseline primarily aims to establish a reference point against which the impact of different interventions can be assessed, focusing on relative changes across scenarios rather than on absolute effects.

The main information sources used for building the baseline have been the Fitness Check, the study supporting the process of the revision of air quality rules on strengthening the provisions on air quality monitoring, modelling and plans (Conlan et al., 2022) and the Inception Impact Assessment.

7.1.2 *Trends in air pollutant emissions and concentrations under the baseline and MTFR scenario*

Effective air quality standards across the EU are essential for Member States to ensure that their citizens are protected from the adverse effects of air pollution. The AAQ Directive aims to set clear and actionable air quality standards that are in accordance with scientific advice to minimise harmful effects on human health and ecosystems. **Under our baseline we assume that air quality standards will be maintained in the form of limit values and target values established for the EU by the current AAQ Directives and its predecessor legislation. In other words, we expect the standards to remain set at the current level in terms of the pollutant coverage as well as the level of stringency.** As noted, the updated WHO Guidelines include recommendations for standard setting which are stricter than EU standards for some pollutants.

Baseline assumptions for the **definitions of different types of air quality standards reflect current legislation** (cf. Directive 2008/50, Articles 2, 12 to 16 and Annexes VII, XI to XIV; Directive 2004/107,

[39] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52022PC0156

Articles 2, 3 and Annex I). This means that current challenges with the definition of standards for different pollutants will continue, building upon the relevance of the actual limit or target value defined by the standards above. Key definition aspects that will impact on the baseline in this regard are the application of limit and target values for specific pollutants, the impact of the Average Exposure Indicator, and consequential Exposure Reduction Targets for each Member State.

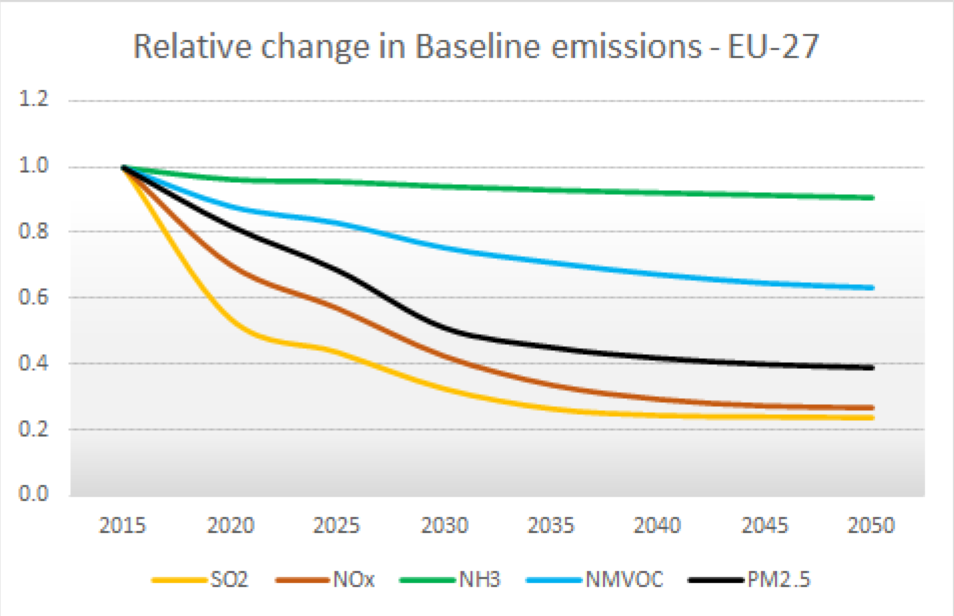
Air pollutant emissions

We estimate that, considering current economic and environmental policies included in the baseline, the EU-27 will continue to see a decline in emissions of key air pollutants (Figure 9). Compared to 2015, by 2030 emissions of $PM_{2.5}$, NO_x, and SO_2 are estimated to drop by 50 to 70%, NMVOC by 25%, while for ammonia (NH_3) about a 5% reduction is expected. The trends are expected to continue towards 2050 but with much smaller further reductions.

The key drivers of emissions change towards 2030 are different for each pollutant:

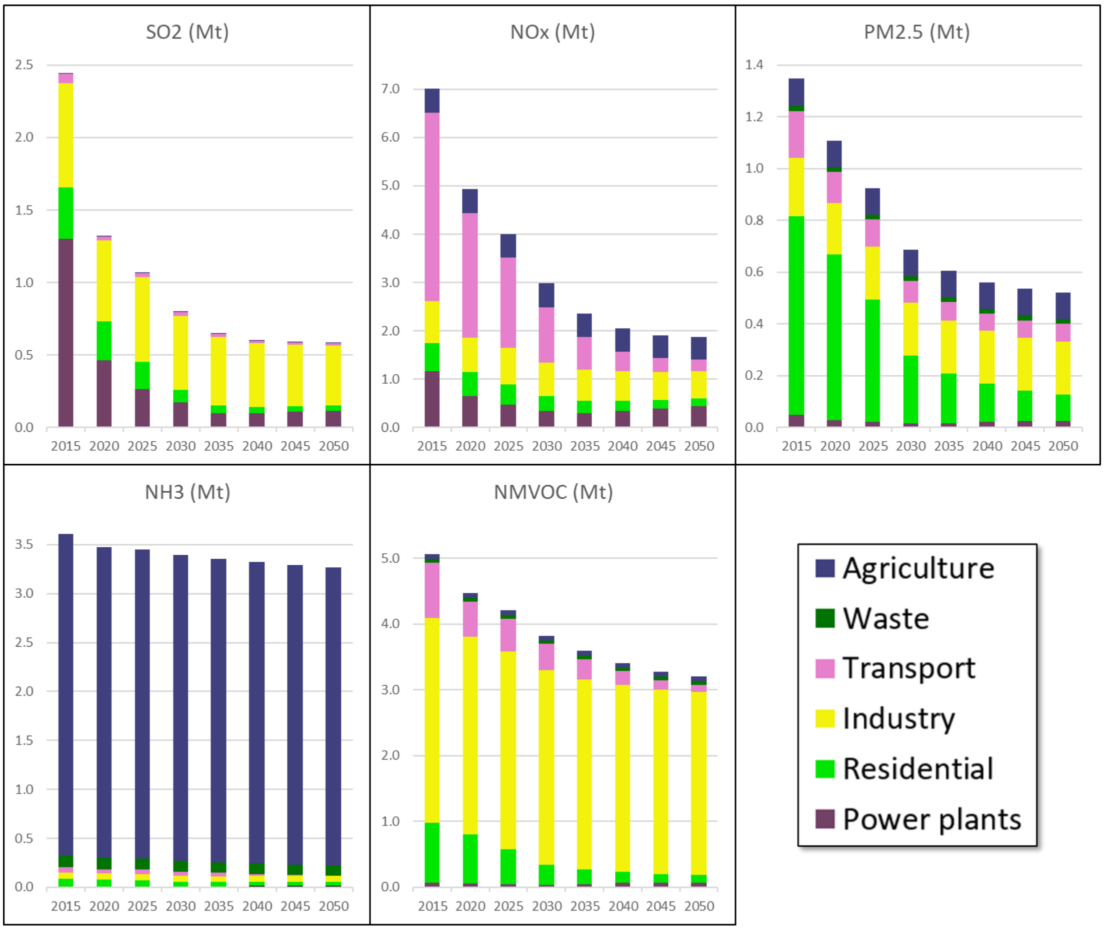
- for $PM_{2.5}$ most of the reduction is due to reduced use of coal and biomass in the residential sector and transition to cleaner technologies,
- for NO_x recent legislation and fuel trends (less diesel and increase of hybrid and full electric vehicles) are the key drivers,
- for SO_2, significant reduction in coal use in power plants and residential coal use decline are among major factors
- For NMVOC, reduction in residential heating sector coal use (see $PM_{2.5}$) and transport changes (see NO_x) are key contributors
- For NH_3, the (limited) decline is mostly driven by structural changes (livestock numbers), including reduction of mineral nitrogen fertilizer application.

Figure 9 - Trends of air pollutant emissions in the EU-27; baseline scenario, GAINS model



These trends continue towards 2050, however at slower rate with much smaller contribution from further reductions in the power sector, which for SO_2 and NO_x show a small increase after 2035 owing to increasing biomass and gas use in the underlying energy scenario (Figure 10). For NMVOC a moderate reduction is estimated, mostly due to changes in the transport sector and residential heating. Emissions of NH_3 do not change much in the baseline, with most of the reduction being due to a change in livestock numbers and improvements in efficiency of fertilizer application rather than application of control measures. Further emission reductions are expected from recently proposed revision of the IED, including cattle and reducing the farm size threshold for pigs and poultry[39].

Figure 10 -Emission of key air pollutants in the Baseline scenario for the EU-27; GAINS model



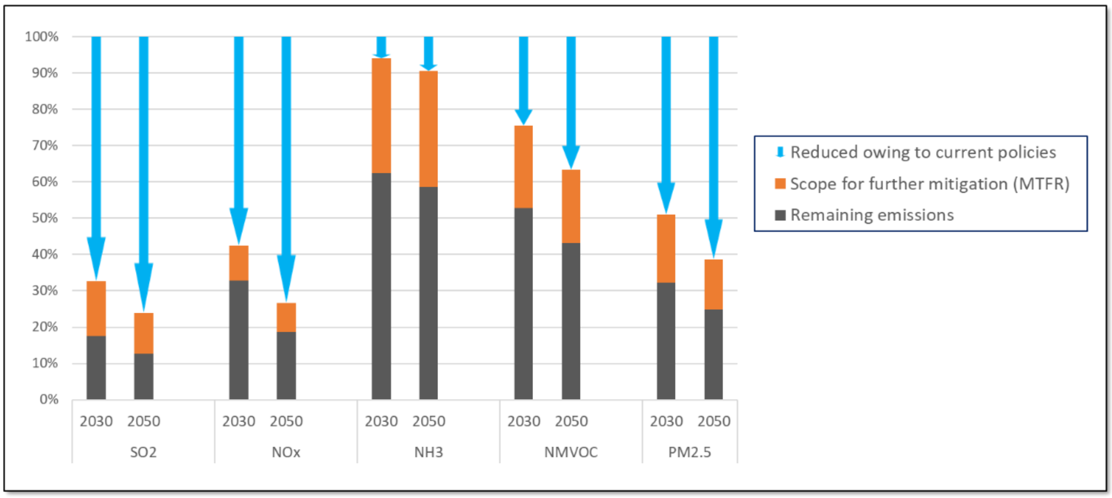
Emissions of air pollutants for all Member States in the baseline scenario, as calculated in the GAINS model, are shown in Table 6 for 2030 and 2050.

Table 6- Emissions of air pollutants under the baseline scenario in 2030 and 2050. Units: kilotons/yr

	$PM_{2.5}$		SO_2		NO_x		NH_3		VOC	
	2030	2050	2030	2050	2030	2050	2030	2050	2030	2050
Austria	10.2	10.4	8.3	6.7	62.0	69.6	64.8	65.0	55.9	42.1
Belgium	13.0	11.9	30.7	28.6	91.8	88.7	68.7	65.9	75.0	66.0
Bulgaria	17.7	11.3	40.7	22.4	66.5	33.5	43.6	43.5	49.7	34.1
Croatia	10.2	5.3	5.8	4.4	25.6	16.9	37.5	35.8	37.0	29.6
Cyprus	0.8	0.7	2.0	2.2	6.3	4.4	8.2	8.5	5.7	4.4
Czech Rep.	15.9	10.8	26.7	14.8	96.6	55.5	93.9	86.5	116.8	94.5
Denmark	10.6	8.0	9.3	5.5	63.1	34.7	67.5	64.0	52.9	44.6
Estonia	2.3	1.7	5.0	2.0	13.3	8.2	11.7	11.4	11.7	10.3
Finland	11.7	9.4	20.7	16.4	72.8	46.8	31.2	33.7	43.7	46.1
France	99.2	81.3	76.0	57.7	379.0	244.7	577.1	564.9	496.0	425.3
Germany	69.5	61.6	139.3	108.9	473.4	272.0	549.8	518.0	687.5	590.1
Greece	22.2	18.6	23.9	17.9	89.1	59.8	56.5	53.4	95.8	73.7
Hungary	30.2	12.2	7.0	6.7	66.4	40.3	73.9	69.7	65.4	42.4
Ireland	6.2	6.2	6.1	5.8	58.1	43.5	124.2	121.3	48.7	48.7
Italy	72.5	49.4	66.2	58.3	290.2	193.5	336.4	313.6	613.0	516.8
Latvia	6.9	3.6	2.8	2.2	25.1	11.8	16.6	16.9	22.4	17.3
Lithuania	7.5	3.8	9.9	5.1	32.2	15.8	43.8	41.6	25.0	15.9
Luxembourg	0.8	0.7	1.1	1.0	8.3	5.1	6.0	5.7	6.6	5.8
Malta	0.2	0.1	0.6	0.5	2.1	1.4	1.3	1.3	2.0	1.7
Netherlands	13.7	11.6	15.4	13.1	116.2	71.5	122.6	120.9	139.2	122.2
Poland	75.0	52.1	136.9	72.1	302.9	171.7	287.1	282.3	362.3	279.6
Portugal	26.3	23.4	20.2	14.3	74.6	46.5	50.7	46.8	89.1	75.8
Romania	43.5	31.4	35.1	27.7	127.1	74.8	166.2	154.2	119.4	91.8
Slovakia	9.4	5.7	11.0	10.8	37.9	28.2	24.9	25.1	69.3	50.3
Slovenia	9.2	3.3	3.1	1.5	16.9	6.7	16.9	16.0	22.6	15.8
Spain	87.0	72.7	82.3	66.7	326.9	191.5	461.0	448.4	424.9	390.4
Sweden	14.5	13.5	13.0	10.7	53.3	33.7	50.0	50.9	84.1	67.5
EU-27	686.2	520.9	799.1	583.7	2977.5	1871.1	3392.1	3265.1	3821.9	3202.9

To define the scope for further (beyond baseline) emission mitigation, the GAINS model was applied to calculate the maximum technically feasible reduction (MTFR) scenario for 2030 and 2050 (Figure 11). This scenario assumes application of further technical measures to the extent feasible by 2030 and 2050, considering the lifetime of installed capacity, i.e., no premature scrapping of existing equipment is considered. No further, beyond what is included in the baseline, structural or behaviour driven measures are considered, at either the local nor regional level. The estimated potential includes local and technological constraints to the extent that they are reflected in the model drawing on previous MS consultations and technology information but ignores any potential financial constraints. For example, on the first aspect, for agricultural NH_3 emissions, the constraints that limit application of specific techniques (e.g., manure injection or trailing shoe technology to reduce loses from manure application on fields) on steep slopes or stony soils are considered. The minimum size of farms on which measures can be introduced according to the specifications of the GAINS model is 15 livestock units (LSU); to be noted that this is far smaller than the size threshold of 150 LSU proposed in the IED revision above which farms fall within the scope of the Directive (as the MTFR scenario strives to project what is possible by using the complete technical potential). There are also some sectors where no further options are available, e.g., road transport where Euro 7 is considered the best technology for internal combustion engines and there are no measures to reduce non-exhaust emissions from transport. While the fact that the model does not include potential further development of current mitigation techniques can be seen as conservative, the calculation assumes that the mitigation technology works as designed and its respective limit values are effectively enforced, which has not been always the case in the past.

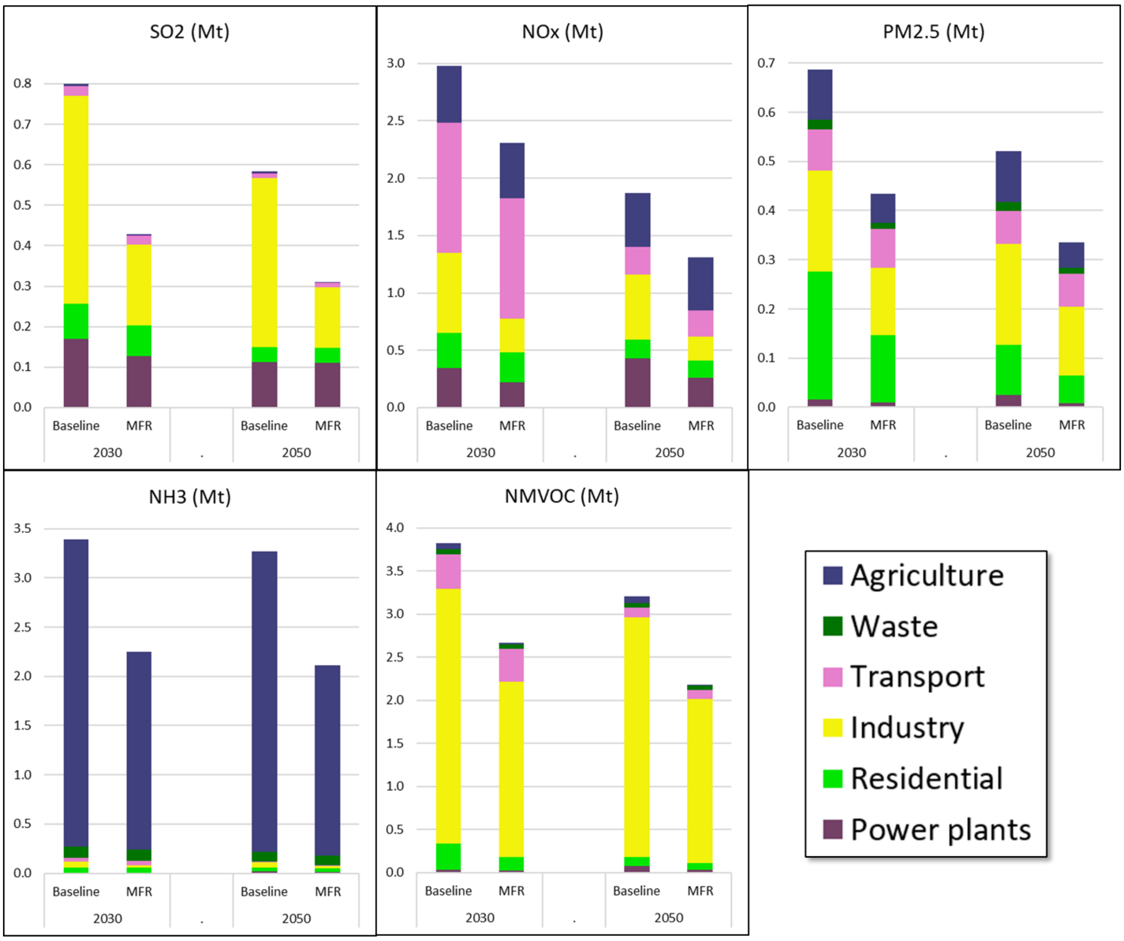
Figure 11 - Scope for further emission mitigation of key precursors of PM2.5 in 2030 and 2050 in the EU27. Changes shown relative to 2015; GAINS model



Since current legislation is expected to reduce emissions of **SO_2** and **NOx**, further potential is rather limited and even declines in the long-term owing to the reduced used of fossil fuels. The remaining potential identified for industrial processes - see Figure 12 – is limited. For **$PM_{2.5}$**, very limited, if any, potential remains to reduce emissions from power or industrial sectors . Key further mitigation can be achieved in the residential sector and also by enforcing bans on the open burning of various agricultural residues that, in spite of existing legislation, are still burned. For **NMVOC**, apart from some potential in the residential sector and agricultural burning, further reductions in solvent use applications were estimated. For **ammonia**, mitigation of emissions from mineral nitrogen fertilizer application (primarily addressing application of urea) and livestock offers significant reduction potential assuming. For livestock, this assumes that measures addressing housing, storage, and application of manures on land would be introduced in an integrated manner (as proposed in the revised IED), but for a much larger number of farms than is currently the case (as per baseline assumptions), especially for cattle.

The mitigation potential shown in Figure 12 varies strongly between MSs depending on the structure of emission sources and local constraints.

Figure 12 - Emission of key air pollutants in the Baseline and MTFR scenario for the EU27; GAINS model



Emissions of air pollutants for all Member States in the MTFR scenario, as calculated in the GAINS model, are shown in Table 7 for 2030 and 2050.

Table 7- Emissions of air pollutants under the MTFR scenario in 2030 and 2050. Units: kilotons/yr

	$PM_{2.5}$		SO_2		NO_x		NH_3		VOC	
	2030	2050	2030	2050	2030	2050	2030	2050	2030	2050
Austria	6.4	6.2	7.2	6.3	47.9	54.7	38.8	38.9	39.4	31.5
Belgium	10.1	8.8	15.3	13.7	76.0	67.9	50.9	48.1	60.4	51.3
Bulgaria	7.7	4.9	19.2	4.9	52.0	26.6	29.9	29.2	30.9	21.9
Croatia	4.0	2.4	2.8	1.9	15.8	9.3	19.3	18.2	16.8	13.6
Cyprus	0.5	0.4	0.3	0.3	4.1	2.1	5.6	5.6	3.6	2.5
Czech Rep.	12.3	7.5	13.9	8.4	63.9	29.1	66.0	59.9	74.6	54.1
Denmark	7.6	6.0	7.2	4.5	52.3	27.7	52.5	48.5	33.7	26.5
Estonia	1.5	1.0	1.8	0.8	10.1	5.9	9.3	9.0	7.9	6.7
Finland	9.4	7.6	10.7	8.0	51.7	28.7	22.3	22.6	30.7	23.5
France	69.4	59.0	54.0	37.0	331.5	194.6	411.3	378.4	382.1	327.4
Germany	57.5	50.3	75.8	62.9	383.1	203.1	331.1	305.5	445.3	374.6
Greece	14.6	13.4	9.5	6.3	72.9	44.3	42.6	39.4	64.7	48.8
Hungary	11.6	8.5	5.0	5.9	49.6	29.6	47.4	43.6	34.9	29.1
Ireland	4.7	4.8	2.1	2.0	48.4	35.8	97.3	94.9	32.9	32.7
Italy	55.4	37.6	32.8	38.4	236.4	133.4	244.0	226.0	456.5	372.3
Latvia	3.4	2.4	2.3	1.9	20.2	9.2	12.8	13.0	11.3	8.3
Lithuania	3.7	2.3	4.7	3.0	24.8	11.2	28.8	26.8	13.6	8.5
Luxembourg	0.7	0.6	0.4	0.4	5.0	1.9	3.7	3.4	4.6	3.7
Malta	0.1	0.1	0.5	0.5	1.7	1.1	0.9	0.9	1.5	1.2
Netherlands	11.7	10.2	10.9	10.1	89.9	55.3	117.3	115.6	108.2	90.1
Poland	48.7	31.2	76.8	29.5	209.3	107.1	165.3	161.7	257.1	193.8
Portugal	11.5	10.2	9.4	6.6	51.5	26.4	32.8	29.7	65.4	55.9
Romania	21.9	14.1	12.1	9.2	93.1	47.5	107.8	96.7	75.6	55.2
Slovakia	4.7	3.6	4.6	5.4	23.2	15.1	15.0	15.0	42.5	28.5
Slovenia	3.3	1.6	2.1	0.6	14.2	4.2	11.2	10.4	12.9	10.4
Spain	38.8	28.3	33.0	30.1	237.9	110.1	252.5	234.8	294.7	256.9
Sweden	13.1	12.4	12.6	10.4	42.6	25.6	35.9	36.1	68.5	53.5
EU-27	435	335	427	309	2309	1307	2252	2112	2670	2182

Air pollutant concentrations (Indicator #1)

Modelling of concentrations based on the emission scenarios has been carried out with the uEMEP/EMEP model configuration. This allows annual mean concentrations to be calculated at high resolution for all of Europe. For calculations at Airbase station sites, all stations included, the resolution is 25m. For mapping and exposure purposes the resolution is 250m. Verification was carried out for the reference year 2015. This showed a negative bias in the modelling for most pollutants. To address this a bias adjustment was assessed to show the effect of model bias for future scenarios. For details concerning the modelling and the bias adjustment see Appendix 3.

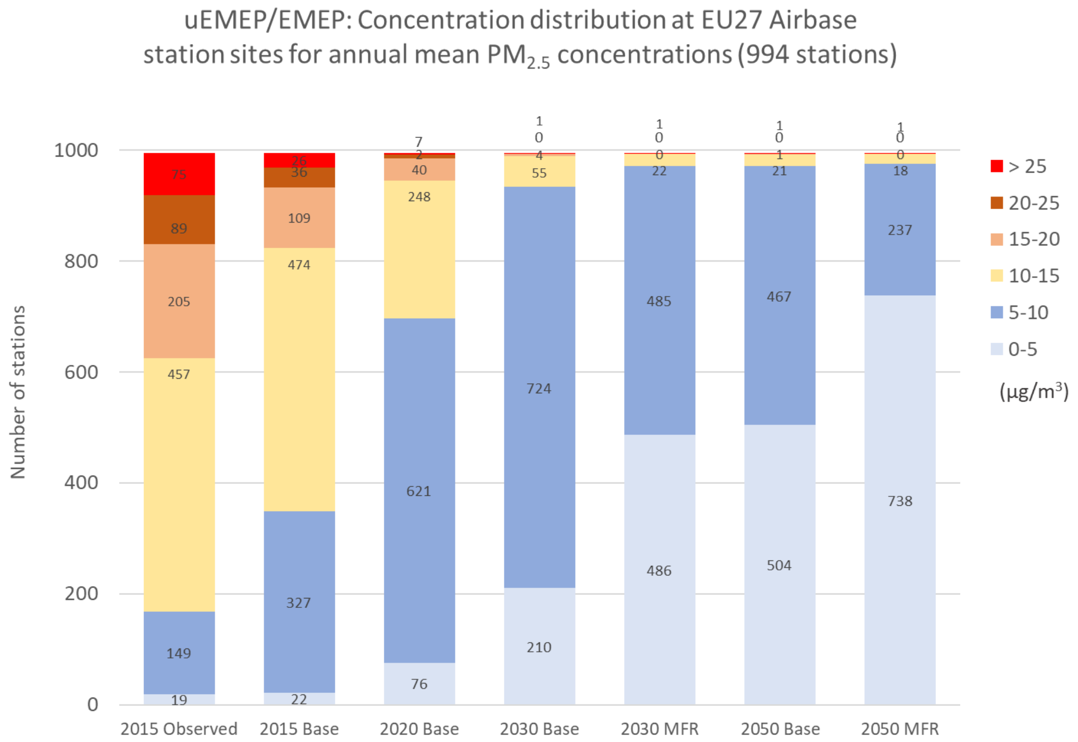
Station exceedances

The concentration distributions at station sites in the EU-27 are shown in the Figure 13 for the Baseline and MTFR scenarios for the downscaled pollutants $PM_{2.5}$, $PM_{2.5}$, NO_2 and BaP. Also shown are the non-downscaled EMEP calculated pollutants for SOMO35, O_3 26'th highest daily 8 hour max and SO_2. The other modelled pollutants of Benzene and CO are not shown as these both have model bias ~ -50%. In addition, Figure 13 shows the calculation with bias adjustment for $PM_{2.5}$ and NO_2. The following points can be noted concerning the station calculations.

$PM_{2.5}$

- $PM_{2.5}$ concentrations for the reference year 2015 have a bias of -19%
- There is a significant reduction in $PM_{2.5}$ concentrations even by 2030 with less than 5 stations exceeding 15 µg/m^3 for the baseline scenario.
- For a large number of stations, $PM_{2.5}$ concentrations of < 5 µg/m^3 remain unattainable, independent of the scenario.
- The one station still above 25 µg/m^3 in 2050 is in Stockholm, caused by non-exhaust road transport emissions. Non-exhaust emissions are not part of the scenario measures but for this city these emissions appear overestimated (see Appendix 3).

Figure 13 Number of EU27 air quality stations calculated to be in exceedance of specified annual mean concentration levels for $PM_{2.5}$ (WITHOUT bias adjustment)

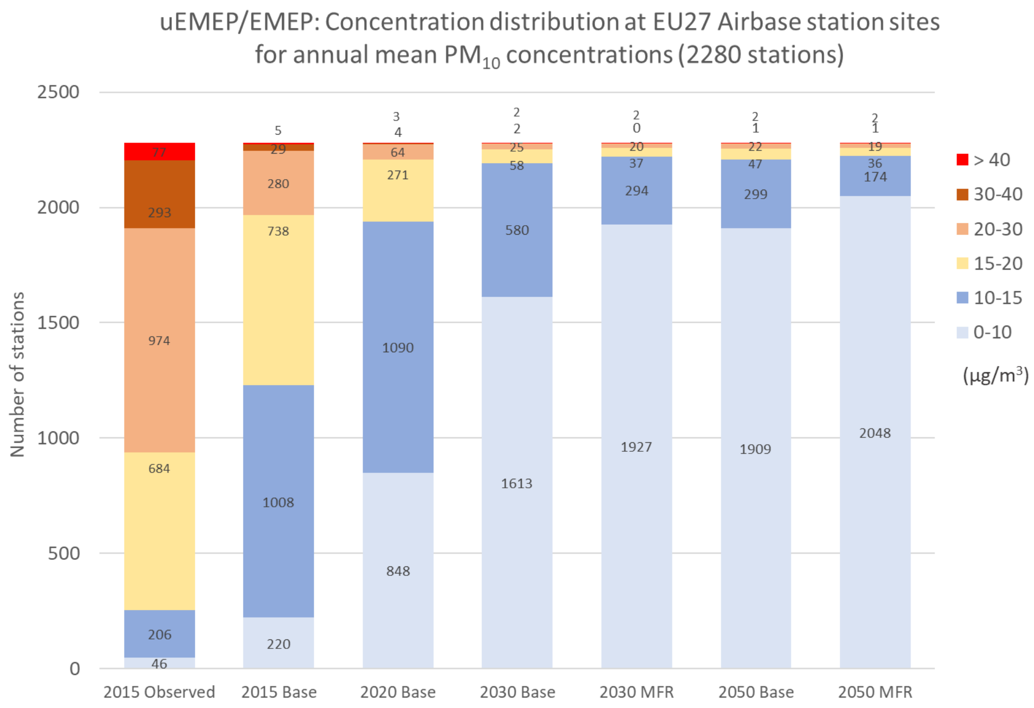


PM_{10}

- PM_{10} concentrations for the reference year 2015 have a bias of -33%
- There are few observed concentrations (77 out of 2280), even in 2015, that exceed the limit value of 40 µg/m^3. The negative model bias results in only 5 sites exceeding 40 µg/m^3 in 2015.
- In 2030 and 2050 there are almost no station sites >15 µg/m^3. This number will be larger in an unbiased model (see next Section)

- The two stations still above 40 µg/m^3 in 2050 are one in Stockholm, due to non-exhaust emissions, and from high PM_{10} industrial emissions near Dunkirk. Non-exhaust emissions in Stockholm are very likely overestimated.

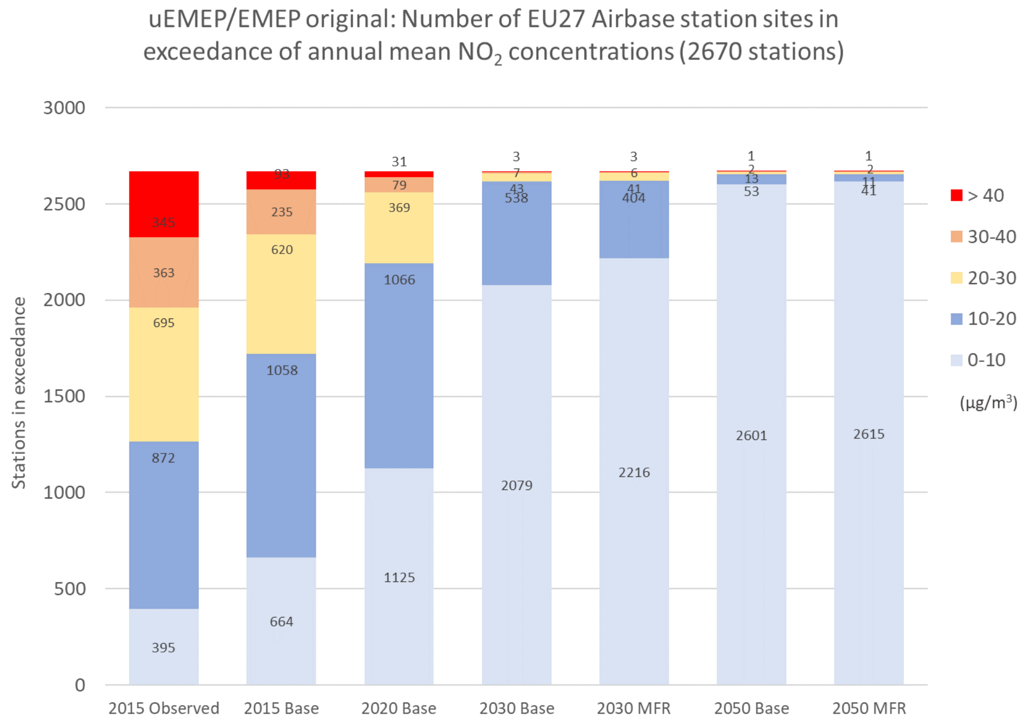
Figure 14 Number of EU27 air quality stations calculated to be in exceedance of specified annual mean concentration levels for PM_{10} (WITHOUT bias adjustment)



NO_2

- NO_2 concentrations for the reference year have a bias of -23%
- There are significant reductions in NO_2 concentrations already in 2030 and further to 2050, when less than 60 stations, representing 2% of all stations, are still above 10 µg/m^3. These reductions are obtained chiefly though NO_X emission reductions from road transport.
- There is little difference between the Baseline and MTFR scenarios.
- The one station still above 40 µg/m^3 in 2050 is in the port city of Genova. Shipping emissions are very likely overestimated here.

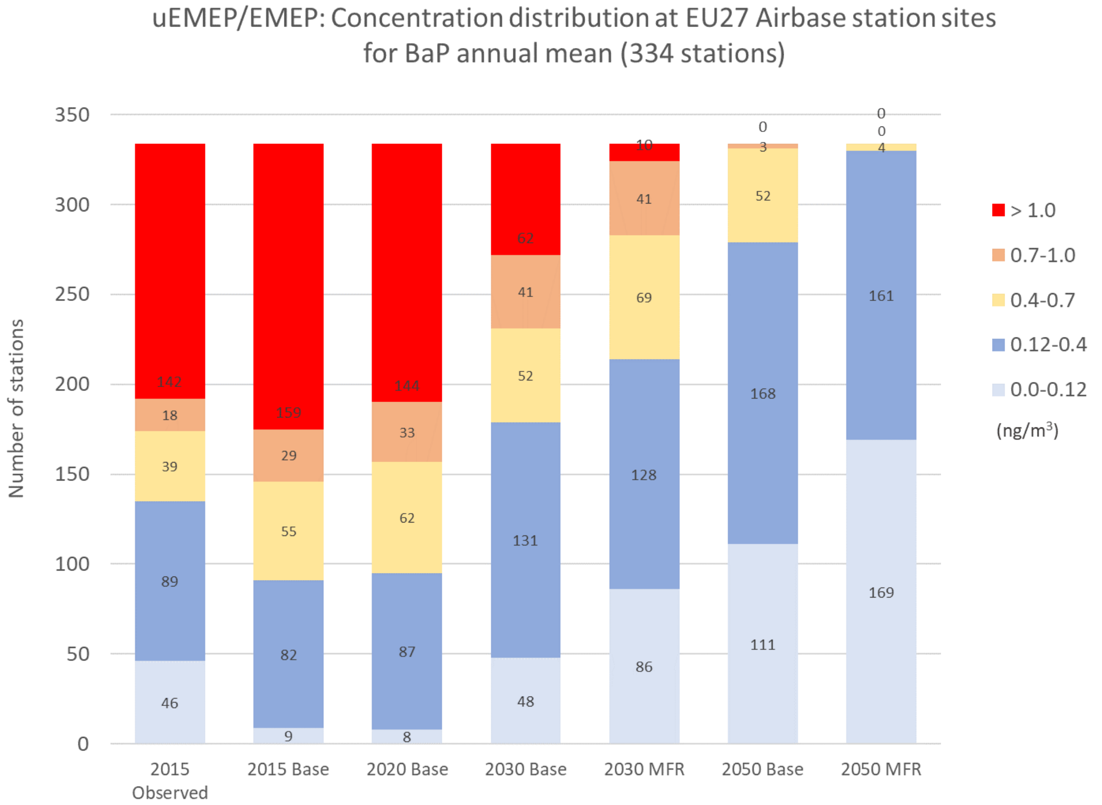
Figure 15 Number of EU27 air quality stations calculated to be in exceedance of specified annual mean concentration levels for NO_2 (WITHOUT bias adjustment)



Benzo(a)pyrene (BaP)

- BaP concentrations are well modelled with a small positive bias, + 11%.
- The high BaP concentrations are primarily dominated by measurement sites in Poland and secondly at measurement sites in Italy and Spain (See Appendix 3)
- The number of stations in exceedance of the AAQD limit value of 1 ng/m^3 does not reduce to 0 until 2050.
- The WHO recommended concentration of 0.12 ng/m^3 is only achieved for more than half the population in the 2050 MTFR scenario.

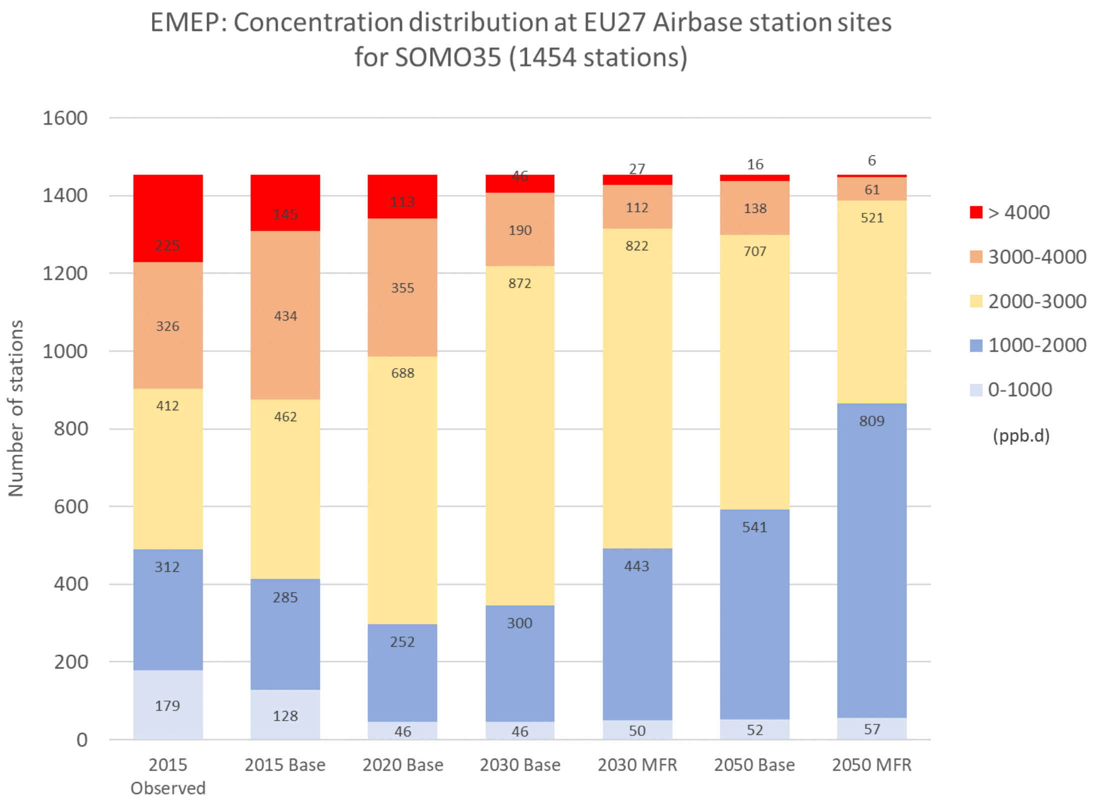
Figure 16 Number of EU27 air quality stations calculated to be in exceedance of specified annual mean concentration levels for BaP. (WITHOUT bias adjustment)



SOMO35

- SOMO35, a health indicator without a limit value, is well modelled with little bias, +1%
- There is a gradual decrease in concentrations from 2020 to 2030 and 2050 with few stations registering above 4000 ppb.d in 2050
- There is also a decrease in SOMO35 with MTFR compared to Baseline

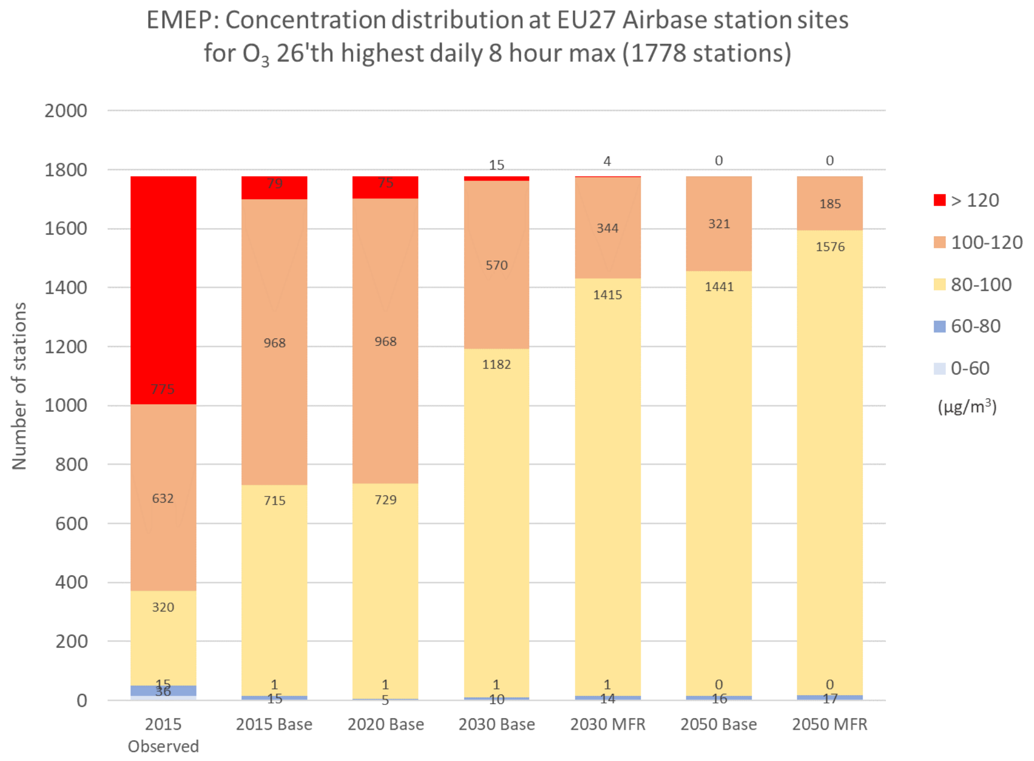
Figure 17 Number of EU27 air quality stations calculated to be in exceedance of specified concentration levels for SOMO35 (WITHOUT bias adjustment)



O_3 26'th highest daily 8 hour max

- This pollutant indicator is not downscaled and results are from the EMEP model
- O_3 26'th daily has a model bias of -11% with a tendency to underestimate higher concentrations (See Appendix 3)
- O_3 26'th daily currently has a target value of 120 µg/m^3 which is exceeded at a large number of stations.
- The tendency to underestimate higher concentrations will also influence the scenario calculations and the modelling estimates in 2030 and 2050 will reflect this.
- There is a slight decrease in O_3 26'th daily with MTFR compared to Baseline and there is a general decreasing trend from 2030 to 2050

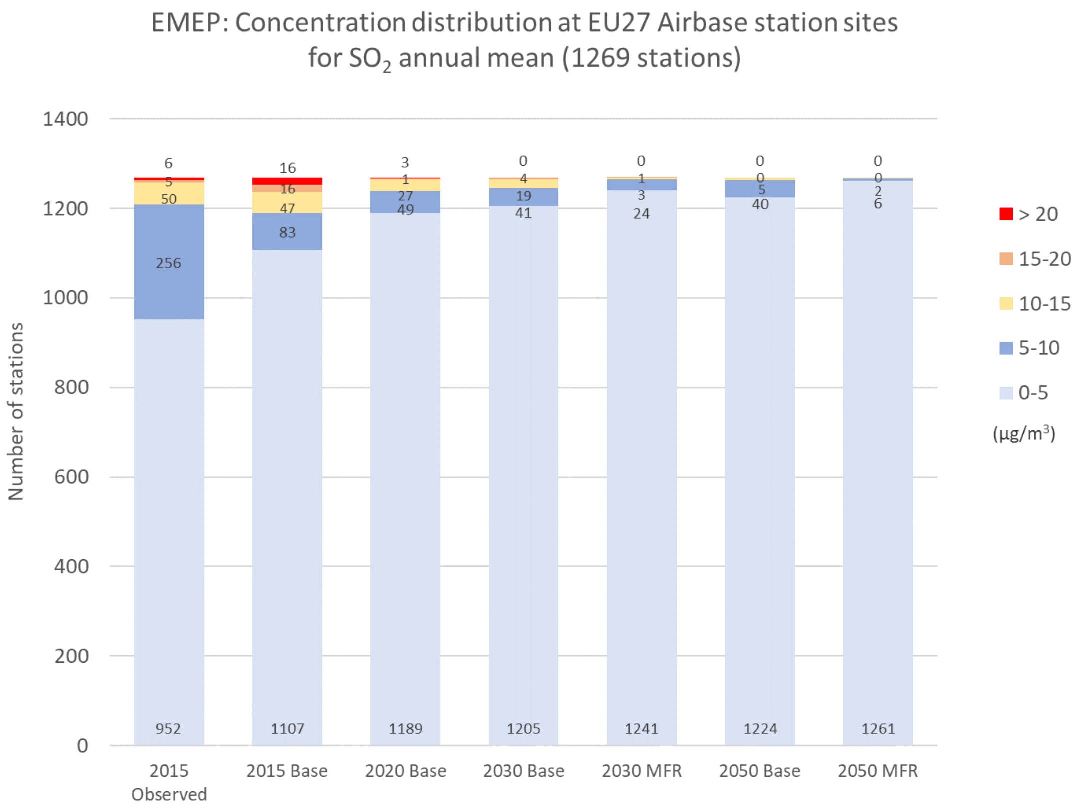
Figure 18 Number of EU27 air quality stations calculated to be in exceedance of specified concentration levels for O_3 26'th highest daily 8 hour max (WITHOUT bias adjustment)



SO_2

- This pollutant indicator is not downscaled and results are from the EMEP model.
- SO_2 concentrations for the reference year have a bias of -27%.
- In 2015 there are very few observed SO_2 exceedances of a 20 µg/m^3 reference value and in 2030 and 2050 there are no modelled exceedance of this value.

Figure 19 Number of EU27 air quality stations calculated to be in exceedance of specified concentration levels for SO_2 (WITHOUT bias adjustment)



The other modelled compounds of CO and Benzene are not shown but presented in the Appendix. These pollutants both showed significant negative bias, around -50%, most likely indicating poor emission data. Modelling results for these two pollutants will have a limited usefulness for any scenario assessment.

Sensitivity to bias adjustment of station concentrations

There is generally a negative bias to the modelled pollutants. To assess the impact of modelled bias on scenario outcomes a bias adjustment has been implemented. The methodology is described in Appendix 3 (Section 'Bias adjustment'). 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.

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 only 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.

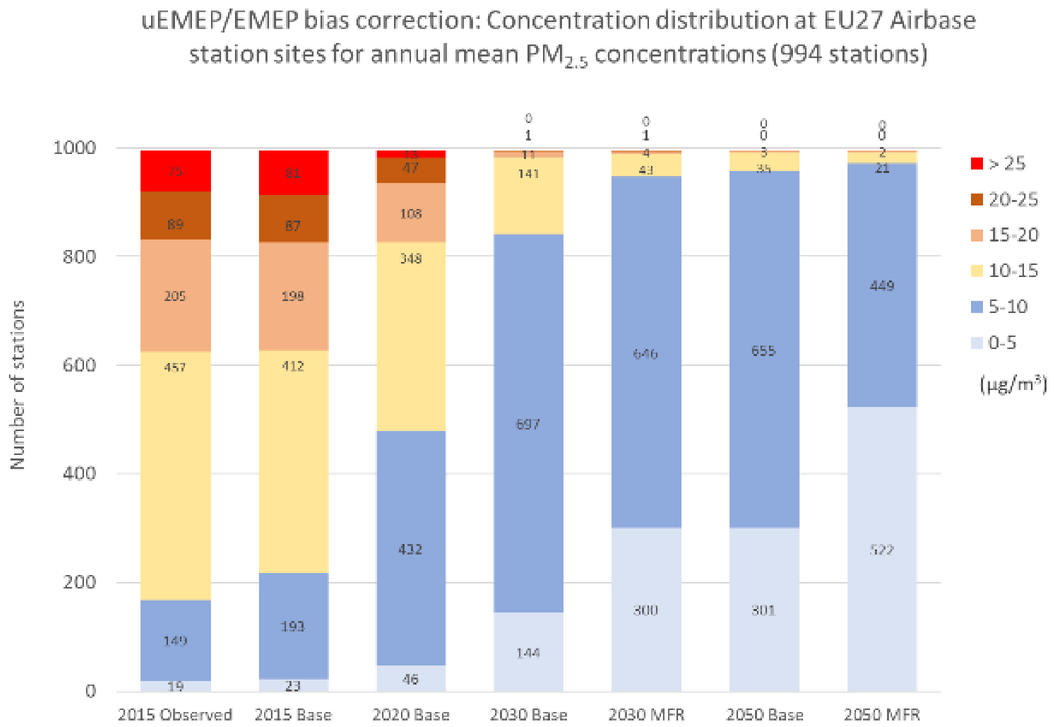
The bias adjustment in the form of a scaling factor was applied to the locally emitted component per country, and applied for all scenarios. The following points can be made concerning this adjustment on these three pollutants:

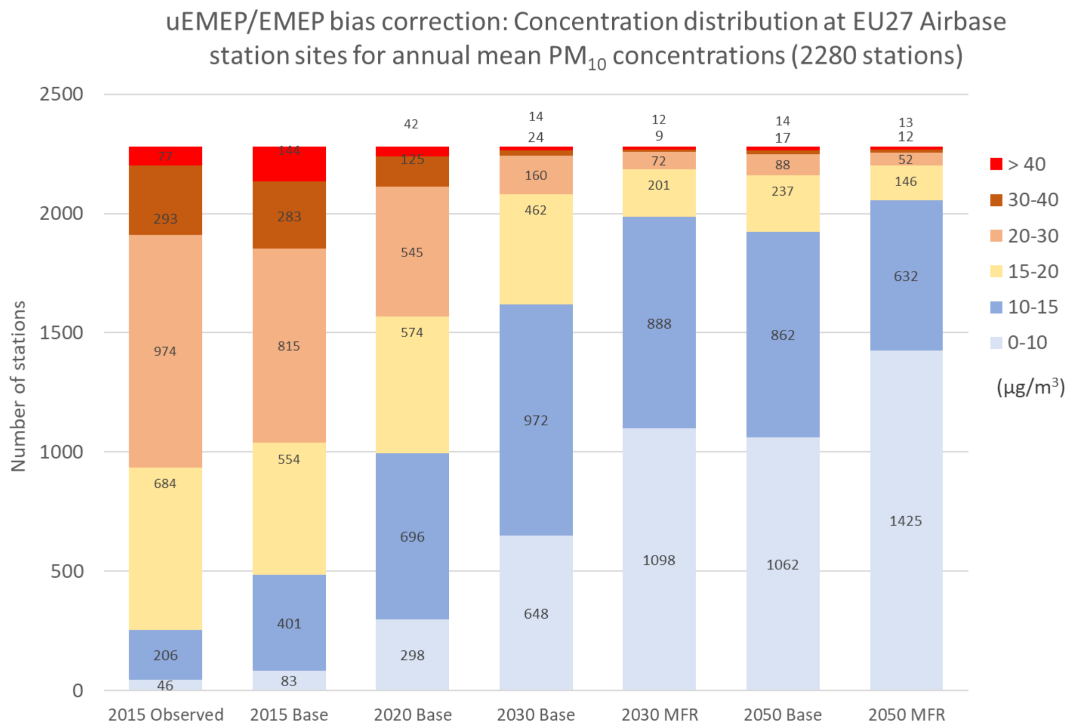
- Bias adjustment for $PM_{2.5}$ gives the same overall picture for station exceedances in 2030 and 2050. The number of stations above > 5 µg/m^3 increases with the adjustment, depending on the scenario. For the 2030 baseline there is almost no change but for the 2050 MTFR the number of stations above > 5 µg/m^3 roughly doubles with the bias adjustment.
- In absolute terms the bias adjustment increases $PM_{2.5}$ station concentrations by an average of 2.6 µg/m^3 in 2015 and by 0.7 µg/m^3 for the 2050 MTFR scenario (the difference in the absolute size of the bias being due to generally reduced concentration levels).
- Bias adjustment for PM_{10} increases the number of stations in the 2030 baseline > 40 µg/m^3 from 2 to 14. This is indicative of the uncertainty surrounding the calculation.
- With bias adjustment for PM_{10} the number of sites in 2030 > 15 µg/m^3 increases from around 60 to 300 – 600, which is a significant increase in station numbers showing a large uncertainty.
- Bias adjustment for NO_2 gives the same overall picture for station exceedances in 2030 and 2050. The number of stations > 10 µg/m^3 in 2030 increases from around 22% to 30%.

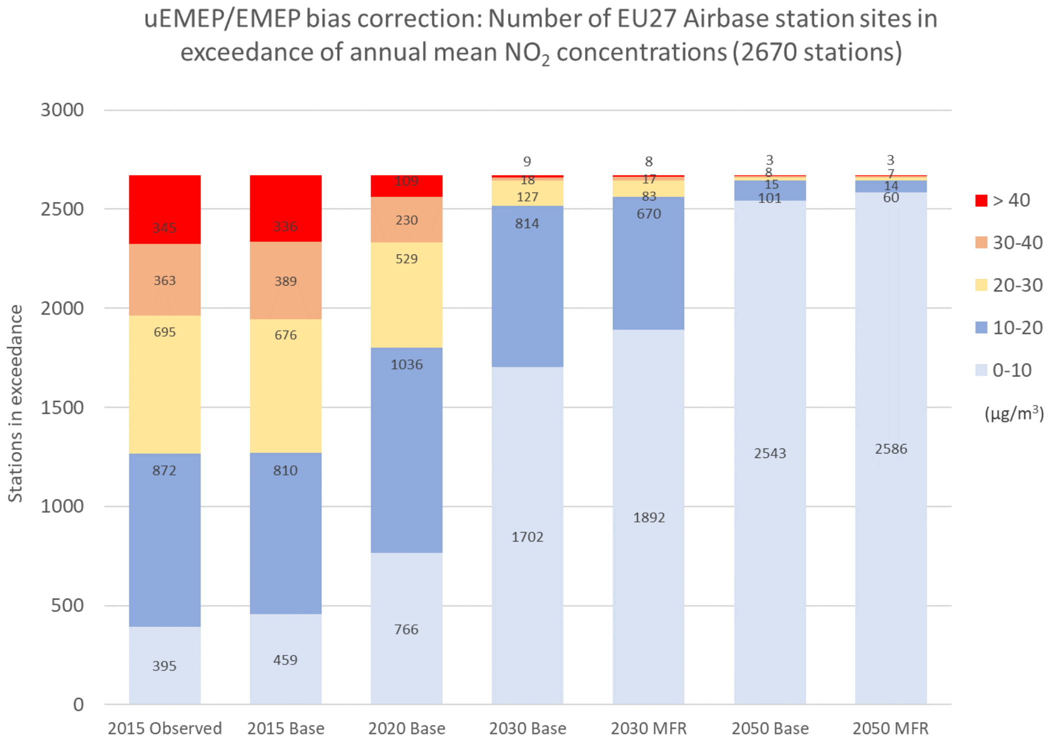
Final results for mapping and exposure do not include this adjustment unless it is specifically mentioned. The existence of modelling bias, though significantly smaller than the overall change in concentrations, should always be kept in mind when drawing conclusions from the results.

We conclude that the overall picture concerning the reduction in pollutant concentrations at station sites remains the same, both with and without bias adjustment, but there remains an uncertainty when the number of stations close to any particular threshold concentration is small. This **uncertainty is largest for PM_{10}** which also had the largest negative bias. When interpreting the scenario results for further application the impact of modelling bias should always be considered.

Figure 20 Number of EU27 air quality stations calculated to be in exceedance of specified concentration levels for $PM_{2.5}$, PM_{10} and NO_2 (WITH bias adjustment)





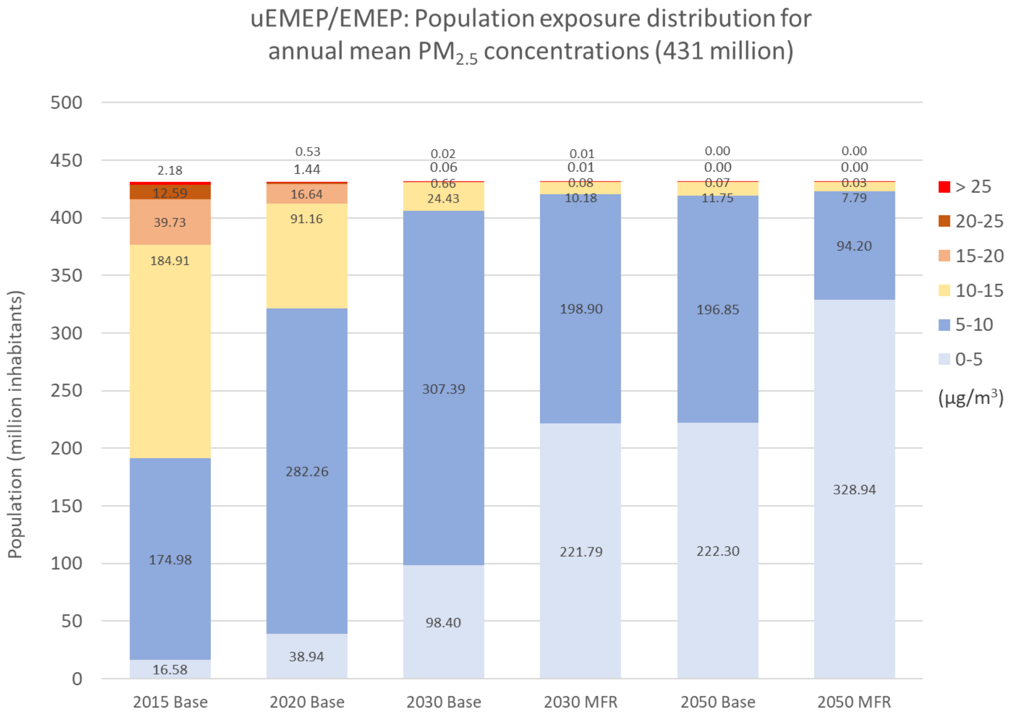


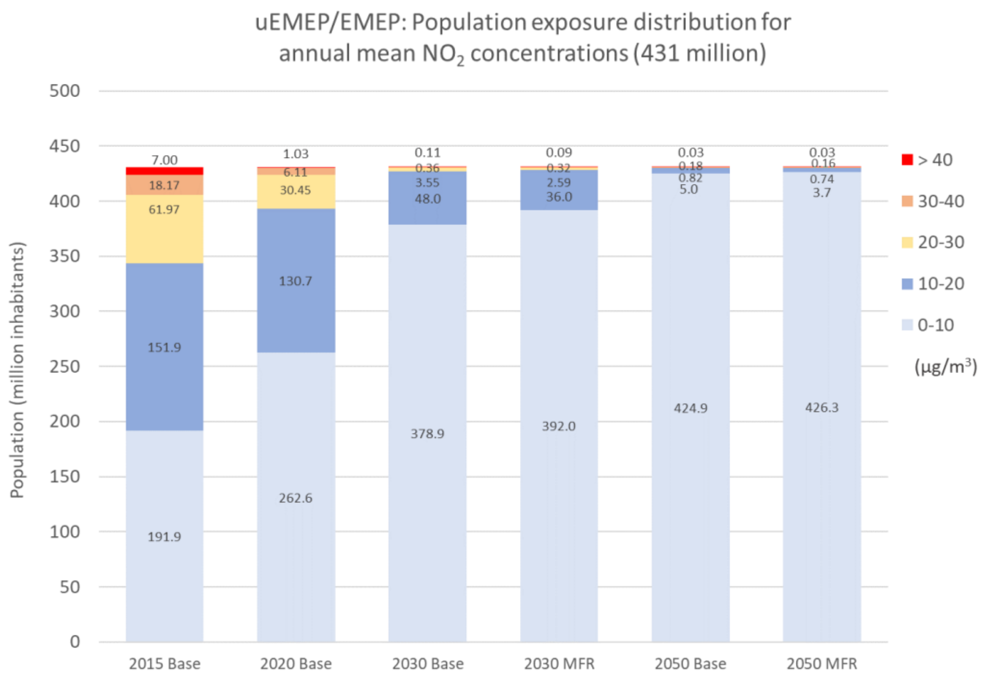
Population exceedance

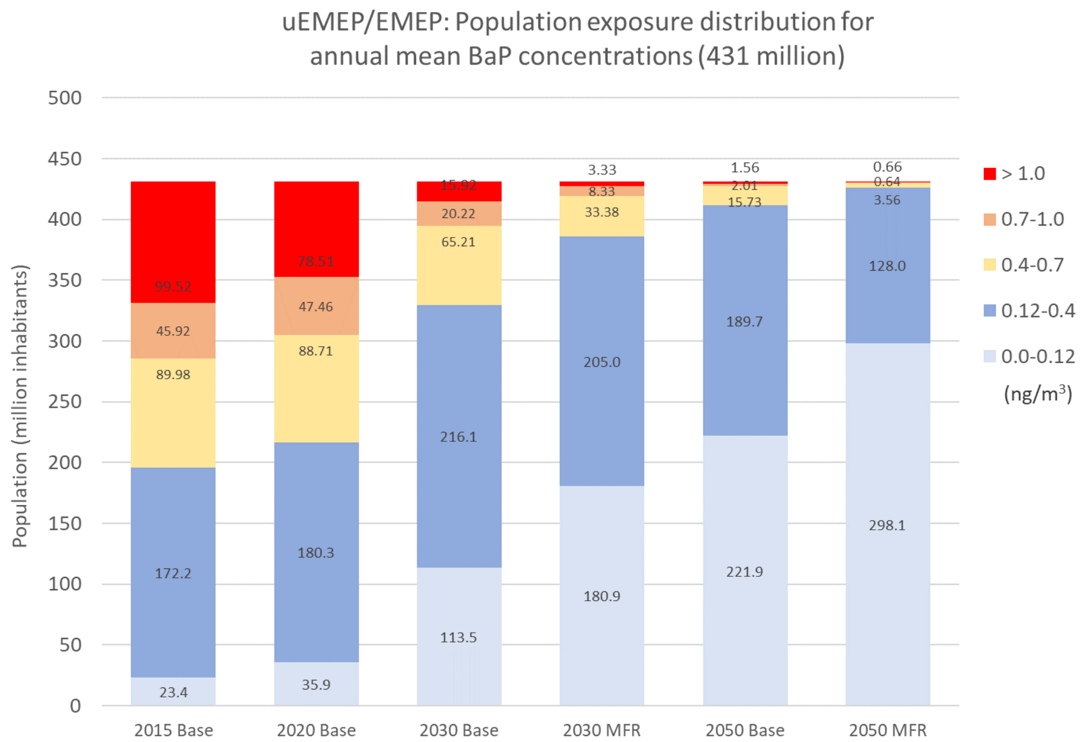
The number of people exposed above selected annual mean concentrations in the EU27 for $PM_{2.5}$, NO_2 and BaP are shown for the baseline and MTFR scenarios in

Figure 21. No bias adjustment is used in the population exposure calculations. In general, these follow very similar scenario trends to the station calculations, but modelled population exposure concentrations tend to be lower than modelled concentrations at station sites. This reflects site positioning that is often intended to measure at high concentrations sites rather than at background exposure sites.

Figure 21 EU27 population in exceedance of specified concentration levels for the pollutants $PM_{2.5}$, NO_2 and BaP for all Baseline and MTFR scenarios **(WITHOUT bias adjustment)**







Population exposure and source contributions

The following figures show the population exposed over the indicated annual mean concentration. The scenarios 2020 base, 2030 base, 2030 MTFR are shown for $PM_{2.5}$ and NO_2. Also included are the relative source contributions for the given exposure level. A detailed description of how the local and non-local source contributions are derived is provided in Appendix 3 (Section 'Explanation of the EMEP/uEMEP downscaling source contribution methodology'). The following points can be noted concerning the station calculations.

$PM_{2.5}$

- 530,000 inhabitants are exposed to $PM_{2.5}$ concentrations > 25 µg/m^3 in 2020 and this is chiefly attributable to residential emissions of primary $PM_{2.5}$.
- 16,000 inhabitants are exposed to $PM_{2.5}$ concentrations > 25 µg/m3 in 2030 but this number is well within the uncertainty of the methodology.
- In 2030 non-exhaust $PM_{2.5}$ emissions from road transport become a significant source contribution in some cities, notably Nordic countries. Non-exhaust emissions remain unchanged for all scenarios.
- Local primary $PM_{2.5}$ sources (all sources in lower case letters), that are emitted from within the ± 0.4° window, account for 22% of the total $PM_{2.5}$ European exposure in 2020.

Figure 22 Population exposure with source contribution for the EU27. Base 2020 $PM_{2.5}$ **(WITHOUT bias adjustment)**

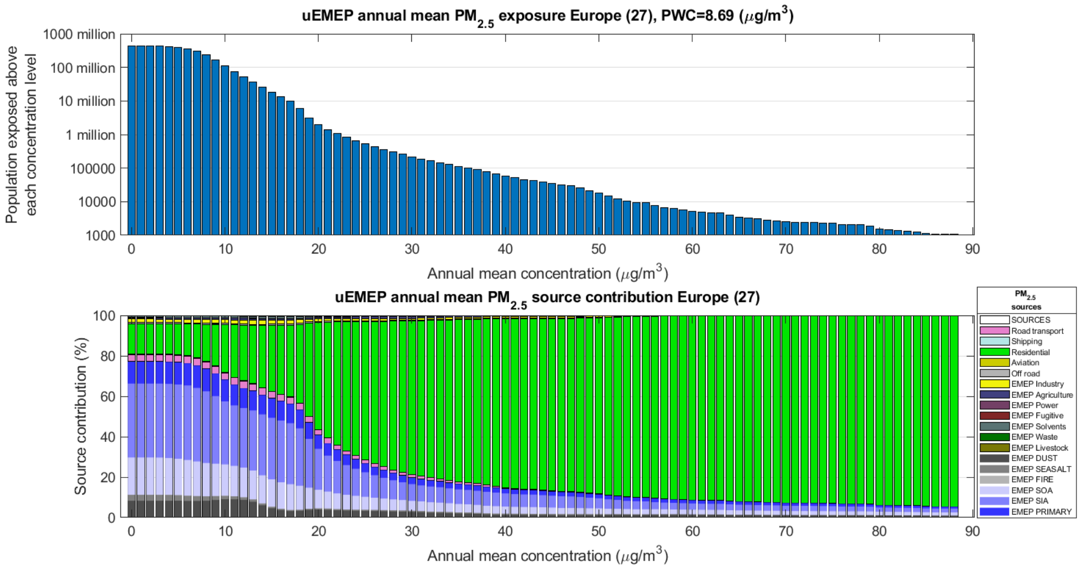


Figure 23 Population exposure with source contribution for the EU27. Base 2030 $PM_{2.5}$ (WITHOUT bias adjustment)

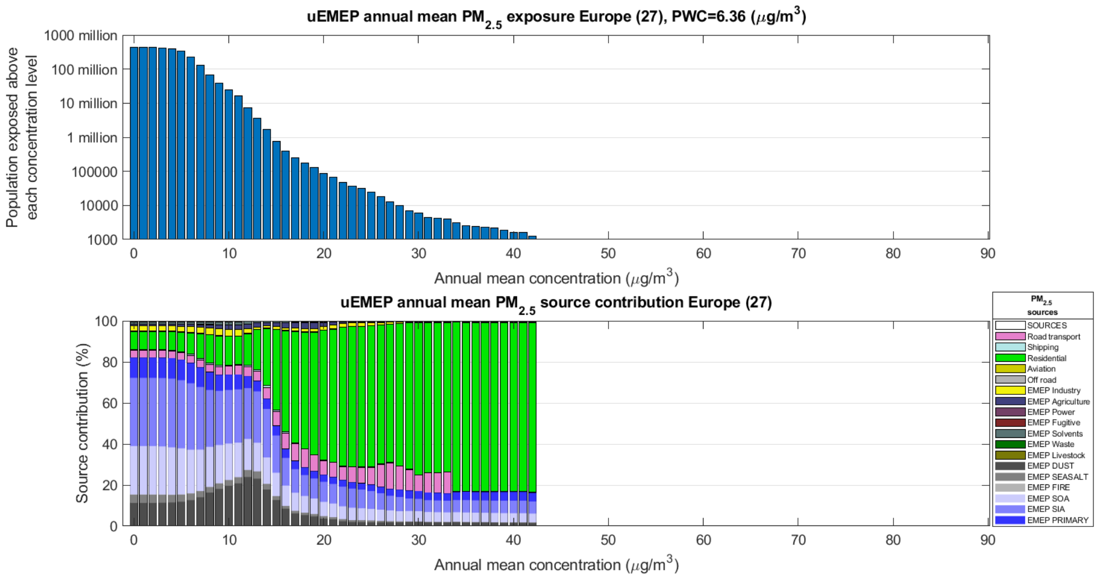
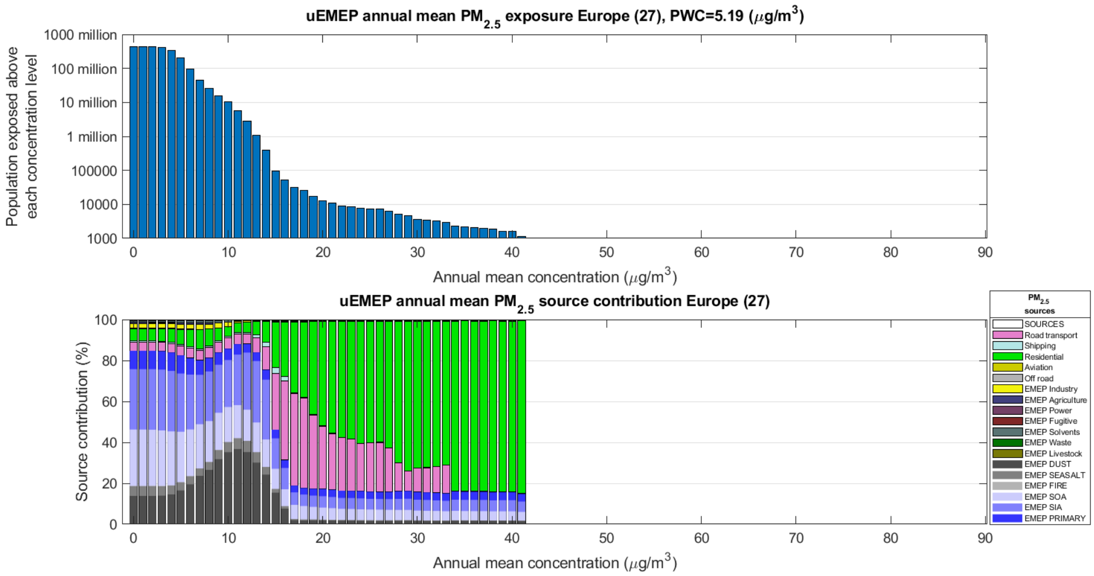


Figure 24 Population exposure with source contribution for the EU27. MTFR 2030 $PM_{2.5}$ (WITHOUT bias adjustment)



NO_2

- In 2020 the major source of NO_X contributing to NO_2 concentrations for all exposure levels is local road traffic, i.e. emitted from within the ± 0.4° window.
- In 2030 road traffic contributes very little and the dominant source leading to exposures above 10 µg/m^3 is shipping. There is a large degree of uncertainty in these local emission sources at ports

Figure 25 Population exposure with source contribution for the EU27. Base 2020 NO_2 (WITHOUT bias adjustment)

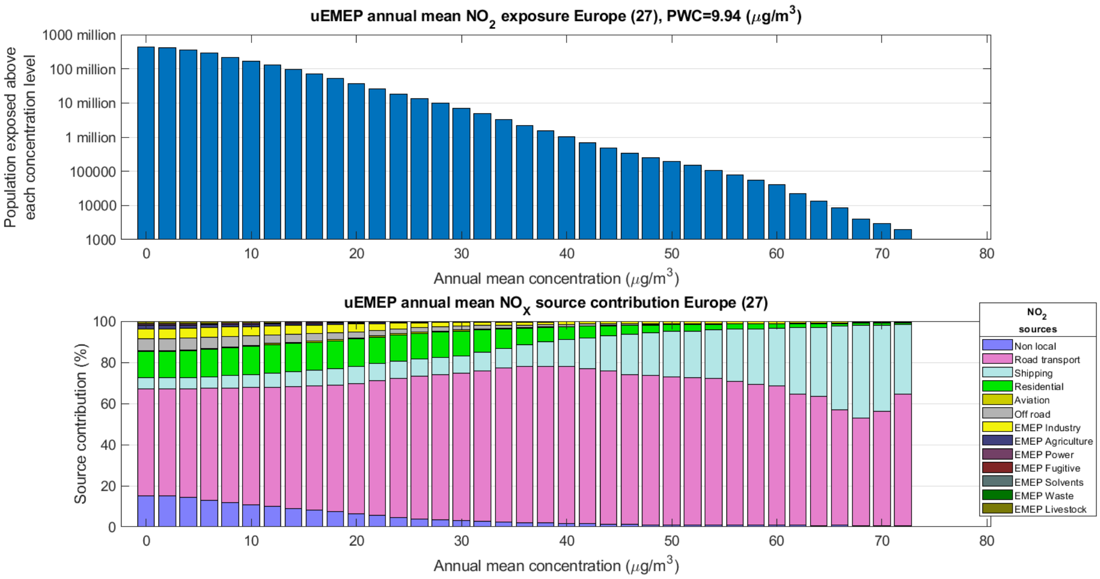


Figure 26 Population exposure with source contribution for the EU27. Base 2030 NO_2 (WITHOUT bias adjustment)

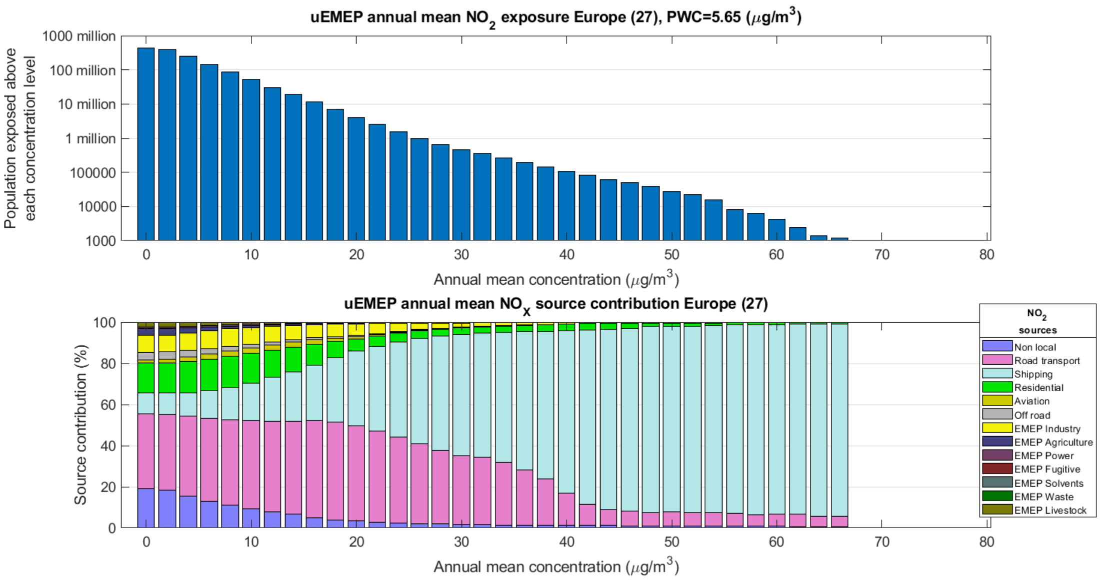
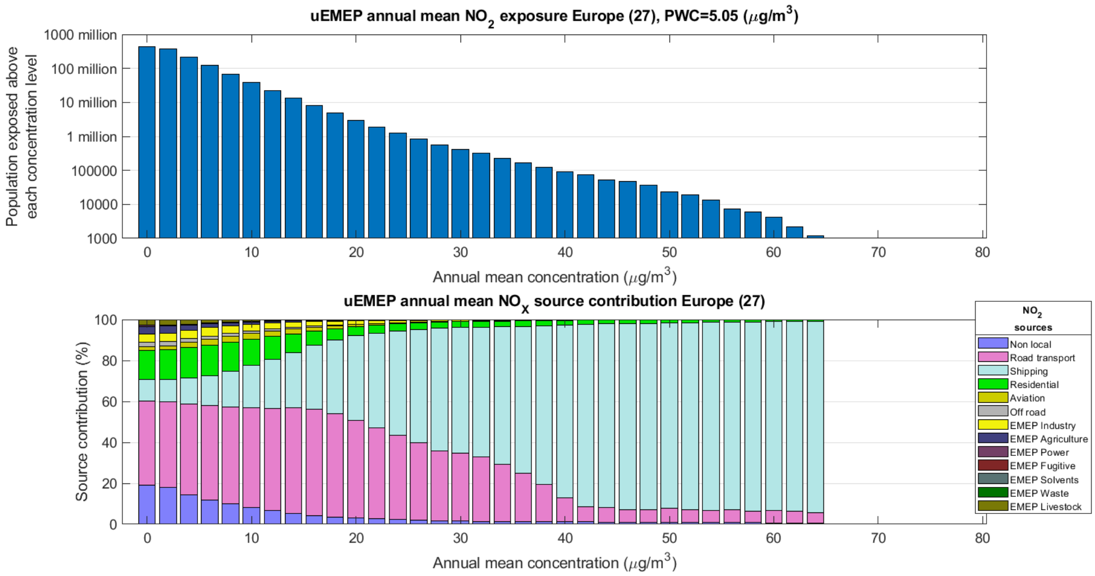


Figure 27 Population exposure with source contribution for the EU27. MTFR 2030 NO_2 (WITHOUT bias adjustment)



BaP

- In 2020 the dominant source for BaP is residential heating, followed by some individual industrial emissions.
- In 2020 around 80 million inhabitants were exposed above the current EU limit value of 1 ng/m^3. This was mostly in Poland and in Northern Italy. In 2030 this is reduced to 15 million.
- In 2030 industrial sources of BaP dominate and are the cause of the remaining exceedances. These exceedances are chiefly the result of one individual industrial plant in Northern Italy, Vicenza, and some lesser contributions in Spain and Poland. To illustrate this, the exposure calculation has been carried out after the removal of Italy. These emissions remain uncertain, both in the present day, and how they will evolve in the future.

Figure 28 Population exposure with source contribution for the EU27. Base 2020 BaP (WITHOUT bias adjustment)

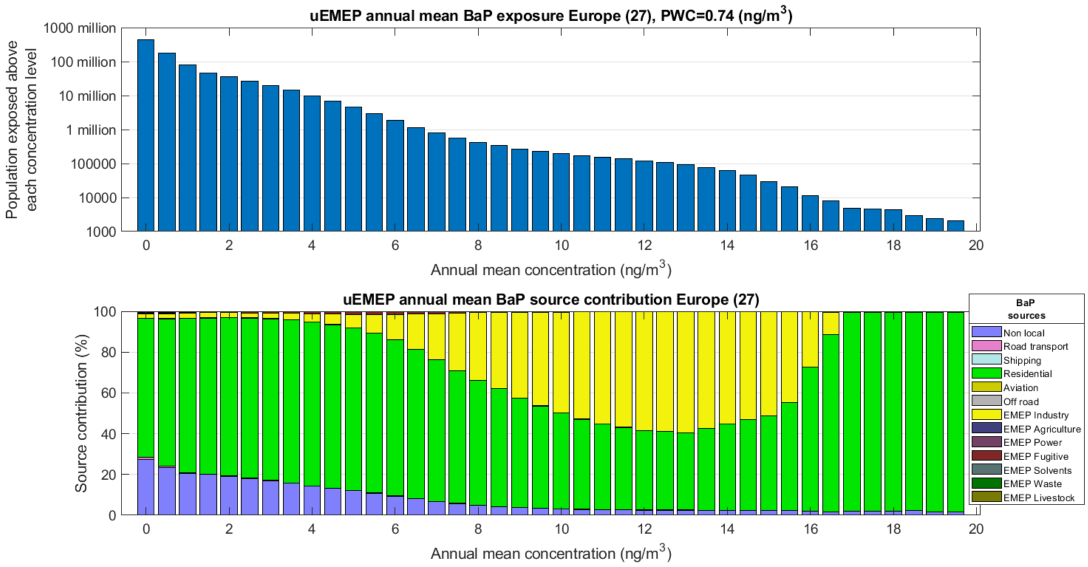


Figure 29 Population exposure with source contribution for the EU27. Base 2030 BaP (WITHOUT bias adjustment)

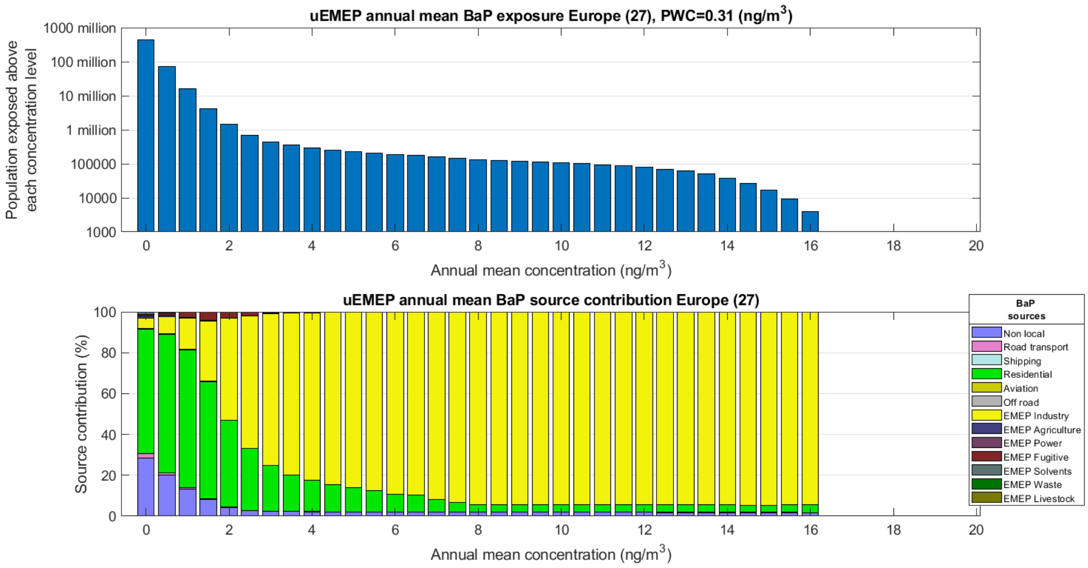
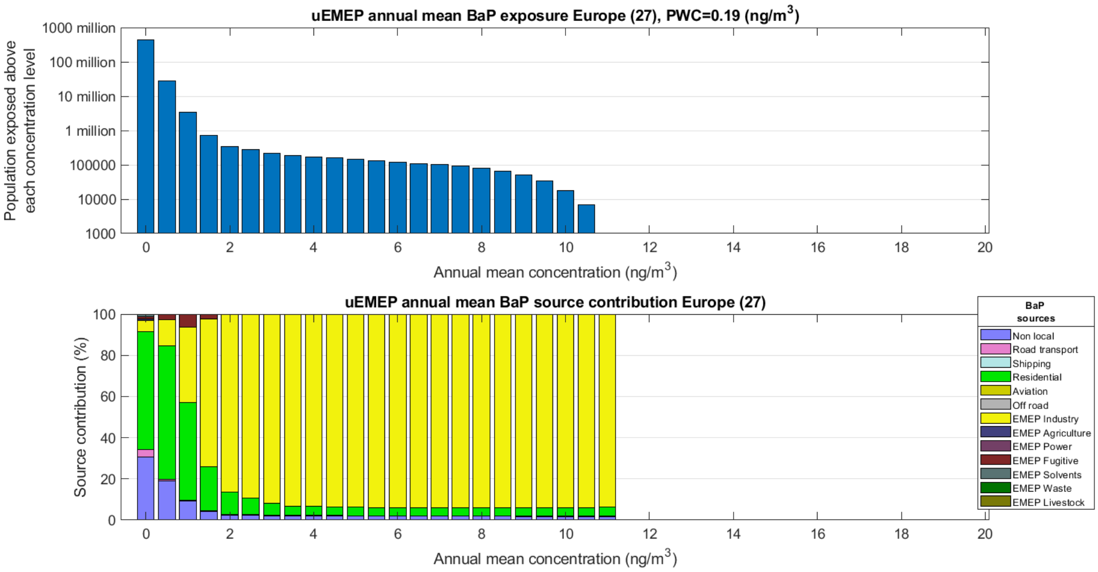


Figure 30 Population exposure with source contribution for the EU27. MTFR 2030 BaP (WITHOUT bias adjustment)



Source contributions per country

To assess the differences between countries, the population weighted source and PM species contributions are provided per country for the pollutants $PM_{2.5}$, NO_2 and BaP. We show the 2020 base, 2030 base and the 2030 MTFR.

$PM_{2.5}$

- The population weighted concentration of $PM_{2.5}$ for the EU27 in 2020 is calculated to be 8.7 µg/m³. This varies across the EU27 from around 4 µg/m³ in Ireland to 14 µg/m³ in Malta. This is reduced to 5.2 µg/m³ for the 2030 MTFR scenario.
- Significant decreases occur from 2020 to 20350 for many European countries, mostly as a result of changes in the primary residential heating sector and secondary inorganic aerosols (SIA)
- The Southern Mediterranean countries of Malta (MT), Cyprus (CY), Greece (EL) and Spain (ES) are significantly influenced by wind-blown dust and to a lesser extent sea salt. These two factors contribute around 7 µg/m³ in Malta.
- Secondary organic aerosols (SOA) change very little between the scenarios

Figure 31 Population weighted concentrations and source contributions per country. Base 2020 $PM_{2.5}$ (WITHOUT bias adjustment)

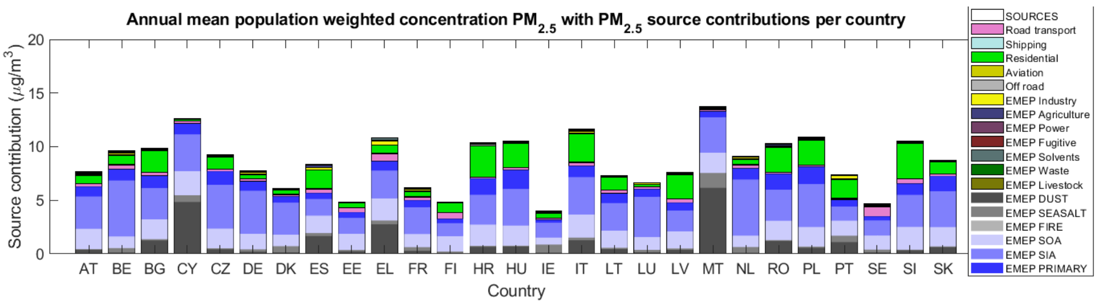


Figure 32 Population weighted concentrations and source contributions per country. Base 2030 $PM_{2.5}$ (WITHOUT bias adjustment)

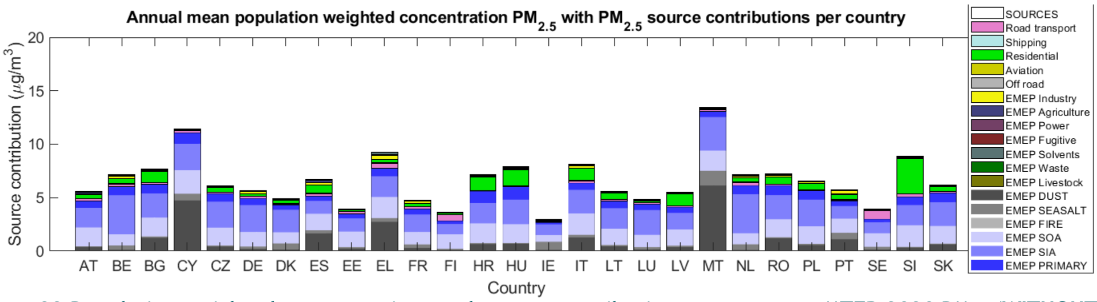
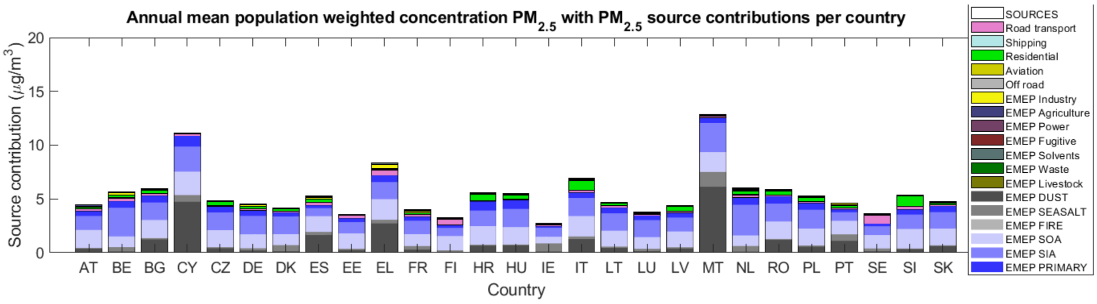


Figure 33 Population weighted concentrations and source contributions per country. MTFR 2030 $PM_{2.5}$ (WITHOUT bias adjustment)



NO_2

- The population weighted concentration of NO_2 for the EU27 in 2020 is calculated to be 9.9 µg/m^3. This varies across the EU27 from around 4 µg/m^3 in Cyprus to 16 µg/m^3 in The Netherlands. This is reduced to 5.1 µg/m^3 for the 2030 MTFR scenario.
- In 2020, all countries have a significant contribution from road traffic, but by 2030 this is predicted to be much reduced.
- 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 NO_2 of any European country.

Figure 34 Population weighted concentrations and source contributions per country. Base 2020 NO_2 (WITHOUT bias adjustment)

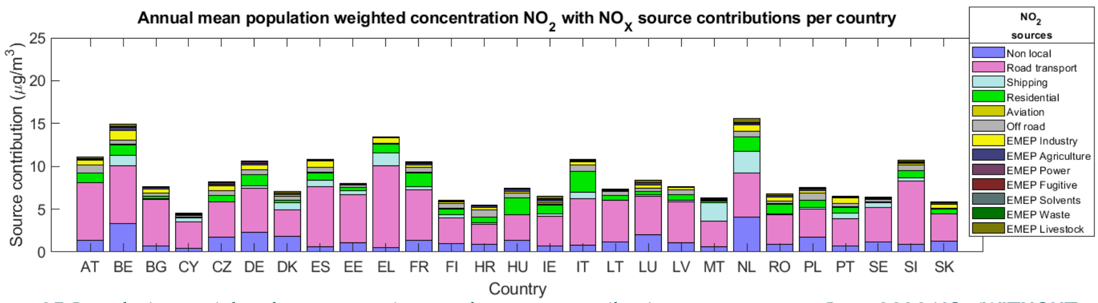


Figure 35 Population weighted concentrations and source contributions per country. Base 2030 NO_2 (WITHOUT bias adjustment)

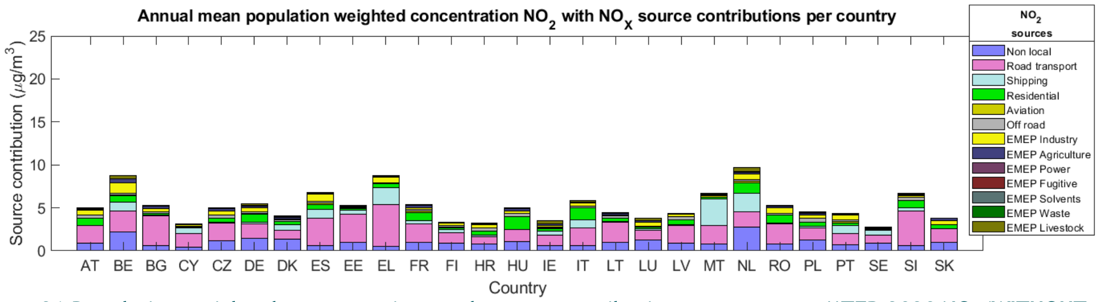
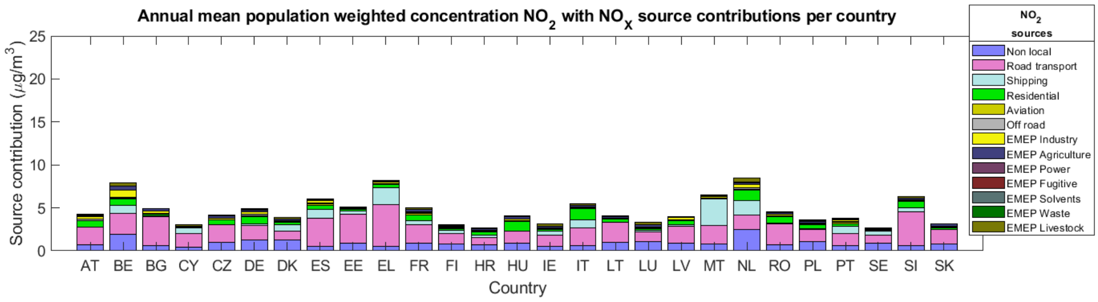


Figure 36 Population weighted concentrations and source contributions per country. MTFR 2030 NO_2 (WITHOUT bias adjustment)



BaP

- The population weighted concentration of BaP for the EU27 in 2020 is calculated as 0.74 ng/m^3. This varies across the EU27 from < 0.1 ng/m^3 in Malta to 3.2 ng/m^3 in Poland. This reduces to 0.2 μg/m^3 for the 2030 MTFR scenario.
- The dominant source of BaP is residential heating. In the emission inventories for the scenario calculations BaP emissions are coupled to $PM_{2.5}$ combustion emissions. The significant decreases in Residential BaP contributions thus also reflects the decrease in $PM_{2.5}$ residential contributions.

Figure 37 Base 2020 BaP (WITHOUT bias adjustment)

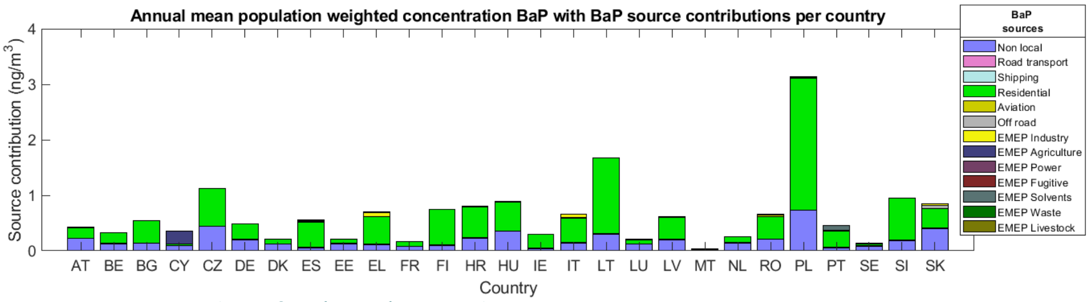


Figure 38 Base 2030 BaP (WITHOUT bias adjustment)

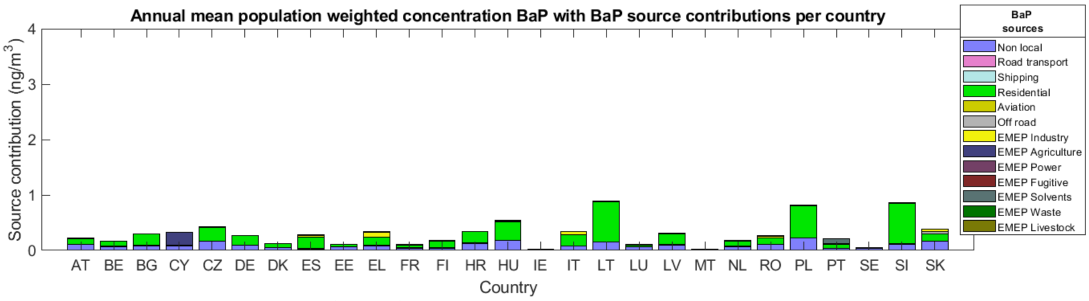


Figure 39 MTFR 2030 BaP (WITHOUT bias adjustment)

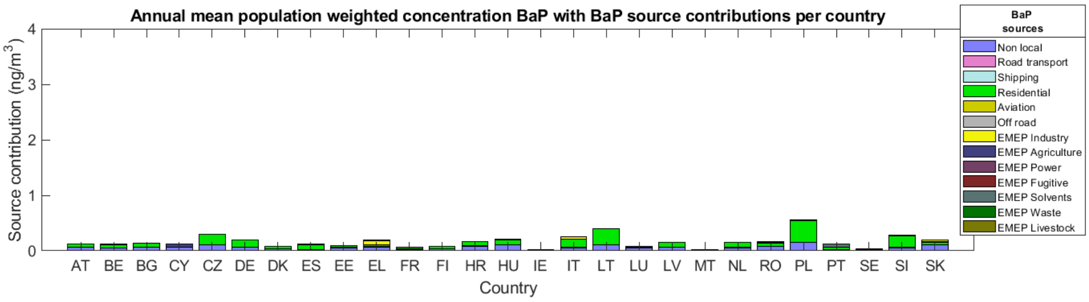
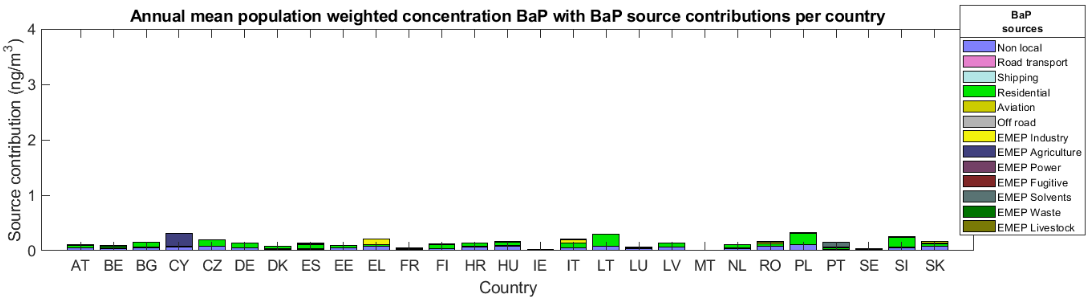


Figure 40 Base 2050 BaP (WITHOUT bias adjustment)



Heavy metals

Heavy metals were not directly captured in the integrated modelling system. As such, a wider review of data and literature has informed the analysis. A review of the latest monitoring data suggests that:

- **Arsenic**
  - 5 monitoring sites out of those with over 85% data coverage[40] do not meet the current EU standard for arsenic of 6 ng/m3.
  - Monitoring sites in industrial areas show the highest arsenic concentrations with an average of 1.38 ng/m3.

[40] Data coverage refers to the annual average percentage of valid measurement. The EEA 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.

    - The median, lower and upper quartiles, and maximum value are lower for background sites compared to industrial sites.
- **Cadmium**
    - 1 monitoring site out of those with over 85% data coverage does not meet the current EU standard for cadmium of 5 ng/m3.
    - Monitoring sites in industrial areas show the highest cadmium concentrations with an average of 0.54 ng/m3.
    - The median, lower and upper quartiles, and maximum value are lower for background sites compared to industrial sites.
- **Lead**
    - All monitoring sites in 2019 with over 85% data coverage were compliant with the EU standard for lead of 0.5 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.
- **Nickel**
    - 2 monitoring sites out of those with over 85% data coverage do not meet the EU standard for nickel of 20 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.

Further disaggregation of the monitoring data can be found in Appendix 4.

The monitoring data show broad compliance with the existing EU standards and WHO AQGs. 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 8. 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 8 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.

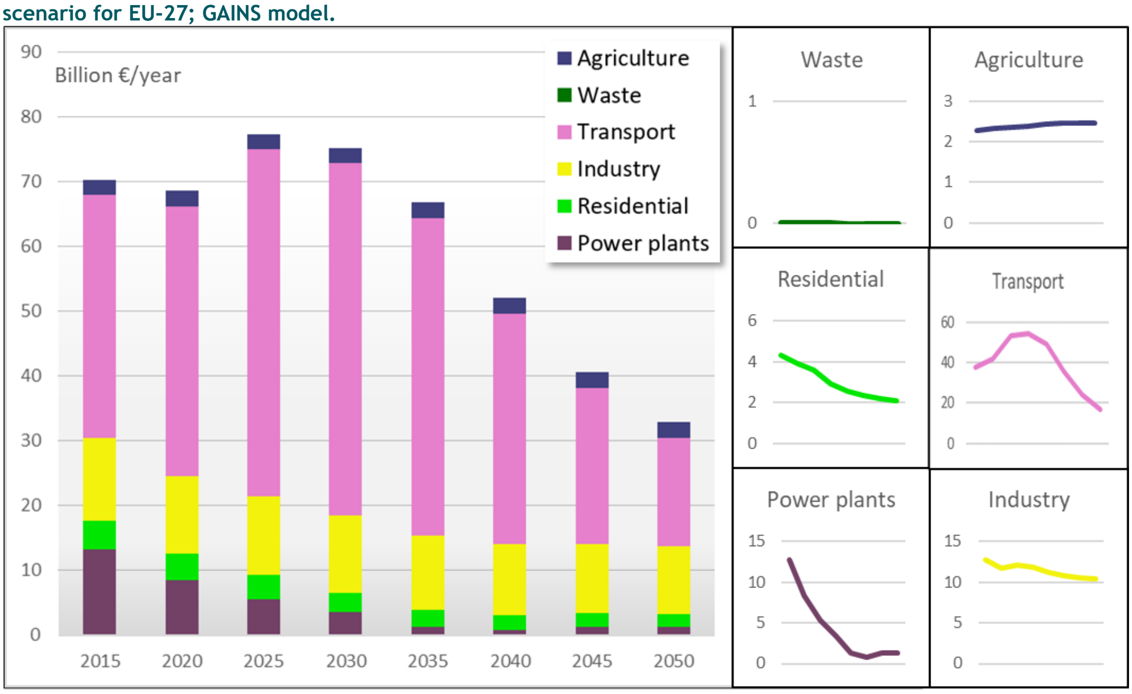
Data Coverage	Arsenic	Lead	Cadmium	Nickel
Above 85%	5	0	1	2
Below 85%	3	0	0	1

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

Costs of air pollution measures

Costs of implemented air pollution policies, specifically including costs associated with emission reduction measures in power plants, industry, transport, residential combustion, and agricultural sectors are estimated at about 75 billion €/year in the EU27 in 2030, similar to current levels. The majority of costs are in the transport and industrial sectors (Figure 41). Costs are estimated to decline in the longer term, i.e., after 2030, primarily due to structural changes embedded in the EU *Fit for 55* strategy, resulting in a strong decline in fossil fuel use which results in a reduced requirement for end of pipe controls in the power sector and later on in transportation owing to the strong increase of alternative propulsion systems.

Figure 41 - Total air pollution control costs (only costs of emission control measures) by sector in the baseline scenario for EU-27; GAINS model.



Employing all available mitigation potential as defined in the MTFR scenario would increase total air pollution mitigation costs in the EU27 by about 24 and 22 billion €/year in 2030 and 2050, respectively (see Section 8.2.2, Figure 80). The majority of additional costs would be associated with measures in industry, agriculture and residential combustion with only minor additional costs for the transport and power sectors. The latter two sectors include most significant structural changes (reducing fossil fuel use) and are subject to strict emission limit standards with only small, if any, further technical mitigation potential.

The cost of air pollution control measures applied in the Baseline scenario, as calculated by the GAINS model for 2030 and 2050, are shown in

Table 9 for each Member State. Cost for the MTFR scenario are available in Section 8.2.2, Table 53 and Table 54).

Table 9 Total air pollution emission control costs under the Baseline scenario as estimated by GAINS. Units: M€/yr.

	2030	2050
Austria	2211	1241
Belgium	2439	1681
Bulgaria	855	337
Croatia	547	194
Cyprus	122	34
Czech Rep.	2328	829
Denmark	1280	737
Estonia	244	75
Finland	1800	966
France	11818	5601
Germany	12845	4641
Greece	1423	393
Hungary	1369	619
Ireland	1093	518
Italy	9526	2970
Latvia	245	68
Lithuania	512	197
Luxembourg	238	51
Malta	64	22
Netherlands	3116	1968
Poland	6957	3392
Portugal	1336	481
Romania	1990	944
Slovakia	534	243
Slovenia	446	135
Spain	8227	3783
Sweden	1649	800
EU-27	75210	32875

7.1.3 *Problem: Projected health and environment outcome shortcomings*

Driver: Exceedances above health guidelines and negative health impacts persist

Health impacts - baseline

Results for attributable mortality (Tier 1)

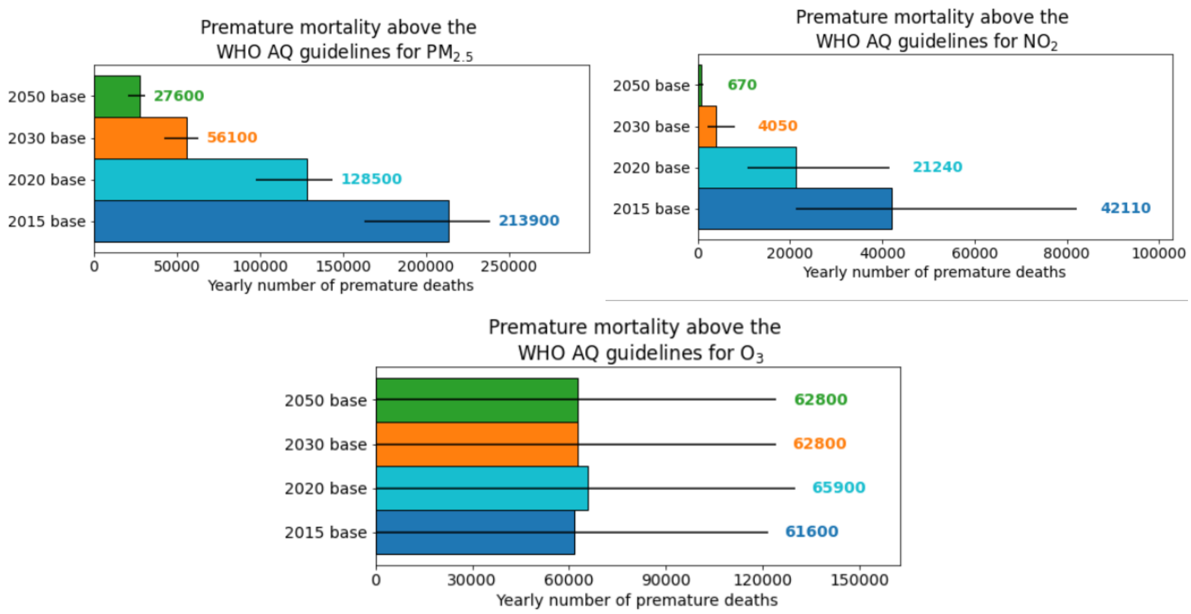
The baseline total number of yearly attributable deaths in the EU-27 for the three pollutants under consideration ($PM_{2.5}$, NO_2, O_3) is shown in the bar graphs in Figure 42. As can be seen from the charts, despite the methodologically conservative approach taken (i.e. only the health impacts of air pollution levels above WHO air quality guideline levels are considered here, which may lead to an underestimate of the total health impacts of air pollution), an important health impact is observed in all the years under consideration. Although there is a significant uncertainty due to the 95% uncertainty range around the relative risks, the order of magnitude of the impact is clear for the two most important pollutants from a health impacts perspective: $PM_{2.5}$ and NO_2. In the historic year (2015), the yearly number of premature deaths is of the order of hundreds of thousands for particulate matter, and of the order of tens of thousands for nitrogen dioxide[41]. For ozone, the central estimate for the yearly number of attributable deaths is also of the order of tens of thousands, but this result is much more uncertain, as the lower boundary of the uncertainty interval is at zero and the upper boundary in the hundreds of thousands.[42]

Under the baseline scenario, which include assumptions on published proposals on more stringent climate policies and vehicle emission standards, the mortality caused by exposure to NO_2 and $PM_{2.5}$ decreases significantly between 2015 and 2030. However, there would still be a considerable number of premature deaths each year observed in 2030, with tens of thousands of attributable deaths per year caused by the exposure to $PM_{2.5}$ and thousands of deaths caused by the exposure to NO_2. These numbers correspond to decreases of attributable mortality of 75% for particulate matter and of 90% for nitrogen dioxide, in comparison with the historical year (2015). By 2050, the attributable mortality is further reduced by a further 50% (in comparison with the 2030 results) for particulate matter, and by 80% (in comparison with the 2030 results) for nitrogen dioxide. These large ameliorations in the health impacts are driven by substantial decreases in the concentrations of the pollutants between 2015 and 2030, and 2050, respectively.

The results for ozone show a different pattern. The mortality caused by the exposure to ozone remains approximately constant from the historical year. Note that these results do not consider the potential impact of climate change, as the meteorological data is the same for each year, which could have a significant impact on the concentrations for ozone peaks (i.e. higher temperatures may lead to more ozone pollution peaks).

[41] Note that these results do not correct for an overlap in the premature deaths between the different pollutants, and, as such, a simple addition of the numbers is not allowed.
[42] Note that these results differ from the results reported by the EEA in its assessment of the air quality in 2015 (EEA, 2017), because updated concentration response functions have been used in the current analysis. A sensitivity study in the annexes focuses on this aspect.

Figure 42 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 scenarios for three pollutants ($PM_{2.5}$, top-left; NO_2, top-right; O_3, bottom)



Notes: Impacts for the four reporting years considered in the study (2015 in blue, 2020 in cyan, 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 NO2 and the nearest 1000 for PM2.5, respectively), while the black lines provide the 95-percentage uncertainty estimate based on the uncertainty on the relative risks.

Figure 43 maps[43] the baseline scenario number of premature deaths attributable to air pollution per capita for all countries in the EU-27 for 2015 and 2030. To facilitate a comparison between 2015 and 2030, the colour scale is fixed per pollutant. The charts indicate a strong regional effect for the chronic mortality caused by the exposure to particulate matter. The impact is larger in Eastern and Southern European countries than in most Northern and Western European countries (with exception from Germany, the Netherlands and Belgium). On a country level, the highest impact is observed in Italy, Croatia, Hungary and Bulgaria, although for Italy most of the impact is in Northern Italy (North West and North East regions), as indicated by the detailed maps per NUTS 1 level in the appendix. Because of the strong reductions in the particulate matter concentrations, the attributable mortality per capita is much smaller in 2030 than in 2015. The spatial pattern also changes slightly, as the relative reductions are smaller in Southern Europe compared to other regions (including Eastern Europe). These results are apparent when the results per NUTS 1 region are considered: all the regions with the highest mortality per capita in 2030 are located around the Mediterranean (Sardinia + Sicily, Malta, Greek Isles (Nisia Aigaiou, Kriti)). Note that part of this impact is related to air pollution from natural sources, which are not reduced by any of the baseline policy measures.

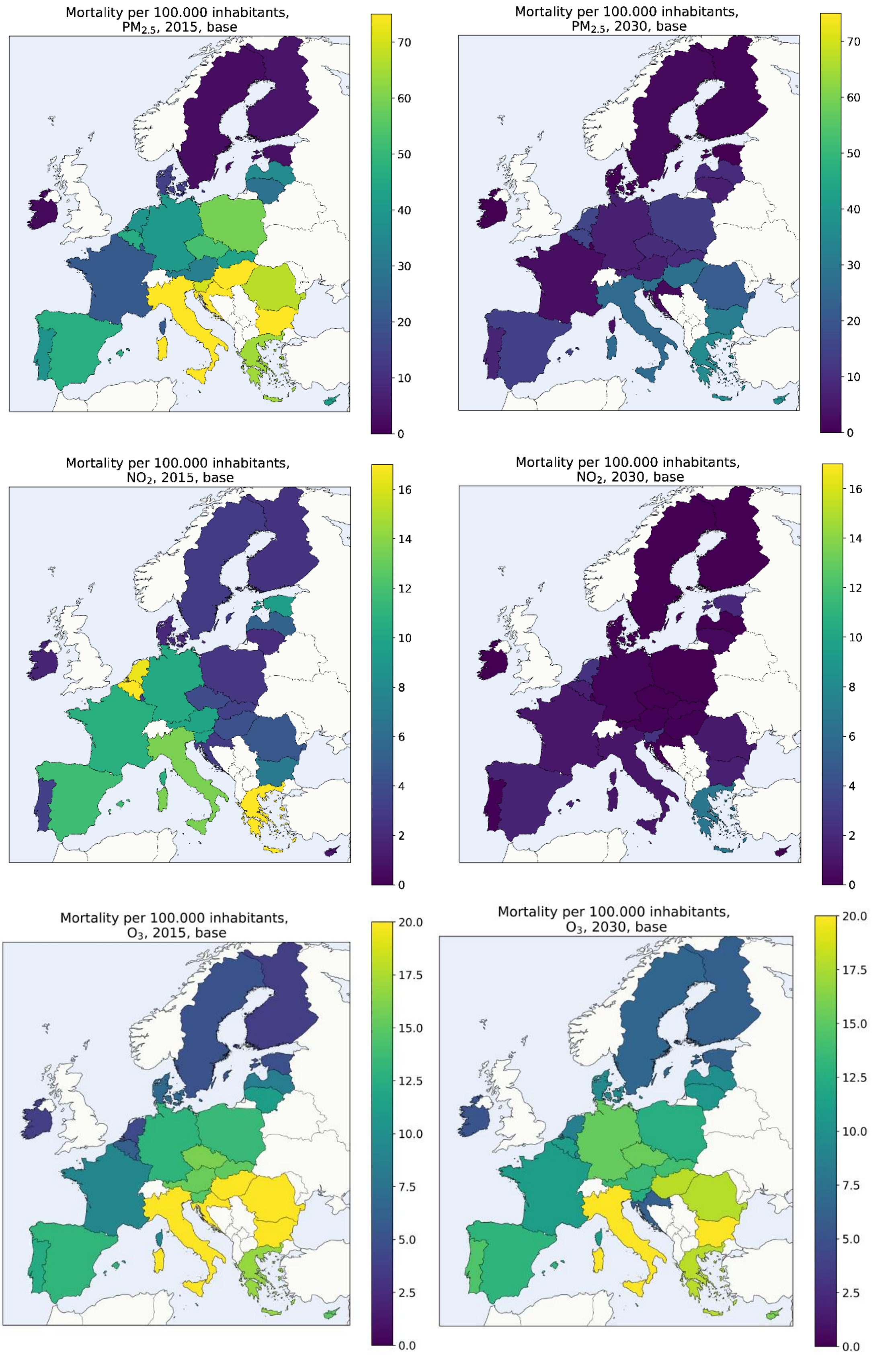
The maps for nitrogen dioxide reflect the nature of nitrogen dioxide pollution: because concentration hotspots are mostly linked to important local road traffic and shipping emissions, the highest impact is also observed at these locations. In the historic baseline year (2015), the highest attributable mortality per capita on a country level is observed in countries with highly polluted cities (Greece, Belgium and

[43] Tables with detailed results on the (absolute) number of attributable deaths are provided in the annex, as are maps per NUTS 1 level.

the Netherlands). Zooming in to the NUTS1 regions, the highest mortality per capita is observed in the regions which surround cities with high traffic and / or shipping emissions, such as Attica (Athens), Madrid, Ile-de-France (Paris), Brussels, Berlin, North West Italy (Milan), Flanders (Antwerp) and West Netherlands (Amsterdam). Due to strong reductions in NO_X emissions, the health impact is also strongly reduced in 2030 in comparison with the baseline year. Because the reductions in road traffic emissions are much larger than the reductions in shipping emissions, there is a shift in high impact locations from regions with significant contributions of road traffic emissions to regions in which both road traffic and shipping emissions are important. For example, in 2030, the list of regions with the highest per capita impact includes East Spain (Valencia and Barcelona) and Northern Greece (Thessaloniki). This effect is even more pronounced in 2050, when all impact is related to high concentrations in several ports around the Mediterranean (due to an increase in international shipping emissions).

For ozone, a strong North-West to South-East gradient is observed: the impact of measures included in the baseline scenario is smaller in Western and Northern Europe compared to Southern and South-Eastern Europe. The countries with the largest remaining health impact per capita are Italy, Croatia, Hungary, Romania and Bulgaria, while detailed results indicate that the highest per-capita remaining health impact per NUTS1 level is observed in North-West Italy (related to high concentrations in the Po Valley), on the Greek Isles (Nisia Aigaiou, Kriti region), and in all regions in Bulgaria. Although the total impact in the EU-27 in 2030 is similar to the total impact in 2015, the charts indicate that the total impact would be distributed differently than in the past. The impact per capita remains high in some of the hotspots (Italy and Bulgaria) but is significantly reduced in other countries (Croatia, and to a lesser extent Hungary and Romania). On the other hand, the impact per capita increases slightly in most Northern and Western European countries, which is partially related to a reduction in NO_x emissions, yielding higher ozone concentrations. Note that these results do not consider the impact of climate change, as the meteorological data assumed for scenario analyses is the same for each year, which could have a significant impact on the concentrations for ozone peaks, especially for the Mediterranean countries.

Figure 43 : 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 ($PM_{2.5}$, top; NO_2, middle; O_3, bottom).



Notes: The maps show results for the baseline in 2015 (left row) and 2030 (right row) per country. The colour scale is the same for both years, but differs between the pollutants.

Results for attributable morbidity (Tier 2 and Tier 3)

Table 10 provides an overview of the morbidity impact from the second (morbidity according to HRAPIE) and third Tiers (additional health outcomes beyond HRAPIE: stroke, lung cancer and asthma in children) of analysis. As with the chronic mortality results, for all health outcomes, the baseline shows a strong reduction in impact over time. Because the underlying incidence rates for the most recent historic data are also used as the incidence rates for the future year, these results only take into account the health impact due to a reduction in the air pollution and due to changes in the demography (according to Eurostat projections). Impacts due to improvements in health care, a more / less healthy lifestyle, etc., are not considered. A notable exception is infant mortality, for which the Eurostat projections concerning the number of deaths in the age group from 0 to 1 year for 2030 and 2050 have been used.

The results also correspond quantitatively with those for chronic mortality related to $PM_{2.5}$ exposure. When comparing the results for the baseline year (2015) and 2030, a reduction of around 75% is observed for most of the health outcomes. In the next 20-year period, a further reduction of around 55 to 60 % (relative to the 2030 baseline morbidity) is expected. The reduction in infant mortality (ca. 85% between 2015 and 2030, and ca. 80% between 2030 and 2050) is even larger, due to a reduction in the baseline mortality rate according to the Eurostat projections. These findings illustrate how the impact for the other health outcomes might be further reduced, if improvements in health care are also considered.

Table 10: Morbidity caused by the exposure to $PM_{2.5}$ pollution in the EU27 under the baseline scenarios for 2015, 2030 and 2050.

Health outcome	Unit	2015	2030	2050
Infant Mortality	Deaths per year	112 (57 ; 192)	15 (7 ; 27)	3 (1 ; 5)
Bronchitis in Children (age 6 -12)	Cases per year	276,000 (0 ; 600,000)	61,000 (0 ; 136,000)	24,500 (0 ; 54,900)
Chronic Bronchitis in adults	Incidence per year	96,400 (35,200 ; 147,000)	24,500 (8,760 ; 38,000)	10,700 (3,820 ; 16,600)
Cardiovascular hospital admissions	Admissions per year	61,600 (11,600 ; 112,000)	14,100 (2,650 ; 25,600)	5,370 (1,010 ; 9,740)
Respiratory hospital admissions	Admissions per year	61,500 (0 ; 127,000)	14,500 (0 ; 30,100)	5,920 (0 ; 12,300)
Restricted activity days	Days per year	244,000,000 (219,000,000 ; 273,000,000)	59,500,000 (53,300,000 ; 66,900,000)	25,600,000 (22,900,000 ; 28,700,000)
Lost working days	Days per year	91,500,000 (78,000,000 ; 105,000,000)	21,200,000 (18,000,000 ; 24,300,000)	8,260,000 (7,030,000 ; 9,470,000)
Stroke (CVA)	Incidence per year	45,800 (39,400 ; 52,000)	11,500 (9,800 ; 13,100)	4,780 (4,090 ; 5,460)
Lung cancer	Incidence per year	17,000 (7,870 ; 25,300)	4,260 (1,950 ; 6,440)	1,800 (823 ; 2,720)
Asthma in children (age < 16 years)	Incidence per year	104,000 (38,000 ; 161,000)	23,700 (8,180 ; 38,300)	9,500 (3,260 ; 15,400)

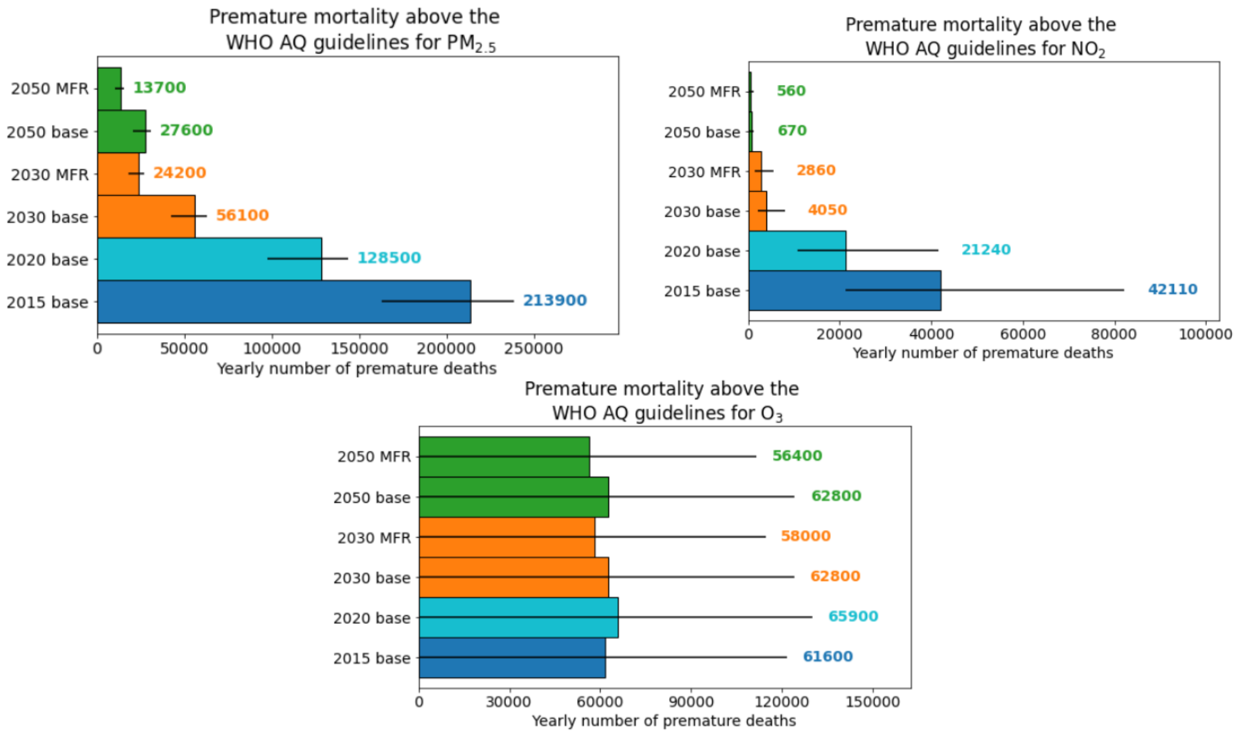
Health impacts: MTFR scenario

Results for attributable mortality (Tier 1)

The impact of the MTFR scenario on the total number of yearly attributable deaths in the EU-27 for the three pollutants under consideration ($PM_{2.5}$, NO_2, O_3) is shown in the bar graphs in Figure 44 (total number of premature deaths) and Figure 45 (relative differences between the baseline and the MTFR). Note that these charts and numbers refer to the health impacts *above* the WHO air quality guideline concentrations, and that all excess mortality caused by concentrations below these cut-offs are not taken into account. As indicated by the sensitivity tests in the annexes, the number of premature deaths avoided under the scenario increases if the cut-off value is lowered (because reductions of concentrations below the WHO air quality guidelines are not taken into account in the current assessment), while the relative impact of the scenarios decreases with a reduction of the cut-off value (because the scenario does not affect a substantial part of the mortality below the counterfactual concentration).

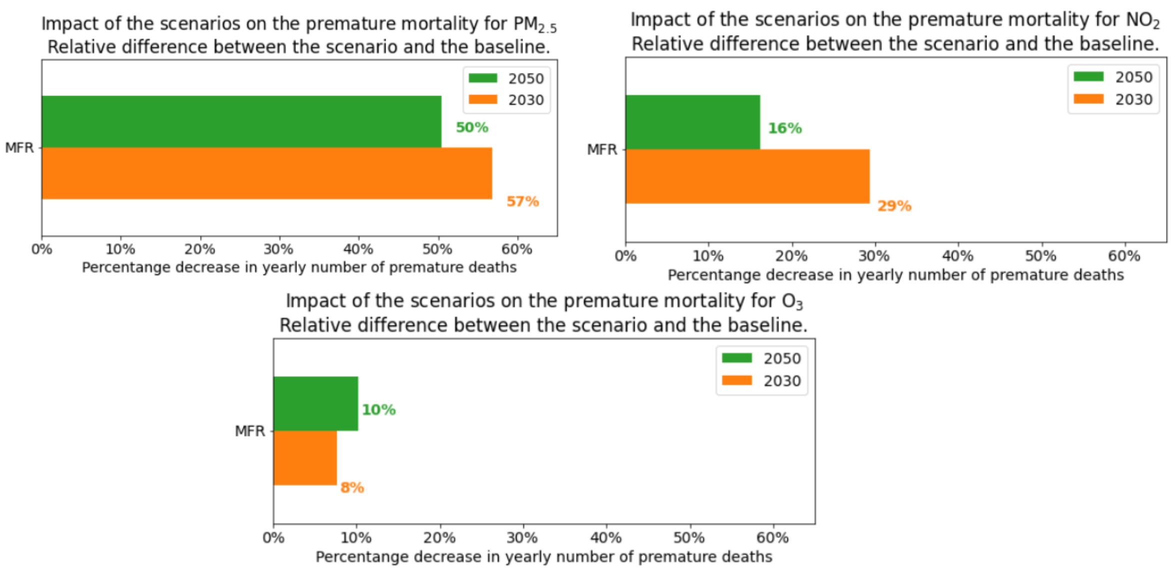
As can be seen from the charts, the measures taken under the MTFR scenario have a significant impact on the health impact caused by exposure to particulate matter. Under the MTFR scenario, the attributable mortality decreases by more than 55% relative to the baseline scenario in 2030, and by approximately 50% relative to the baseline scenario in 2050. Despite these strong reductions, a significant health impact due to air pollution still remains with the MTFR scenario, with more than 20,000 yearly attributable deaths in 2030 and more than 10,000 yearly attributable deaths in 2050. The impact of the scenarios for nitrogen dioxide is somewhat more limited, with relative reductions of 29% (2030) and 16% (2050) for the MTFR scenario. Under the MTFR scenario, more than 2,500 yearly attributable deaths remain in 2030, a number that further decreases to approximately 500 yearly attributable deaths in 2050. For ozone, the impact of the scenarios is limited. Under the MTFR scenario, the number of premature deaths reduces by 10% in 2030 and by 8% in 2050.

Figure 44 : Number of yearly premature deaths in the EU-27 caused by exposure to air pollution at levels above the WHO AQ guidelines for the MTFR scenario for three pollutants ($PM_{2.5}$, top-left, NO_2, top-right, O_3, bottom).



Notes: Impacts for the four reporting years considered in the study (2015 in blue, 2020 in cyan, 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.

Figure 45: Relative 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-left, NO_2, top-right, O_3, bottom).



Notes: Impacts for the two future reporting years considered in the study (2015 in blue, 2020 in cyan, 2030 in orange and 2050 in green) are included.

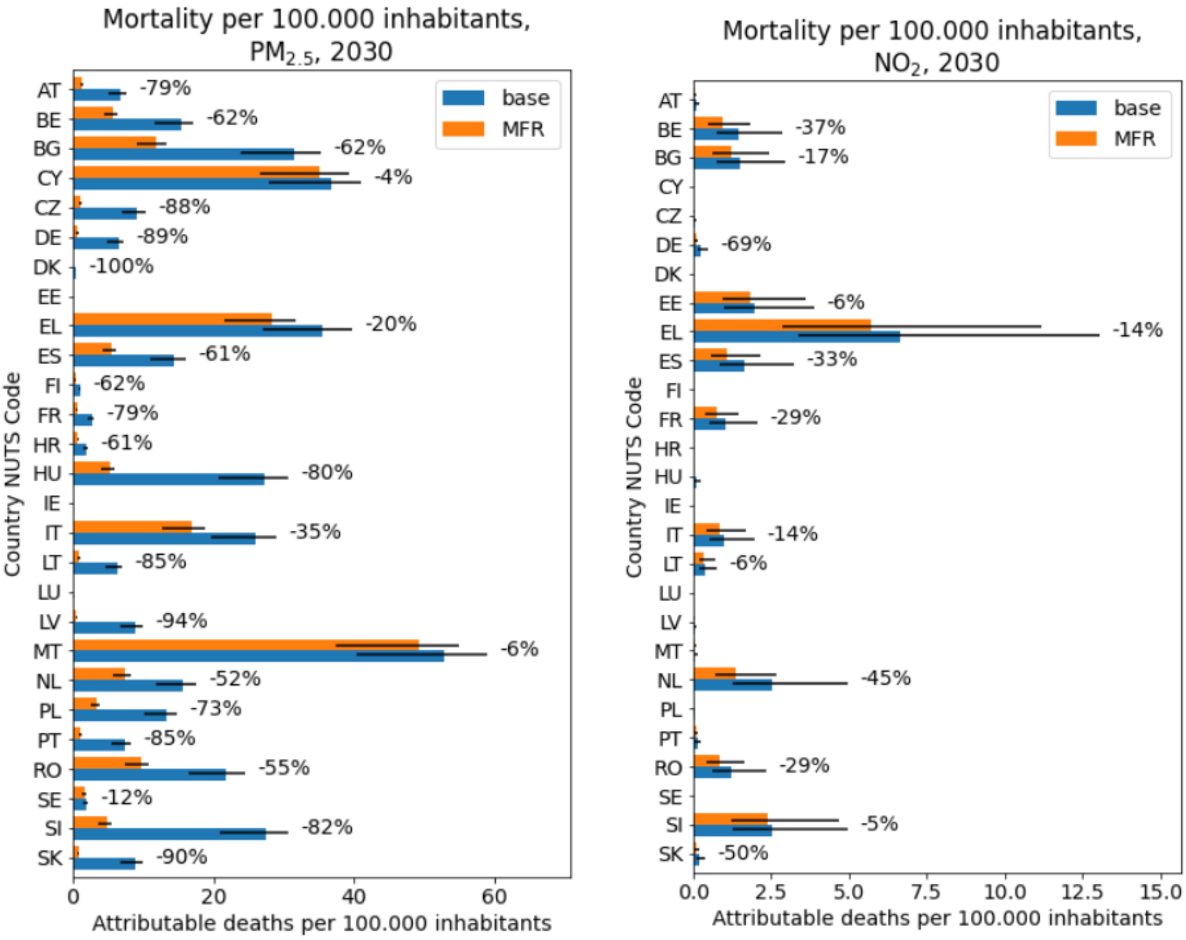
The bar graphs in Figure 46 and Figure 47 show the impact of the MTFR scenario on the number of yearly attributable deaths per capita for all countries in the EU-27, while the maps in Figure 48 show the relative impact of the MTFR scenario per NUTS 1 region. Note that we do not provide the regional breakdown of the impact of the MTFR for ozone, because this (and other) scenario(s) only has a limited impact on health impacts.

The bar plots indicate a strong regional difference in the impact of the MTFR scenario on the chronic mortality caused by the exposure to particulate matter. Smaller impacts are observed in Southern Europe in comparison with the impact in other regions. The relative reduction in mortality is markedly smaller in Cyprus, Greece and Malta (with impact of the MTFR less than 20% for all these countries in 2030 and 2050), and to a lesser extent in Italy (impact around 35% in 2030 and 2050). In this region, the natural contribution to the concentrations is much larger, and this important share of the total pollution cannot be reduced by the emission scenarios. The modest relative impact of the MTFR for the Mediterranean regions becomes especially evident on the maps at NUTS1 level, with a minor impact of the scenarios observed in all NUTS 1 regions in Greece, Italy, Malta and Cyprus, and in Southern Spain, both in 2030 and 2050. The relative reduction is also limited in Eastern-Sweden (mainly due to limited reductions in non-exhaust traffic emissions in the Stockholm area), but the baseline health impact is already low in this region. (The maps for the OPT-scenarios presented in Section 8 are similar to the maps for the MTFR-scenario (although with smaller relative reductions), and also reflect the remarks made in this paragraph).

The maps for nitrogen dioxide reflect the nature of nitrogen dioxide pollution: because concentration hotspots are mostly linked to important local emission hotspots, and the highest reductions in attributable mortality under the MTFR scenarios are observed at the hotspots for which the emissions are reduced by the greatest margin. The charts indicate that the largest impact is observed in the countries with impact mainly related to road traffic and industrial emissions (Belgium, Spain, the Netherlands and France in 2030 and Greece and Spain in 2050), while the impact of the MTFR scenario is limited in the countries in which (international) shipping emissions provide an important contribution (Greece, Italy and Slovenia in 2030; and Italy and Malta[44] in 2050). The maps per NUTS1 region further substantiate these findings.

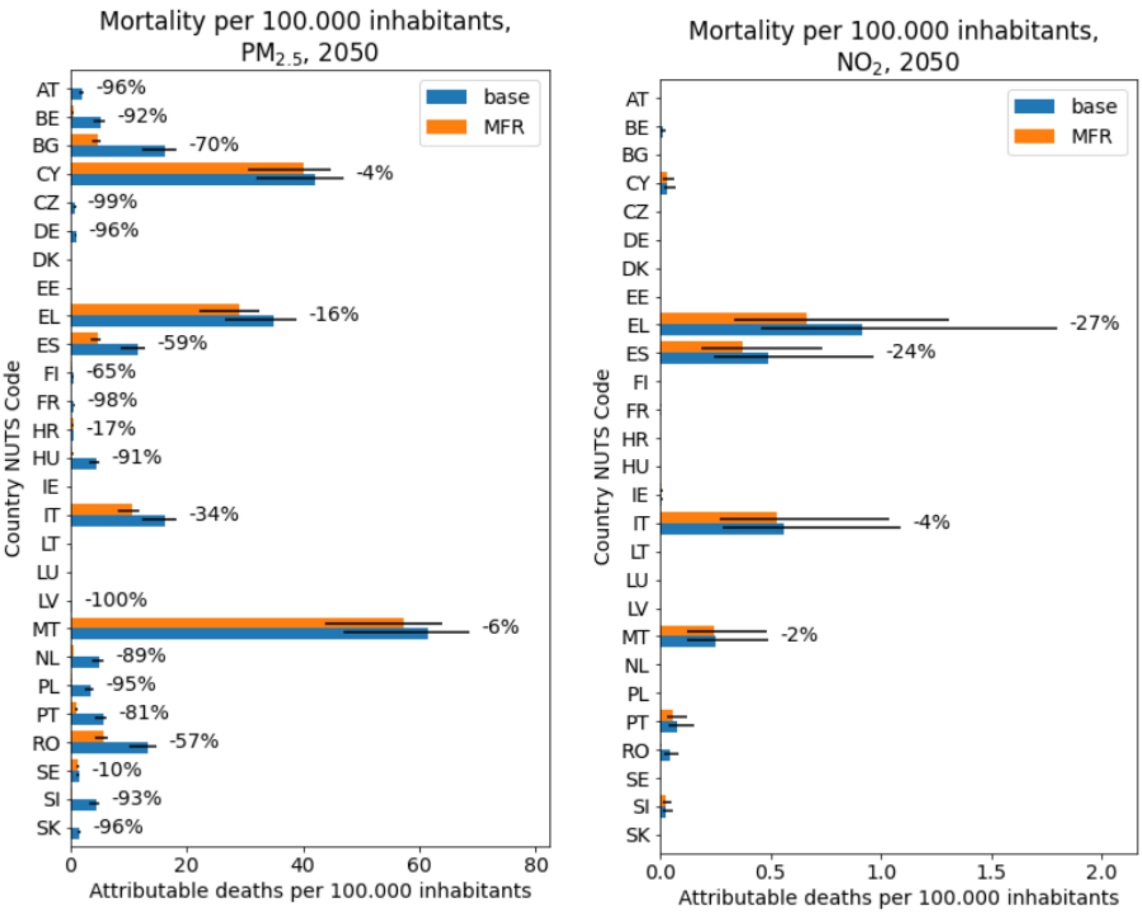
[44] Note that the premature mortality related to the exposure to nitrogen dioxide increases between 2030 and 2050 due to increase in international shipping emissions at a single port. Because of the small total population of Malta, these local effects dominate the country totals.

Figure 46 Impact of the MTFR scenario 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, NO_2, right). Impacts for 2030 are considered.



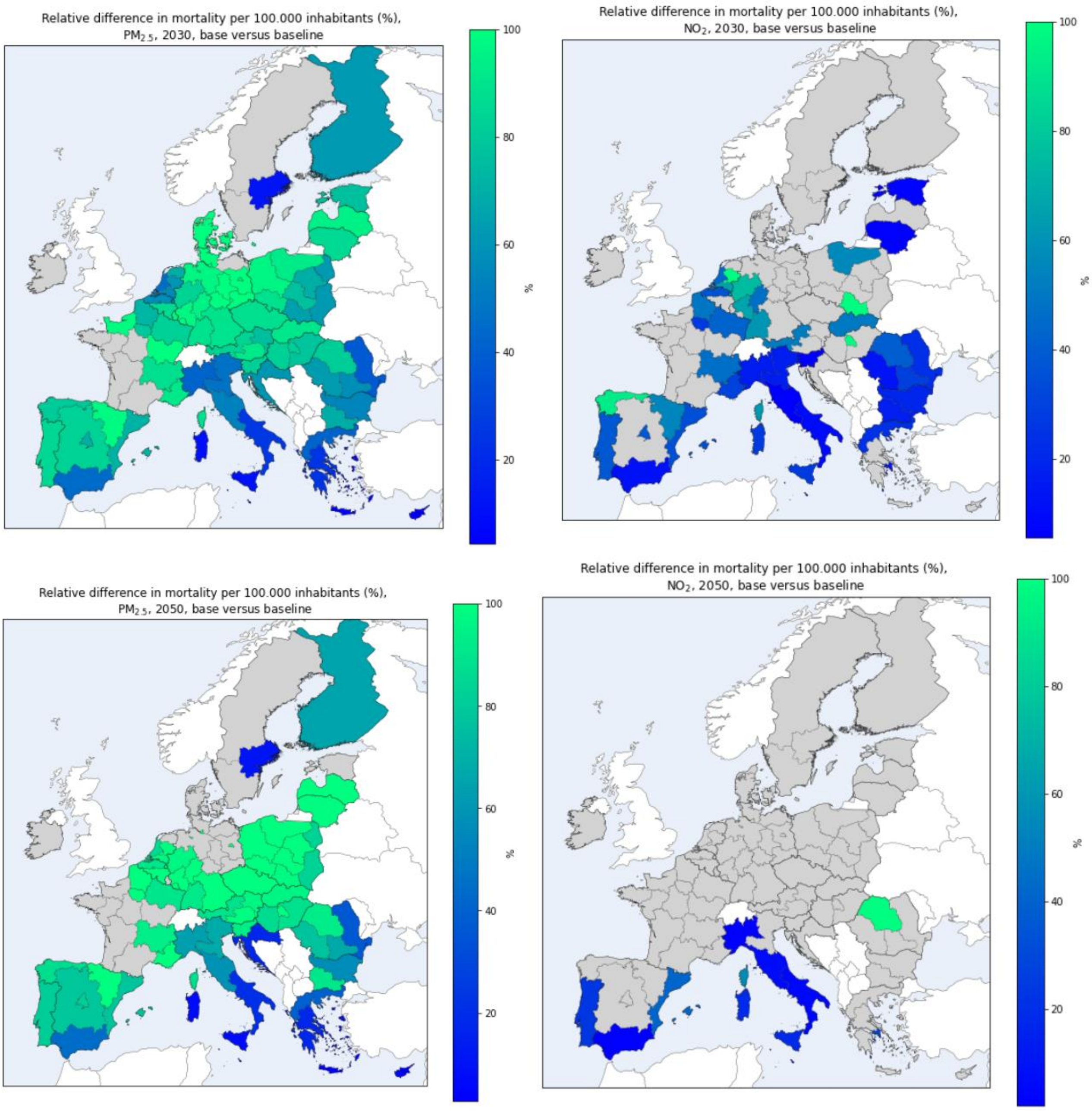
Notes: The filled bars refer to the central estimate for the number of attributable deaths per 100.000 inhabitants, while the black lines provide the 95-percentage uncertainty estimate based on the uncertainty on the relative risks. The values indicate the percentual change between the base line and the MTFR scenario. These values have been hidden for countries with less than 1 death per 1 million inhabitants under the baseline scenario (because the uncertainty on the relative reductions is very large for these locations).

Figure 47 Impact of the MTFR scenario 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, NO_2, right). Impacts for 2050 are considered.



Notes: The filled bars refer to the central estimate for the number of attributable deaths per 100.000 inhabitants, while the black lines provide the 95-percentage uncertainty estimate based on the uncertainty on the relative risks. The values indicate the percentual change between the base line and the MTFR scenario. These values have been hidden for countries with less than 1 death per 1 million inhabitants under the baseline scenario (because the uncertainty on the relative reductions is very large for these locations).

Figure 48 Relative impact of the MTFR scenario on the number of yearly premature deaths per NUTS1 region caused by the exposure to air pollution for two pollutants ($PM_{2.5}$, left; NO_2, right). Impacts for the MTFR scenario in 2030 (top figures) and 2050 (bottom figures) are considered.



Notes: Results have been hidden for regions with less than 1 death per 1 million inhabitants under the baseline scenario (grey locations).

Results for attributable morbidity (Tier 2 and Tier 3)

Table 11 provides an overview of the impact of the MTFR scenario on the morbidity outcomes considered in the second (morbidity according to HRAPIE) and third Tier (additional health outcomes beyond HRAPIE: stroke, lung cancer and asthma in children).

As with the results for chronic mortality, for all health outcomes, a strong reduction in impact under the MTFR scenario is observed. The results also correspond quantitively with those for the chronic mortality caused by $PM_{2.5}$ exposure. The relative impact of the MTFR scenario for 2030 varies from 56% (for chronic bronchitis) to 61% (for respiratory hospital admissions), which is in line with a 57% reduction in overall mortality. For 2050, the relative impact of the MTFR scenario is between 50% (for chronic bronchitis) and 55% (for cardiovascular hospital admissions), which is also in line with the 50% reduction in overall mortality.

Table 11: Morbidity caused by the exposure to $PM_{2.5}$ pollution in the EU27 under the baseline and MTFR scenarios for 2030 and 2050. Values have been rounded to the nearest integer.

Health outcome	Unit	2030 baseline	2030 MTFR	2050 baseline	2050 MTFR
Infant Mortality	Deaths per year	15 (7 ; 27)	6 (3 ; 11)	3 (1 ; 5)	1 (0 ; 2)
Bronchitis in Children (age 6 -12)	Cases per year	61,000 (0 ; 136,000)	25,500 (0 ; 57,100)	24,500 (0 ; 54,900)	11,600 (0 ; 25,900)
Chronic Bronchitis in adults	Incidence per year	24,500 (8,760 ; 38,000)	10,700 (3,820 ; 16,600)	10,700 (3,820 ; 16,600)	5,260 (1,880 ; 8,160)
Cardiovascular hospital admissions	Admissions per year	14,100 (2,650 ; 25,600)	5,540 (1,040 ; 10,100)	5,370 (1,010 ; 9,740)	2,430 (456 ; 4,410)
Respiratory hospital admissions	Admissions per year	14,500 (0 ; 30,100)	5,670 (0 ; 11,800)	5,920 (0 ; 12,300)	2,680 (0 ; 5,560)
Restricted activity days	Days per year	59,500,000 (53,300,000 ; 66,900,000)	25,800,000 (23,100,000 ; 29,000,000)	25,600,000 (22,900,000 ; 28,700,000)	12,500,000 (11,200,000 ; 14,100,000)
Lost working days	Days per year	21,200,000 (18,000,000 ; 24,300,000)	8,390,000 (7,150,000 ; 9,630,000)	8,260,000 (7,030,000 ; 9,470,000)	3,790,000 (3,220,000 ; 4,340,000)
Stroke (CVA)	Incidence per year	11,500 (9,800 ; 13,100)	4,830 (4,130 ; 5,520)	4,780 (4,090 ; 5,460)	2,270 (1,950 ; 2,600)
Lung cancer	Incidence per year	4,260 (1,950 ; 6,440)	1,830 (835 ; 2,760)	1,800 (823 ; 2,720)	876 (401 ; 1,320)
Asthma in children (age < 16 years)	Incidence per year	23,700 (8,180 ; 38,300)	9,840 (3,370 ; 15,900)	9,500 (3,260 ; 15,400)	4,420 (1,530 ; 7,120)

Health impacts – summary baseline and MTFR

From the analysis, several conclusions can be drawn regarding health impacts under the baseline and MTFR scenarios:

- Under the baseline policy plans, the mortality caused by exposure to NO_2 and $PM_{2.5}$ decreases significantly from 2015 to 2030. However, there would still be a considerable number of premature deaths each year observed in 2030, with tens of thousands of attributable deaths per year caused by exposure to $PM_{2.5}$ and thousands of deaths caused by exposure to NO_2.
- For particulate matter, the baseline attributable mortality is larger in Eastern and Southern European countries, in comparison with the impact in most Northern and Western European countries (which is in line with the spatial pattern of the baseline emissions and natural contributions)
- The results for nitrogen dioxide reflect the nature of nitrogen dioxide pollution: because concentration hotspots are mostly linked to important local shipping and traffic emissions. The highest baseline mortality is also observed at these locations
- Results for morbidity follow the same pattern as those observed for the $PM_{2.5}$ mortality.

- The impact of the MTFR scenario is somewhat more limited for the mortality caused by nitrogen dioxide pollution (relative reductions of 29% (2030) and 16% (2050) scenario).

Costs to society

The human and environmental effects of air pollution place a cost on society. The costs to society are estimated on the basis of the health impacts calculated for Indicator #2 and ecosystem impacts for Indicator #3. These effects are combined with monetary impact values to capture the cost to society. In the case of human health, this represents impact on: lost utility or welfare, lost labour (or productivity) and health care costs. By monetising the effects of air pollution they can be more readily compared to the costs of mitigation action.

Detail on the approach taken to monetisation is included in Appendix 6. For human health impacts, the monetary unit values applied in CAO2 have been applied, where relevant. The CAO2 proposed monetary values were derived from an extensive literature review of the latest valuation approaches (by organisations such as the OECD) which concluded in December 2020. This impact assessment study has also considered pathways not included in CAO2 under Tier 3 – for these pathways, a targeted literature review was undertaken to underpin the selection of an appropriate monetary value.

The results of the analysis are presented in the following tables, which present the absolute effects for the baseline and MTFR scenario, alongside the difference (or net effect) of the scenario relative to the baseline. In line with CAO2, two sets of results are presented which present different approaches to monetising the impacts on mortality: a 'VSL' or value of statistical life approach, which monetises the number of deaths, and a VOLY or Value of statistical life year approach, which instead monetises life years lost. The results present the monetary benefits in the given assessment year. For the aggregate assessment, the mortality effects associated with NO_2 are excluded to avoid the risk of overlap with the mortality effects of $PM_{2.5}$.

Table 12 presents costs to society, showing that air pollution continues to place a heavy burden on society going forward. The human health costs of ongoing exposure to unsafe levels of air pollution are estimated to be up to €740 bn per annum in 2020 (based on the higher VSL approach). The health burden reduces in the baseline through continued improvements as a consequence of policies in the baseline. The MTFR scenario could deliver significant societal benefits – around €141 bn per annum in 2030 and €77 bn in 2050. The size of the potential benefit reduces due to the ongoing improvements in the baseline, which reduce the potential additional benefit that can be achieved.

Table 12-Costs to society (valuation of health impacts) - central (all values €bn 2015 prices, EU27)

	Scenario	2020	2030	2050
VSL	Baseline	739	444	332
VSL	MTFR	-	303	256
VOLY	Baseline	251	140	90
VOLY	MTFR	-	92	68
Net VSL	*MTFR*	-	*141*	*77*
Net VOLY	*MTFR*	-	*48*	*22*

Links with climate change

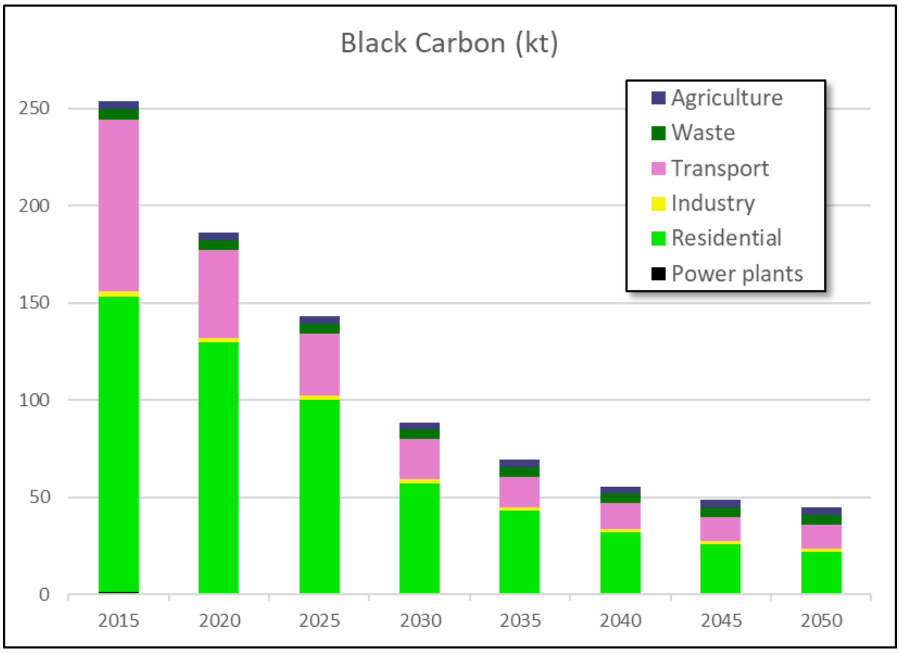
The baseline scenario includes EU climate goals of EU-wide reduction of GHG emissions by at least 55% by 2030, compared to 1990 levels[37] resulting, among others, in decline of fossil fuel use. Beyond CO_2, these changes also have co-benefits on emissions of non-CO_2 greenhouse gases (not shown) as well as short-lived climate forcers (SLCFs), including cooling (e.g., SO_2) and warming (e.g., black carbon (BC)) species. However, the energy scenario underlying this strategy also implies further use of biomass combustion in power generation and for residential heating. Combustion of biomass leads to emissions of air pollutants, including black carbon, especially from older and inefficient residential heating installations. Compared to the Reference scenario, the 'MIX55' scenario[37,45] used here for the baseline and all other scenarios, has (beyond an increase of biomass use in the power sector) a slower decline of biomass use for residential heating resulting in a trade-off for air pollution and climate as emissions of PM2.5 and BC from the residential sector are slightly higher in the MIX55 scenario, compared to the Reference scenario, although in both of them they continue to decline. As indicated below, the baseline scenario includes assumptions about technology improvement over time and the MTFR case explores potential for further reduction through a more rapid roll-out of the cleanest combustion technologies; yet the assumed amount of energy generation from biomass is the same in the baseline and MTFR.

The SO_2 trend is shown above in Figure 9 and Figure 10, and will lead to additional warming of the atmosphere, which will be partly offset by the reduction of CO_2 and CH_4 (lesser demand for fossil fuels results in lower losses from coal, oil, and gas production and distribution systems, e.g., Hoglund et al., 2020) as well as black carbon (BC).

Additionally, air pollution measures have an impact on SLCFs, including SO_2 as well as black carbon (BC), where fleet turnover, wider penetration of more efficient and pellet stoves and boilers will result in further reductions of BC emission. Figure 49 shows the trend in BC emissions in the baseline, highlighting the impact of fuel shifts as well as application of technology in transport and residential heating sectors that dominate current emissions and will remain key sources of BC, albeit the total emissions are estimated to decline by 65% to 2030, and by over 80% to 2050, compared to 2015.

[45] 'Reference' and 'MIX' scenarios refer to scenarios modelled in the context of the Fit for 55 package of climate measures; For details of the Reference scenario refer to Annex 10.4

Figure 49 -Emission of black carbon (BC) in the baseline scenario for the EU-27; GAINS model



Ecosystem impacts

This section presents indicators on ecosystem impacts in terms of acidification and eutrophication from excess deposition of nitrogen (for acidification and eutrophication) and sulphur (for acidification). Results are calculated with the GAINS model using critical loads approved by the Air Convention in 2017 (Hettelingh et al., 2017).

Maps of ecosystem areas exceeding critical loads for acidification and eutrophication from deposition of nitrogen and sulphur are shown in Figure 50 to Figure 54 for the Baseline and MTFR scenarios. Table 13 to Table 16 present the exceedance of critical loads (percentages of area above critical load) for eutrophication and acidification respectively under the Baseline scenario in 2030 and 2050, for different types of ecosystems. Eutrophication is still a widespread problem in Europe, with an estimated 74% of all ecosystem areas exceeding critical loads. Despite improvements in 2030 and even further in 2050, ~65% of ecosystem areas are still expected to exceed critical loads for eutrophication in 2050 under the Baseline. Under the MTFR scenario, this is reduced to 48% in 2050. Acidification is much less of an issue, with 4.8% of ecosystem areas currently exceeding the critical loads, decreasing to 3.1% in 2030 and 2.4% in 2050 under the Baseline scenario (1.2% in 2050 under the MTFR scenario).

Figure 50 . Shares of ecosystem area exceeding critical loads for eutrophication (left) and acidification (right) in 2020.

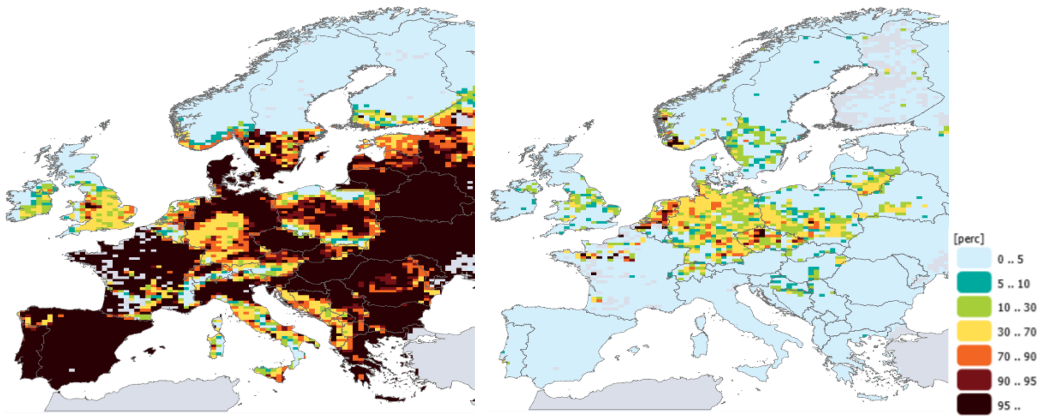


Figure 51 – Shares of ecosystem areas exceeding critical loads for eutrophication in 2030: Baseline (left) and MTFR (right)

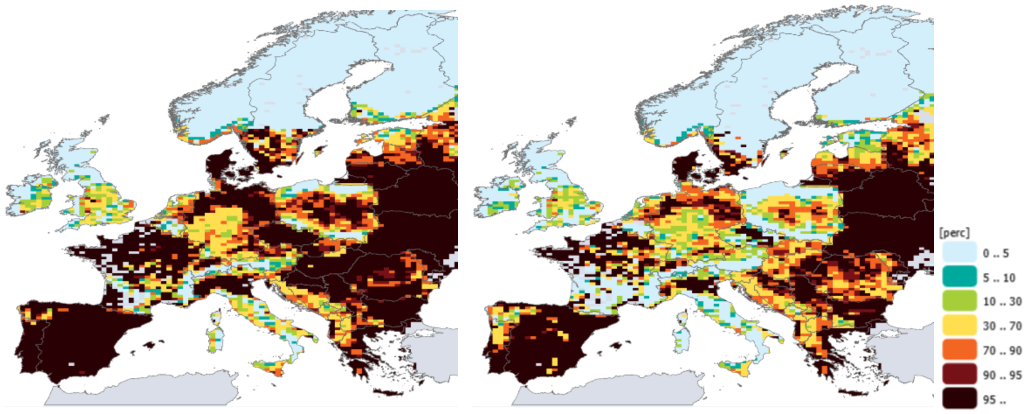


Figure 52 – Shares of ecosystem areas exceeding critical loads for eutrophication in 2050: Baseline (left) and MTFR (right)

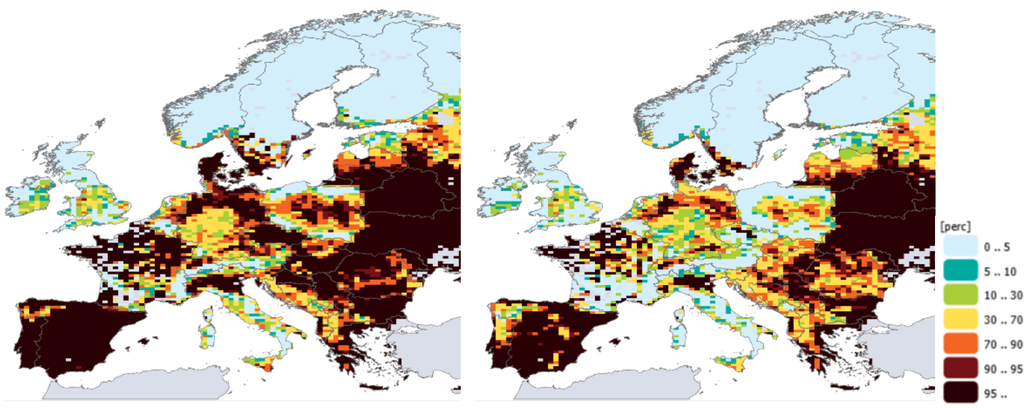


Figure 53- Shares of ecosystem areas exceeding critical loads for acidification in 2030: Baseline (left) and MTFR (right)

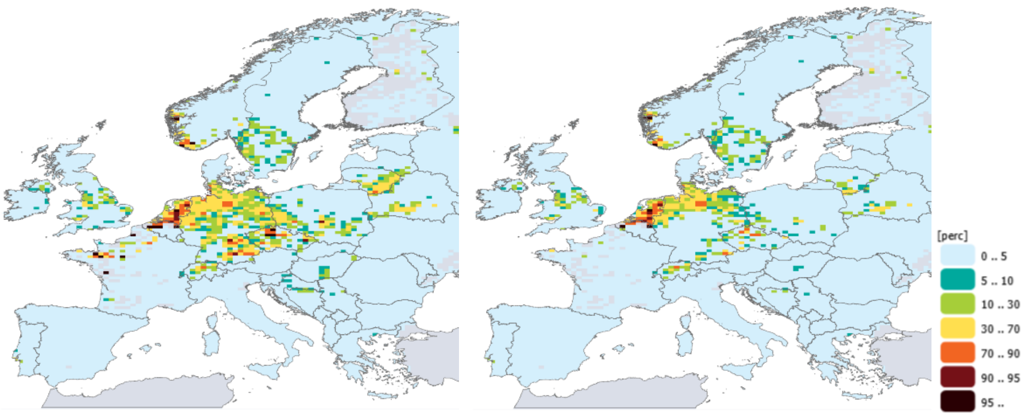


Figure 54- Shares of ecosystem areas exceeding critical loads for acidification in 2050: Baseline (left) and MTFR (right)

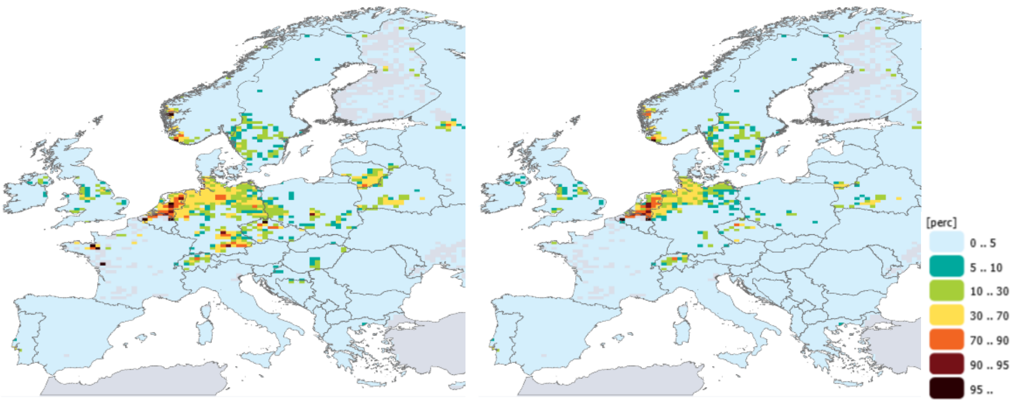


Table 13 - Exceedance of critical loads (percentages of area above critical load) for eutrophication in 2020 for different types of ecosystems; GAINS model

	% Total ecosystems area exceeded	% Forest area exceeded	% Catchment area exceeded	% Semi-natural area exceeded
	2020	2020	2020	2020
Austria	48.6	50.1	0	43.2
Belgium	2.5	0.8	0	79.9
Bulgaria	96.7	95.2	0	100
Croatia	86	74.6	0	100
Cyprus	100	100	0	100
Czech Rep.	100	100	0	0
Denmark	100	100	0	100
Estonia	70.6	66.8	0	79.7
Finland	1.5	1.2	5.9	0
France	73.1	72.8	0	79.1
Germany	71.8	72.4	8.8	54.4
Greece	95.6	85.9	0	100
Hungary	95.6	92.5	0	100
Ireland	7	22.7	0	0.1
Italy	44.6	46.3	64.5	40.8
Latvia	92.4	87.8	0	99.8
Lithuania	98.8	98.4	0	100
Luxembourg	100	100	0	100
Malta	99.7	95	0	100
Netherlands	71.4	83	27.2	66.6
Poland	60.5	61.4	0	9.1
Portugal	99.5	99.6	0	99.5
Romania	94.6	91.9	0	100
Slovak Republic	93.7	92	0	100
Slovenia	97.3	96.5	0	100
Spain	98.2	98	0	98.3
Sweden	12.3	0	0	12.3
EU-27 avg.	74.2	74.1	10.5	75.4

Table 14 - Exceedance of critical loads (percentages of area above critical load) for eutrophication under the Baseline scenario in 2030 and 2050, for different types of ecosystems.

	% Total ecosystems area exceeded		% Forest area exceeded		% Catchment area exceeded		% Semi-natural area exceeded	
	2030	2050	2030	2050	2030	2050	2030	2050
Austria	34.8	31	36.6	31.9	0	0	28.5	27.9
Belgium	1	0.8	0.4	0.2	0	0	29.1	28.6
Bulgaria	93.6	90.5	90.7	86.2	0	0	100	100
Croatia	82.9	82.3	69	67.8	0	0	100	100
Cyprus	100	100	100	100	0	0	100	100
Czech Rep.	100	96.1	100	96.1	0	0	0	0
Denmark	99.7	98.9	99.5	98	0	0	100	100
Estonia	38.7	15.5	28.3	3.6	0	0	63.3	44.1
Finland	0.8	0.6	0.2	0	4.5	3.7	0	0
France	65.1	60.9	64.6	60.2	0	0	78.5	78.1
Germany	66.9	62.7	67.4	63.3	6.4	2.7	51.5	43.3
Greece	94.1	93.1	81.2	78	0	0	100	100
Hungary	89.3	80.1	81.7	65.9	0	0	100	100
Ireland	7.2	5.9	22.7	19.2	0	0	0.4	0.1
Italy	34.7	30.2	35.1	30	55.8	53.3	33.7	30.2
Latvia	87.1	71.7	79.2	54.6	0	0	99.7	99.1
Lithuania	98.1	96.9	97.4	95.9	0	0	100	99.5
Luxembourg	100	99.9	100	100	0	0	100	99.8
Malta	100	100	100	100	0	0	100	100
Netherlands	69.2	67.5	81.5	80.8	20.9	14.3	64.5	62.9
Poland	52.3	45.5	53.1	46.2	0	0	5	3.2
Portugal	99.1	98.3	98.8	97.7	0	0	99.4	99
Romania	93.8	92	90.7	88	0	0	100	100
Slovak Republic	90.2	88.2	87.6	84.9	0	0	100	100
Slovenia	81.2	77.6	76	71.4	0	0	99.8	99.7
Spain	97.5	97.1	97.1	96.5	0	0	97.8	97.5
Sweden	9.6	6.1	0	0	0	0	9.6	6.1
EU-27 avg.	69.2	65.5	67.2	62.3	8.4	7	73.7	72.5

Table 15 - Exceedance of critical loads (percentages of area above critical load) for acidification in 2020 for different types of ecosystems; GAINS model

	% Total ecosystems area exceeded	% Forest area exceeded	% Catchment area exceeded	% Semi-natural area exceeded
	2020	2020	2020	2020
Austria	0	0	0	0
Belgium	0.7	0.7	0	0
Bulgaria	0	0	0	0
Croatia	1.9	3.4	0	0
Cyprus	0	0	0	0
Czech Rep.	40.8	40.8	0	0
Denmark	3	5.4	0	0
Estonia	0	0	0	0
Finland	0.4	0	0.4	0
France	2.1	1.2	0	24.1
Germany	31.2	31	96.4	37
Greece	0.1	0.2	0	0
Hungary	4.2	7.2	0	0
Ireland	0.3	0.3	3	0
Italy	0	0	0	0
Latvia	1.5	2.5	0	0
Lithuania	25.3	35.1	0	0
Luxembourg	10.2	15.3	0	0
Malta	0	0	0	0
Netherlands	85.9	92	32.5	75.2
Poland	15.1	15.3	0	0.5
Portugal	0.4	0.7	0	0
Romania	0.1	0.1	0	0
Slovak Republic	1.7	2.1	0	0
Slovenia	0	0	0	0
Spain	0	0	0	0
Sweden	2.8	0	2.8	0
EU-27 avg.	4.8	7.4	2.8	0.9

Table 16- Exceedance of critical loads (percentages of area above critical load) for acidification under the Baseline scenario in 2030 and 2050, for different types of ecosystems

	% Total ecosystems area exceeded		% Forest area exceeded		% Catchment area exceeded		% Semi-natural area exceeded	
	2030	2050	2030	2050	2030	2050	2030	2050
Austria	0	0	0	0	0	0	0	0
Belgium	0.5	0.5	0.5	0.5	0	0	0	0
Bulgaria	0	0	0	0	0	0	0	0
Croatia	0.8	0.4	1.4	0.8	0	0	0	0
Cyprus	0	0	0	0	0	0	0	0
Czech Rep.	18.9	9.8	18.9	9.8	0	0	0	0
Denmark	0.8	0.5	1.4	1	0	0	0	0
Estonia	0	0	0	0	0	0	0	0
Finland	0.4	0.4	0	0	0.4	0.4	0	0
France	0.7	0.2	0.6	0.2	0	0	3.8	0.8
Germany	22	16.6	21.8	16.3	88.7	82	27.6	24.1
Greece	0.1	0.1	0.2	0.2	0	0	0	0
Hungary	2.1	1.7	3.5	2.9	0	0	0	0
Ireland	0.3	0.2	0.3	0.2	3	3	0	0
Italy	0	0	0	0	0	0	0	0
Latvia	1.1	0.6	1.8	0.9	0	0	0	0
Lithuania	22	19.2	30.5	26.6	0	0	0	0
Luxembourg	6.9	0.3	10.4	0.4	0	0	0	0
Malta	0	0	0	0	0	0	0	0
Netherlands	84.3	83.1	91.3	90.5	19.9	16.6	72.4	70.3
Poland	6.3	3.3	6.4	3.4	0	0	0.4	0.2
Portugal	0.4	0.4	0.7	0.7	0	0	0	0
Romania	0	0	0	0	0	0	0	0
Slovak Republic	0.8	0.1	1	0.2	0	0	0	0
Slovenia	0	0	0	0	0	0	0	0
Spain	0	0	0	0	0	0	0	0
Sweden	2.3	2.2	0	0	2.3	2.2	0	0
EU-27 avg.	3.1	2.4	4.7	3.4	2.3	2.2	0.5	0.4

Valuation of ecosystem impacts

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 monetising these impacts in this study are the same as those deployed under CAO2 (further detail is included in Appendix 6).

The following table presents the monetised impacts of air pollution on the environment under the baseline and MTFR scenario. The MTFR can deliver substantial ecosystem benefits, however the aggregate size of these benefits is still smaller than the human health benefits (estimates range from EUR bn 48 – 141 per annum in 2030 – see Section 7.1.3).

The size of the damage in the baseline reduces over time alongside further emissions reductions delivered through current policy. This is particularly the case for materials damage driven by ongoing falls in SO_2. The highest material damage in the baseline in 2030 is estimated for Germany, followed by Poland.

The analysis considers all agricultural crop production in the EU, focused on the effects of ozone. The countries most affected by crop damages are France, Italy and Spain in the baseline, and hence these are also those that gain most under the MTFR scenario.

Table 17- Monetised material damage impacts per annum - baseline and MTFR - EURm 2015 prices

	2015	2020	2025	2030	2035	2040	2045	2050
Baseline	1,871	1,136	914	662	517	465	447	442
MTFR	-	-	-	436	-	-	-	269
Net MTFR	-	-	-	*226*	-	-	-	*172*

Table 18- Monetised crop damage impacts per annum - baseline and MTFR - EURm 2015 prices

	2015	2020	2025	2030	2035	2040	2045	2050
Baseline	11,758	10,691	10,320	9,877	9,629	9,518	9,450	9,459
MTFR	-	-	-	9,472	-	-	-	9,110
Net MTFR	-	-	-	*404*	-	-	-	*348*

Table 19- Monetised forest damage impacts per annum - baseline and MTFR - EURm 2015 prices - LOW[46]

Total damage by scenario	2015	2020	2025	2030	2035	2040	2045	2050
Baseline	20,326	19,050	18,551	17,975	17,648	17,478	17,371	17,374
MTFR	-	-	-	17,486	-	-	-	16,954
Net MTFR	-	-	-	*488*	-	-	-	*420*

Table 20- Monetised forest damage impacts per annum - baseline and MTFR - EURm 2015 prices - HIGH

Total damage by scenario	2015	2020	2025	2030	2035	2040	2045	2050
Baseline	20,326	19,050	18,551	17,975	42,882	42,470	42,211	42,217
MTFR	-	-	-	17,486	-	-	-	41,194
Net MTFR	-	-	-	*488*	-	-	-	*1,023*

[46] Note that there is no difference between HIGH and LOW estimate for forest damage in 2030 as only after 2030 different assumptions are used to monetise the reduced carbon sequestration potential due to forest damage.

Table 21- Monetised ecosystem damage impacts per annum - baseline and MTFR - EURm 2015 prices - LOW

Total damage by scenario	2015	2020	2025	2030	2035	2040	2045	2050
Baseline	4,215	3,901	3,769	3,588	3,485	3,422	3,386	3,375
MTFR	-	-	-	2,588	-	-	-	2,328
Net MTFR	-	-	-	*1,000*	-	-	-	*1,047*

Table 22- Monetised ecosystem damage impacts per annum - baseline and MTFR - EURm 2015 prices - HIGH

Total damage by scenario	2015	2020	2025	2030	2035	2040	2045	2050
Baseline	12,644	11,702	11,308	10,765	10,455	10,267	10,157	10,124
MTFR	-	-	-	7,765	-	-	-	6,984
Net MTFR	-	-	-	*3,000*	-	-	-	*3,140*

7.1.4 *Problem: Projected enforcement and governance shortcomings*

Driver: Insufficient penalties and damages linked to exceedance

Where the established limit values or target values for ambient air quality are not met, the Directives require Member States to prepare and implement air quality plans and measures. Directive 2008/50/EC requires Air Quality Plans to identify the main emission sources responsible for pollution, detail the factors responsible for exceedances, and spell out the abatement measures planned to reduce pollution. Air quality plans shall be reported to the Commission no later than two years after the exceedance occurred. Member States can select the measures to achieve the air quality standards, but exceedance periods must be kept as short as possible. However, it has been found (European Commission, 2021) that the current framework under the AAQ Directives has resulted in delays in implementing measures across Member States, with data showing persistent exceedances of the current air quality standards for at least one air pollutant in the majority of Member States. While the number of Member States continuing to exceed the limit values has begun to decrease, the problem persists. Directive 2008/50/EC currently states, as per Article 30, that Member States shall lay down the rules on penalties applicable to infringements of the national provisions adopted pursuant to that Directive. Article 9 provides the equivalent for Directive 2004/107/EC. These articles do not, however, set a specific level at which penalties must be set nor does it specify which provision might be concerned, stating only that penalties must be effective, proportionate and dissuasive. This lack of detail has led to a limited use of penalties in Member State with little impact on air pollution reduction. Access to justice and compensation for health damage suffered from air pollution is currently not addressed in the Ambient Air Quality Directives. It is assumed that the current problems that derive from the nature of the existing provisions under the AAQ Directives would remain present and would limit their effectiveness to a similar extent.

If the provisions on **penalties** (Article 30 under Directive 2008/50/EC and Article 9 under Directive 2004/107/EC) remain the same, and if no **provisions on access to justice and health damage compensations are added,** the situation as regards the exceedances of air quality standards will remain as currently is. Namely, many Member States exceed the limit values for different pollutants, even though the number of Member States that do exceed the limit values has slowly been decreasing. The baseline therefore does not anticipate the current situation worsening, it is more likely to remain the same or slightly improve. The penalties provisions in place under the AAQ Directives will also therefore remain the same, without further specifying the types of penalties, their levels or how damages should be compensated. Under the baseline situation the current AAQ Directives do not provide individuals with an explicit provision on access to justice. In practice this means that individuals do not have an explicit provision derived from EU legislation to rely upon before national courts in cases of air quality rules stemming from the AAQ Directives.

Driver: Air Quality Plans and measures have often proven ineffective

The requirement to prepare air quality plans when limit or target values are exceeded is one of the fundamental provisions of the AAQ Directives. There is an obligation to prepare and publish an air quality plan within two years of the identification of an exceedance. Article 23 of Directive 2008/50/EC sets a clear obligation for competent authorities to take action to keep the exceedance period “as short as possible”. This obligation has resulted in actions to improve air quality in the EU, including enforcement and legal actions initiated by individuals, NGOs and the Commission.

However, while many air quality plans have been prepared across Europe at national, regional and local level to comply with the AAQ Directives, the continuing (although decreasing) high levels of air pollution show that air quality plans have not been sufficient to ensure compliance with limit and target values as soon as possible. Findings from the Fitness Check indicate that air quality plans have not always delivered improvements in air quality or addressed all sources effectively. Some measures may be ineffective or seem disproportionate. As of May 2022, a total of 29 infringement cases against 18 Member States are ongoing for exceedances of PM_{10}, $PM_{2.5}$, NO_2 or SO_2 concentration levels or flawed monitoring.[47] Fifteen of these cases have been referred to the Court of Justice of the European Union, of which eleven cases have received a ruling. This indicates that air quality plans are continuing to fail to deliver the required improvement in air quality.

Under the baseline scenario, **requirements for action required in case of exceedances, including the establishment of Air Quality Plans** (i.e., intervention area C under Policy Area 2), are assumed to remain identical to what is currently in place. The assumption followed is that the current problems that derive from the nature of the existing requirements for action in case of exceedances would remain present and would limit the effectiveness of the AAQ Directives to a similar extent.

The effectiveness of air quality plans is expected to be limited in the same way with the measures contained therein not always being updated to match the changing air quality context of a location (for instance new drivers of air pollution or worsening air quality in general) nor the best available solutions.

An additional underlying issue affecting the effectiveness of air quality plans is poor coordination between public authorities and the unclear allocation of responsibilities. This can lead to insufficient action being taken by public authorities or to a mismatch of action. Added to this, citizens are not systematically consulted in the development of air quality plans. Their contribution could make the plans more legitimate and more effective.

[47] In addition, there is also an infringement case against the United Kingdom addressing exceedances of NO_2.

Driver: Some measures may seem disproportionate, ineffective

Annex XV to Directive 2008/50/EC states a number of essential elements that are required for an air quality plan. While respondents to a survey (Conlan et al., 2022) reported that all of these remain essential and were to be included in plans, the most important of these elements according to the stakeholders responding were: *Determining the sources responsible for pollution*, followed by *Localisation of excess pollution, e.g. region, city or measuring station* and *Analysis of the situation e.g. details of those factors responsible for the exceedance*. A third of stakeholders said that air quality plans still required improvement. Improvements suggested included better characterisation of the exceedance, specifying the area where the measures should apply, and targeted action to improve the effectiveness of the measures themselves. Reviews of Air Quality Plans show that current practice by almost all Member States is to include hundreds of measures in their plans, many of which are not likely to be highly effective in solving the air quality problem as soon as possible but are longer term and strategic.

Furthermore, many Member States either do not provide any quantification on the projected attainment of limit values or use less robust methods to illustrate impacts of measures within their Air Quality Plans. In a survey for (Conlan et al., 2022), 71% of respondents used complex modelling to quantify baseline concentrations. However, only 26% used complex modelling to estimate future projections with and without measures to determine when compliance is likely. Assumptions within modelling are not always apparent and there is often a lack of evidence to justify that these are not overly optimistic. Very few Air Quality Plans explain the methods used for forecasting the evolution of air quality and the underlying assumptions and uncertainties. Therefore, even when modelling is used to support air quality planning it is often difficult to judge whether the modelling is fit for purpose and whether compliance is likely with the implementation of the chosen measures.

Where plans include future projections of concentrations these scenarios are often modelled only for five-year intervals. Such practice makes it difficult to verify whether other measures would allow achieving compliance at an earlier date. In addition, in a recent targeted stakeholder survey (Conlan et al., 2022) of air quality managers at local, regional and national level, most respondents said that measures in their current plan are expected to deliver the desired effect within three to four years. However, four stakeholders thought that the current plan will never provide the expected impact. The overall consequence is unknown confidence in when, or indeed if, measures included in Air Quality Plans will improve air quality sufficiently to protect human health.

This means that some measures set-up by competent authorities within Member States are expected to remain insufficiently ambitious to reduce air pollution to a safe level, partly due to the fact that the obligation for measures to keep the exceedance period as short as possible is not specific enough in the text of the Directive. This problem is also partly due to a lack of coordination between short-term action plans and air quality plans, which can lead to insufficient action as well as inefficient actions being taken by public authorities.

Driver: Local air quality is impacted by emissions outside control

Air Quality Plans are required to clearly localise the excess pollution, provide an assessment of the pollution situation, list and quantify the main emission sources responsible for the pollution and provide details of those factors responsible for the exceedance, and detail possible measures for the improvement of air quality. Measures adopted with a view to reducing pollution need to be described, including with a timetable for implementation as well as estimates of the improvement in air quality. In line with the principle of subsidiarity, the choice of measures is left to Member States, to ensure that these are appropriate and cost-effective within the specific context of respective local and national circumstances. However, as stated in Section 3, competences, and the division of responsibilities to implement the measures are not always suitably defined, and coordination between different levels of governance (national, regional, local) is a key challenge. In addition, stakeholders are not systematically consulted when Air Quality Plans are designed.

If the provisions to **guide the development of Air Quality Plans, including on who to involve and on vertical and horizontal coordination between levels of governance in their establishment and their implementation** (i.e., intervention area D under Policy Area 2), are not further specified, the same consequences as described above are expected, namely that Air Quality Plans and associated measures would remain insufficient, inefficient and/or ineffective in some instances. In the conclusions on coherence in the Ambient Air Quality Fitness Check, it is stated that "gaps in coordination in many Member States remain an obstacle to achieving the AAQ Directives' objectives, as does coordination between national and sub-national authorities." The assumption taken in the baseline is that this situation would not significantly improve without further EU intervention.

Driver: Lack of flexibility to adapt to evolving science and new recommendations

EU standards are not fully aligned with the latest scientific advice. The AAQ Directives have enabled a review of stringency in the past, but this is not systematic. Directive 2008/50, Article 32 provided grounds for one 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. To ensure relevance of AAQ Directives, appropriate mechanisms are needed to flexibly adapt to evolving science and new recommendations to protect human health. Without measures to ensure that the AAQ Directives set meaningful standards to protect human health and ecosystems in accordance with evolving scientific understanding, current standards might lose relevance as new scientific and technological evidence become available.

Under the baseline we assume that all of the air pollutants currently covered by the Directive continue to be relevant, as their respective harmful effects are confirmed (Fitness Check). Directives 2004/107 and 2008/50 might not cover all the pollutants that might have harmful effects on health. Evidence also shows that there is a need for ongoing assessment of whether standards for pollutants not currently in scope of the AAQ Directives[48] should be added to ensure relevance of the directives.

7.1.5 *Problem: Projected air quality assessment and monitoring shortcomings*

Driver: Monitoring rules offering flexibility are stretched in certain instances

Member States have been monitoring air quality for many decades and by 2020 there were over 4 000 air quality monitoring stations with nearly 16 000 sampling points (

[48] Scientific evidence points to serious adverse health effects at lower concentration levels than set by the EU air quality standards for several air pollutants, most notably for particular matter, sulphur dioxide, benzene and benzo(a)pyrene (and to a lesser degree also for ground-level ozone) (European Commission, 2019).

Table 23) to measure specific pollutants across Europe.

Monitoring, using common methods to assess air quality, has been a key component of the previous Air Quality Framework Directive and its daughter Directives, which has been carried through the current AAQ Directives 2004/461/EC and 2008/50/EC. Directive 2008/50/EC provides rules to assess ambient air quality, including how, when, and where to assess air quality. This includes provisions related to fixed measurements of air pollutant concentrations, and when and how it is appropriate to supplement fixed measurements of air pollutant concentrations with other assessment methods (i.e. modelling, objective estimation, indicative measurements). Directive 2008/50/EC also includes definitions of data quality objectives for the different methods and different air pollutants.

In terms of fixed measurements of pollutant concentrations, the provisions include: minimum numbers of sampling points for each pollutant, criteria for siting of these sampling points, and the reference methods for assessment of pollutant concentrations. Consequently, the assessment of air quality has, most commonly relied on monitoring techniques using fixed reference methods as specified in these Directives rather than indicative measurements or modelling.

The AAQ Directive requires a minimum number of monitoring sites per zone and pollutant, depending on its air pollution levels and population density (Annexes V and IX of the AAQ Directive). In most of the analysed zones, the legal provisions for the minimum number of monitoring sites are fulfilled. However, in some zones PM2.5 monitoring sites were missing.

Table 23 shows data from the total number of monitoring stations and the number of sampling points per pollutant as reported by Member States to the data repository Central Data Repository (CDR) for the year 2020. To assess the extent to which the minimum number of sampling points required by the AAQ Directives is achieved, it is necessary to review air pollution levels and population density (as per the criteria for determining the minimum sampling points in Annexes V and IX of the AAQ Directive). Further requirements specify the ratio between PM10 and PM2.5 monitoring sites, and between urban background/traffic sites (both with a ratio of between 0.5 and 2, respectively).

Based on a sample of zones in Austria, France, Germany, Italy and Poland, an assessment (European Parliament, 2019) on the extent to which the minimum number of sampling points is met concluded:

- NO_2 and PM (PM_{10} + $PM_{2.5}$): Minimum number of sampling points achieved
- O_3: Minimum number of sampling points achieved, except in the case of one zone (PL1201, Kraków)
- $PM_{2.5}$ and PM_{10} ratio: Ratio is exceeded in a number of zones
- Urban background/traffic site ratio: Dedicated traffic-related monitoring sites are often missing and the ratio of NO_2 urban background to urban traffic sites is outside the prescribed range in several zones

Table 23 Total number of monitoring stations and number of sampling points per pollutant by Member State for the year 2020 (EEA, 2021)

Member State	Stations	PM_{10}	$PM_{2.5}$	SO_2	NO_2	O_3	CO	C6H6	Pb in PM_{10}	As in PM_{10}	BaP in PM_{10}	Cd in PM_{10}	Ni in PM_{10}
AT	177	120	58	65	138	104	26	20	11	11	32	12	11
BE	218	67	69	25	122	43	19	32	29	29	20	23	29
BG	42	40	10	28	25	21	18	20	11	7	15	12	7
CY	6	2	5	3	3	3	2	1	2	2	1	2	2
CZ	183	150	93	60	96	67	22	39	59	58	53	59	59
DE	590	368	216	102	532	256	84	104	89	88	105	89	89
DK	15	7	10	2	13	7	6	3	4	4	2	4	4
EE	10	7	8	9	9	10	7	4	5	5	5	5	5
ES	596	471	259	413	517	421	194	117	123	120	99	120	119
FI	53	28	17	11	22	15	1	3	3	5	7	5	5
FR	589	378	194	111	409	316	21	64	57	54	56	54	55
GR	25	20	12	12	22	20	10	8	3	2	3	3	3
HR	22	11	11	8	13	15	4	3	2	2	3	2	2
HU	36	30	17	24	24	19	22	14	16	16	18	16	16
IE	51	39	36	10	21	18	5	2	5	5	5	5	5
IS	10	7	6	8	9	1	1	1	1	1	1	1	1
IT	631	530	291	209	587	323	198	231	131	136	161	136	133
LT	18	13	5	12	13	13	9	2	5	5	5	5	5
LU	11	5	4	3	8	6	3	1	2	2	2	2	2
LV	13	6	6	7	9	8	2	6	5	5	5	5	5
MT	5	3	5	3	4	5	2	2	3	3	1	3	3
NL	79	65	46	15	70	45	9	6	1	1	3	1	1
PL	277	242	124	103	142	102	69	61	74	73	158	72	72
PT	63	53	23	25	51	44	14	3	1	1	1	1	1
RO	145	27	7	37	122	71	25	38	30	23	4	32	29
SE	80	47	24	2	44	26	4	2	1	1	1	1	1
SI	20	18	6	5	12	8	3	2	4	4	4	4	4
SK	43	37	37	16	29	18	15	12	6	6	16	6	6
Total	4008	2791	1599	1263	3066	2005	795	801	683	669	786	680	674

While this established monitoring network provides comparable, reliable and often real time information to the public a number of issues have been identified for improvement which are specific to monitoring (Fitness Check (European Commission, 2019) and (Conlan et al., 2022)). The AAQ Directive also affords flexibility regarding the microscale criteria, which applies only "in so far as practicable" (and the macroscale criteria only "where feasible"). The data collected by both the Fitness Check and the (Conlan et al., 2022) study from stakeholder consultation indicates that the way certain flexibilities permitted by the Directives have been interpreted and implemented by Member States has hampered comparability at EU level. Assuming no change to the baseline, the inconsistency in the calculation of exposure and exceedance indicators would be expected to continue as would the limited use of Member States reporting exceedance/ exposure indicators and the application of the micro siting criteria. As the determination of exposure indicators is intrinsically linked to the concept of sampling point representativeness, this would also continue to affect the comparability of monitoring between Member States.

Under the baseline scenario, **requirements for monitoring of air pollutants**, are assumed to remain identical to what is currently in place. However, over recent years there have been technological developments in monitoring techniques, and it is likely these will continue to develop. For example, some Member States use low-cost sensors, and there has been much discussion through the AQUILA[49]

[49] AQUILA, or the Network of Air Quality Reference Laboratories. The objectives of the Aquila network are to provide expert judgement, to promote the harmonisation of air quality measurements among EU, EFTA and CCs, to co-

and FAIRMODE air quality expert communities on their merits. However, until a quality standard for low-cost sensors is agreed within the air quality community, uncertainty around their quality will remain. The use of passive diffusion tubes to supplement NO_2 fixed reference monitoring has increased in recent years and it is assumed this is likely to continue while there remains an NO_2 exceedance issue.

Furthermore, while requirements under the AAQ Directive 2008/50/EC remain the same there is likely to be limited scope to adequately address the identified shortcomings across Europe. The spatial representativeness of sampling points, linked with the minimum number of sampling points, is likely to remain an issue and the comparability of air quality data may not improve. Without clarification regarding the ambiguities in the provisions for the microscale siting criteria, coupled with the issues identified for the number and distribution of monitoring stations, the extent to which the microscale siting criteria will ensure representative and consistent monitoring strategies for air pollutants in all zones will be limited.

Driver: Modelling ability has improved, allows for much more detail

While there is an option within the AAQ Directives to use modelling to supplement information from fixed sampling points, there is no obligation to do so. The Fitness Check concluded that the number of Member States submitting modelling results as part of the assessment documentation (under Dataflow D on the EIONET portal) has increased significantly in recent years (from four in 2013 to 12 in 2017) (European Commission, 2019). As part of the (Conlan et al., 2022) study, survey respondents reported that a reason for not submitting modelling results as part of the assessment documentation (despite having access to modelling results) is a lack of clarity on how and under which conditions modelling can be used to support the implementation of the Directive and air quality management practices in general. Added to this, the lack of technical guidance to enhance and harmonise modelling quality further deters Member States from submitting modelling results as part of the assessment documentation (Conlan et al., 2022). Depending on the purpose of the modelling application, different fitness-for-purpose criteria might exist. At present, current practices on the use of modelling remain disparate across Member States.

Modelling has improved in recent years and under the baseline this is likely to continue. The FAIRMODE air quality expert community is working on a number of improvement tasks including methods for source apportionment, micro-scale modelling, high resolution emissions, exposure and exceedance indicators and robustness of air quality projections. It is expected that this work will further promote and support the harmonised use of models by Member States, with emphasis on model application under the AAQ Directives. This is somewhat likely to address the identified shortcomings of the Directives. However, FAIRMODE is a voluntary working group, with consensus associated with the production of guidance that requires discussion and time. Therefore, while it is envisaged that modelling will continue to be improved, the use of models within Member States is likely to remain variable. Consequently, modelling associated with **air quality plan development** is also unlikely to significantly improve under the baseline scenario. Table 24 sets out the number of Member States reporting modelling and indicative measurement data and exceedance/exposure indicator reporting. Little change is expected to happen in the future without changes to the underlying drivers.

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ordinate QA/QC activities, method development and validation, to participate in standardisation activities, to develop common research projects and pilot studies and to offer a forum for information exchange in form of training courses, workshops and conferences. For further information see: https://www.eea.europa.eu/themes/air/links/networks/aquila-network

Table 24 Number of Member States reporting data and likely change without intervention

Indicator	2020	Likely evolution without intervention
# Member States reporting indicative measurement data	7 (3 for NO_2)	Slight increase
# Member States reporting modelled data	12*	Slight increase
# Member States reporting Ecosystem Area exposed	6	Static
# Member States reporting Population indicative measurement data	15	Static
# Member States reporting Road Length in exceedance	6	Static
# Member States reporting Surface Area in Exceedance	16	Static

*Value for 2017

7.1.6 *Problem: Information and communication shortcomings*

The AAQ Directives include provisions on reporting and dissemination of public information enabling improved reporting systems. The EEA launched an upgraded air quality database available via the EIONET portal which follows the rules for reciprocal exchange of information and reporting on AAQ Directive 2004/107/EC and Directive 2008/50/EC and the rules set out in the Commission Implementing Decision 2011/850/EU and the Commission's guidance documents IPR Guidance Part I and IPR Guidance Part II. The Air Quality e-Reporting database contains current / live data on the status of air quality collected from the Member States and reported to the EEA (European Commission, 2019).

The air quality data reported by Member States is made available to the public by the EEA; both in their original form, as well as via aggregated assessment data. Air quality information is also made available by national, as well as by regional and local authorities in many cases. More recently, there is also evidence that information is made available by private operators (e.g. AirCare (AirCare, 2022), AirVisual (IQAir, 2022)). The extent to which this information is comparable at EU level is limited. Namely owing to the fact that the AAQ Directives have not defined information and alert thresholds for some pollutants which has resulted in a non-harmonised approach across Member States, entailing extensive differences in government and/or media coverage of alarming levels of air pollution. Similarly, the absence of a common metric used for publicised air quality indices often means that the same data is presented in different ways in different locations (national air quality indices in different European countries are different from one another and from the European Air Quality Index in terms of 'bands' and 'thresholds'). Furthermore, it was found in the above mentioned studies that not all air quality data reported is equally useful and the successful establishment of an EU-wide e-reporting based on machine-readable formats now allows for further efficiency gains – and opens the way for further up-to-date reporting of air quality data and to make further use of air quality modelling (which is increasingly reported, but would benefit from further guidance).

Furthermore, the results of the Fitness Check and the (Conlan et al., 2022) study show that under the current legislative framework of the AAQ Directive the general public is not sufficiently informed regarding health impacts from air pollution. The European Court of Auditors reviewed air quality information made available online across six different Member States, and found that the quality and availability of public information on air quality in the Member States was not always clear or useful for the citizens regarding the health impacts and measures to take to mitigate risks (European Court of Auditors, 2018).

If the legislative framework is maintained, the general public will remain insufficiently informed regarding air quality/pollution and its impact on their health, or how it compares to neighbouring Member States. Furthermore, inefficiencies and certain administrative burdens for public authorities will remain in relation to reporting. Currently the roles and responsibilities of different tiers of Member States' national governments are not clearly delineated and understood by public authorities.

7.1.7 *Summary of the baseline*

In the absence of further changes to the AAQ Directives, other factors will continue to have an influence on the achievement of its objectives going forward.

Compliance with existing air quality standards is anticipated to continue to improve. Emission policies (e.g., air pollutant legislation, but also climate change policies to meet new greenhouse gas emissions targets such as Fit for 55) and sector specific policies (e.g. vehicle emissions standards, efficiency standards and emission limits for residential heating installations) will continue to place downward pressure on emissions. In addition, Member States may also continue to take action to work towards compliance with the existing EU and national legislation and developments in non-EU countries will impact on transboundary pollution. However, there are drivers of change that would be expected to increase emissions of air pollutants, which will contrast against emission and sectoral policies (regulating emissions at source). For example, demographic changes and higher incomes (that may otherwise lead to an increase in activities resulting in higher air pollutant emissions, e.g., consumption, fuel use, vehicle ownership, etc.) will likely continue to place an upward pressure on emissions.

From the detailed modelling, as presented in further detail in section 7.1.2 above, overall, current policies will result in a continued decline in emissions of key air pollutants. Compared to 2015, emissions of $PM_{2.5}$, NOx, and SO_2 are estimated to drop by 50 to 70% to 2030, NMOVC by 25%, while for ammonia (NH_3) only about 5% reduction is calculated by 2030. The trends are expected to continue towards 2050 but with much smaller further reductions. This reduction in emissions translates into improvements in air pollutant concentrations to 2030 and 2050. For instance, much lower numbers of people are expected to be exposed to $PM_{2.5}$ concentrations above the current WHO recommendation by 2030 and 2050. However, it is unlikely that compliance with WHO recommended (and even existing) air quality standards will be achieved in all places up to 2050.

Meanwhile it is likely that the underlying scientific evidence base linking air pollution to environment and health impacts will continue to be strengthened. Likewise technological solutions will continue to progress, with more effective air pollution mitigation measures likely becoming available or more cost-effective over time.

With respect to issues around AQ governance and monitoring, as experience and knowledge associated with the implementation of air quality plans grows, there may be some sharing of best practice and learning across local, regional, national authorities and between Member States. This will happen to the extent that it is encouraged, practices are transparent and the mechanisms exist to facilitate information sharing. Furthermore, where there is public awareness around air quality issues, there may be pressure placed on authorities to improve practices. However, without legislative change, such progress is not guaranteed. Comprehensive progress across all Member States would be even less likely. Furthermore, progress is not guaranteed to comprehensively address the various issues identified around governance and monitoring to date, namely that: penalties are insufficient and citizens do not have access to justice, plans and the measures contained in them, are ineffective or disproportionate, and stakeholders are not appropriately engaged in the development of plans. As such, it is highly likely that a subset of Air Quality Plans are likely to continue to fail to deliver compliance in the shortest time possible. With respect to access to justice, where further cases for compensation are brought to court, this could build up case law at a national level[50]. However, comprehensive and consistent access for all EU citizens is not guaranteed.

External (regional or transboundary) pollution sources will continue to be a key factor resulting in some localised exceedances(external sources are critical in many cases, but not all). This issue may increase with the general drive to lower levels of concentrations overall (background becomes higher proportion of overall concentrations). In some cases, emitters of 'external' pollution may engage in the formulation of Air Quality Plans (e.g. where there is public awareness of an issue, and/or where this fits with industry desires, e.g. CSR schemes). But there is no guarantee that this will take place comprehensively across all Member States and all exceedances, nor that any engagement will follow best practice (such as relevant stakeholders being engaged at the right time, in the right way and regarding the right issues) and be effective to assist the quality of the Air Quality Plan.

Over recent years there have been technological developments in monitoring techniques, which are likely to continue. E.g. some Member States are using low-cost sensors and passive diffusion tubes. Modelling has also improved in recent years and under the baseline this is likely to continue. The FAIRMODE air quality expert communities are working on a number of improvement tasks including methods for source apportionment, micro-scale modelling and high resolution emissions. It is expected that this work will further promote and support the harmonised use of models. As better practices become normalised, the cost of adopting these practices should also decrease.

Interest and attention amongst citizens regarding air pollution is particularly high at present which could drive authorities to respond to the issue at local level, increasing the disparities between regions and Member States. With increasing focus, more activities and information might be brought forward by business organisations, environmental organisations or non-governmental organisations (e.g. mobile device applications, advice services). However, where information is disseminated by third parties or authorities, this will likely continue to differ in terms of the presentation, messaging, content, underpinning evidence base and advice provided.

The following table presents a summary of the baseline, which forms the reference benchmark against which the analysis of interventions in the remaining sections of this report is performed.

[50] For example, see the recent C-286/21 PM_{10} case in France. Compensation is addressed in the preliminary reference case C-61/21 for which the AG opinion has been delivered, but not yet the CJEU ruling.

Table 25- Summary of the baseline

Problem	Assumptions on whether / how this problem persists
(I) Environment and health shortcomings are likely to persist (even if some further air quality improvements can be expected as air emissions decrease)	• Further reduction in air pollutant concentrations will lead to continued reduced exposure to air pollution and reductions in health burden. • However, EU air quality standards remain significantly above WHO recommendations, resulting in health (and environmental) challenges. • Without updated EU air quality standards (and associated requirement to take action when there are exceedances) there is little incentive to act. • As scientific understanding of health impacts of air pollution is further updated, EU air quality standards may need corresponding updates.
(II) Governance and enforcement shortcomings are very likely to persist, leading to continued persistent air quality exceedance situations	• Continued (limited) air quality improvement in air quality will reduce pressure on Member States to act (despite continued health impacts). • Low level of coordination when designing and implementing air quality plans between different levels of governance hampers additional action. • Air quality plans and measures contained therein are not reviewed, nor updated for changing context, even if plans are deemed insufficient. • Member States continue to interpret EU rules differently leading to different approaches to implementation and limited enforcement action.
(III) Monitoring and assessment shortcomings are likely to persist (at least partially), even if some aspects of this can be addressed by non-legislative measures	• While air quality monitoring and assessment continues to deliver a generally sound basis for policy action, but inconsistencies remain. • Without further guidance or legislation, there remains an incentive to stretch monitoring rules in order to avoid monitoring all exceedances. • Spatial representativeness of sampling points is likely to remain an issue hampering the reliability and comparability of air quality assessments. • The use of models is likely to remain variable, and modelling associated with air quality plan development is not used to its full potential.
(IV) Information and communication shortcomings are likely to persist (at least partially), even if some aspects of this can be addressed by non-legislative measures	• A wealth of information on current air quality, and the health and environment impacts of air pollution, is collected and made available. • Accessibility of information on air quality will continue to improve, but authorities are not expected to go beyond the mandatory requirements. • There is a risk of continued lack of comparability of air quality data and health assessments (especially when disseminated by third parties). • General public (and vulnerable populations) will continue to feel insufficiently informed regarding air quality and its impact on health.

7.2 Intervention areas and long-list of interventions

As set out in Section 3, the revision of the Directives is considering multiple, connected problems and drivers. To better consider the linkages between the problems and drivers, three Policy Areas were defined in the Intervention Logic:

- Policy Area 1: a closer alignment of the EU air quality standards with scientific knowledge including the latest recommendations of the World Health Organization (WHO)
- Policy Area 2: improving the air quality legislative framework, including provisions on penalties and public information, in order to enhance effectiveness, efficiency and coherence
- Policy Area 3: strengthening of air quality monitoring, modelling and plans.

Under each Policy Area, long-lists of interventions were identified to tackle the problems and drivers. These interventions were defined based on: (a) the Fitness Check; (b) the feedback provided by stakeholders to the Inception Impact Assessment, including the AQUILA and FAIRMODE air quality expert communities; (c) the expertise of the project team, (d) input from the parallel study 'Strengthening of air quality monitoring, modelling and plans under the Ambient Air Quality Directives' and (e) the literature review. Where several interventions address a common theme or driver, interventions have been grouped into 27 Intervention Areas. The 27 Intervention Areas are presented in

Figure 55 below.

Figure 55 – List of intervention areas and mapping to current AAQ Directives Articles and Annexes

Policy Area	Intervention area	Intervention area name	Mapping to Directive 2004/107	Mapping to Directive 2008/50
2	A	How to ensure the timely adjustment of EU air quality standards to evolving scientific or technological knowledge?	8	32
2	B	Which types of air quality standards or combination thereof are appropriate?	2, 3	2, 12-16 Annex II
2	C	What action should be mandated in case air quality standards are not respected?	3	17, 18, 19, 23, 24
2	D	Who should be involved in the preparation of air quality plans, and how should their preparation and implementation be coordinated?		23 Annex XV
3	M	How to assess and address transboundary air pollution in local/regional air quality management?		20-21
2	E	What legal tools should be available to address breaches of the obligations?	9	30
2	F	How to best inform the public on air quality?	7	26, 27 Annex XII
3	G	How to improve air quality assessment regimes, including the scope to combine monitoring, modelling and other assessment methods?	4	5-11 Annex II
3	H	How to improve the minimum number and type of sampling points required for measuring air pollution concentrations?		Annex III, V, VIII
3	I	How to ensure continuity in the monitoring of air quality?		Annex V
3	J	How to ensure the reliable micro and macroscale siting of monitoring stations?		Annex III
3	K	Which requirements on data quality are needed to assess and report air quality?		Annex I
3	L	Which additional air pollutants should be measured and to what extent should monitoring requirements be expanded?		Annex III, V, X
3	N	Which minimum information should be included in an air quality plan?		Annex XV
1	O	EU air quality standards for particulate matter (PM2.5)		Annex XIV
1	P	EU air quality standards for particulate matter (PM10)		Annex XI

Policy Area	Intervention area	Intervention area name	Mapping to Directive 2004/107	Mapping to Directive 2008/50
1	Q	EU air quality standards for nitrogen dioxide (NO2)		Annex XI
1	R	EU air quality standards for ozone (O3)		Annex VII
1	S	EU air quality standards for sulphur dioxide (SO2)		Annex XI, XII, XIII
1	T	EU air quality standards for carbon monoxide (CO)		Annex XI
1	U	EU air quality standards for benzene		Annex XI
1	V	EU air quality standards for benzo(a)pyrene (BaP)	Annex I	
1	W	EU air quality standards for lead (Pb)		Annex XI
1	X	EU air quality standards for arsenic (As)	Annex I	
1	Y	EU air quality standards for cadmium (Cd)	Annex I	
1	Z	EU air quality standards for nickel (Ni)	Annex I	
1	Ø	EU air quality standards for pollutants of emerging concern	N/A	

In total, 69 interventions were identified and considered as part of the Impact Assessment study: 22 in Policy Area 1 (further assessed in groups of 7 scenarios), 27 in Policy Area 2 and 20 in Policy Area 3. These are listed in the tables below.

Table 26 – Interventions under Policy Area 2 (i.e. the legal framework)

Improving the air quality legislative framework, including provisions on penalties and public information

Intervention area A: How to ensure the timely adjustment of EU air quality standards to evolving scientific or technological knowledge?

- (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).
- (A2) Introduce a mechanism for adjusting EU air quality standards based on technical progress in air pollution reduction.
- (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.
- (A4) Keep and periodically update a list of priority air pollutants to ensure air pollutants of emerging concern are monitored.

Intervention area B: Which types of air quality standards or combination thereof are appropriate?

- (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.
- (B2) Define alert thresholds and information thresholds for all air pollutants as triggers for alerting the public and taking short-term action.
- (B3) Expand the application of the exposure reduction targets (relative reduction in exposure).
- (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).

Intervention area C: What action should be mandated in case air quality standards are not respected?

- (C1) Further specify the obligation to take measures to keep exceedance periods as short as possible.

- (C2) Reformulate the term "as short as possible" with a defined time period.
- (C3) Require a clearer coordination between short-term action plans and air quality plans.
- (C4) Introduce an obligation for effective short-term action plans for each pollutant to prevent / tackle air pollution events.
- (C5) Mandate regular updates of air quality plans.

Intervention area D: Who should be involved in the preparation of air quality plans, and how should their preparation and implementation be coordinated?

- (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.
- (D2) Introduce a requirement for Member States harmonise air quality plans and air quality zones (and require a 'one zone, one plan' approach).

Intervention area M[51]: How to assess and address transboundary air pollution in local/regional air quality management?

- (M1) Require the use of an agreed methodology when assessing transboundary air pollution/contributions to local/regional air pollution.
- (M2) Require transboundary cooperation and joint action on air quality if assessments of transboundary air pollution/contributions above certain thresholds (to be defined)

Intervention area E: What legal tools should be available to address breaches of the obligations?

- (E1) Introduce minimum levels for financial penalties.
- (E2) Introduce specific provisions that guarantee a right to compensation for damage to health.
- (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.
- (E4) Introduce an explicit 'access to justice' clause in the Ambient Air Quality Directives.

Intervention area F: How to best inform the public on air quality?

- (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) Require Member States to provide specific health / and health protection information to public as soon as exceedances occur.
- (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).
- (F4) Require Member States to use harmonised air quality index bands.

Other:

- Merge provision of Directives 2008/50 and 2004/107

Table 27– Interventions under Policy Area 3 (i.e. air quality monitoring, modelling and plans)

Intervention area G: How to improve air quality assessment regimes, including the scope to combine monitoring, modelling and other assessment methods?

- (G1) Allow / continue to allow the use of indicative monitoring to substitute fixed monitoring as part of air quality assessment.
- (G2) Make the use of air quality modelling mandatory as part of air quality assessment (in some circumstances).
- (G3) Require a regular review of the assessment regime following clear criteria defined in the Directive.

Intervention area H: How to improve the minimum number and type of sampling points required for measuring air pollution concentrations?

- (H1) Change the minimum number of sampling points that are required per air quality zone.
- (H2) The minimum number of sampling points for measuring PM10 and PM2.5 will be considered independently from each other.

[51] Intervention area M falls between D and E as originally this sat as part of Policy Area 3, but was moved during the course of the study to sit under Policy Area 2, but the original naming convention was retained.

- (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.

Intervention area I: How to ensure continuity in the monitoring of air quality?

- (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.
- (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).
- (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.

Intervention area J: How to ensure the reliable micro and macroscale siting of monitoring stations?

- (J1) Further clarify (and reduce flexibilities related to) the macro-siting criteria for sampling points.
- (J2) Further clarify (and reduce flexibilities related to) the micro-siting criteria for sampling points.
- (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).

Intervention area K: Which requirements on data quality are needed to assess and report air quality?

- (K1) Further define the data quality requirements for sampling points / measurements used for air quality assessments.
- (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.
- (K3) Introduce a standardized 'modelling quality objective' as a quality control mechanism to assess whether a modelling based assessment is fit-for-purpose.
- (K4) Modify the definition of measurement uncertainty by defining it in absolute values and not in percentage values (or a combination of both).

Intervention area L: Which additional air pollutants should be measured and to what extent should monitoring requirements be expanded?

- (L1) Require monitoring stations that measure continuously certain emerging air pollutants (e.g. called "supersites" across the Member States).
- (L2) Require monitoring of additional air pollutants at a minimum number of sampling points and with relevant data quality requirements.
- (L3) Expand the list of required and/or recommended volatile organic compounds (VOCs) to measure.

Intervention area N: Which minimum information should be included in an air quality plan?

- (N1) Refine the minimum information to be included in an air quality plan.

Table 28– Interventions under Policy Area 1 (i.e. air quality standards for specific pollutants)

Closer alignment of the EU air quality standards with scientific knowledge including the latest recommendations of the World Health Organization (WHO)

Intervention area O: EU air quality standards for particulate matter (PM2.5)

- (O1) Revise long-term (annual) air quality standards
- (O2) Introduce short-term air quality standards and/or alert/information thresholds
- (O3) Revise average exposure obligations and reduction targets

Intervention area P: EU air quality standards for particulate matter (PM10)

- (P1) Revise long-term (annual) air quality standards
- (P2) Revise short-term air quality standards and/or alert/information thresholds
- (P3) Introduce average exposure obligations and reduction targets

Intervention area Q: EU air quality standards for nitrogen dioxide (NO2)

- (Q1) Revise long-term (annual) air quality standards
- (Q2) Revise short-term air quality standards and/or alert/information thresholds
- (Q3) Introduce average exposure obligations and reduction targets

Intervention area R: EU air quality standards for ozone (O3)

- (R1) Revise long-term (peak-season) air quality standards

- (R2) Revise short-term air quality standards and/or alert/information thresholds
- (R3) Introduce average exposure obligations and reduction targets

Intervention area S: EU air quality standards for sulphur dioxide (SO2)

- (S1) Revise long-term (annual) air quality standards
- (S2) Revise short-term air quality standards and/or alert/information thresholds

Intervention area T: EU air quality standards for carbon monoxide (CO)

- (T1) Revise short-term air quality standards

Intervention area U: EU air quality standards for benzene

- (U1) Revise long-term (annual) air quality standards

Intervention area V: EU air quality standards for benzo(a)pyrene (BaP)

- (V1) Revise long-term (annual) air quality standards

Intervention area W: EU air quality standards for lead (Pb)

- (W1) Revise long-term (annual) air quality standards

Intervention area X: EU air quality standards for arsenic (As)

- (X1) Revise long-term (annual) air quality standards

Intervention area Y: EU air quality standards for cadmium (Cd)

- (Y1) Revise long-term (annual) air quality standards

Intervention area Z: EU air quality standards for nickel (Ni)

- (Z1) Revise long-term (annual) air quality standards

Intervention area Ø: EU air quality standards for pollutants of emerging concern

- (Ø1) Introduce air quality standards for additional pollutants

7.3 Assessment and constructing illustrative policy options

As described in Section 6, all 69 interventions across the 27 Intervention Areas have been assessed based on their effectiveness, efficiency and coherence and have been scored against the 12 indicators. The detail of the analysis is set out in the Assessment Sheets presented in the Appendix, and summarised in Section 9. The appraisal of the interventions under Policy Area 1 also draws on the more detailed quantitative modelling, the results of which are set out in Section 8.

Underneath the interventions, different variants are possible. These variants have been considered in the analysis, in particular where and how the scoring may change depending on the variant.

Following the assessment, the interventions have then been grouped into illustrative policy packages, combining interventions across Intervention and Policy Areas. The first stage in policy option analysis was to construct a number of illustrative packages. These are combined and assessed in order to explore the interactions, linkages and dependencies between interventions in different Intervention and Policy areas, but do not necessarily include the final, preferred package for implementation.

For the interventions in Policy Area 1, the illustrative Policy Packages directly reflect potential EU standards suggested for either 2030 or 2050, respectively – for each of the 12 air pollutants. This corresponds to 13 different possible intervention areas, i.e. one per pollutant + 1 for ‘new’ pollutants. Our analysis looked at combinations of these standards in 7 sets of standards (or scenarios), each of which reflected a combination of standards for all pollutants for 2030 or 2050 respectively (4 levels of ambition for 2030, 3 for 2050).

For interventions under Policy Areas 2 and 3, identifying which can be grouped into high, medium and low ambition packages is broadly based on the value to be derived from the intervention, taking account of the costs and benefits but also the linkages and interactions between interventions across Policy Area.

8 Results of quantitative analysis to support revision to air quality standards

8.1 Environmental impacts

8.1.1 *Impacts on air pollution emissions (Indicator #1)*

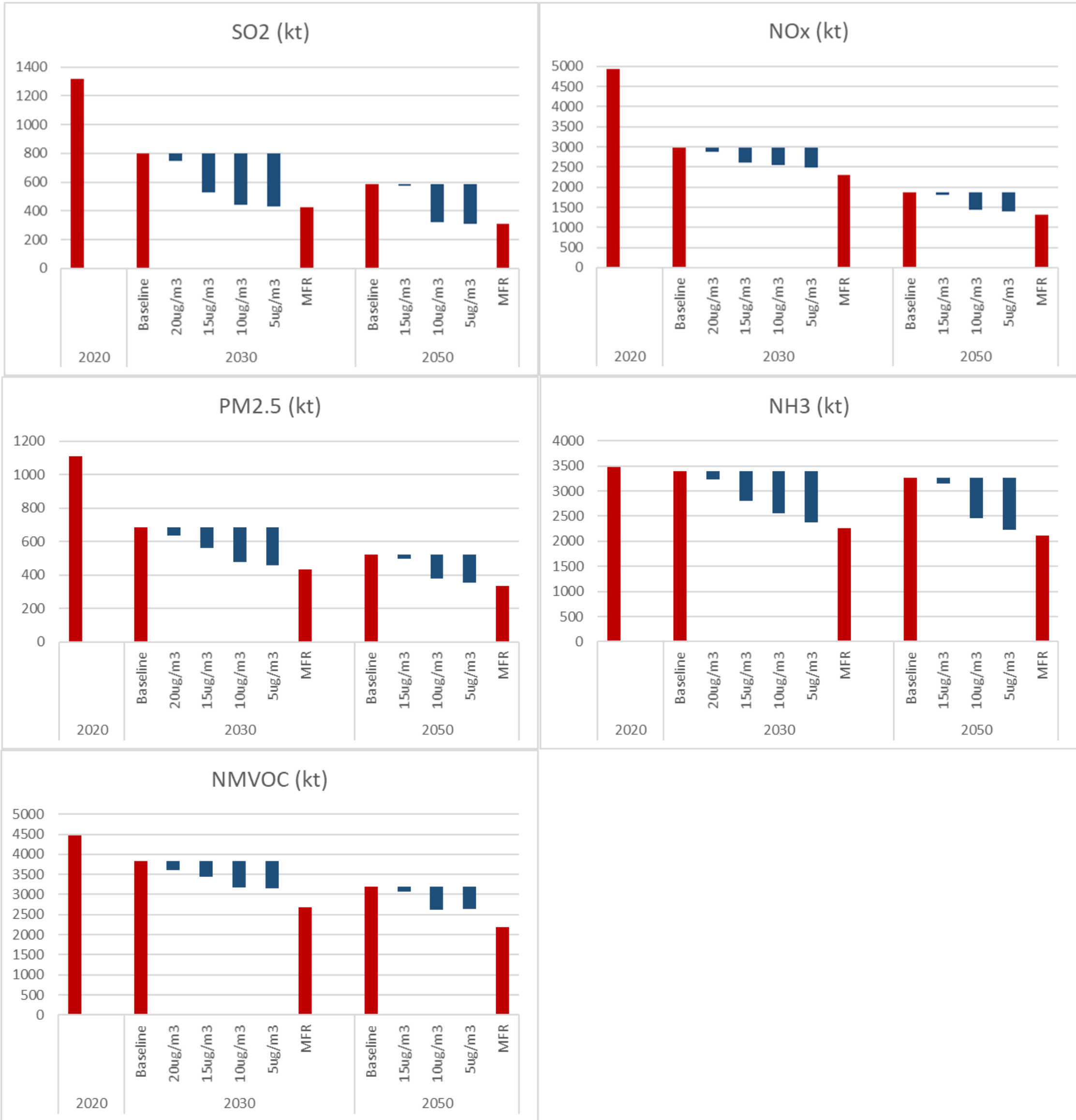
As discussed in Section 6, under baseline scenario assumptions, emissions are expected to decline for all air pollutants, however, for ammonia the change is only expected to be marginal. Implementation of all technical measures (excluding any further structural, transformational measures, e.g., driven by lifestyle changes) defined in the GAINS model could reduce emissions further and doing so identifies scope for further strengthening emission limit values, introducing new legislation or accelerating wide application of proven but not yet widespread measures - this is illustrated in the maximum feasible reduction (MTFR) case.

Figure 56 shows the baseline and MTFR emissions, as well as the emission reductions necessary compared to the baseline (from the cost optimal point of view – see Appendix 3) to achieve the policy targets (to the extent they are achievable within the scope for mitigation identified in the GAINS model) of 20, 15, 10 and to 5 µg/m3, respectively, for annual mean ambient $PM_{2.5}$ concentrations for 2030 and 2050.

The preliminary analysis (using the concentration modelling functionality in GAINS, i.e. prior to the more detailed concentration modelling exercise deploying EMEP) indicates that achieving the 20 and 15 ug/m^3 targets for $PM_{2.5}$ by 2030 or 2050 appears to be feasible and does not require significant additional emission reduction at the EU-27 level, compared to the baseline scenario trajectory, which already includes Fit-for-55 policy developments resulting in significant GHG reductions that support strong reduction of air pollutant emissions associated with reduced fossil fuel use. Achieving these targets would also not require significant reductions in emissions of individual Member States - several countries could stay at the baseline level while some are estimated to only need to moderately reduce their emissions.

The picture changes when more stringent targets of 10 ug/m^3 and then 5 ug/m^3 are applied, for the latter the emissions are nearly at the MTFR level and there are several grids (regions) where such concentrations cannot be achieved. As was indicated in Section 6.2, the more stringent targets cannot be reached in all grid cells, even in the MTFR scenario, i.e., for the 5 ug/m^3 case, in about 40% of all EU27 grids such concentrations are not achievable according to GAINS calculations (see more details about target setting in Appendix 3). For both targets the emission reductions are large at the EU level (Figure 56) and also for individual Member States.

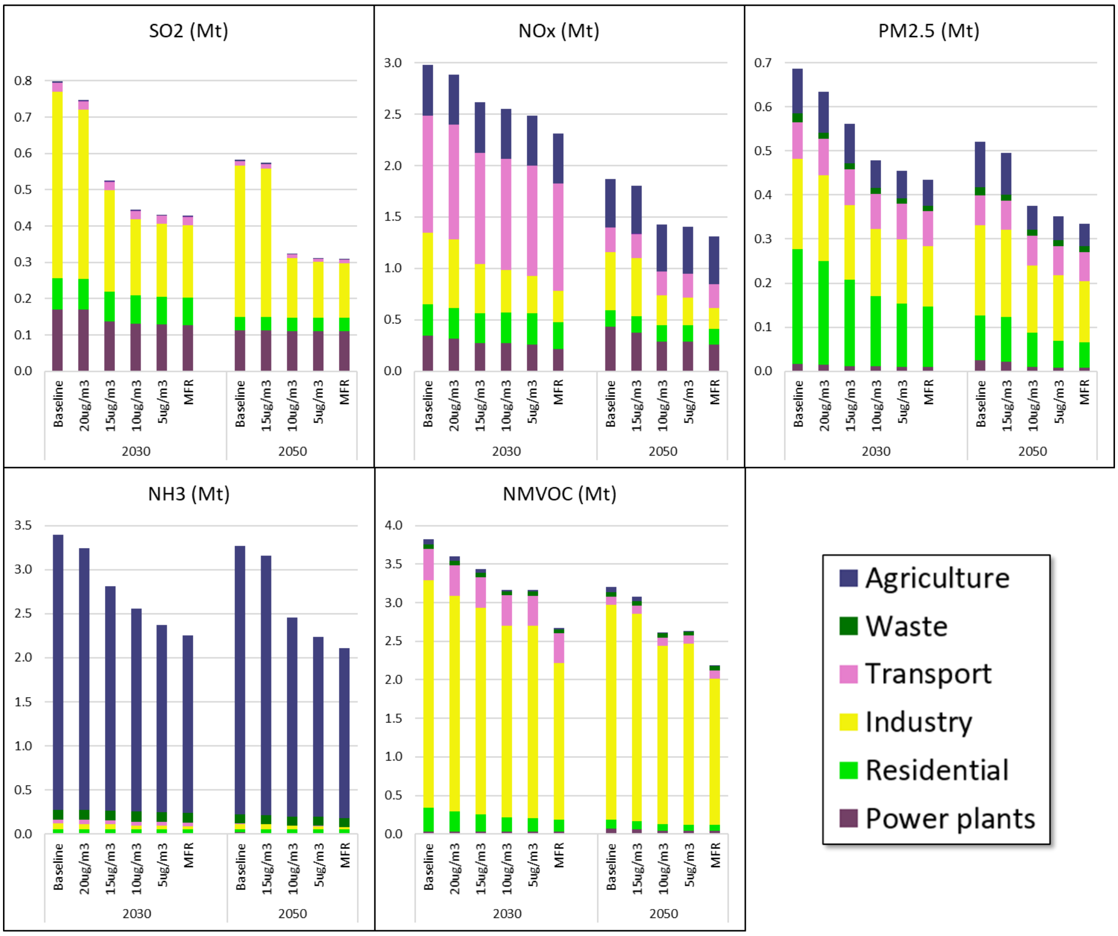
Figure 56 Emission trajectories for key air pollutants in the baseline, policy, and MTFR scenarios. EU-27; GAINS model



Notes: Figure shows the baseline and MTFR emissions (red bars) and emission reductions calculated for the respective policy targets (blue bars); note the text above (and Appendix 3) about the feasibility of the more ambitious targets.

Key sectors where major emission reductions are achieved in the cost-optimal scenarios where the 10 and 5 ug/m^3 targets are set are: industry, agriculture (NH_3) and residential heating ($PM_{2.5}$). Reduction of industrial emissions (both combustion and processes) is relevant for several pollutants. For residential heating, $PM_{2.5}$ emissions can be reduced by addressing biomass combustion for residential hearing, since the role of coal is declining and abatement potential around coal becomes less and less relevant (assuming effective implementation of the climate related targets for reduction of reliance on, and use of, fossil fuels).

Figure 57 - Emission trajectories for key air pollutants, and by key sector, in the baseline, policy, and MTFR scenarios. EU-27; GAINS model



Emissions of air pollutants under the different policy scenarios in 2030 are given in Table 29 to Table 33, under scenarios in 2050 in Table 34 to Table 38

Table 29 - Emissions of SO_2 for different policy scenarios in 2030. Units: kilotons/yr

Member State	Baseline	Target 20ug/m³	Target 15ug/m³	Target 10ug/m³	Target 5ug/m³	MTFR
Austria	8	8	8	8	7	7
Belgium	31	31	17	17	15	15
Bulgaria	41	41	19	19	19	19
Croatia	6	6	3	3	3	3
Cyprus	2	2	2	0	0	0
Czech Rep.	27	27	16	14	14	14
Denmark	9	9	8	8	7	7
Estonia	5	5	2	2	2	2
Finland	21	21	13	14	12	11
France	76	76	64	54	54	54
Germany	139	121	89	80	77	76
Greece	24	24	10	10	10	10
Hungary	7	7	5	5	5	5
Ireland	6	6	6	5	2	2
Italy	66	36	33	33	33	33
Latvia	3	3	3	3	2	2
Lithuania	10	10	5	5	5	5
Luxembourg	1	1	1	1	1	0
Malta	1	1	1	1	1	1
Netherlands	15	15	12	12	11	11
Poland	137	137	77	77	77	77
Portugal	20	20	20	10	9	9
Romania	35	34	12	12	12	12
Slovakia	11	11	5	5	5	5
Slovenia	3	3	2	2	2	2
Spain	82	82	82	33	33	33
Sweden	13	13	13	13	13	13
EU-27	799	748	526	444	431	427

The following figure shows an illustration of the tabulated Member State results highlighting additional mitigation effort beyond the baseline. The additional mitigation efforts are split into sectoral contributions at an aggregated level (more detailed sector/measure allocation are provided in Appendix 3). For SO_2, key additional reductions are achieved in the power sector and industry (see Appendix 3 for more details). In the OPT20 case, additional mitigation is only estimated to be required for a few countries, predominantly Italy where additional mitigation is necessary, including for other precursors of $PM_{2.5}$. The level of additional mitigation required increases in OPT15 towards OPT5, but between OPT10 and OPT5 cases there is not a lot of additional reduction as most of the potential is already achieved in the OPT10 case (compared to the MTFR levels). In general, the mitigation potential is not large in absolute terms as current legislation is expected to effectively reduce SO_2 emissions compared to current levels.

Figure 58 - Emissions reduction of SO_2 for different policy scenarios in 2030, split by MS. Units: kilotons/yr

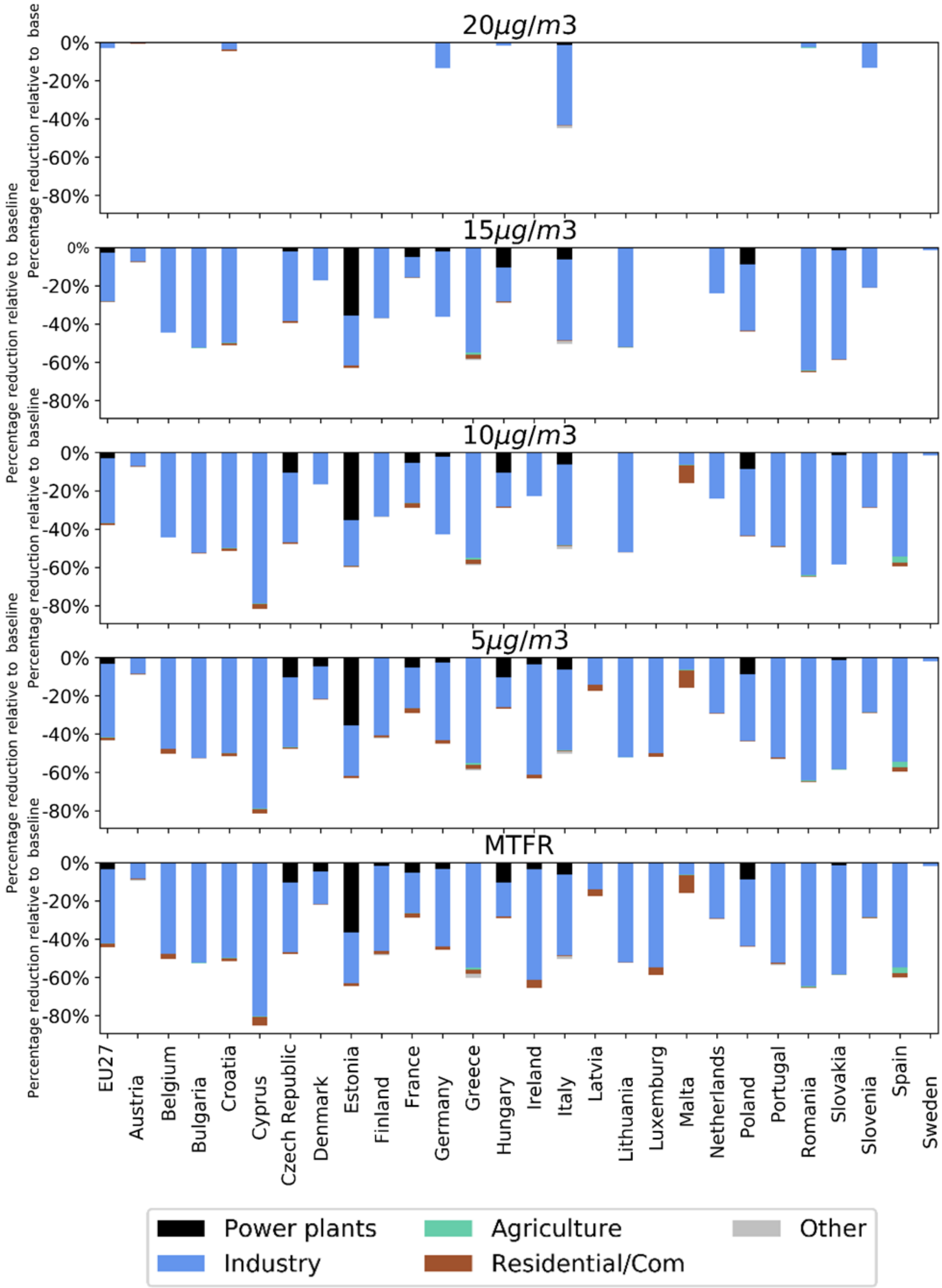


Table 30. Emissions of NO_X as calculated from GAINS under different policy scenarios in 2030. Units: kilotons/yr

Member State	Baseline	Target 20ug/m^3	Target 15ug/m^3	Target 10ug/m^3	Target 5ug/m^3	MTFR
Austria	62	60	54	55	51	48
Belgium	92	92	84	84	78	76
Bulgaria	67	66	55	55	55	52
Croatia	26	25	20	19	18	16
Cyprus	6	6	6	4	4	4
Czech Rep.	97	95	73	74	73	64
Denmark	63	63	58	58	55	52
Estonia	13	13	13	13	12	10
Finland	73	72	66	68	62	52
France	379	375	370	358	346	331
Germany	473	454	405	408	396	383
Greece	89	89	74	77	76	73
Hungary	66	65	51	53	57	50
Ireland	58	58	58	58	52	48
Italy	290	248	247	241	241	236
Latvia	25	25	24	24	21	20
Lithuania	32	32	26	26	26	25
Luxembourg	8	8	8	8	8	5
Malta	2	2	2	2	2	2
Netherlands	116	116	103	103	95	90
Poland	303	289	225	232	244	209
Portugal	75	75	75	72	59	52
Romania	127	125	102	102	102	93
Slovakia	38	38	26	26	29	23
Slovenia	17	15	15	16	15	14
Spain	327	326	326	265	260	238
Sweden	53	53	49	49	47	43
EU-27	2978	2886	2616	2549	2485	2309

As for SO_2, the following figure shows illustration of the tabulated Member State results highlighting additional mitigation effort required beyond the Baseline for NO_x. More detailed sector/measure allocation is provided in Appendix 3. Key additional reductions, although rather small in absolute terms compared to current levels, are achieved in industry and non-road machinery (see Appendix 3 for more details). Similarly to SO_2, the level of additional mitigation increases from the OPT15 case with only small additional reductions when moving from the OPT10 to OPT5 targets; as discussed earlier and in Appendix 3, the limited mitigation potential constrains the achievement of targets for large areas, especially in the OPT5 case.

Figure 59 - Emissions reductions of NO_X as calculated from GAINS under different policy scenarios in 2030, split by MS. Units: kilotons/yr

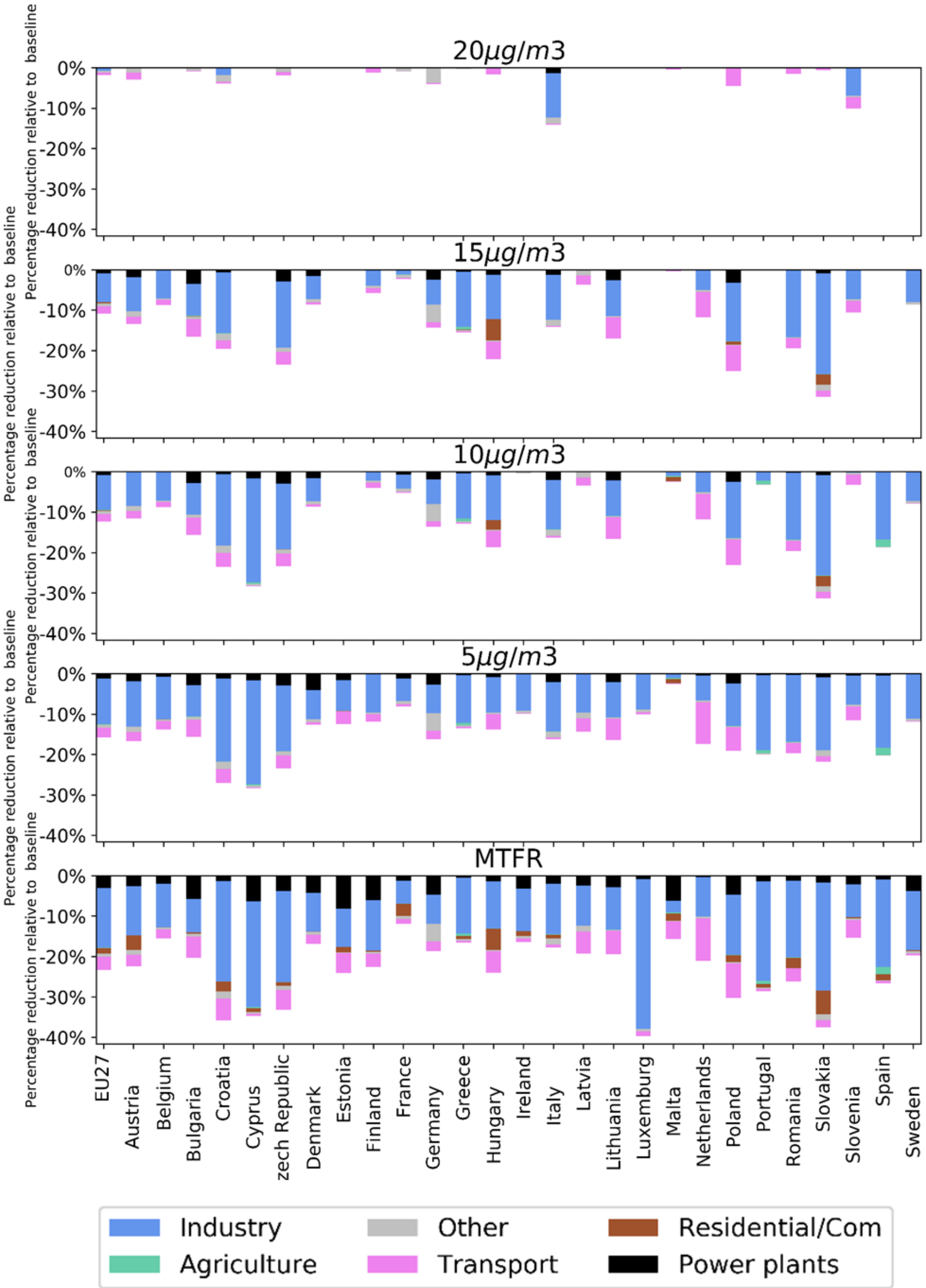


Table 31. Emissions of NH_3 as calculated from GAINS for different policy scenarios in 2030. Units: kilotons/yr

Member State	Baseline	Target 20ug/m³	Target 15ug/m³	Target 10ug/m³	Target 5ug/m³	MTFR
Austria	65	61	51	51	41	39
Belgium	69	69	69	61	51	51
Bulgaria	44	42	33	32	32	30
Croatia	37	37	23	19	21	19
Cyprus	8	8	8	6	6	6
Czech Rep.	94	90	68	68	68	66
Denmark	67	67	62	62	55	52
Estonia	12	12	12	12	9	9
Finland	31	31	31	31	23	22
France	577	576	559	463	431	411
Germany	550	533	398	417	339	331
Greece	56	54	43	44	44	43
Hungary	74	73	47	48	48	47
Ireland	124	124	124	123	115	97
Italy	336	254	253	249	251	244
Latvia	17	17	17	17	14	13
Lithuania	44	41	29	29	31	29
Luxembourg	6	6	6	6	4	4
Malta	1	1	1	1	1	1
Netherlands	123	122	120	119	117	117
Poland	287	281	166	166	172	165
Portugal	51	50	50	50	36	33
Romania	166	159	118	111	113	108
Slovakia	25	23	15	15	15	15
Slovenia	17	14	13	15	12	11
Spain	461	447	447	290	282	252
Sweden	50	50	50	50	38	36
EU-27	3392	3239	2811	2554	2369	2252

The following figure illustrates the additional mitigation effort required beyond the Baseline for NH_3 for the tabulated Member States . More detailed sector/measure allocation is provided in Appendix 3. Key additional reductions are achieved in agriculture (a key NH_3 source) to address mineral nitrogen application and improve storage and application of livestock manures on land (see Appendix 3 for more details). Since NH_3 still offers significant mitigation potential, there is a steady increase in mitigation effort beyond the baseline that is fairly equally distributed across Member States in the OPT10 and especially OPT5 case, which is approaching the maximum possible reductions achievable with technical measures (MTFR) although it is still not possible to attain the targets in a large number of grid-cells, especially under the OPT5 case (see Appendix 3 for more details about grid-cell based target setting).

Figure 60 - Emissions reductions of NH_3 as calculated from GAINS under different policy scenarios in 2030, split by MS. Units: kilotons/yr

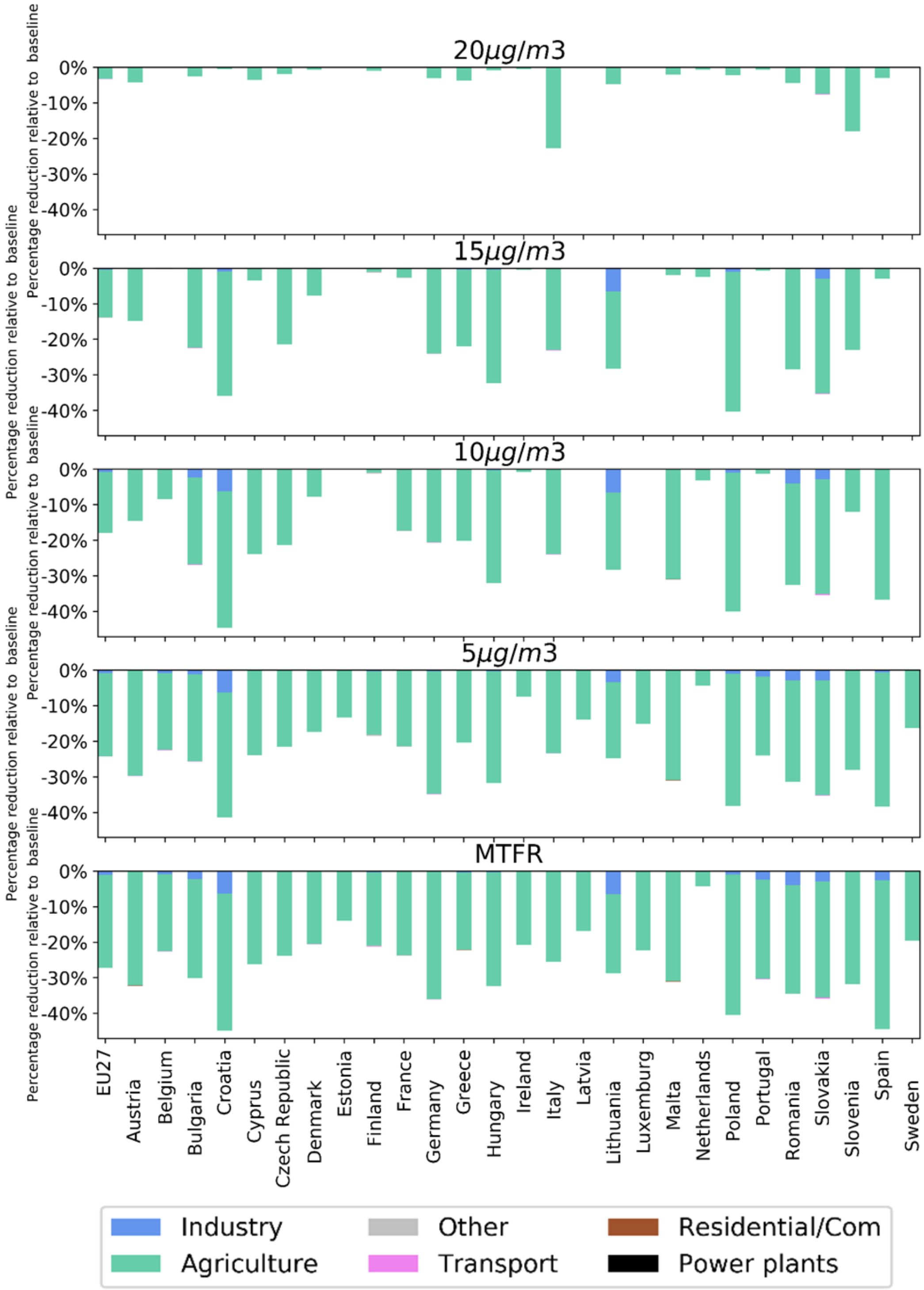


Table 32. Emissions of VOC as calculated from GAINS for different policy scenarios in 2030. Units: kilotons/yr

Member State	Baseline	Target 20ug/m^3	Target 15ug/m^3	Target 10ug/m^3	Target 5ug/m^3	MTFR
Austria	56	54	52	49	46	39
Belgium	75	74	74	72	67	60
Bulgaria	50	43	41	39	38	31
Croatia	37	32	28	18	18	17
Cyprus	6	5	5	5	5	4
Czech Rep.	117	111	104	94	92	75
Denmark	53	52	52	52	50	34
Estonia	12	11	11	11	11	8
Finland	44	42	41	41	39	31
France	496	489	486	439	448	382
Germany	687	661	604	568	564	445
Greece	96	95	75	72	72	65
Hungary	65	64	42	44	45	35
Ireland	49	47	47	47	47	33
Italy	613	529	518	467	474	456
Latvia	22	21	19	19	18	11
Lithuania	25	23	20	20	20	14
Luxembourg	7	7	7	7	7	5
Malta	2	2	2	2	2	2
Netherlands	139	138	137	137	129	108
Poland	362	336	317	303	303	257
Portugal	89	85	85	81	78	65
Romania	119	99	92	94	94	76
Slovakia	69	66	60	60	59	43
Slovenia	23	17	21	17	16	13
Spain	425	418	418	328	342	295
Sweden	84	82	82	82	76	68
EU-27	3822	3602	3440	3166	3161	2670

The following figure shows illustrates the additional mitigation effort required beyond the Baseline for NMVOC for the tabulated Member States More detailed sector/measure allocation is provided in Appendix 3. Key additional reductions are achieved in solvent use (included in 'Other' in the figure below) and the residential sector through accelerated implementation of cleaner biomass burning technologies for residential heating (see Appendix 3 for more details). Since NMVOC emissions are not a major $PM_{2.5}$ precursor, the additional mitigation is not as widespread as for other precursors. Owing to the fact that the cost-effective solutions, aiming to achieve the set policy targets, are always sought from the baseline case, there is a possibility that more ambitious reductions are calculated for a single country in less ambitious policy cases than for the next more ambitious target, e.g., see Slovenia. This is because of the transboundary pollution impact, typically, due to emission reductions in neighbouring, often large, countries that are needed to attain their own targets. However, more stringent policy targets (e.g., OPT10, OPT5) will require further measures to be implemented locally, resulting in increasing mitigation efforts as shown below for the case of Slovenia (see also Section 8.1.2 and Appendix 3 for detailed discussion of target setting).

Figure 61 - Emissions reductions of VOC as calculated from GAINS under different policy scenarios in 2030, split by MS. Units: kilotons/yr

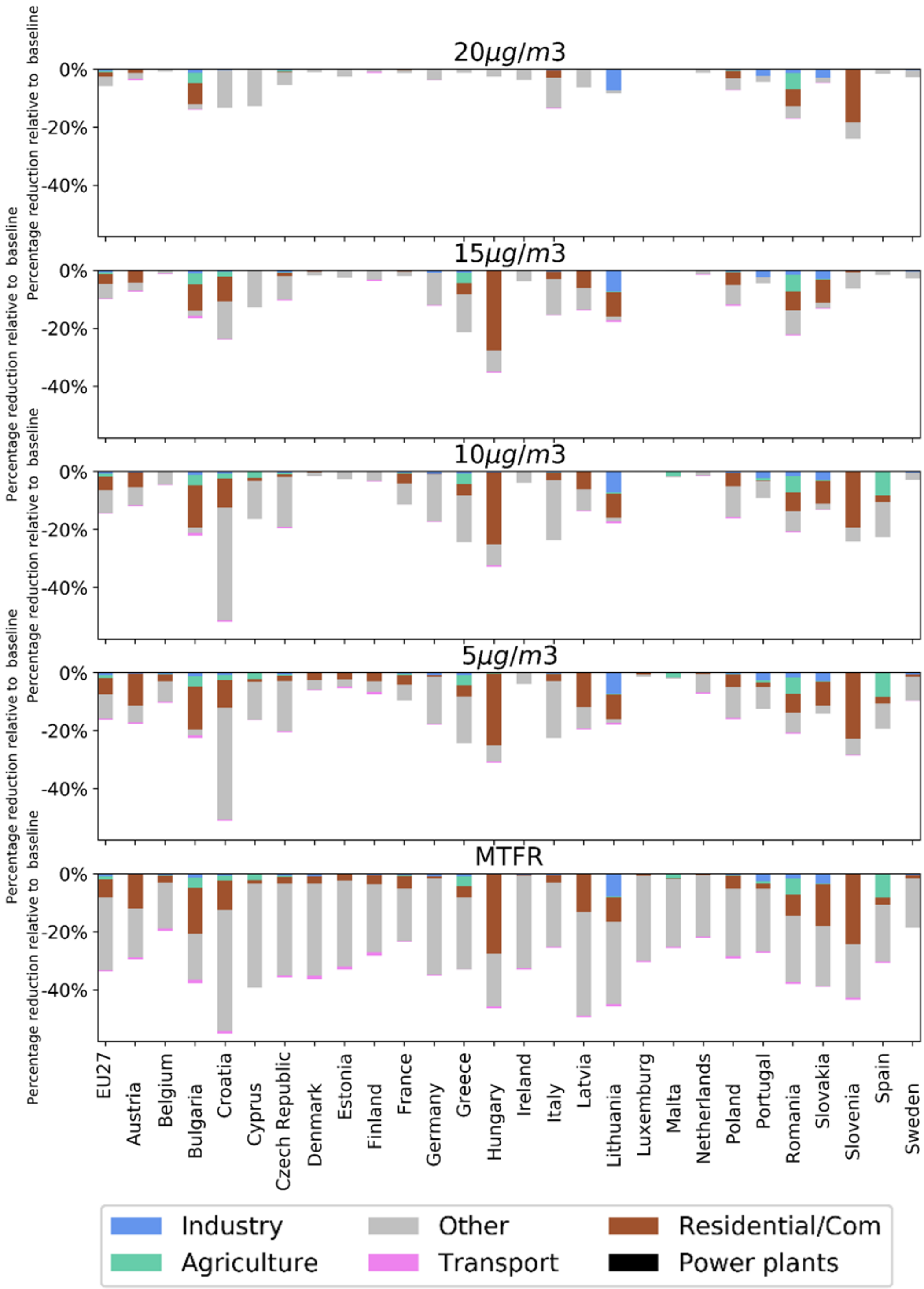


Table 33. Emissions of $PM_{2.5}$ as calculated from GAINS for different policy scenarios in 2030. Units: kilotons/yr

Member State	Baseline	Target 20ug/m^3	Target 15ug/m^3	Target 10ug/m^3	Target 5ug/m^3	MTFR
Austria	10	10	8	8	7	6
Belgium	13	13	13	12	10	10
Bulgaria	18	12	12	9	8	8
Croatia	10	10	6	4	5	4
Cyprus	1	1	1	1	1	0
Czech Rep.	16	15	14	14	13	12
Denmark	11	11	10	10	8	8
Estonia	2	2	2	2	2	1
Finland	12	11	11	11	10	9
France	99	97	92	72	72	69
Germany	69	68	64	64	60	58
Greece	22	22	15	15	15	15
Hungary	30	30	12	13	13	12
Ireland	6	6	6	6	6	5
Italy	73	58	56	56	56	55
Latvia	7	7	5	5	4	3
Lithuania	7	7	4	4	4	4
Luxembourg	1	1	1	1	1	1
Malta	0	0	0	0	0	0
Netherlands	14	13	13	13	12	12
Poland	75	70	51	51	52	49
Portugal	26	26	26	18	12	11
Romania	43	27	23	24	24	22
Slovakia	9	9	6	6	5	5
Slovenia	9	5	9	5	4	3
Spain	87	87	87	40	40	39
Sweden	15	14	14	14	13	13
EU-27	686	634	561	478	455	435

The following figure shows illustrates the additional mitigation effort required beyond the Baseline for $PM_{2.5}$ for the tabulated Member States More detailed sector/measure allocation is provided in Appendix 3. Key additional reductions are achieved in the residential sector through the accelerated implementation of cleaner biomass burning technologies as well as agriculture measures (the effective banning of open burning of agricultural residues) and, in some cases, industrial processes (see Appendix 3 for more details). For some Member States, the additional mitigation is estimated already for the OPT20 case, e.g., Italy, Romania, Bulgaria, Slovenia, owing to local pollution. The residential sector mitigation potential plays a key role and it also delivers most in terms of reducing PM exposure as is shown later in the report. As discussed for NMVOC, the impact of transboundary pollution can result in counterintuitive results when policy ambition increases and always starting from the baseline case; see Slovenia and the discussion in the NMVOC section, section 8.1.2, as well as in Appendix 3 about target setting.

Figure 62 – Emissions reductions of $PM_{2.5}$ as calculated from GAINS under different policy scenarios in 2030, split by MS. Units: kilotons/yr

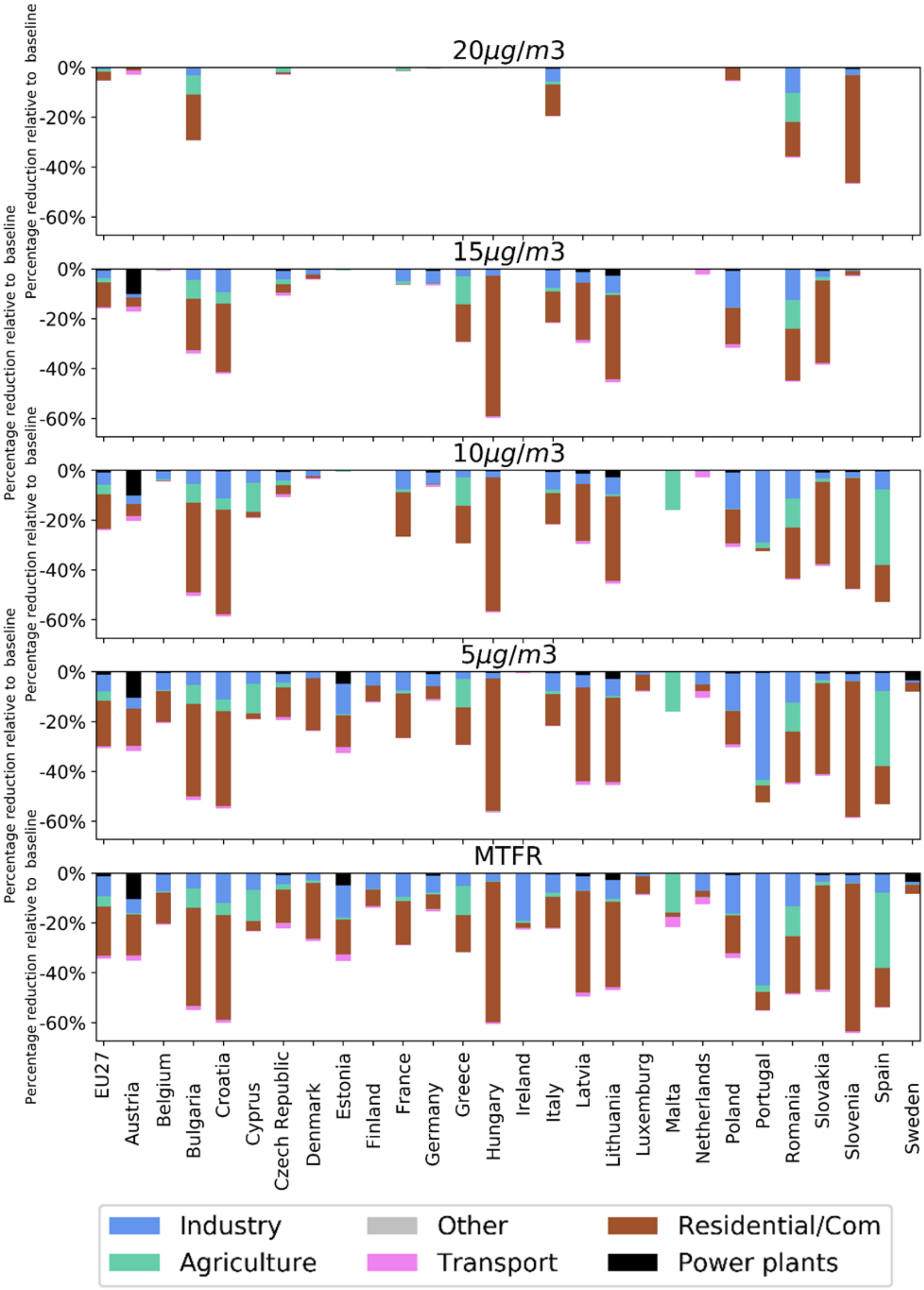


Table 34. Emissions of SO_2 as calculated from GAINS for different policy scenarios in 2050. Units: kilotons/yr

Member State	Baseline	Target 15ug/m^3	Target 10ug/m^3	Target 5ug/m^3	MTFR
Austria	7	7	6	6	6
Belgium	29	29	18	14	14
Bulgaria	22	22	5	5	5
Croatia	4	4	2	2	2
Cyprus	2	2	0	1	0
Czech Rep.	15	15	8	8	8
Denmark	5	5	5	4	4
Estonia	2	2	1	1	1
Finland	16	16	10	9	8
France	58	58	37	37	37
Germany	109	109	63	63	63
Greece	18	18	6	6	6
Hungary	7	7	6	6	6
Ireland	6	6	6	3	2
Italy	58	57	38	38	38
Latvia	2	2	2	2	2
Lithuania	5	5	3	3	3
Luxembourg	1	1	1	1	0
Malta	1	1	0	0	0
Netherlands	13	13	11	10	10
Poland	72	72	29	29	29
Portugal	14	14	7	7	7
Romania	28	21	9	9	9
Slovakia	11	11	5	5	5
Slovenia	1	1	1	1	1
Spain	67	67	30	30	30
Sweden	11	11	10	10	10
EU-27	584	576	322	311	309

Table 35 - Emissions of NOx as calculated from GAINS for different policy scenarios in 2050. Units: kilotons/yr

Member State	Baseline	Target 15ug/m^3	Target 10ug/m^3	Target 5ug/m^3	MTFR
Austria	70	67	58	58	55
Belgium	89	89	80	68	68
Bulgaria	33	32	27	27	27
Croatia	17	16	12	11	9
Cyprus	4	4	2	2	2
Czech Rep.	56	51	34	38	29
Denmark	35	35	29	29	28
Estonia	8	8	8	7	6
Finland	47	45	40	37	29
France	245	231	200	200	195
Germany	272	268	221	208	203
Greece	60	58	47	46	44
Hungary	40	40	30	31	30
Ireland	44	43	43	38	36
Italy	193	184	134	134	133
Latvia	12	12	11	10	9
Lithuania	16	16	11	12	11
Luxembourg	5	5	5	3	2
Malta	1	1	1	1	1
Netherlands	71	71	66	58	55
Poland	172	160	110	126	107
Portugal	47	47	42	33	26
Romania	75	71	49	51	47
Slovakia	28	28	16	19	15
Slovenia	7	6	6	4	4
Spain	191	183	118	125	110
Sweden	34	34	29	29	26
EU-27	1871	1805	1430	1407	1307

Table 36. Emissions of NH_3 as calculated from GAINS for different policy scenarios in 2050. Units: kilotons/yr

Member State	Baseline	Target 15ug/m^3	Target 10ug/m^3	Target 5ug/m^3	MTFR
Austria	65	62	50	42	39
Belgium	66	66	66	48	48
Bulgaria	43	42	32	31	29
Croatia	36	35	19	20	18
Cyprus	8	8	6	6	6
Czech Rep.	87	82	62	61	60
Denmark	64	63	58	50	49
Estonia	11	11	11	9	9
Finland	34	34	32	24	23
France	565	561	470	400	378
Germany	518	499	392	315	306
Greece	53	51	40	40	39
Hungary	70	69	44	44	44
Ireland	121	121	121	112	95
Italy	314	282	231	231	226
Latvia	17	17	17	13	13
Lithuania	42	39	27	29	27
Luxembourg	6	6	6	4	3
Malta	1	1	1	1	1
Netherlands	121	120	118	116	116
Poland	282	274	162	173	162
Portugal	47	47	46	33	30
Romania	154	145	100	103	97
Slovakia	25	22	15	15	15
Slovenia	16	15	13	11	10
Spain	448	433	267	264	235
Sweden	51	51	51	38	36
EU-27	3265	3156	2456	2234	2112

Table 37. Emissions of VOC as calculated from GAINS for different policy scenarios in 2050. Units: kilotons/yr

Member State	Baseline	Target 15ug/m^3	Target 10ug/m^3	Target 5ug/m^3	MTFR
Austria	42	41	38	38	32
Belgium	66	65	63	59	51
Bulgaria	34	31	29	28	22
Croatia	30	25	14	15	14
Cyprus	4	4	3	3	3
Czech Rep.	95	89	66	71	54
Denmark	45	44	43	41	26
Estonia	10	10	10	10	7
Finland	46	45	32	31	24
France	425	419	376	388	327
Germany	590	569	475	474	375
Greece	74	72	55	57	49
Hungary	42	40	36	36	29
Ireland	49	47	47	47	33
Italy	517	498	381	382	372
Latvia	17	16	15	15	8
Lithuania	16	16	15	15	8
Luxembourg	6	6	6	6	4
Malta	2	2	2	2	1
Netherlands	122	120	119	114	90
Poland	280	263	235	242	194
Portugal	76	74	69	68	56
Romania	92	75	71	71	55
Slovakia	50	49	47	46	29
Slovenia	16	14	14	13	10
Spain	390	382	281	304	257
Sweden	68	65	65	60	53
EU-27	3203	3079	2608	2635	2182

Table 38 Emissions of $PM_{2.5}$ as calculated from GAINS for different policy scenarios in 2050. Units: kilotons/yr

Member State	Baseline	Target 15ug/m^3	Target 10ug/m^3	Target 5ug/m^3	MTFR
Austria	10	10	7	6	6
Belgium	12	12	12	9	9
Bulgaria	11	9	7	5	5
Croatia	5	5	3	3	2
Cyprus	1	1	0	0	0
Czech Rep.	11	11	9	8	8
Denmark	8	8	8	6	6
Estonia	2	2	2	1	1
Finland	9	9	9	8	8
France	81	80	62	62	59
Germany	62	61	55	53	50
Greece	19	18	14	14	13
Hungary	12	12	9	9	9
Ireland	6	6	6	6	5
Italy	49	43	38	38	38
Latvia	4	4	3	3	2
Lithuania	4	4	3	2	2
Luxembourg	1	1	1	1	1
Malta	0	0	0	0	0
Netherlands	12	11	11	10	10
Poland	52	52	37	33	31
Portugal	23	23	14	11	10
Romania	31	20	16	16	14
Slovakia	6	6	4	4	4
Slovenia	3	3	3	2	2
Spain	73	72	29	29	28
Sweden	13	13	13	12	12
EU-27	521	495	376	352	335

8.1.2 *Impacts on air pollution concentration (Indicator #1)*

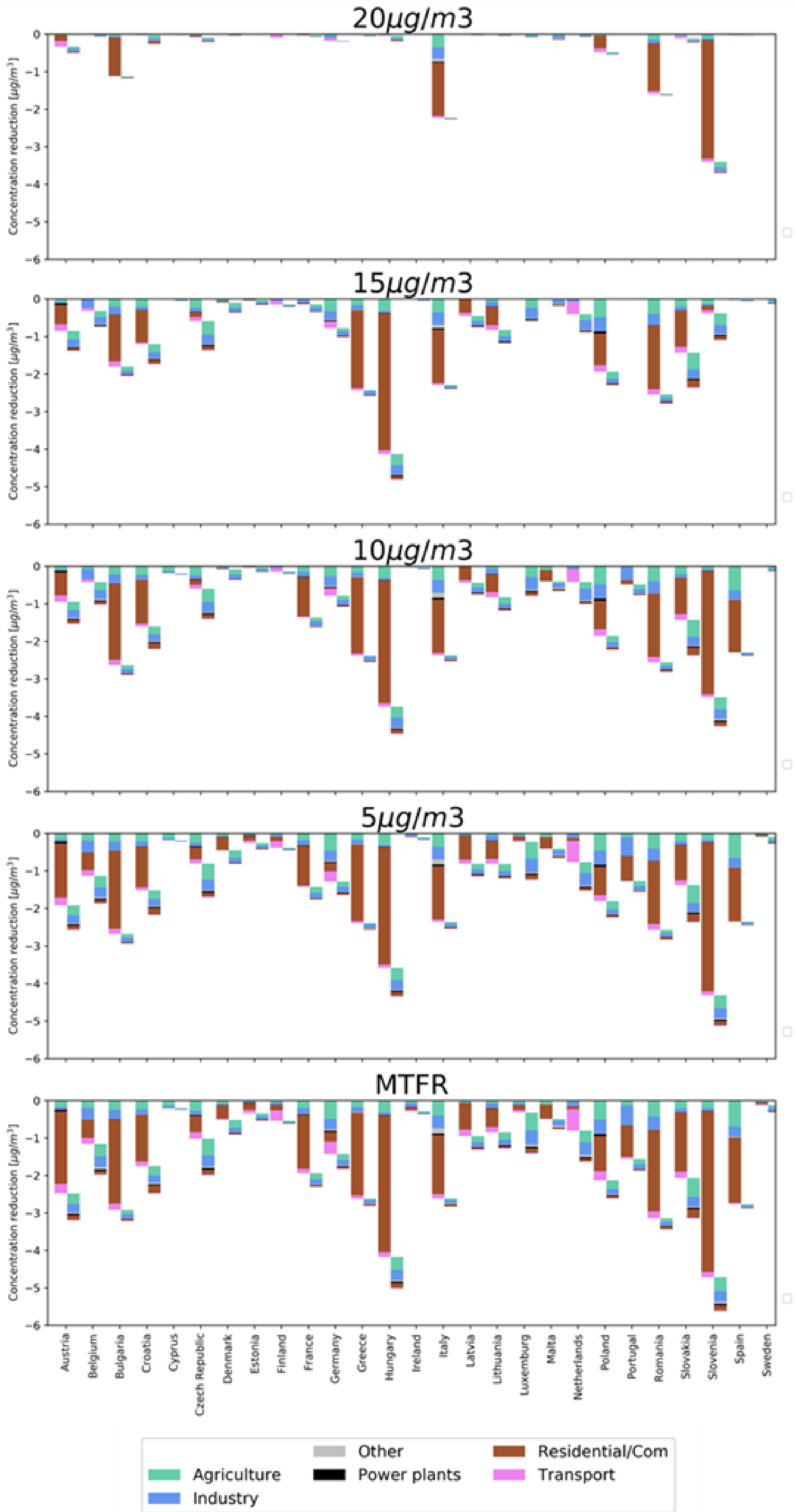
Reduction of population mean exposure in 2030

The Member State level impact of local and regional mitigation efforts (beyond the Baseline), in order to address the specified policy targets are illustrated below.

As previously shown, limited additional efforts are needed in the 20 µg/m^3 case, with the exception of a few countries, e.g., Italy, Bulgaria, Romania, Slovenia and primarily involving emission reductions from residential heating. The objective of achieving 15 µg/m^3 in 2030 requires many countries to employ additional measures. These are mostly in residential heating and agriculture (involving measures to reduce ammonia emissions as well as primary $PM_{2.5}$ from the open burning of residues, that remains a common practice in some countries). Moving towards 10 µg/m^{3}requires an increase in efforts, as has been shown before (Section 8.1.1). Considering the Baseline scenario and the technical mitigation potential defined in the GAINS model, there is not much additional mitigation possible when setting the ambition to a level of 5 µg/m^3, which is close to MTFR levels. Note the feasibility issues that remain within the scenarios/modelling framework – as discussed earlier in the report in Section 6. Overall, the largest benefits result from addressing residential combustion and agriculture.

The contribution of transboundary air pollution varies across countries (shown on the right-hand – extended bar for each Member State), but it is important for the less ambitious targets. It is evident that there are some 'trade-offs' between local and transboundary contributions to the reduction of concentrations – due to transboundary impacts, e.g. in Slovenia (see the discussion in Section 8.1.1).

Figure 63 - Reduction of population mean concentrations in 2030 (Member States own and transboundary contribution (right-extended bar)); GAINS model

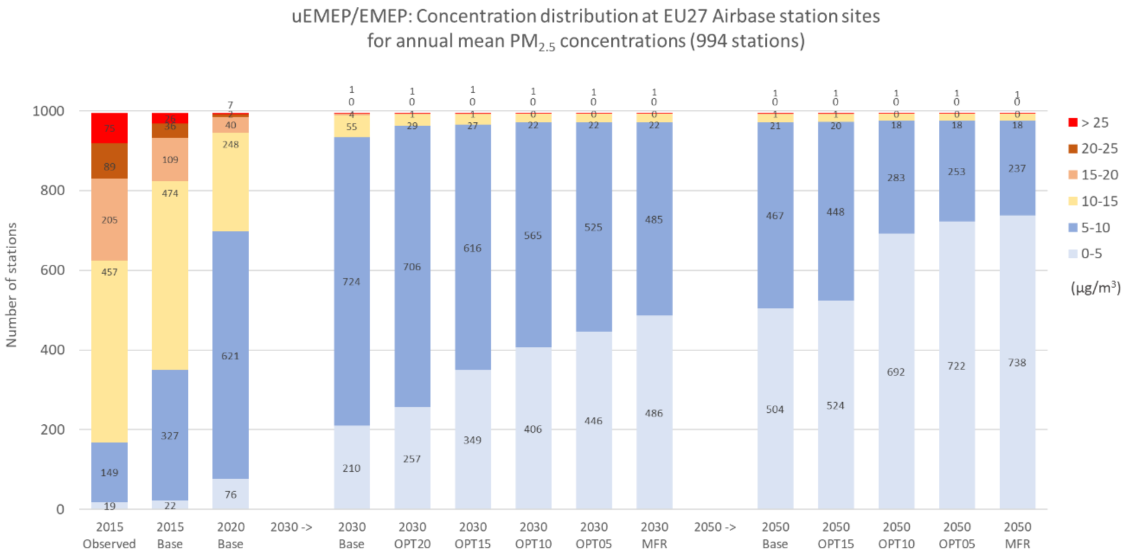


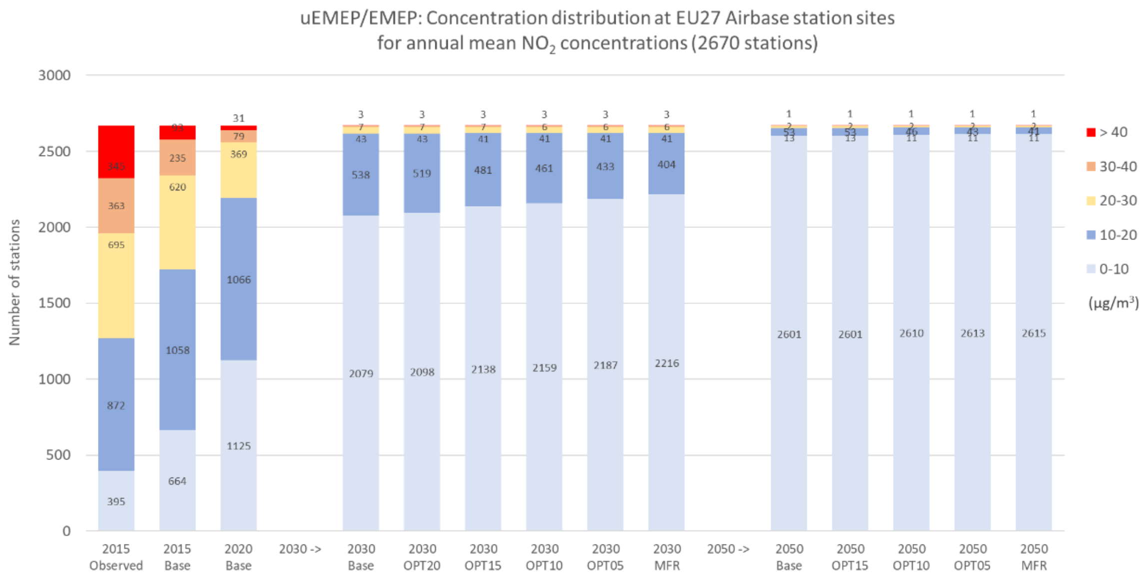
Station exceedances

The number of EU27 stations within selected annual mean concentration ranges are presented for $PM_{2.5}$ and NO_2. All Baseline, MTFR and optimised (OPT) scenarios are presented. Baseline and MTFR results have already been presented in Section 7.1.2. The following points can be made:

- For $PM_{2.5}$, the optimised scenarios show steady reductions in the region between Baseline and MTFR. Even so, the optimised scenarios for 5 µg/m^3 (OPT05) do not manage to achieve their goals with 270 out of 994 station sites still having concentrations > 5 µg/m^3.
- For NO_2, there is little difference as a result of optimisation. Indeed, there is little difference between the Baseline and MTFR scenarios for NO_2. Almost all the possible reductions in NO_X emissions have already been achieved in the baseline scenario.

Figure 64 Number of stations above selected annual mean concentrations in the EU27 for $PM_{2.5}$ and NO_2 (WITHOUT bias adjustment)

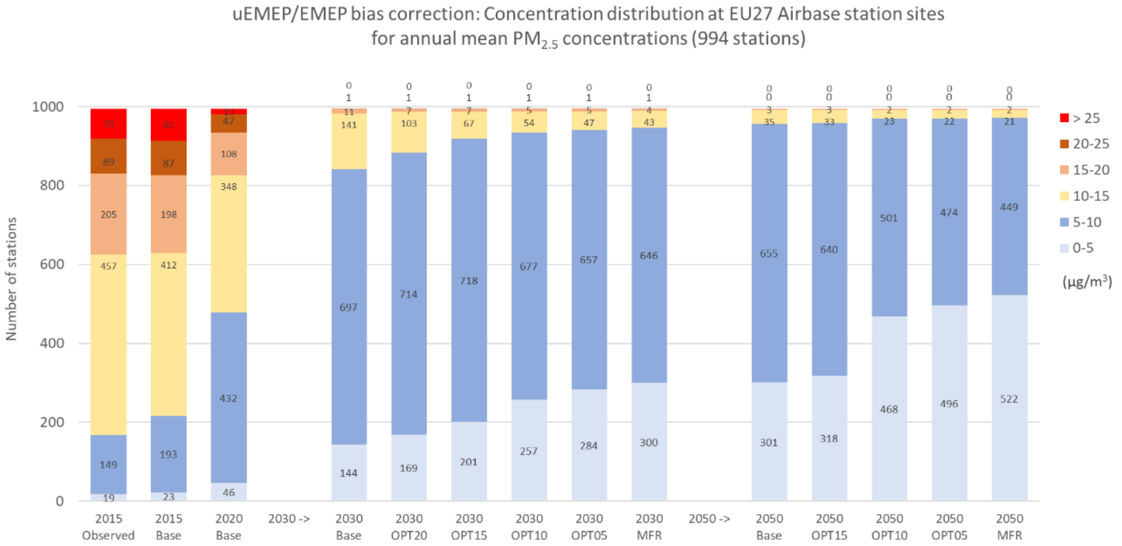


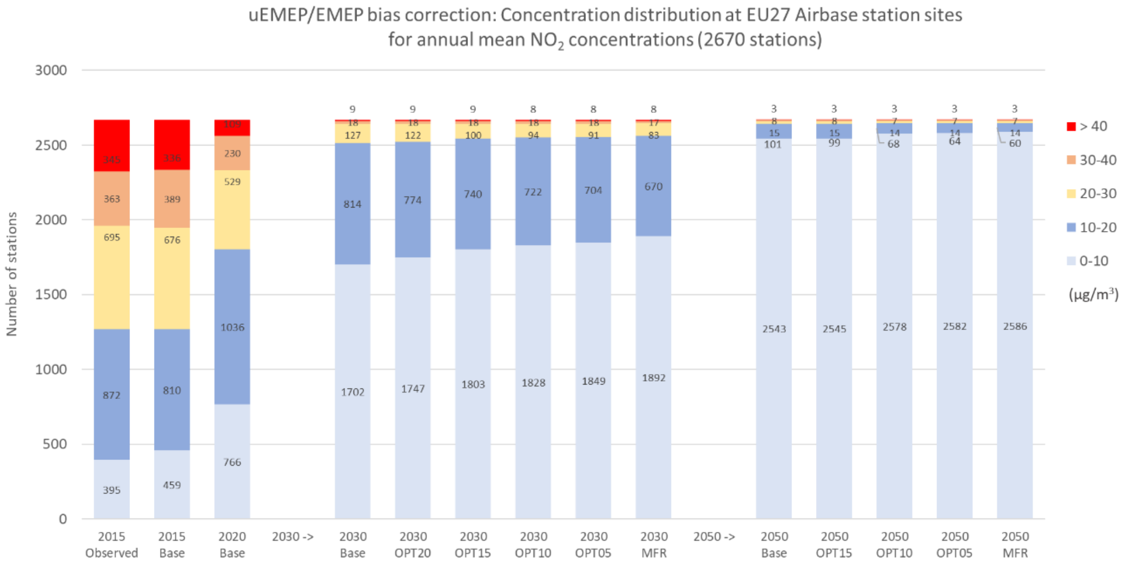


Sensitivity to bias adjustment

As noted in Section 7.1.2, there is generally a negative bias to the modelled pollutants. To correct for the impact of modelled bias on scenario outcomes a bias adjustment has been implemented. The methodology is described in Appendix 3 (Section 'Bias adjustment'). The figure below presents the 'bias corrected' results for the impacts of the scenarios on the concentrations at Airbase station sites for $PM_{2.5}$ and NO_2.

Figure 65 - Number of stations above selected annual mean concentrations in the EU27 for $PM_{2.5}$ and NO_2 (WITH bias adjustment)



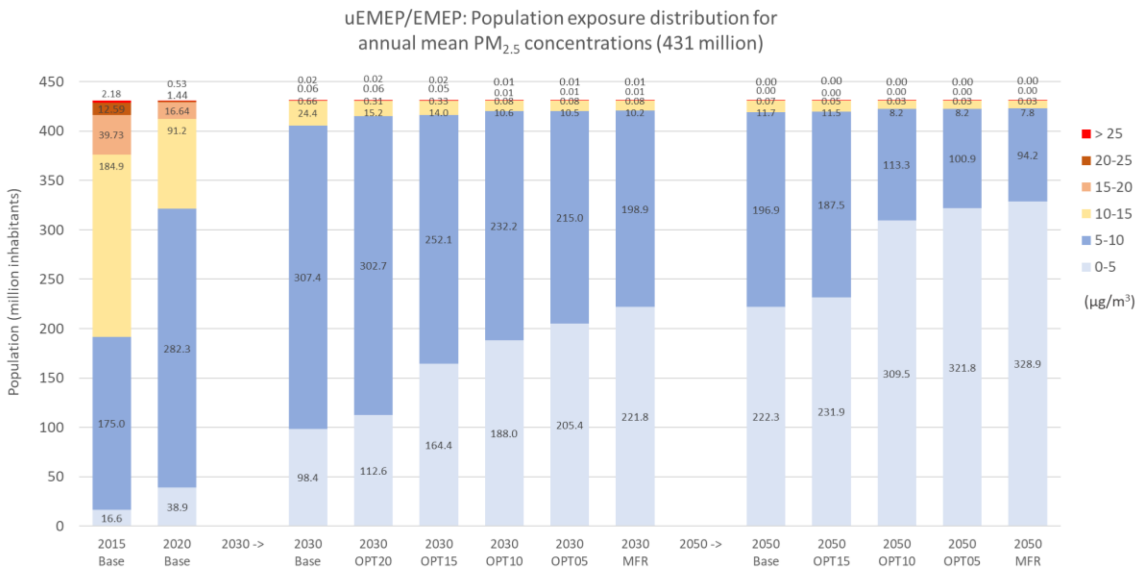


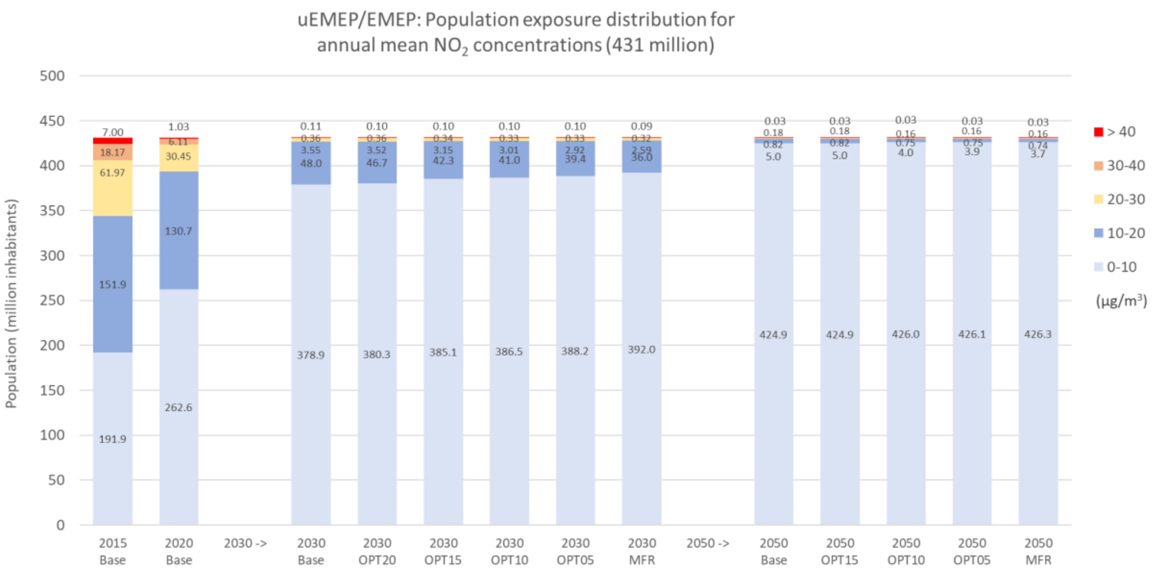
Population exceedance

The number of people exposed in the EU27 to above selected annual mean concentration ranges is presented for the pollutants $PM_{2.5}$ and NO_2. All Baseline, MTFR and optimised (OPT) scenarios are presented. Baseline and MTFR results have already been presented in Section 7.1.2. The following points can be made:

- The exposure calculations follow the same trends as seen for the station site calculations.
- As in the station calculations the optimised scenarios do not attain their goals, with the exception of the less ambitious optimisations of 20 and 15 µg/m^3 with < 80 thousand inhabitants exposed above 15 µg/m^3. This is well within the uncertainty of the calculations.
- By 2050 all scenarios come close to attaining the WHO recommended NO_2 concentration level of 10 µg/m^3 but there would still be 4 – 6 million inhabitants exposed above this level.

Figure 66 Number of people exposed above selected annual mean concentrations in the EU27 for $PM_{2.5}$ and NO_2 (WITHOUT bias adjustment)





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:

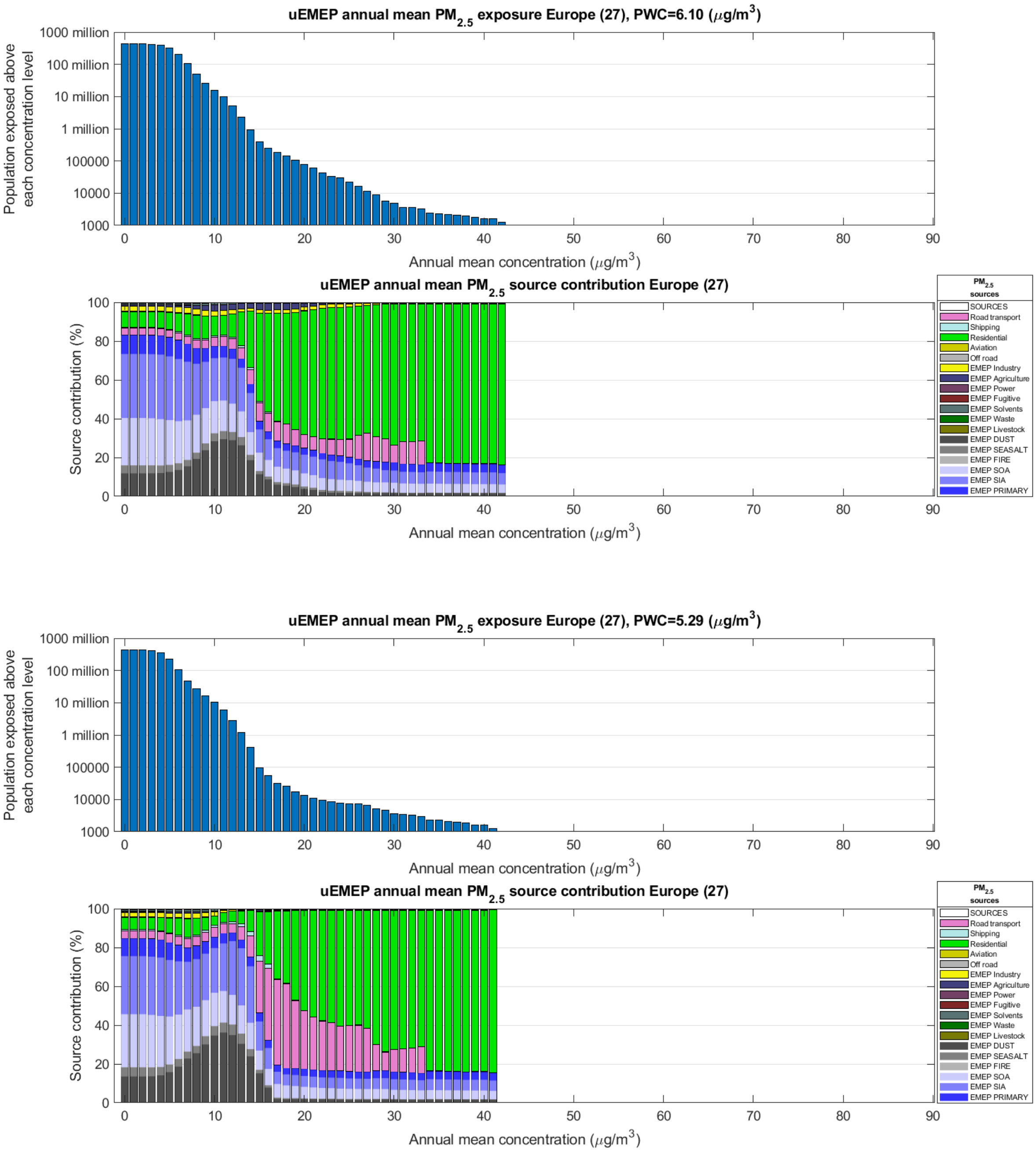
- Members State specific population weighted exposure to NO_2 and $PM_{2.5}$ changes by less than 0.2 ug/m^3, however effects locally can be more significant.
- Reduced concentrations at a small number of stations are observed with mostly moderate concentration levels.
- NO_2 and $PM_{2.5}$ exposure 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. Further detail is provided in Appendix 9.

Population exposure and source contributions

The optimised calculations show similar results to the baseline and MTFR scenarios but with a general reduction in concentrations from Baseline to MTFR. These have already been presented in Section 7. In Figure 67 we show the exposure distribution for the two optimised, OPT20 and OPT05, for the 2030 calculation of $PM_{2.5}$. These are quite similar, but the OPT05 calculation shows some further reduction in the residential sector, leading to a reduction in $PM_{2.5}$ exposure > 10 µg/m^3 from 15.6 to 10.6 million inhabitants.

Figure 67 Population exposure with source contribution for the EU27. OPT20 (top) and OPT05 (bottom) 2030 $PM_{2.5}$ (WITHOUT bias adjustment)



Heavy metals

As noted in Section 7, heavy metals were not directly captured by the integrated modelling.

Analysis of the latest monitoring data is presented in the table below. This shows, for each heavy metal, the number of monitoring sites above different thresholds, disaggregated by monitoring site type: background, industrial, and traffic. The thresholds refer to the proposed thresholds (Table 39) 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 39 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/m³			Lead µg/m³			Arsenic ng/m³			Cadmium ng/m³		
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 40 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*.

Targeted Stakeholder Survey Thresholds	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

This simple analysis shows that small reductions in standards across the pollutants will only bring a relatively low number of new exceedances, but larger changes would implicate a much larger number of sites in exceedances. Furthermore, the 'new' exceedances will not be limited to industrial monitoring stations, but also background. For Nickel, 2 stations are in exceedance for the current limit value, but when this is substantially reduced to 2.5 ng/m³ 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).

The analysis looked further into the potential sources of pollution at current exceedance sites. 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 metal producers, copper manufacturers, flat glass manufacturers, and non-ferrous crude metals producers, and are located between 0.5 km and 3.6 km from the monitoring sites exceeding EU standards. However, for some sites no point source could be identified. As such there is still large uncertainty in the underlying data linking measured concentrations to sources, making it challenging to assess what the implications of lower standards would be.

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 limit values for heavy metals, more evidence is required to bring more confidence. 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. A systematic investigation of the causes of these exceedances would become still more important. More comprehensive and systematic reported data from industrial sites and air monitoring sites would provide wider evidence to support the evaluation of potential future changes to the EU heavy metal standards.

8.1.3 *Health impacts (Indicator #2)*

Results for attributable mortality (Tier 1)

The impact of the various scenarios on the total number of yearly attributable deaths in the EU-27 for the three pollutants under consideration ($PM_{2.5}$, NO_2, O_3) is shown in the bar graphs in Figure 68 (total number of premature deaths) and Figure 69 (relative differences between the baseline and the scenarios).

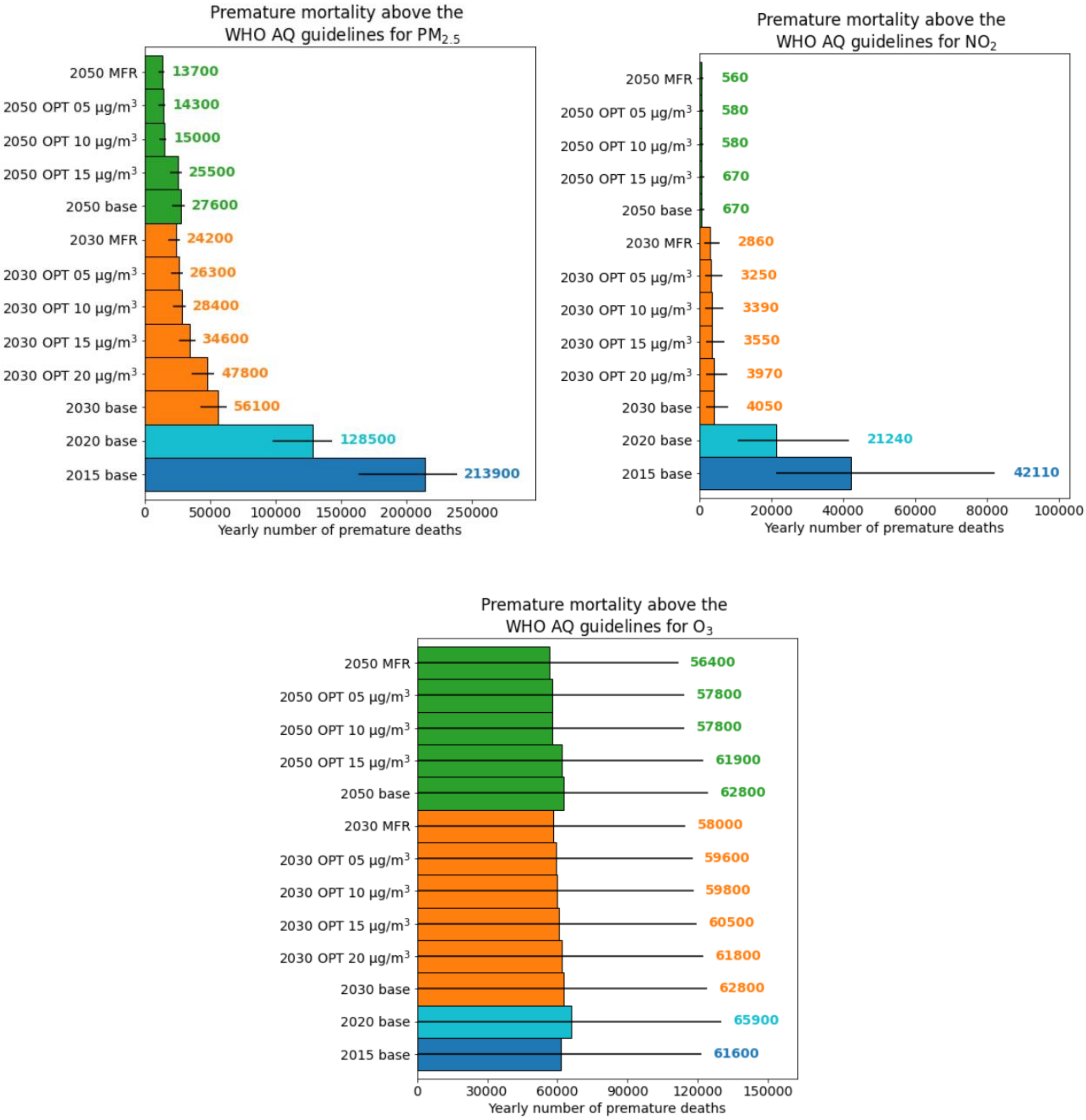
For particulate matter, the relative impact of the OPT scenarios depends on the nature of the scenario. If the baseline concentrations are already close to the target concentrations of the scenarios (as e.g. for the OPT20µg/m^3 scenario in 2030 and the OPT15µg/m^3 in 2050), the health impact of the scenarios is rather limited (respectively 15% and 8% for the OPT20µg/m^3 scenario in 2030 and the OPT15µg/m^3 in 2050). For all other scenarios, the health impact for the OPT scenarios is significant (at least 38% in 2030 and at least 46% in 2050), and in many cases the difference between the health impact of the OPT scenarios and the MTFR scenario is rather limited. For example, the difference in health impact between the OPT10µg/m^3 and the MTFR is only 8% in 2030 and only 4% in 2050.

For nitrogen dioxide, the impact (relative to the baseline) for the OPT scenarios depends on the year under consideration. For 2030, the OPT20µg/m^3 only has a limited impact (2%), while the impact gradually increases for the more stringent scenarios (12%, 16%, and 20% respectively for OPT15µg/m^3, OPT10µg/m^3 and OPT05µg/m^3). In 2050, the impact (relative to the baseline) of the OPT15µg/m^3 scenario is small (1%), while the impact for the other OPT-scenarios is very similar to the impact of the MTFR scenario (14% reduction for both the OPT10µg/m^3 and OPT05µg/m^3, compared to 16% for MTFR).

Finally, for ozone, the impact of the OPT scenarios is small, with only marginal reductions for the OPT20µg/m^3 and the OPT15µg/m^3 scenario.

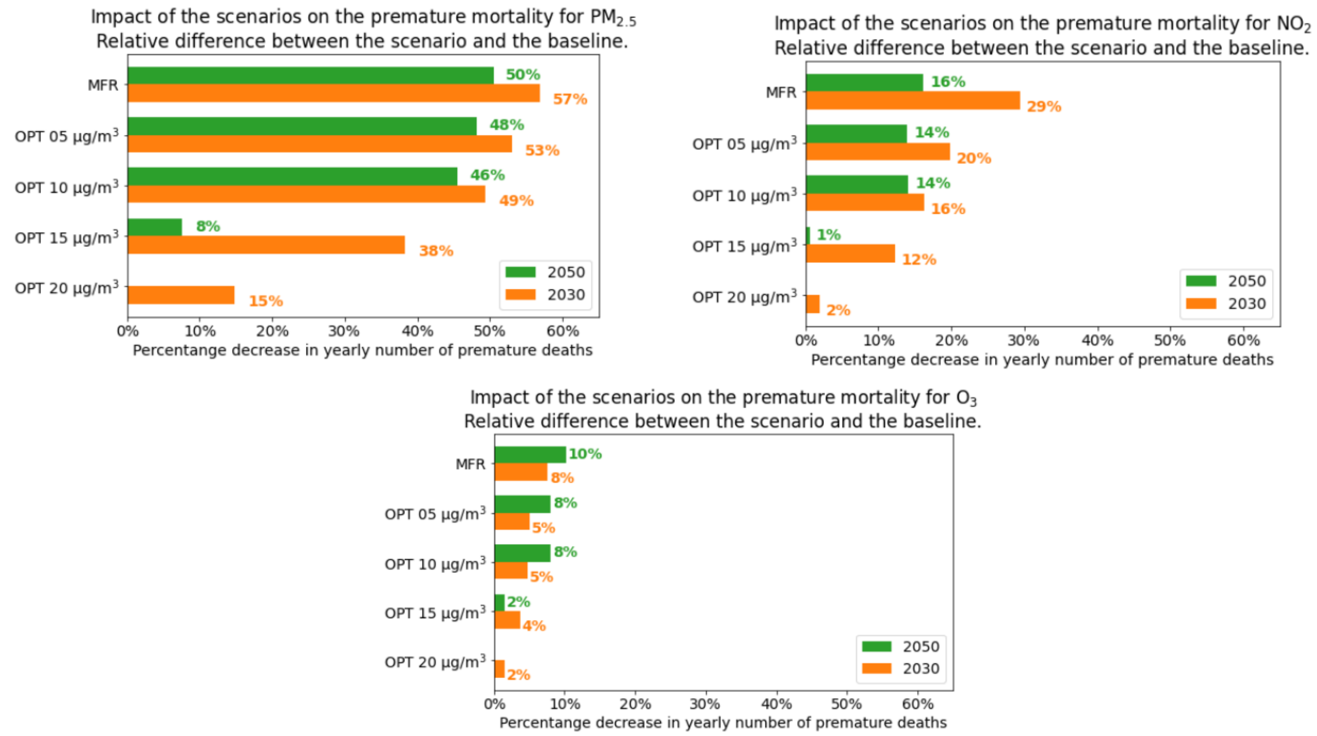
The bar graphs in Appendix 5 show the impact of the OPT scenarios on the number of yearly attributable deaths per capita for all countries in the EU-27. These charts indicate that the spatial pattern of the relative impact of the OPT-scenarios is similar to the spatial pattern of the relative impact of the MTFR scenario (although with smaller relative reductions). All remarks and conclusions concerning the spatial pattern of the impact of the MTFR scenario are thus valid for the OPT scenario.

Figure 68 : Number of yearly premature deaths in the EU-27 caused by the exposure to air pollution at levels above the WHO AQ guidelines for all scenarios for three pollutants ($PM_{2.5}$, top-left, NO_2, top-right, O_3, bottom).



Notes: Impacts for the four reporting years considered in the study (2015 in blue, 2020 in cyan, 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.

Figure 69 Relative 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-left, NO_2, top-right, O_3, bottom).

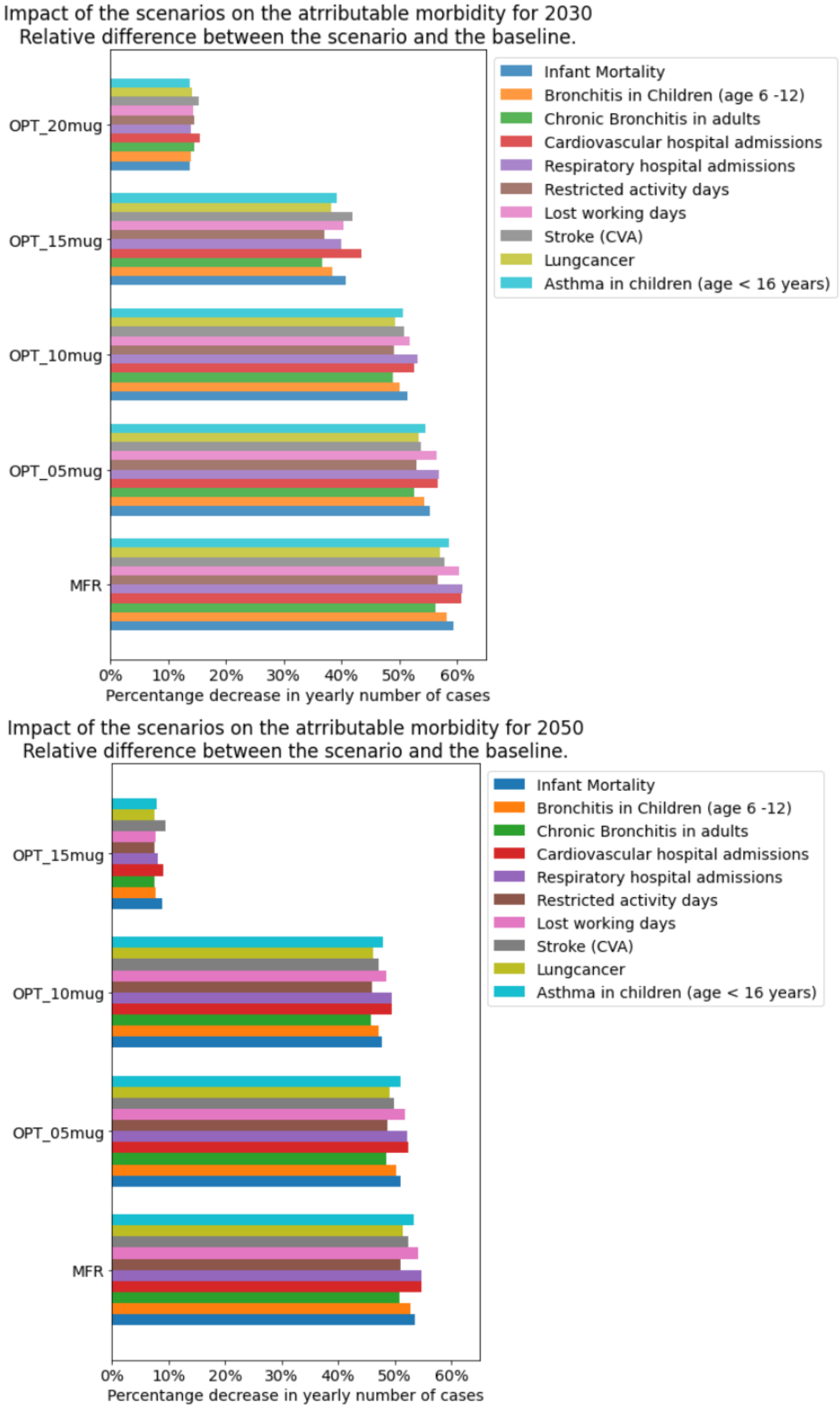


Notes: Impacts for the two future reporting years considered in the study (2030 in orange and 2050 in green) are included.

Results for attributable morbidity (Tier 2 and Tier 3)

Figure 70 provides an overview of the relative impact of the scenarios on the morbidity from the second (morbidity according to HRAPIE) and third Tiers (additional health outcomes beyond HRAPIE: stroke, lung cancer and asthma in children). For all health outcomes, the results correspond qualitatively and quantitively with those for the chronic mortality caused by $PM_{2.5}$ exposure. The relative impact of the OPT scenarios depends on the nature of the scenario. If the baseline concentrations are already close to the target concentrations of the scenarios, the health impact of the scenarios is rather limited, in line with the results for mortality (see Figure 69). For all other scenarios, the health impact for the OPT scenarios is significant, and in many cases the difference between the health impact of the OPT scenarios and the MTFR scenario is rather limited.

Figure 70 Relative impact of the scenarios on the morbidity in the EU-27 caused by the exposure to air pollution at levels above the WHO AQ guidelines for 2030 (top) and 2050 (bottom).



Notes: The various bars correspond to the various morbidity outcomes considered in the main analysis of the study (Tier 2 and Tier3).

Health impacts - summary results

The following conclusions regarding the health impacts of the scenarios can be drawn from this analysis:

- The measures taken under the MTFR scenario have a significant impact on the health impact caused by the exposure to particulate matter (reductions of more than 55% in 2030, and of approximately 50% in 2050). Despite these strong reductions, a significant health impact remains under the application of the MTFR scenario, with more than 20,000 yearly attributable deaths in 2030 and more than 10,000 yearly attributable deaths in 2050.

- The relative impact of the other scenarios depends on the nature of the scenario. If the baseline concentrations are already close to the target concentrations of the scenarios (e.g. OPT20µg/m^3 scenario in 2030 and the OPT15µg/m^3 in 2050), the health impact of the scenarios is rather limited. For all other scenarios, the difference in health impact for the OPT scenarios is similar to the health impact of the MTFR scenario.
- For particulate matter, a strong regional difference in the impacts of the MTFR scenario is observed, with smaller relative impacts observed in Southern Europe in comparison with other regions (due to the impact of natural contributions and the minor reductions in shipping emissions). For nitrogen dioxide, the highest reduction in attributable mortality is observed at the hotspots for which the emissions are reduced by the greatest margin.
- Results for morbidity show a similar pattern to the results for mortality.

8.1.4 *Ecosystem impacts (Indicator #3)*

Maps of ecosystem areas exceeding critical loads for acidification and eutrophication from deposition of nitrogen and sulphur are shown in Section 7 for the Baseline and MTFR scenarios. Table 41 to Table 44 differentiate the impacts of the different scenarios in terms of area shares of different types of ecosystems where critical loads for eutrophication and acidification are exceeded by Member State.

Table 41. - Percent of total ecosystem area exceeding critical loads for eutrophication from deposition of nitrogen for different policy scenarios in 2030.

Member State	Baseline	Target 20ug/m^3	Target 15ug/m^3	Target 10ug/m^3	Target 5ug/m^3	MTFR
Austria	34.8	31.6	20.4	20.6	11.6	9.2
Belgium	1	1	0.9	0.5	0.4	0.4
Bulgaria	93.6	92.1	85.2	83.8	83.9	80.5
Croatia	82.9	82.1	78.1	75.7	75.2	71.7
Cyprus	100	100	100	100	100	100
Czech Rep.	100	99.4	51.4	52.8	42.4	33.9
Denmark	99.7	99.6	99.2	99.2	98.7	98.3
Estonia	38.7	37	20.5	20.5	12.8	11.7
Finland	0.8	0.8	0.7	0.7	0.4	0.1
France	65.1	63.8	62	46.8	41.5	37.8
Germany	66.9	66	58.2	58.5	52.6	51.3
Greece	94.1	93.4	89.7	89.9	89.7	88.7
Hungary	89.3	87.6	70.3	70.3	70.1	69.9
Ireland	7.2	6.8	6.7	6.5	4.8	2.6
Italy	34.7	22.1	21.2	19.7	19.6	18
Latvia	87.1	85.6	70.7	70.7	62.4	58.3
Lithuania	98.1	97.6	94.2	94.2	94	92.8
Luxembourg	100	100	99.9	99.9	97.7	94.5
Malta	100	100	100	99.7	99.7	99.7
Netherlands	69.2	69	67.7	67.1	61.3	59.9
Poland	52.3	50.6	26.7	27	25.2	22.2
Portugal	99.1	99	99	96.1	84.9	79.8
Romania	93.8	93.3	84.5	82.9	83	80.6
Slovakia	90.2	89.4	78.9	77.7	77.4	74.5
Slovenia	81.2	72.7	65.6	67.3	63.8	62.6
Spain	97.5	97.4	97.3	92	90.6	88.2
Sweden	9.6	9.6	7	6.7	5.5	5.1
EU-27	69.2	67.3	61.3	58	55.2	52.9

Table 42- Percent of total ecosystem area exceeding critical loads for acidification from deposition of nitrogen and sulphur for the different policy scenarios in 2030.

Member State	Baseline	Target 20ug/m^3	Target 15ug/m^3	Target 10ug/m^3	Target 5ug/m^3	MTFR
Austria	0	0	0	0	0	0
Belgium	0.5	0.5	0.5	0.4	0.1	0.1
Bulgaria	0	0	0	0	0	0
Croatia	0.8	0.5	0.1	0.1	0	0
Cyprus	0	0	0	0	0	0
Czech Rep.	18.9	16.3	8.2	8.1	8	7.4
Denmark	0.8	0.7	0.3	0.3	0.3	0.3
Estonia	0	0	0	0	0	0
Finland	0.4	0.4	0.4	0.4	0.4	0.4
France	0.7	0.6	0.4	0.1	0.1	0
Germany	22	20.5	12.8	12.9	9.4	8.8
Greece	0.1	0.1	0.1	0.1	0.1	0.1
Hungary	2.1	2.1	0.4	0.4	0.3	0.3
Ireland	0.3	0.3	0.3	0.3	0.1	0
Italy	0	0	0	0	0	0
Latvia	1.1	0.9	0.1	0.1	0	0
Lithuania	22	21.6	8.4	8.4	8.6	7.6
Luxembourg	6.9	6.7	0.3	0.3	0	0
Malta	0	0	0	0	0	0
Netherlands	84.3	84.2	83.1	82.8	81.9	81.7
Poland	6.3	5.7	1.6	1.6	1.4	1.2
Portugal	0.4	0.4	0.4	0.4	0.3	0.3
Romania	0	0	0	0	0	0
Slovakia	0.8	0.5	0	0	0	0
Slovenia	0	0	0	0	0	0
Spain	0	0	0	0	0	0
Sweden	2.3	2.3	2.2	2.1	2.1	2.1
EU-27	3.1	3	1.9	1.8	1.6	1.5

Table 43. - Percent of total ecosystem area exceeding critical loads for eutrophication from deposition of nitrogen for different policy scenarios in 2050.

Country	Baseline	Target 15ug/m³	Target 10ug/m³	Target 5ug/m³	MTFR
Austria	31	27.4	13.6	7.1	5.9
Belgium	0.8	0.6	0.5	0.2	0.1
Bulgaria	90.5	89.7	77.8	76.6	74
Croatia	82.3	81.4	68.3	68.2	64.2
Cyprus	100	100	100	100	100
Czech Rep.	96.1	84.3	28.5	23	21.6
Denmark	98.9	98.7	97	93.3	92.4
Estonia	15.5	14.6	10.8	9.5	9.3
Finland	0.6	0.6	0.3	0.1	0
France	60.9	59.7	41.9	33.1	30.1
Germany	62.7	61.5	52.6	46.1	44.8
Greece	93.1	92.4	88.7	88.6	88.1
Hungary	80.1	77.9	67.8	67.7	66.3
Ireland	5.9	5.8	5.6	3.8	2.3
Italy	30.2	25.1	15.9	15.6	14.7
Latvia	71.7	69.8	56.2	50.8	48.9
Lithuania	96.9	96.4	89.6	89.6	86.3
Luxembourg	99.9	99.9	98	91.7	72.2
Malta	100	100	100	100	100
Netherlands	67.5	67.3	60.9	57.2	56.7
Poland	45.5	43.4	17.6	18.3	15.6
Portugal	98.3	98	92.5	82.3	77.9
Romania	92	90.3	74.4	75.5	71.2
Slovakia	88.2	86.3	68	67.8	64.4
Slovenia	77.6	72.2	62.4	60.1	57.7
Spain	97.1	96.8	89.3	88.5	85.5
Sweden	6.1	6	4.7	3.3	3.2
EU-27	65.5	64	52.8	50.2	47.9

Table 44. Percent of total ecosystem area exceeding critical loads for acidification from deposition of nitrogen and sulphur for the different policy scenarios in 2050

Country	Baseline	Target 15ug/m³	Target 10ug/m³	Target 5ug/m³	MTFR
Austria	0	0	0	0	0
Belgium	0.5	0.5	0.2	0	0
Bulgaria	0	0	0	0	0
Croatia	0.4	0.4	0	0	0
Cyprus	0	0	0	0	0
Czech Rep.	9.8	8.8	5.9	5.1	4.3
Denmark	0.5	0.3	0.3	0.3	0.2
Estonia	0	0	0	0	0
Finland	0.4	0.4	0.4	0.4	0.4
France	0.2	0.2	0.1	0	0
Germany	16.6	15.7	9	6.1	5.7
Greece	0.1	0.1	0.1	0.1	0.1
Hungary	1.7	1	0	0	0
Ireland	0.2	0.2	0.2	0	0
Italy	0	0	0	0	0
Latvia	0.6	0.5	0	0	0
Lithuania	19.2	16.2	6.6	6.6	6.5
Luxembourg	0.3	0.3	0.2	0	0
Malta	0	0	0	0	0
Netherlands	83.1	82.9	81.4	79.6	79.3
Poland	3.3	2.9	0.7	0.7	0.6
Portugal	0.4	0.4	0.4	0.4	0.3
Romania	0	0	0	0	0
Slovakia	0.1	0.1	0	0	0
Slovenia	0	0	0	0	0
Spain	0	0	0	0	0
Sweden	2.2	2.2	2	2	2
EU-27	2.4	2.3	1.5	1.2	1.2

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. Further detail is provided in Appendix 9.

Valuation of ecosystem impacts

The following table presents the monetised impacts of air pollution on ecosystems under the baseline and MTFR scenario. The size of the damage in the baseline and scenarios reduces over time alongside further emissions reductions delivered through current policy. The monetised benefits increase with the ambition under each scenario, as further reductions in air pollutant emissions are delivered. The scenarios and MTFR can deliver substantial ecosystem benefits, however the aggregate size of these benefits is still smaller than the human health benefits.

Table 45- Monetised material damage impacts per annum - baseline and MTFR - EURm 2015 prices

Total damage by scenario	2015	2020	2025	2030	2035	2040	2045	2050
Baseline	1,871	1,136	914	662	517	465	447	442
Target 20ug/m3	-	-	-	633	-	-	-	
Target 15ug/m3	-	-	-	481	-	-	-	430
Target 10ug/m3	-	-	-	466	-	-	-	286
Target 5ug/m3	-	-	-	458	-	-	-	281
MTFR	-	-	-	436	-	-	-	269
Benefit by scenario relative to Baseline								
Target 20ug/m3	-	-	-	*29*	-	-	-	-
Target 15ug/m3	-	-	-	*181*	-	-	-	*12*
Target 10ug/m3	-	-	-	*196*	-	-	-	*156*
Target 5ug/m3	-	-	-	*204*	-	-	-	*160*
MTFR	-	-	-	*226*	-	-	-	*172*

Table 46 - Monetised crop damage impacts per annum - baseline and MTFR - EURm 2015 prices

Total damage by scenario	2015	2020	2025	2030	2035	2040	2045	2050
Baseline	11,758	10,691	10,320	9,877	9,629	9,518	9,450	9,459
Target 20ug/m3	-	-	-	9,809	-	-	-	
Target 15ug/m3	-	-	-	9,689	-	-	-	9,415
Target 10ug/m3	-	-	-	9,623	-	-	-	9,200
Target 5ug/m3	-	-	-	9,600	-	-	-	9,201
MTFR	-	-	-	9,472	-	-	-	9,110
Benefit by scenario relative to Baseline								
Target 20ug/m3	-	-	-	*67*	-	-	-	-
Target 15ug/m3	-	-	-	*188*	-	-	-	*44*
Target 10ug/m3	-	-	-	*254*	-	-	-	*259*
Target 5ug/m3	-	-	-	*276*	-	-	-	*258*
MTFR	-	-	-	*404*	-	-	-	*348*

Table 47- Monetised forest damage impacts per annum - baseline and MTFR - EURm 2015 prices - LOW[52]

Total damage by scenario	2015	2020	2025	2030	2035	2040	2045	2050
Baseline	20,326	19,050	18,551	17,975	17,648	17,478	17,371	17,374
Target 20ug/m3	-	-	-	17,906	-	-	-	
Target 15ug/m3	-	-	-	17,752	-	-	-	17,321
Target 10ug/m3	-	-	-	17,688	-	-	-	17,082
Target 5ug/m3	-	-	-	17,659	-	-	-	17,080
MTFR	-	-	-	17,486	-	-	-	16,954
Benefit by scenario relative to Baseline								
Target 20ug/m3	-	-	-	69	-	-	-	
Target 15ug/m3	-	-	-	222	-	-	-	52
Target 10ug/m3	-	-	-	287	-	-	-	292
Target 5ug/m3	-	-	-	316	-	-	-	293
MTFR	-	-	-	488	-	-	-	420

Table 48- Monetised forest damage impacts per annum - baseline and MTFR - EURm 2015 prices - HIGH

Total damage by scenario	2015	2020	2025	2030	2035	2040	2045	2050
Baseline	20,326	19,050	18,551	17,975	42,882	42,470	42,211	42,217
Target 20ug/m3	-	-	-	17,906	-	-	-	-
Target 15ug/m3	-	-	-	17,752	-	-	-	42,090
Target 10ug/m3	-	-	-	17,688	-	-	-	41,505
Target 5ug/m3	-	-	-	17,659	-	-	-	41,501
MTFR	-	-	-	17,486	-	-	-	41,194
Benefit by scenario relative to Baseline								
Target 20ug/m3	-	-	-	*69*	-	-	-	-
Target 15ug/m3	-	-	-	*222*	-	-	-	*127*
Target 10ug/m3	-	-	-	*287*	-	-	-	*712*
Target 5ug/m3	-	-	-	*316*	-	-	-	*716*
MTFR	-	-	-	*488*	-	-	-	*1,023*

[52] Note that there is no difference between HIGH and LOW estimate for forest damage in 2030 as only after 2030 different assumptions are used to monetise the reduced carbon sequestration potential due to forest damage.

Table 49 - Monetised ecosystem damage impacts per annum - baseline and MTFR - EURm 2015 prices - LOW

Total damage by scenario	2015	2020	2025	2030	2035	2040	2045	2050
Baseline	4,215	3,901	3,769	3,588	3,485	3,422	3,386	3,375
Target 20ug/m3				3,488				
Target 15ug/m3				3,140				3,291
Target 10ug/m3				2,883				2,585
Target 5ug/m3				2,726				2,443
MTFR				2,588				2,328
Benefit by scenario relative to Baseline								
Target 20ug/m3				*101*				
Target 15ug/m3				*448*				*83*
Target 10ug/m3				*706*				*790*
Target 5ug/m3				*863*				*931*
MTFR				*1,000*				*1,047*

Table 50- Monetised ecosystem damage impacts per annum - baseline and MTFR - EURm 2015 prices - HIGH

Total damage by scenario	2015	2020	2025	2030	2035	2040	2045	2050
Baseline	12,644	11,702	11,308	10,765	10,455	10,267	10,157	10,124
Target 20ug/m3				10,463				
Target 15ug/m3				9,420				9,874
Target 10ug/m3				8,648				7,754
Target 5ug/m3				8,177				7,330
MTFR				7,765				6,984
Benefit by scenario relative to Baseline								
Target 20ug/m3				*302*				
Target 15ug/m3				*1,345*				*250*
Target 10ug/m3				*2,117*				*2,370*
Target 5ug/m3				*2,588*				*2,794*
MTFR				*3,000*				*3,140*

8.1.5 *Links with climate change (Indicator #4)*

As discussed earlier in Section 7.1.3, the *Fit for 55* strategy brings in reductions in the use of fossil fuels and efficiency improvements that result in lower emissions of CO_2 and short-lived climate forcers (SLCFs). For Black Carbon, this impact is shown in the evolution of the baseline emissions while the additional reduction associated with the technical mitigation measures necessary to achieve the increasing ambition of $PM_{2.5}$ concentrations is shown for the respective policy scenarios as well as MTFR (see Figure 71; blue bars for policy scenarios).

Figure 71- Emissions of black carbon (BC) in the baseline and MTFR scenarios (red bars) and additional mitigation of BC achieved in the cost-optimal policy scenarios targeting $PM_{2.5}$ concentration targets; GAINS model

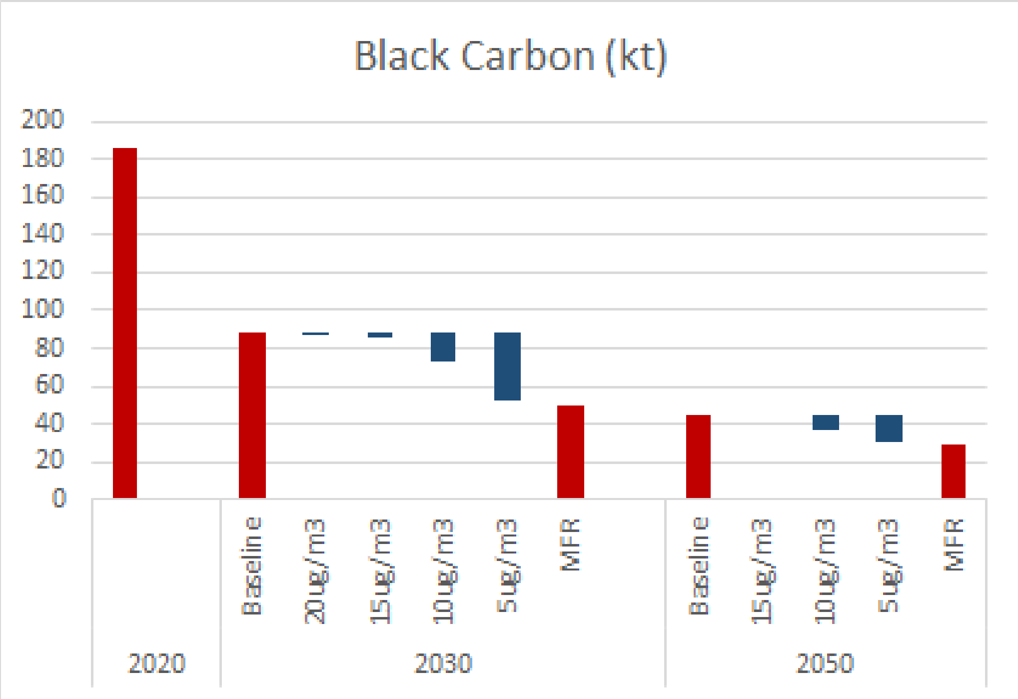
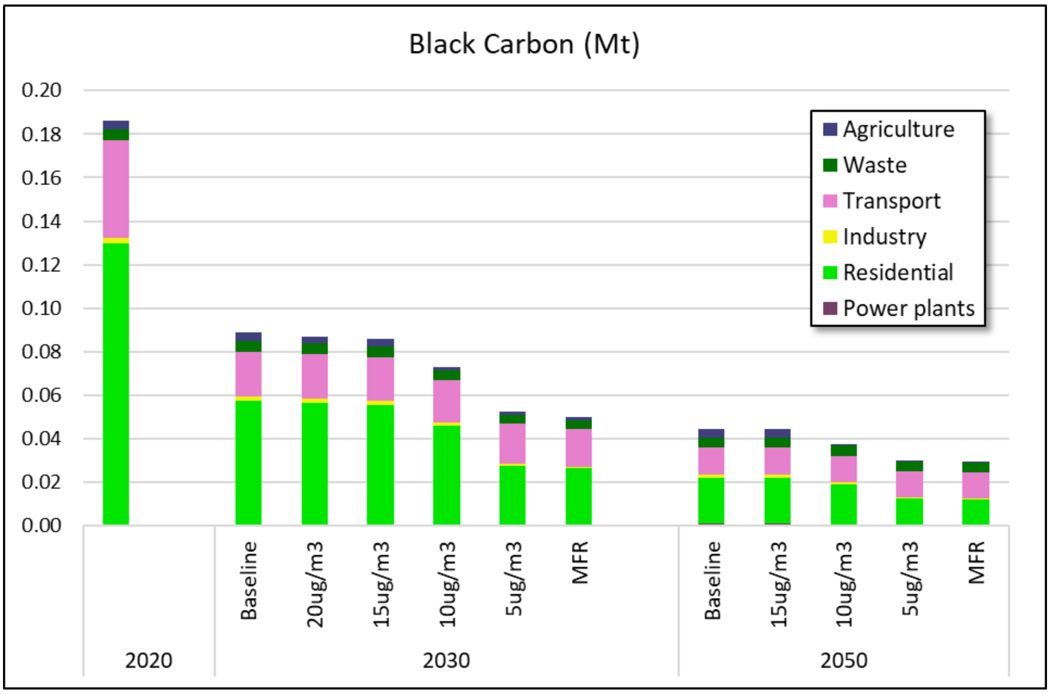


Figure 72 - Emission of BC for the baseline, policy, and MTFR scenarios by sector for the EU27; GAINS model



Achieving $PM_{2.5}$ policy targets of 20 and 15 ug/m^3 in 2030 and 2050 is not associated with significant additional measures, compared to the baseline (also compare Section 8.1.1), and therefore no sizable reductions of BC are visible. The more ambitious targets of 10 ug/m^3 and especially 5 ug/m^3 necessitate mitigation of primary sources of $PM_{2.5}$ and therefore results in co-beneficial BC reduction. Most of the reduction is achieved as a result of changes in the residential heating sector, i.e. introducing cleaner burning technologies, and effective enforcement of a ban on the field burning of agricultural residues (Figure 72).

8.1.6 *Synergies with other EU policies (Indicator #11)*

Synergies with the Zero Pollution Action Plan

The Commission adopted the EU Action Plan “Pathway to a Healthy Planet for All: EU Action Plan: ‘Towards Zero Pollution for Air, Water and Soil’” on 12th May 2021 as a part of the European Green Deal. To deliver the objectives of the EU Zero Pollution Action Plan, a set of key action areas has been identified, with the AAQ Directives playing an important role alongside relevant source policies in reducing air pollution. To evaluate synergies with the Action Plan, several of its goals are mapped to corresponding indicators in this impact assessment:

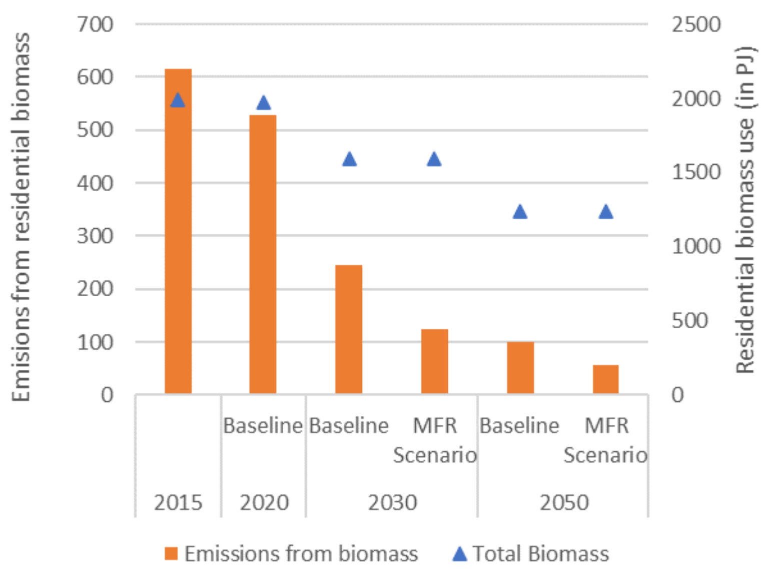
- Premature death reduction goal (Indicator 2)
- Ecosystem impact goal (Indicator 3)
- Noise pollution (Indicator 11)
- Indoor air pollution (Indicator 11).

Indoor air pollution

Indoor air quality is highly affected by both indoor and outdoor sources of pollution (European Court of Auditors, 2018). Key assumptions for synergy analysis are that a) outdoor air can enter and affect the indoor environment and b) indoor air pollution from incomplete fuel combustion poses an important direct health risk in households (WHO, 2014).

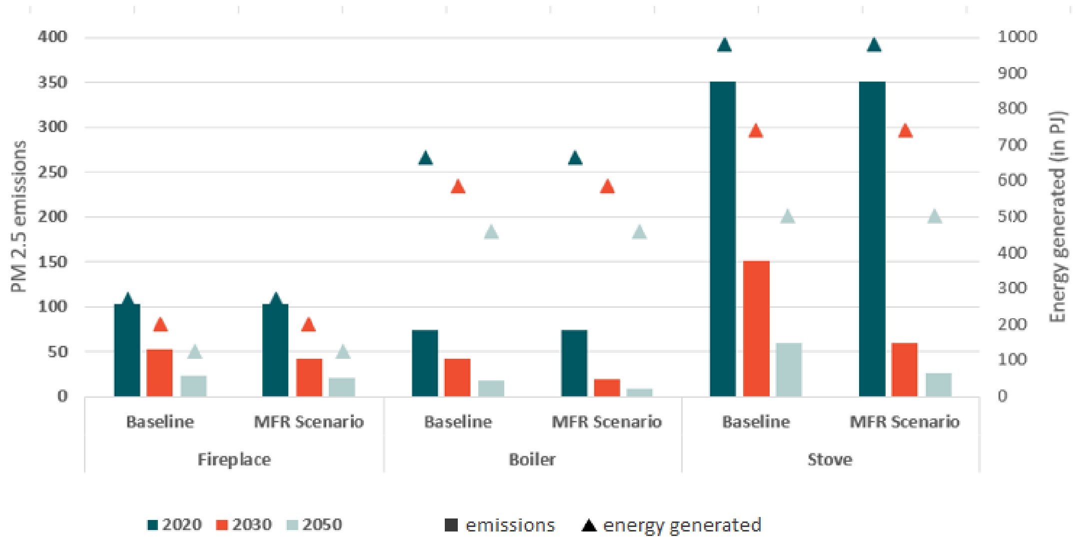
In 2020, emissions from biomass combustion for residential heating represented nearly 50% of total anthropogenic emissions of $PM_{2.5}$ in the EU27 (GAINS model). 83% of $PM_{2.5}$ emissions from domestic use came from biomass in 2020. This poses challenges for both AAQ Directives and ZPAP and the NEC Directive. Total residential biomass use is expected to decrease by 19% by 2030, compared to 2020, and then to decline by a further 22% between 2030 and 2050. However, the residential sector will continue to partly rely on the use of biomass to meet its energy needs.

Figure 73- Residential Biomass Activity and Emissions GAINS model



Residential boilers, stoves and fireplaces are the key technologies used for biomass combustion. They therefore represent key activity sources for ambient air pollution and indoor air pollution. Emissions from small-scale residential biomass combustion are a major source of indoor and outdoor particulate matter (PM) air pollution. As a result of the decline in residential biomass use in these three key technologies, $PM_{2.5}$ emissions significantly decline. The performance of stoves, boilers, and fireplaces has also been shown to be influenced by fuel properties, technology, and user behaviour (firing procedures).

Figure 74- Residential Biomass Activity and Emissions from stoves and fireplaces ($PM_{2.5}$ emissions and energy use in petajoules (PJ)); GAINS model[53]



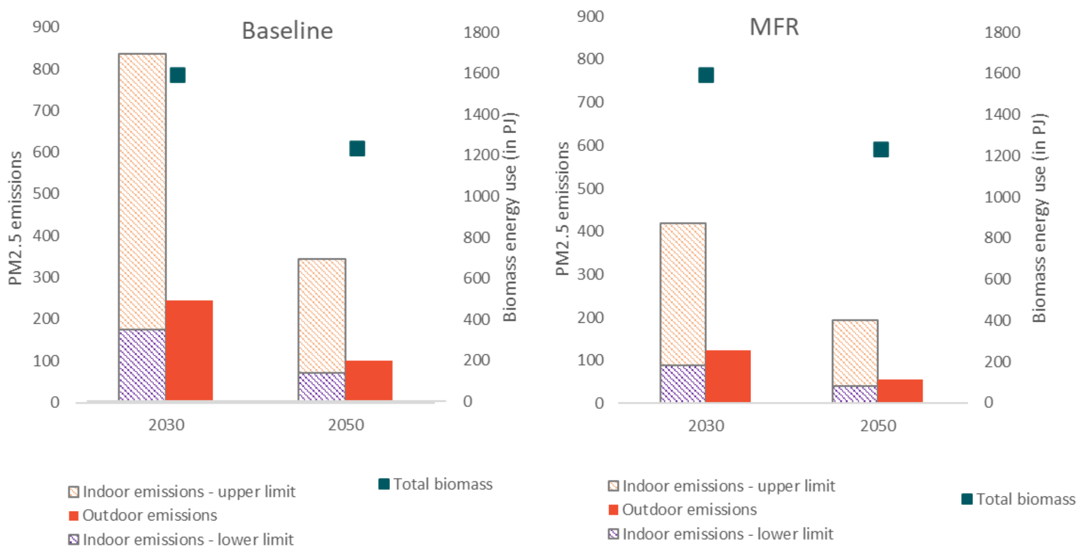
In the baseline, $PM_{2.5}$ emissions linked to residential biomass combustion in fireplaces, stoves and boilers compared to 2020 are expected to decline by 54% by 2030 and then by an additional 59% between 2030 and 2050. In the MTFR Scenario, $PM_{2.5}$ emissions will fall by more than 75% by 2030 compared to 2020. By 2050, $PM_{2.5}$ emissions will be reduced by a further 54% compared to 2030, which corresponds to $PM_{2.5}$ emissions of only 11% of 2020 levels (**Error! Reference source not found.**Figure 74 above). In addition to reducing the residential use of biomass, the main driver of this significant reduction in $PM_{2.5}$ pollution is improved technology[54]. While in 2020, open fireplaces are estimated to represent 53% of all fireplaces, their share is expected to be reduced to 19% by 2030 in the baseline scenario. In the MTFR Scenario, such fireplaces are expected to account for only 2% of all fireplaces in 2030. Newly built 'closed' fireplaces will be dominant, reducing emissions further.

Reduction of outdoor air pollution will also reduce indoor pollution. Improved performance of fireplaces, stoves or boilers will result in lower indoor-outdoor (I/O) ratios. Currently available literature on I/O ratios only focuses on different sources of pollution from biomass combustion, e.g. in fireplaces, boilers or stoves under different circumstances (e.g. ventilation, season). The literature does not provide comparisons of different technologies. As a result, we consider the range of I/O ratios between 0.7 and 3.4 for $PM_{2.5}$ emissions regardless of the type or technology of residential heating

[53] Note - 2020 data is all from baseline, it has only been used for comparative purposes in MTFR.
[54] PRIMES energy projection, compatible with the Fit for 55 goals provides development of total biomass use in residential sector but the split of installations (stoves, pellets, etc) are estimated independently in GAINS.

(Chen & Zhao, 2011) (Figure 75). We see clear synergies between the objectives of ambient air pollution and indoor air pollution reduction from residential biomass combustion.

Figure 75 - Indoor - Outdoor Air quality relationship - Baseline (left) and MTFR Scenario (right)

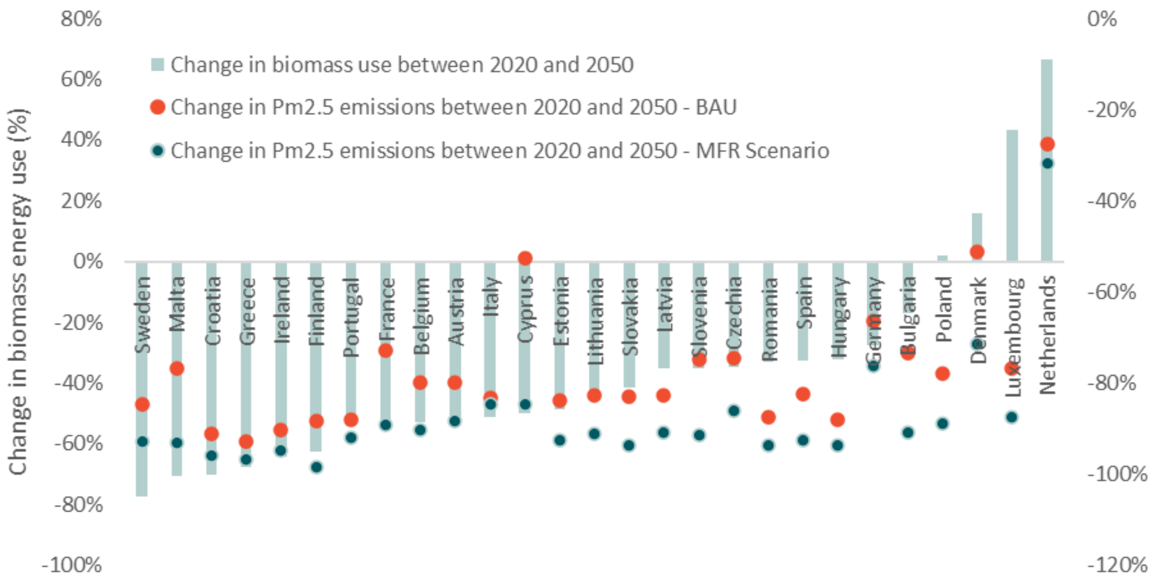


However, the reduction in outdoor and indoor air pollution will vary significantly across EU Member States due to different changes in biomass use and technology improvements. Residential biomass use is expected to decline in most EU countries between 2020 and 2050 (unlike use of biomass for power generation, which is expected to increase, as above). The reduction is expected to range from almost 80% in Sweden to only 17% in Bulgaria. However, in Poland, Denmark, Luxembourg and the Netherlands the residential use of biomass is expected to increase. While in Poland the growth is modest, at only 2%, in the Netherlands residential biomass use, especially biogas, is expected to increase by 67% between 2020 and 2050. The use of firewood in residential properties is expected to decline in all EU Member States except Denmark and Luxembourg. Additionally, several EU MS promote biogas production, with a subsequent impact on ambient air pollutants. There are several routes to producing biogas and biomethane, with energy crops being the primary source of growth in Europe to date. The gasification route to biomethane uses woody biomass (in addition to municipal solid waste and agricultural residues) as a feedstock, which consists of residues from forest management and wood processing (IEA, 2020). Crop residues[55] are another prominent feedstock option.

Despite some slight increases in biomass use in some EU countries, $PM_{2.5}$ emissions are expected to decline in all Member States as a result of improved technology. In 16 Member States, $PM_{2.5}$ is expected to decrease by at least 80% between 2020 and 2050 in the baseline scenario with even further reductions in the MTFR Scenario. The lowest decline is expected in the Netherlands, only 28% in baseline scenario and 32% in MTFR Scenario. This is due to the use of closed fireplaces with air control and more advanced stoves already being widespread in 2020.

55 Residues from the harvest of wheat, maize, rice or other coarse grains, sugar cane and other oilseeds.

Figure 76 - Residential biomass use outlook in the baseline across EU27; GAINS model

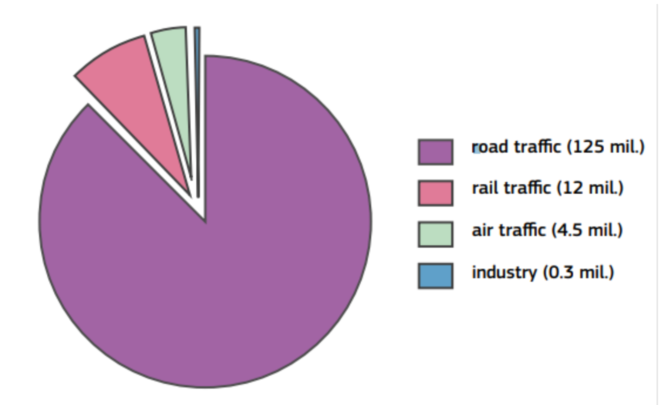


Note: Netherlands increase is mainly driven by increase in biogas use.

Noise pollution

Road traffic is the top source of noise pollution in Europe (EEA, 2020), followed by rail, aircraft and industry. Literature review shows that an estimated 113 million people are affected by long-term day-evening-night traffic noise levels of at least 55 dB (EEA, 2020). In addition, 22 million citizens are exposed to high levels of railway noise, 4 million to high levels of aircraft noise and less than 1 million to high levels of noise caused by industry. These values are likely to be underestimates, given that the Environmental Noise Directive does not comprehensively cover all urban areas, roads, railways and airports across Europe.

Figure 77 Distribution of European population exposed to sound levels above 55 dB Lden, by noise source (millions). Includes populations living in large agglomerations (>100 000 inhabitants) and close to major infrastructure



The Europe-wide trends are confirmed by granular country level data on sources of noise pollution included in the '2021 Noise country fact sheets'[56]. The trend of road transport being the key source of noise pollution is confirmed in different geographical parts of Europe as per the following examples:

[56] Country fact sheets summarise information on noise pollution for selected EEA member countries and are based on the latest official noise data reported every five years by EEA member countries under the Environmental Noise Directive (END) (EEA, 2021).

- Finland - the main source of noise pollution is noise from roads, followed by rail and air (though the latter two being a marginal source).
- Germany - the main source is road transport, closely followed by rail, with air and industry being a small source of noise pollution.
- Portugal - while road noise is still the main source of noise pollution, the next most significant source is air, with rail having a small impact.
- Romania - road noise is the main source, followed by a small share of rail, industry and air.

Road transport is a key contributor towards ambient air pollution, with cars representing the highest share of $PM_{2.5}$ and NO_x emissions in the transport sector in 2020. A significant reduction of both NO_x and $PM_{2.5}$ emissions from road transport is expected in the baseline scenario due to stricter vehicle emission standards, but also due to the expected progressive shift in the fuels used in road transport from liquid, notably fossil fuels, to electricity. Typically electric vehicles emit less noise than conventionally fuelled vehicles, hence the transition to less air polluting vehicles will also have consequences for noise pollution. The use of vehicles with EURO6/VI standard will increase between 2020 and 2030 for diesel, gasoline and gas road transport vehicles across all categories (cars, buses, heavy duty vehicles, light duty vehicles). Use of both diesel and gasoline is however expected to decrease in cars, light duty vehicles, buses and heavy-duty vehicles, while the use of electricity in road transport increases. This is a result of the anticipated shift from internal combustion engines (ICEs) towards the use of electric power trains. By 2050 all liquid fuels for ICEs will drop significantly and will be substituted by the use of electricity. The highest increase of electricity use is expected in cars and light duty vehicles, where it will account for 85% and 76%, respectively, of total energy use by 2050.

Figure 78 - Energy use and $PM_{2.5}$ emissions in baseline in different transport activities (in PJ)

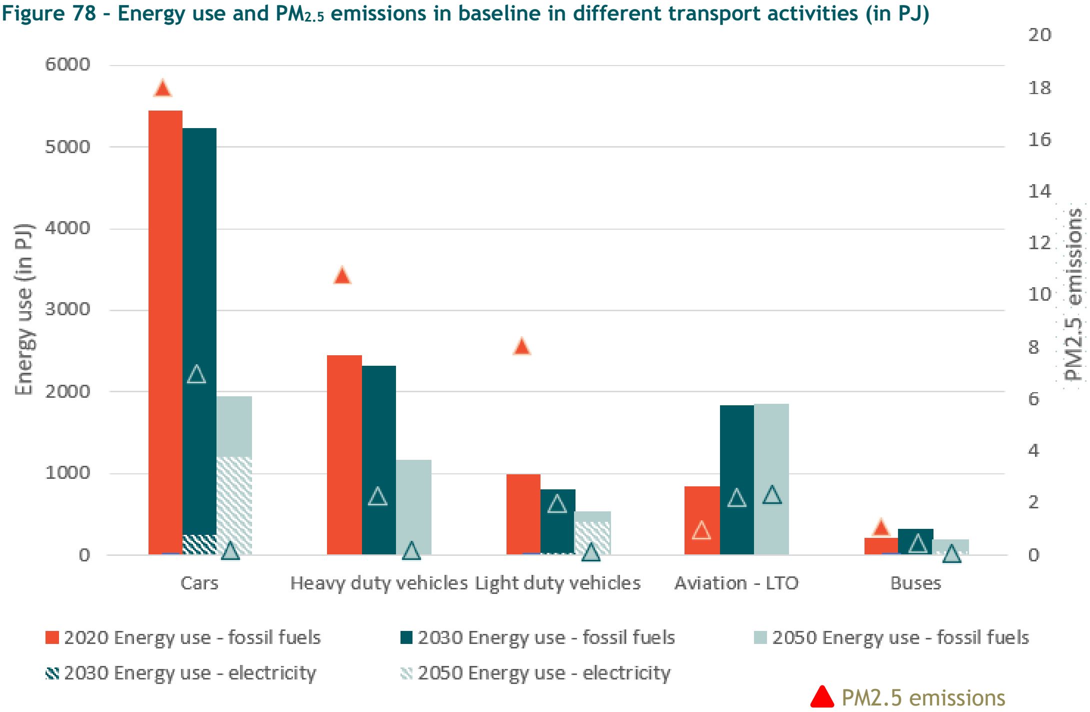
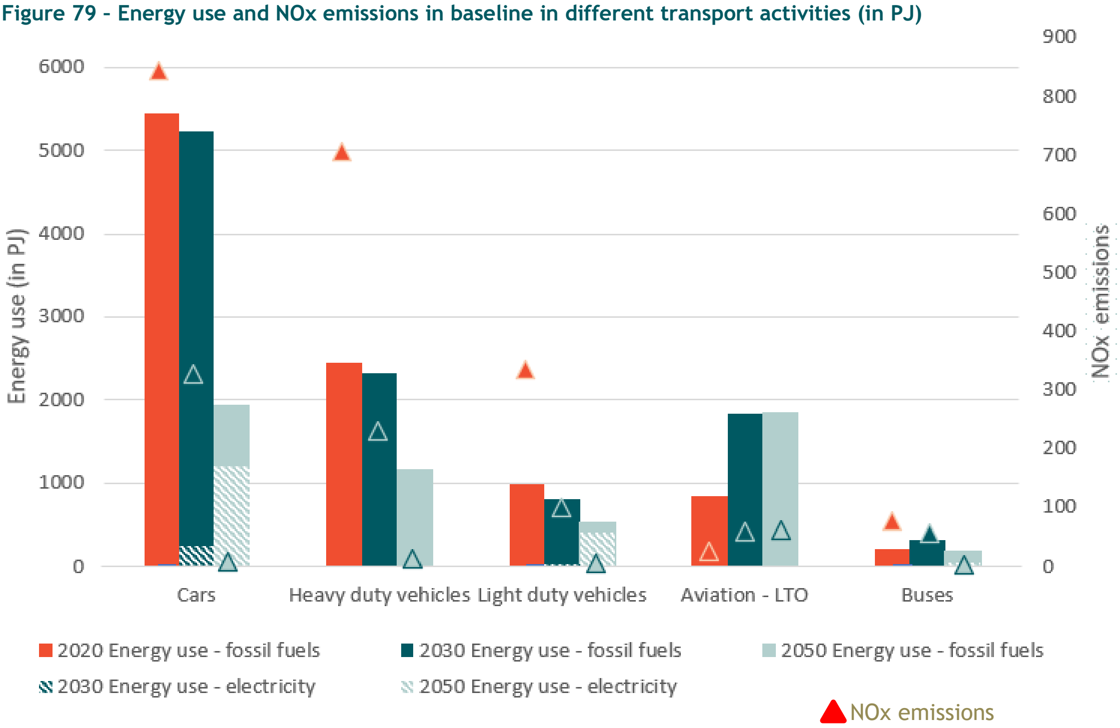


Figure 79 - Energy use and NOx emissions in baseline in different transport activities (in PJ)



The Environmental Noise Directive obliges the EU Member States to prepare action plans to reduce noise from transport in agglomerations. Reduction of noise in urban areas will require a mix of global and local actions, with the improvement of the vehicle fleet needs to be accompanied by the deployment of better tyres and better roads. The 'avoid and shift strategy' aims to reduce road transport via the promotion of active mobility modes, such as walking or cycling, which are emissions free. Promoting the use of public transport, so that it contributes a greater share of overall km of vehicle travel, sis also part of this strategy.. Support for the electrification of transport is considered as one of the key measures to reduce ambient air pollution from transport. While electric vehicles produce PM pollutants from tyre and break friction, they produce no tailpipe emissions, thus electrification reduces PM, NOx and SOx from fuel combustion. Electric power trains emit less noise pollution than ICE, but tyre road friction still causes some noise pollution. In urban environments, 2-wheelers and trucks are particularly polluting in terms of noise. While significant electrification is envisaged for cars, LDVs and some buses, HDVs are lagging behind due to a lack of technological alternatives. In spite of an expected reduction in local air pollutants, an increase of noise is foreseen for all modes by 2030 relative to 2015 due to the increase in the number of vehicles. By 2050 the increased number of electric vehicles could lead, for road only, to a limited benefit in terms of noise reduction[57]. Synergies between air pollution and noise are therefore of primary importance in the urban environment. A full spectrum of measures needs to be considered to maximise synergies, including an overall reduction in road transport in urban areas and improvements to vehicle tyres and road surfaces to reduce both noise and air pollution. The impacts of electrification on noise would therefore remain limited unless other specific measures are adopted that benefit the fleet renewal and at the same time target noise, as well as CO_2 and air pollutant emissions reductions[57].

8.2 Economic impacts

8.2.1 *Costs and benefits to society (Indicator #5)*

Table 51 shows the results of the analysis, presenting the absolute effects for the baseline and each scenario, alongside the difference (or net effect) of the scenarios relative to the baseline, each valuing the human health impacts of the scenarios. In line with CAO2, two sets of results are presented which present different approaches to monetising the impacts on mortality: a 'VSL' or value of statistical life approach, which monetises the number of deaths, and a VOLY or Value of a life year approach, which instead monetises life years lost. The results present the monetary benefits in the given assessment year. For the aggregate assessment, the mortality effects associated with NO_2 are excluded to avoid the risk of overlap with the mortality effects of $PM_{2.5}$.

[57] https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX%3A52020SC0331

Table 51- Costs and benefits ("NET" values) to society (valuation of health impacts - both mortality and morbidity) per year - central (all values €bn 2015 prices, EU27)

Approach to valuing mortality	Scenario	2020	2030	2050
VSL	Baseline	739	444	332
VSL	OPT20	-	408	-
VSL	OPT15	-	352	320
VSL	OPT10	-	325	266
VSL	OPT5	-	317	263
VSL	MTFR	-	303	256
VOLY	Baseline	251	140	90
VOLY	OPT20	-	128	-
VOLY	OPT15	-	109	87
VOLY	OPT10	-	100	71
VOLY	OPT5	-	97	70
VOLY	MTFR	-	92	68
Net VSL	*OPT20*	-	36	-
Net VSL	*OPT15*	-	92	12
Net VSL	*OPT10*	-	119	66
Net VSL	*OPT5*	-	127	69
Net VSL	*MTFR*	-	141	77
Net VOLY	*OPT20*	-	12	-
Net VOLY	*OPT15*	-	31	3
Net VOLY	*OPT10*	-	40	19
Net VOLY	*OPT5*	-	43	20
Net VOLY	*MTFR*	-	48	22

As can be seen from the results in the table, there is a range in the monetised human health benefits (i.e. reduced costs) depending on the approach taken and scenario. Monetised benefits are smaller under the VOLY than VSL approach. The benefits increase, as expected, with the ambition of the scenario. The benefits reduce over time as more progress is made in the baseline, which erodes the additional benefit of further action under the mitigation scenarios. Across all scenarios, mortality effects contribute the vast majority of the overall valued effects: the share of morbidity effects in the total valuation of human health benefits ranges from 1-6% across scenarios and years under the VSL approach, to 5-19% under the VOLY approach.

8.2.2 *Costs of measures (Indicator #6)*

Costs of air pollution emission control measures applied in the different policy scenarios, relative (additional) to the baseline scenario costs, are shown in Figure 80. Consistently with the results for emission reductions associated with the policy options analysed in this work, the additional costs of reaching 20 and 15 µg/m^3 targets in 2030 and 2050, respectively, are very small, especially when considering total air pollution mitigation costs (see Section 7.1.2).

The costs increase strongly for the scenarios addressing 10 and 5 µg/m^3 targets with cost burden shared primarily between industry, residential sector, and agriculture. As discussed earlier (Section 6.2, 7.1.1, and Appendix 3), the feasibility of attaining the 5 ug/m^3 policy target is very limited for a large number of grid-cells for which even the MTFR scenario does not enable concentrations to reduce below 5 ug/m^3 and the costs would increase further, by over a factor of three, compared to the 5 ug/m^3 policy case.

Figure 80 - Air pollution control costs (EU-27 total) beyond the Baseline, for different policy scenarios and sectors; Source: GAINS model.

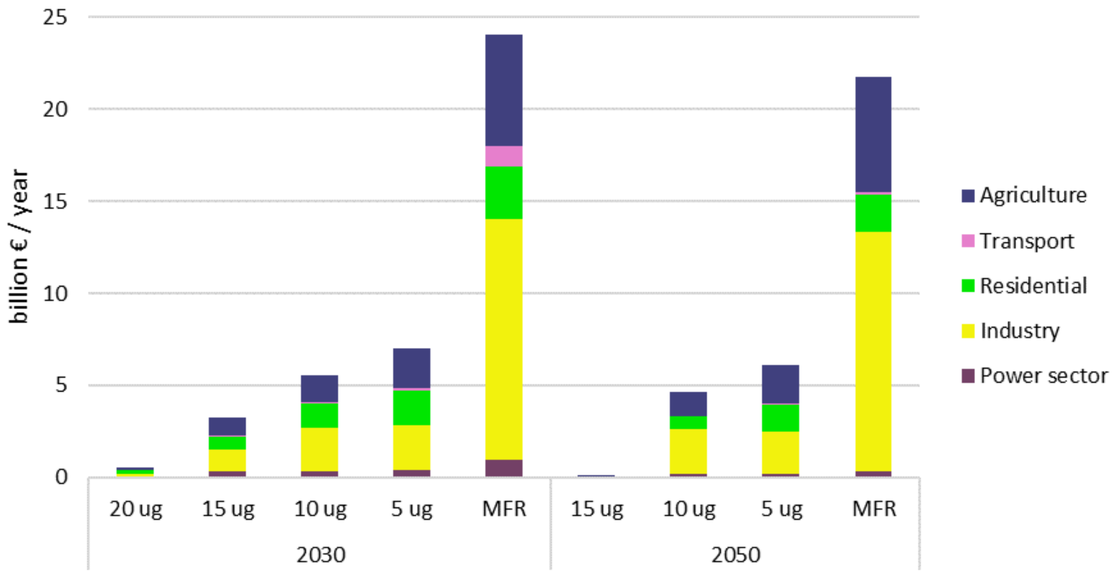


Table 52- Air pollution control costs (EU-27 total) beyond the Baseline, per year, for different policy scenarios (all values €bn 2015 prices); Source: GAINS model.

	Scenario	Power sector	Industry	Residential	Transport	Agriculture	Total
2030	OPT20	0.02	0.19	0.16	0.01	0.18	0.56
	OPT15	0.30	1.18	0.72	0.08	1.00	3.28
	OPT10	0.33	2.40	1.29	0.08	1.47	5.58
	OPT5	0.41	2.44	1.87	0.13	2.16	7.02
	MTFR	0.96	13.09	2.84	1.14	6.04	24.06
2050	OPT15	0.01	0.02	0.01	0.00	0.01	0.05
	OPT10	0.18	2.47	0.65	0.02	1.35	4.67
	OPT5	0.18	2.33	1.45	0.03	2.09	6.08
	MTFR	0.33	13.00	2.06	0.10	6.25	21.74

Table 53- Air pollution control costs (by MS and EU-27) beyond the Baseline, for different policy scenarios in 2030 (all values €bn 2015 prices); Source: GAINS model.

Country	OPT20	OPT15	OPT10	OPT5	MTFR
Austria	0.000	0.031	0.034	0.206	0.585
Belgium	0.000	0.026	0.033	0.208	0.435
Bulgaria	0.001	0.078	0.142	0.142	0.337
Croatia	0.000	0.040	0.131	0.110	0.260
Cyprus	0.000	0.000	0.009	0.009	0.042
Czech Rep.	0.000	0.107	0.163	0.234	0.878
Denmark	0.000	0.016	0.015	0.122	0.595
Estonia	0.000	0.005	0.004	0.030	0.092
Finland	0.000	0.021	0.017	0.101	0.781
France	0.000	0.026	0.864	1.009	3.777
Germany	0.002	0.360	0.418	1.058	4.089
Greece	0.000	0.187	0.164	0.174	0.731
Hungary	0.000	0.263	0.190	0.161	0.559
Ireland	0.000	0.000	0.001	0.023	0.342
Italy	0.448	0.550	1.020	0.910	2.042
Latvia	0.000	0.007	0.007	0.041	0.169
Lithuania	0.000	0.104	0.103	0.088	0.263
Luxembourg	0.000	0.000	0.000	0.005	0.046
Malta	0.000	0.000	0.002	0.002	0.009
Netherlands	0.000	0.021	0.022	0.169	0.749
Poland	0.000	0.965	0.897	0.706	2.313
Portugal	0.001	0.001	0.024	0.101	0.505
Romania	0.094	0.389	0.426	0.423	1.042
Slovakia	0.000	0.068	0.066	0.056	0.329
Slovenia	0.010	0.008	0.011	0.041	0.123
Spain	0.000	0.000	0.811	0.816	2.577
Sweden	0.000	0.005	0.004	0.075	0.393
EU-27	**0.558**	**3.278**	**5.580**	**7.021**	**24.063**

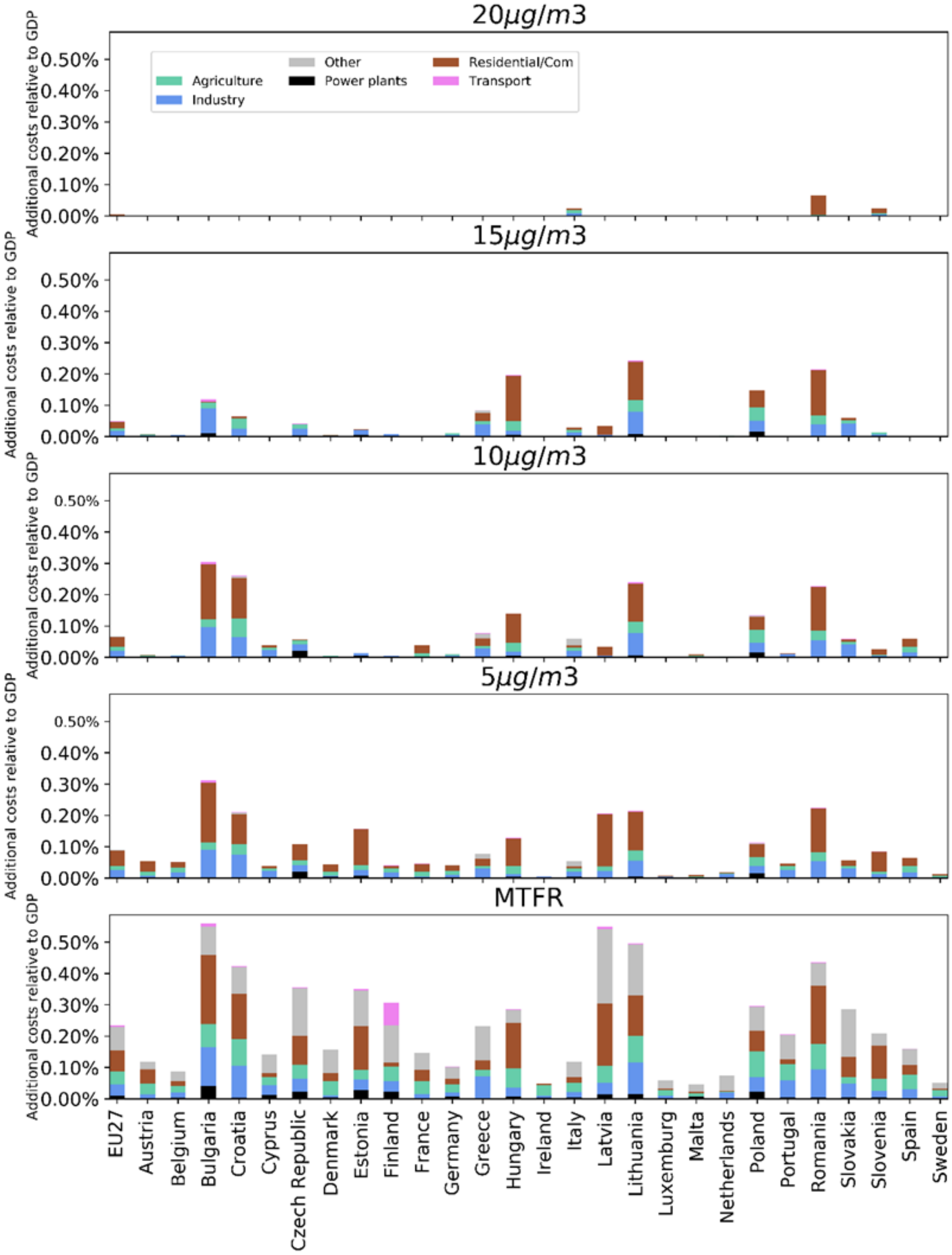
Table 54- Air pollution control costs (by MS and EU-27) beyond the Baseline, for different policy scenarios in 2050 (all values €bn 2015 prices); Source: GAINS model.

Country	OPT15	OPT10	OPT5	MTFR
Austria	0.000	0.047	0.155	0.499
Belgium	0.000	0.017	0.173	0.404
Bulgaria	0.000	0.074	0.156	0.307
Croatia	0.000	0.102	0.093	0.224
Cyprus	0.000	0.010	0.010	0.040
Czech Rep.	0.000	0.100	0.162	0.758
Denmark	0.000	0.008	0.104	0.556
Estonia	0.000	0.003	0.026	0.081
Finland	0.000	0.013	0.074	0.457
France	0.000	0.490	0.689	3.405
Germany	0.000	0.367	0.869	3.883
Greece	0.000	0.134	0.128	0.702
Hungary	0.000	0.146	0.147	0.485
Ireland	0.000	0.000	0.015	0.311
Italy	0.020	1.057	1.008	1.977
Latvia	0.000	0.000	0.037	0.158
Lithuania	0.000	0.057	0.067	0.220
Luxembourg	0.000	0.000	0.003	0.044
Malta	0.000	0.002	0.001	0.009
Netherlands	0.000	0.003	0.150	0.710
Poland	0.000	0.692	0.621	1.940
Portugal	0.001	0.030	0.108	0.453
Romania	0.027	0.395	0.365	0.920
Slovakia	0.000	0.059	0.060	0.315
Slovenia	0.000	0.006	0.044	0.103
Spain	0.000	0.855	0.747	2.432
Sweden	0.000	0.004	0.067	0.351
EU-27	**0.049**	**4.670**	**6.079**	**21.744**

The distribution of additional control costs associated with the air pollution technology in 2030, , is provided in Figure 81 below showing these costs in relation to GDP. OPT20 requires only minor additional effort in a limited number of countries. Efforts need to increase significantly to achieve OPT10. Further efforts, for all countries, are estimated to be required for the OPT5 case, but as shown before (Section 6.2, 7.1.1, and Appendix 3), there is an issue of feasibility in this scenario/model setting. There is a large increase in costs in MTFR (as shown above: over three times the total cost associated with OPT5).

EU27 additional air pollution control costs in 2030 remain below 0.10% of EU27 GDP for all scenarios apart from the MTFR (where they increase to around 0.25%). For some individual Member States the additional costs reach or surpass 0.20% of national GDP in scenarios OPT15 and more ambitious scenarios and reach up to above 0.50% of national GDP in the MTFR scenario in a few MSs.

Figure 81 – Additional (compared to baseline) air pollution control costs in 2030 for policy scenario and MTFR, shown as % of GDP; GAINS model



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. Further detail is provided in Appendix 9.

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*

8.2.3 *Macro-economic effects, international competitiveness and trade (Indicator #7)*

Air pollution has detrimental welfare impacts by affecting health outcomes. In addition, related healthcare expenditures, crop yield losses due to ozone, absence from work due to illness (including of dependent children) and lower productivity at work can imply a drag on the economy. Improving air quality can therefore bring economic gains. However, air pollution control comes at a gross cost, as it requires costly investments and purchases of abatement equipment. A priori, it is unclear whether air pollution control policies therefore lead to net economic gains or losses, and how these are distributed across stakeholders. To shed some light on these trade-offs, the JRC has conducted a cost-benefit-analysis by linking the GAINS model with the JRC-GEM-E3 model. This has been done in previous work, such as the 1st and 2nd Clean Air Outlook (European Commission, 2022), and both models feature in a broader modelling toolbox e.g. in the assessment of the EU long-term climate strategy (Weitzel et al. 2019). The key information that flows from GAINS to JRC-GEM-E3 is the abatement cost associated to further air pollution controls induced by more ambitious policy measures and targets. These costs serve as inputs into the JRC-GEM-E3 analysis.

The JRC-GEM-E3 model represents the whole economy and the interactions between key actors: firms, households and governments in the EU and in the rest of the world. End-of-pipe abatement costs from GAINS are treated as costly (intermediate) expenditures on abatement goods and services, and therefore generate additional demand for the sectors that deliver these goods and services. Furthermore, the model captures the potential loss in competitiveness of firms that need to incur abatement costs by reflecting price-driven international trade flows. For households, a loss of income or raised expenditure on abatement technologies will imply that less funds are available to purchase other goods. The economic modelling framework covers these interactions to provide an economy-wide picture of the implications of additional air pollution control costs.

On the benefit side, this analysis concentrates on productivity gains from clean air. The empirical basis stems from recent OECD work (Dechezleprêtre, Rivers, & Stadler, 2019) that quantifies the causal impact of $PM_{2.5}$ pollution on productivity in the EU for the period 2000-2015. More specifically, we derive labour productivity gains by combining the point estimate on the impact of $PM_{2.5}$ on GDP per worker, with the changes (compared to Reference) in population-weighted $PM_{2.5}$ concentrations from the GAINS model. The corresponding changes in labour productivity feed into the JRC-GEM-E3 model, where labour constitutes an input to the production process of the various economic sectors.

The results are displayed in

Table 55. They are complementary to estimates of the direct benefits brought by air pollution control measures presented earlier. Results are presented here as percentage changes compared to the baseline – in each column, the numbers on the left-hand side indicate the impact when the macroeconomic benefits from cleaner air are not considered (excluding market benefits), the numbers on the right side include market benefits of cleaner air.

The key insight is that all scenarios improve aggregate economic outcomes in the EU compared to a situation of unchanged policy. The most ambitious 5 µg/m^3 scenarios (i.e. 6 and 7) imply larger gross costs, but these are more than compensated for by productivity gains, as reflected by the positive impact on GDP and private consumption. The size of the net benefit increases with the ambition of the scenario – so OPT5 delivers a greater net benefit than OPT20. Although the level of mitigation action and associated costs increases with ambition, so too do the benefits – and the increase in the benefits is greater than the increase in costs as standards become more stringent. The net benefits in 2030 are greater than those in 2050. This is driven by the underlying reduction in emissions and improvement in concentrations which occurs anyway in the baseline. Overtime, these improvements reduce the amount of additional effort needed under the scenarios to achieve higher ambition standards, hence also reducing the associated impacts (costs and benefits) of the mitigation scenarios.

With the exception of livestock-based agriculture, all sectors raise output compared to the baseline when productivity gains of clean air are accounted for. While productivity benefits limit output reduction in the livestock sector, they are not sufficient to fully offset output losses induced by higher abatement spending.

Once the productivity gains from clean air are factored in, results indicate enhanced competitiveness of the EU economy as indicated by an improved trade balance and higher exports. With respect to exports, it is true that the additional mitigation costs will place upward pressure on prices, and *ceteris paribus* EU goods/services become less competitive. That said, under the scenarios there is also a more productive labour force, which implies more competitive industry as labour is an important production factor. This effect also feeds through to prices, with the net effect being a reduction in prices and increase in exports. Imports also increase because there is an overall net increase in economic output, which subsequently leads to a net increase in income for households. This translates to a net increase in consumption, of which a portion will be imports, hence overall imports also increase.

On the benefit side, this analysis concentrates on productivity gains from clean air. The empirical basis stems from recent OECD work (Dechezleprêtre et al. 2019) that quantifies the causal impact of PM2.5 pollution on productivity in the EU for the period 2000-2015. More specifically, we derive labour productivity gains by combining the point estimate on the impact of PM2.5 on GDP per worker, with the changes (compared to Baseline) in population-weighted PM2.5 concentrations from the GAINS model. The corresponding changes in labour productivity feed into the JRC-GEM-E3 model, where labour constitutes an input into the production process of the various economic sectors. A few caveats are important to take into consideration when interpreting these results. Here, we focus exclusively on productivity benefits from clean air, which implies that other 'market' benefits are not included, such as reduced healthcare expenditures and increased crop yields. Furthermore, additional 'non-market' benefits, such as ecosystem impacts and reductions in premature mortality or life years lost due to air pollution, are not included in the results displayed in the table below. While these benefits are not included in the economy-wide assessment in this section, they are discussed in other sections of this report.

Table 55 Results of macro-economic benefit-cost analysis. Source: JRC-GEM-E3.

<table>
<tr><th>Cost only | Net effect incl. benefits % change relative to baseline</th><th>20µg 2030</th><th>15µg 2030</th><th>10µg 2030</th><th>5µg 2030</th><th>15µg 2050</th><th>10µg 2050</th><th>5µg 2050</th></tr>
<tr><td>Gross Domestic Product</td><td>0 | 0.10</td><td>-0.02 | 0.26</td><td>-0.04 | 0.38</td><td>-0.05 | 0.44</td><td>0 | 0.03</td><td>-0.02 | 0.29</td><td>-0.03 | 0.36</td></tr>
<tr><td>Private Consumption</td><td>0 | 0.12</td><td>-0.02 | 0.34</td><td>-0.03 | 0.49</td><td>-0.04 | 0.57</td><td>0 | 0.04</td><td>-0.02 | 0.37</td><td>-0.02 | 0.46</td></tr>
<tr><td>Exports*</td><td>0 | 0.11</td><td>-0.02 | 0.32</td><td>-0.03 | 0.46</td><td>-0.03 | 0.56</td><td>0 | 0.04</td><td>-0.02 | 0.37</td><td>-0.02 | 0.48</td></tr>
<tr><td>Imports**</td><td>0.01 | 0.02</td><td>0.03 | 0.06</td><td>0.05 | 0.10</td><td>0.07 | 0.13</td><td>0 | 0</td><td>0.04 | 0.08</td><td>0.05 | 0.11</td></tr>
<tr><td>Sector output</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Crops</td><td>-0.02 | 0.15</td><td>-0.19 | 0.30</td><td>-0.26 | 0.45</td><td>-0.32 | 0.50</td><td>0 | 0.06</td><td>-0.17 | 0.38</td><td>-0.30 | 0.36</td></tr>
<tr><td>Livestock</td><td>-0.09 | 0.05</td><td>-0.45 | -0.06</td><td>-0.62 | -0.05</td><td>-1.01 | -0.36</td><td>-0.01 | 0.05</td><td>-0.54 | -0.10</td><td>-0.91 | -0.37</td></tr>
<tr><td>Power sector</td><td>0 | 0.11</td><td>0 | 0.30</td><td>0.01 | 0.44</td><td>0.01 | 0.50</td><td>0 | 0.04</td><td>0.02 | 0.34</td><td>0.02 | 0.41</td></tr>
<tr><td>Fossil fuels</td><td>-0.01 | 0.08</td><td>-0.09 | 0.18</td><td>-0.10 | 0.28</td><td>-0.11 | 0.32</td><td>0 | 0.03</td><td>-0.04 | 0.24</td><td>-0.03 | 0.29</td></tr>
<tr><td>Industry</td><td>0 | 0.13</td><td>0.02 | 0.38</td><td>0.01 | 0.53</td><td>0.02 | 0.63</td><td>0 | 0.05</td><td>0 | 0.40</td><td>0.01 | 0.51</td></tr>
<tr><td>Services</td><td>0 | 0.09</td><td>0 | 0.26</td><td>0 | 0.38</td><td>0 | 0.45</td><td>0 | 0.03</td><td>0 | 0.29</td><td>0 | 0.37</td></tr>
</table>

Notes: Economic outcomes of clean air policy in the EU. Source: JRC-GEM-E3. The first number in a cell, before the "|", represents gross costs only. The second number in a cell (after the vertical line) represents the net effect, i.e. benefits minus costs. ; * positive exports denotes an increase in exports; ** positive imports denotes an increase in imports.

8.3 Social impacts

8.3.1 *Effects of scenarios on spatial regions with a low/high proportion of population in a vulnerable age group (indicator #8)*

This section details the results of analysis to understand how the modelled changes in air quality are likely to impact spatial regions with a low/high proportion of residents who are likely to be vulnerable to changes in pollutant concentration due to their age. A description of the methodology used to undertake this analysis is detailed in Appendix 7. In summary, the approach takes the 2030 modelled air pollutant impacts across the different scenarios for the four pollutants with the highest documented impact on human health ($PM_{2.5}$, PM_{10}, NO_2, Ozone), and overlays these with various mapped demographic characteristics to explore whether there a trends or patterns in the spatial distribution of effects across different demographic groups.

The following subsections provide commentary as to how each scenario is predicted to change the concentration of each pollutant ($PM_{2.5}$, PM_{10}, NO_2, Ozone) in scaled areas with low (quintile 1) or high (quintile 5) proportions of citizens whose health is most likely to be impacted by the changes in pollutant concentration due to their age. This analysis looks at the effects on spatial areas which have a low/high proportion of inhabitants under the age of 14 years old, or older than 65 years old.

This section of the report provides a summary of the results of the analysis – detailed results are presented in Appendix 7. The analysis investigates whether there is a statistical correlation between the proportion (low-high) of citizens in each demographic and the change in baseline concentration value, this was undertaken using the Spearman Rank Correlation technique. The results are presented in tabulated form for each pollutant at the end of this section.

Correlation analysis of the changes in pollutant concentration from the 2030 baseline model

A Spearman's rank correlation analysis was undertaken for each pollutant, scenario and sensitivity group to investigate the link between demographic characteristic and level of air pollutant reduction. Results displaying a positive figure show a positive correlation - i.e. the reduction in air pollutant concentration is lower in the areas representing the lower proportion of the demographic (quintile 1), compared to the level of reduction in areas with a higher proportion (quintile 5). A negative value indicates the reverse. The maximum values, showing the strongest possible trend, displayed using this technique can only be -1 or 1, values close to 0 represent a weak trend. For the following tables, the quantity for each demographic rises with quintiles – i.e. the number of children or elderly is highest in quintile 5, and lowest in quintile 1.

Table 56 Spearman rank correlation analysis of change in $PM_{2.5}$ pollutant concentration to sensitive demographic

Spatial scale	Sensitivity class	Pollutant correlation coefficient				
		MTFR	OPT_05mug	OPT_10mug	OPT_15mug	OPT_20mug
NUTS 3	Citizens aged under 14	-0.06	-0.07	-0.08	-0.12	-0.28
	Citizens aged over 65	-0.22	-0.21	-0.18	-0.16	-0.05

Table 57 Spearman rank correlation analysis of change in PM_{10} pollutant concentration to sensitive demographic

Spatial scale	Sensitivity class	Pollutant correlation coefficient				
		MTFR	OPT_05mug	OPT_10mug	OPT_15mug	OPT_20mug
NUTS 3	Citizens aged under 14	-0.06	-0.07	-0.08	-0.12	-0.28
	Citizens aged over 65	-0.23	-0.21	-0.19	-0.17	-0.06

Table 58 Spearman rank correlation analysis of change in NO_2 pollutant concentration to sensitive demographic

Spatial scale	Sensitivity class	Pollutant correlation coefficient				
		MTFR	OPT_05mug	OPT_10mug	OPT_15mug	OPT_20mug
NUTS 3	Citizens aged under 14	0.09	-0.02	-0.03	-0.02	-0.25
	Citizens aged over 65	-0.37	-0.28	-0.29	-0.27	-0.08

Table 59 Spearman rank correlation analysis of change in Ozone pollutant concentration to sensitive demographic

Spatial scale	Sensitivity class	Pollutant correlation coefficient				
		MTFR	OPT_05mug	OPT_10mug	OPT_15mug	OPT_20mug
NUTS 3	Citizens aged under 14	-0.36	-0.39	-0.35	-0.29	-0.31
	Citizens aged over 65	0.03	0.08	0.03	-0.02	0.02

Table 57**Error! Reference source not found.** and Table 56**Error! Reference source not found.** show that for PM_{10} and $PM_{2.5}$ respectively the pattern of results shows there is not a strong correlation between change in pollutant concentration under the modelled scenarios for children or for elderly groups. The table shows that the coefficient remains fairly constant across the scenarios, suggesting the pattern of effects remains consistent across scenarios. Table 58 shows similar findings with the respect to changes in NO_2 pollutant, with the exception of elderly groups, where a moderate negative correlation is observed for several scenarios – i.e. the reductions in NO_2 are found to be smaller for areas with higher numbers of elderly people, relative to areas with fewer elderly people.

Table 59**Error! Reference source not found.** shows that for ozone there is a fairly strong correlation between quintile class and change in pollutant concentration for children, but the relationship for elderly groups is weak. For children, the correlation coefficients across all scenarios are negative – namely the reduction in air pollutant concentrations is greater for areas with a lower proportion of children. Again, the coefficient remains fairly constant across the scenarios, suggesting the pattern of effects remains consistent across scenarios.

In summary, the effects appear to vary by pollutant and demographic characteristic. Under the mitigation scenarios, there is the potential for the elderly to benefit disproportionately less from reductions in $PM_{2.5}$, PM_{10} and $NO_{2;}$ whilst children may benefit disproportionately less from changes in Ozone. This may be because these groups tend to live in areas with lower air pollution levels to begin with. A useful finding is that the pattern of impacts remains consistent across scenarios – i.e. all are predicted to have a similar distributional effect.

8.3.2 *Societal effects (indicator #9)*

Taking action to achieve lower air pollutant standards will place a range of impacts on citizens, and different groups in society. Action will provide both benefits, namely through reductions in exposure to harmful air pollutants, but also costs. These effects could vary between different groups in society depending on a range of parameters. This study has taken a quantitative approach to considering the potential patterns of air pollution exposure effects across different groups, and has assessed the potential variation in costs between demographic groups qualitatively.

Quantitative analysis of the distribution of air pollution reduction benefits

The same approaches described within section 8.3.1 have been used to also understand the impacts of each modelled scenario on sensitive social groups. To understand the impacts, this analysis has used the euro per inhabitants (i.e. income per person), rate of unemployment and level of education datasets available from the Eurostat database. These datasets were only available at NUTS 2 spatial resolution.

This resolution is lower than that which was available to understand the impacts on sensitive demographic groups, meaning that the results from this analysis were more generalised than those shown in 8.3.1. Further detail on the results and underlying methodology can be found in Appendix 7.

The following tables details the results from the analysis undertaken to understand the strength of correlations between the two factors. Generally across all combinations of pollutant, scenario and demographic variables, the correlation is weak. The only exception is for ozone and levels of education, where a moderate negative correlation is identified across all scenarios – i.e. the pollutant reduction scenarios appear to deliver smaller reductions in areas where there is a greater proportion of people with low levels of educational attainment.

Table 60 Spearman rank correlation analysis of change in $PM_{2.5}$ pollutant concentration to sensitive demographic

Spatial scale	Sensitivity class	Pollutant correlation coefficient				
		MTFR	OPT_05mug	OPT_10mug	OPT_15mug	OPT_20mug
NUTS 2	Euros per inhabitant	-0.08	-0.08	-0.25	-0.21	-0.01
	Rate of unemployment	-0.03	-0.02	0.02	-0.15	-0.04
	Proportion educated at levels 5-8 institutions	-0.05	-0.05	-0.15	-0.33	-0.43

Table 61 Spearman rank correlation analysis of change in PM_{10} pollutant concentration to sensitive demographic

Spatial scale	Sensitivity class	Pollutant correlation coefficient				
		MTFR	OPT_05mug	OPT_10mug	OPT_15mug	OPT_20mug
NUTS 2	Euros per inhabitant	-0.08	-0.08	-0.26	-0.21	-0
	Rate of unemployment	0	0.01	0.04	-0.14	-0.03
	Proportion educated at levels 5-8 institutions	-0.05	-0.04	-0.15	-0.33	-0.42

Table 62 Spearman rank correlation analysis of change in NO_2 pollutant concentration to sensitive demographic

Spatial scale	Sensitivity class	Pollutant correlation coefficient				
		MTFR	OPT_05mug	OPT_10mug	OPT_15mug	OPT_20mug
NUTS 2	Euros per inhabitant	0.04	0.1	-0.04	-0.01	0.03
	Rate of unemployment	0	-0.01	-0.03	-0.19	-0.12
	Proportion educated at levels 5-8 institutions	0.15	0.12	0.02	-0.11	-0.31

Table 63 Spearman rank correlation analysis of change in Ozone pollutant concentration to sensitive demographic

Spatial scale	Sensitivity class	Pollutant correlation coefficient				
		MTFR	OPT_05mug	OPT_10mug	OPT_15mug	OPT_20mug
NUTS 2	Euros per inhabitant	-0.19	-0.18	-0.28	-0.26	-0.13
	Rate of unemployment	-0.12	-0.1	-0.1	-0.22	-0.19
	Proportion educated at levels 5-8 institutions	-0.44	-0.45	-0.49	-0.49	-0.48

Qualitative analysis of distribution of costs

There will be costs associated with the implementation of mitigation techniques to reduce emissions of air pollutants. As for the benefits, the costs falling on different groups in society, economic sectors and countries may vary. Patterns of distribution in how the costs fall will depend on 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 sectors (i.e. industry, agriculture) could be impacted differently by these costs, also affecting 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.

No definitive conclusions can be drawn at this stage regarding distributional patterns of costs associated with the mitigation potential as ***the distribution of costs will be strongly determined by the specific policy actions adopted in each Member State, region or local level to deliver the technical abatement***. However, the analysis has identified a number of risk factors (and opportunities) – i.e. factors that suggest there is potential for a certain societal group to face disproportionate costs, relative to other groups. These are only risk factors because (as noted above), the true risk will depend on the specific policy mechanisms. Furthermore, competent authorities could introduce complementary policies to mitigate any potential distributional effects. However, if left unchecked, these risk factors could evolve into disproportionate impacts for more vulnerable groups in society. Opportunities have also been identified – i.e. where there is the potential for vulnerable groups to benefit proportionally more from mitigation measures.

A number of risk factors have been identified for lower income households. Meanwhile, there is no strong evidence to conclude that demographic groups such as children or elderly people would have to bear higher costs than other groups. 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 sectors and households, in others the potential impacts (and risks) will be indirect. The table below sets out the risk factors identified in this analysis.

Table 64. 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	• 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
	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 costs of using public transport, depending on how improvements are funded	

As shown in the table, there are a number of risk factors and opportunities for low income households from efforts to implement mitigation measures. The potential for distributional effects will need to be carefully managed by competent authorities to ensure that opportunities are seized, and risks managed properly.

8.3.3 *Employment impacts (Indicator #10)*

The JRC-GEM-E3 modelling results also include outcomes on employment changes by sector. In these simulations, we have assumed that wage setting is flexible such that it can fully accommodate labour market adjustments. This implies that aggregate, national unemployment levels are driven by fundamental factors that are unaffected by clean air policy. In other words, this assumption implies that the results will not pick up any potential aggregate net job creation associated with increased GDP and output levels as shown in Table 55 , and the results may therefore be interpreted as conservative estimates.

The results displayed in Table 65 indicate two consistent findings across all scenarios and years. First, we observe a creation of jobs in industry, which relates directly to the production of equipment required to abate emissions and the associated investments. While industry also faces increased abatement costs as shown in Figure 80, in terms of net effect on jobs, this is more than offset by increased demand for abatement goods from all sectors (including households). Second, the agricultural sector experiences job losses compared to the reference, which relates to output losses (livestock sector) or a transition of workers into the 'industry' sector (from crops sector).

Overall, the magnitude of the employment changes is limited in relative terms such that they may be largely absorbed by ongoing labour market dynamics (entry into, and exit from, the labour market), and may be dwarfed by other economic developments. One caveat worth mentioning here is that the productivity benefits are applied uniformly across all sectors. A stronger empirical evidence base would help refining (the sector-specific elements of) the analysis, e.g. by differentiating productivity impacts of air pollution for vulnerable workers.

Table 65. Employment transition across sectors in the EU..

	$PM_{2.5}$ at 10 µg/m3	$PM_{2.5}$ at 15 µg/m3	$PM_{2.5}$ at 10 µg/m3	$PM_{2.5}$ at 10 µg/m3			
Cost only | Net effect (benefit-cost) 1000 jobs, change rel. to baseline	20µg 2030	15µg 2030	10µg 2030	5µg 2030	15µg 2050	10µg 2050	5µg 2050
Employment							
Crops	-1 | -2	-15 | -17	-18 | -18	-19 | -19	0 | 0	-10 | -9	-17.4 | -16
Livestock	-2 | -3	-20 | -24	-23 | -29	-25 | -31	0 | -1	-17 | -20	-18.9 | -22
Power sector	0 | -2	0 | -6	0 | -7	0 | -8	0 | -1	0 | -4	0.2 | -5
Fossil fuels	0 | 0	0 | 0	0 | 0	0 | -1	0 | 0	0 | 0	0 | 0
Industry	3 | 24	25 | 81	30 | 104	34 | 115	0 | 7	15 | 66	22.6 | 81
Services	1 | -17	10 | -33	11 | -49	10 | -57	0 | -6	12 | -33	13.5 | -38

Source: JRC-GEM-E3. Given the assumption of flexible wage setting, positive and negative employment effects balance out for a given year and scenario. Adding of numbers in a given column of this table does not yield zero in all cases due to rounding

9 Analysis of interventions

9.1 Overview

All 69 interventions across the 27 Intervention Areas have been assessed based on their effectiveness, efficiency and coherence and have been scored against the 12 indicators. The detail of the analysis is set out in the Assessment Sheets presented in the Appendix 10. This section presents a summary of the analysis of the interventions across each Policy Area.

The classification used to determine the significance of the impacts against the 12 indicators is presented below together with the colour coding used in the summary analysis tables included in this section.

Table 66 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 (e.g. Indicator 1 – Air Quality: full alignment WHO AQG for $PM_{2.5}$)
++	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. Indicator 6 – Mitigation Costs: costs of maximum feasible technical potential (MTFR) and more)

9.2 Policy area 1

9.2.1 *Summary of analysis*

Intervention reference	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
20 / 15 ug/m^3	+	+	+	+	+	-	+	+	+ / -	+	+	-
10 ug/m^3	++	++	++	++	++	--	+	++	+ / -	+	++	--
5 ug/m^3	+++	+++	+++	+++	+++	---	+	+++	+ / -	+	+++	---
O1	**Revise standards for annual $PM_{2.5}$** A sample of variants has been selected for the modelling in distinct 5 ug steps. More ambitious standards can achieve greater improvements in air quality, with corresponding benefits for health and ecosystems. Administrative burden will also scale with ambition (impacting Member State competent authorities) as the more ambitious the standard, the more new zones will be identified as requiring measures to avoid exceedances. Similarly, mitigation/adjustment costs increase with ambition. The costs of such action are uncertain and depend on the starting point for each one, but these could imply significant change in behaviour at local or national level. As the level of ambition increases, the cost of mitigation/adjustment measures will increase on a non-linear basis. There are several challenges for implementation (see Section 9.2.2). Specific to $PM_{2.5}$ is the fact that this pollutant may be emitted directly by natural sources. It is also a transboundary pollutant. The extent to which standards can address these issues is uncertain. Stakeholders firmly recognise the value of an annual average standard for $PM_{2.5}$, which applies as a limit value to all territories in the EU, but opinions vary on what level of ambition is appropriate by when. **[BCR: High*** (*Compliance which more ambitious standards requires non-technical or local mitigation, the costs of which are uncertain)**]**											
O2	0 to +++	0 to +++	0 to +++	0 to +++	0 to +	0 to ---	+ / -	0 to ++	+ / -	0	0 to +++	0 to ---
	Introduce standards for daily $PM_{2.5}$: The intervention considers the introduction of a new standard. Variants take the same approach as described for O1. Short-term standards are not modelled explicitly, and hence judgements regarding the balance of costs and benefits are more uncertain. Greater health benefits 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. Administrative burden will also scale with ambition (impacting Member State competent authorities). 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. Challenges for implementation are the same as for O1. 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. **[BCR: High].** 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											

Intervention reference	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
	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	0 to ++	0 to ++	0 to ++	0 to ++	0 to ++	0 to --	0 to +	0 to +++	+ / -	0 to +	0 to ++	0 to --
	Revise average exposure standards for $PM_{2.5}$: The extent to which this intervention contributes to air quality improvements is partly dependent on the level of ambition. However, regardless of the level of ambition, revisions to average exposure targets can facilitate targeted reductions of $PM_{2.5}$ and attaining the reduction obligations is expected to deliver health benefits. A benefit of setting average exposure targets is that they can complement limit values by targeting background concentrations more specifically. Benefits to ecosystems will occur as a co-benefit of the measures implemented to attain the reduction targets. Costs can be significant depending notably on the level of ambition, 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. **[BCR: High]**											
P1	0 to +++	0 to +++	0 to +++	0 to +++	0 to +	0 to ---	0 to +	0 to +++	+ / -	0 to +	0 to +++	0 to --
	Revise standards for annual PM_{10}: Modelling shows that this intervention could have a significant positive impact on air quality. The health effects across the variants will scale with the level of ambition, even if health effects are more closely associated with exposure to finer particulate matter ($PM_{2.5}$). The mitigation costs of lower standards for PM_{10} have not been modelled. Many of the measures which mitigate $PM_{2.5}$ would also mitigate PM_{10} emissions, hence the measures and costs would be similar. Administrative burden will also scale with ambition (impacting Member State competent authorities). There are several challenges for implementation (see discussion for Policy Area 1). Stakeholders firmly recognise the value of an annual average standard for PM10, which applies as a limit value across all territories of the EU. Furthermore, stakeholders also affirm the additional value of a standard for PM_{10} alongside $PM_{2.5}$ and show a general interest for improvement. However, opinion varies on what level of ambition is appropriate and by when it should be achieved. **[BCR: high].** 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	0 to +++	0 to +++	0 to +	0 to +	0 to +	0 to ---	+ / -	0 to ++	+ / -	0	0 to +++	0 to --
	Revise standards for daily PM_{10}: Short-term standards are not modelled, and hence judgements regarding the balance of costs and benefits are more uncertain. Greater health benefits are typically associated with chronic exposure and with $PM_{2.5}$, but where the risk of peaks is quite high and considering this intervention in isolation, the benefits would be much more significant. The mitigation costs will increase with the level of ambition and will depend on the action taken. Expert judgement suggests many of the actions taken to mitigate peak concentrations will be the same as those to tackle annual average concentrations, which means the costs may be similar in order of magnitude. Administrative burden will also scale with ambition (impacting Member State competent authorities). There are several challenges for implementation (see Section 9.2.2). It appears that											

Intervention reference	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
	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. Stakeholders voted positively that they see additional value in a standard to manage peak concentrations of PM_{10}. However, the additional value of a short-term PM_{10} standard may be limited if set alongside a corresponding standard for $PM_{2.5}$, since both are likely to share similar sources and hence, control strategies **[BCR: High]** 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/m3 standard, and the highest scoring associated with a 45 ug/m3 standard.											
P3	0 to ++	0 to ++	0 to ++	0 to ++	0 to +	0 to --	0 to +	0 to ++	+ / -	0 to +	0 to ++	0 to --
	Introduce average exposure standards for PM_{10}: The extent to which this intervention contributes to air quality improvements is partly dependent on the level of ambition. A benefit of setting average exposure targets is that they can complement limit values by targeting background concentrations more specifically. Benefits to ecosystems will occur as a co-benefit of the measures implemented to attain the reduction targets. Costs can be significant, depending notably on the level of ambition, and 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. An average exposure standard for PM_{10} may not offer significant additional value alongside the similar existing standard for $PM_{2.5}$, since both are likely to share similar sources and hence, control strategies. [BCR: Medium to Low]											
Q1	0 to +++	0 to ++	0 to +++	0 to +	0 to ++	0 to --	0 to +	0 to +	+ / -	0 to +	0 to ++	0 to ---
	Revise standards for annual NO_2: The health benefits of action targeting the revision of NO_2 concentrations may be smaller (assuming there are no co-benefits by way of particulate or GHG emission reductions). The mitigation costs of lower standards for NO_2 have not been modelled, as such contrasting benefits and costs is more uncertain. The modelling does show however a broad alignment with a 20 µg/m^3 standard by 2030, and with the WHO Air Quality Guidelines by 2050, with only a small number of people which remain exposed to concentrations above these levels (around 4- 6 million respectively). Hence the additional costs and benefits of these options are both negligible (although in practice a reduction in the 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). Several challenges for implementation have been identified (see Section 9.2.2). 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 interest for improvement but opinion varies on what level of ambition is appropriate and by when it should be achieved. The majority of stakeholders feel alignment with the WHO Air Quality Guidelines 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. **[BCR: high]** 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.											

Intervention reference	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
Q2	0 to +++	0 to +	0 to ++	0 to +	0 to +	0 to --	+ / -	0 to +	+ / -	0	0 to ++	0 to --
	Revise/introduce standards for hourly/daily NO_2: The measure considers both the 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. It appears that there is also merit in having a standard to manage peak alongside annual average concentrations – this is underlined by stakeholders and the WHO Air Quality Guidelines, 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. Short-term standards are not modelled, and hence judgements regarding the balance of costs and benefits is more uncertain. Greater health benefits are typically associated with chronic exposure, but where the risk of peaks is quite high and considering this intervention in isolation, the benefits would be much more significant. The mitigation costs will increase with the level of ambition and will depend on the action taken. Expert judgement suggests many of the actions taken to mitigate peak concentrations will be the same as those to tackle annual average concentrations – which implies the costs may be a similar order of magnitude. Administrative burden will also scale with ambition (impacting Member State competent authorities). **[BCR: High]** 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 daily 40 ug/m3 standard, and the highest scoring associated with a daily 25 ug/m3 standard.											
Q3	0 to ++	0 to +	0 to ++	0 to +	0 to +	0 to -	0 to +	0 to +	+ / -	0 to +	0 to +	0 to -
	Introduce average exposure standards for NO_2: The impact on air quality and ecosystems will vary, notably with the level of ambition, and benefits only become significant with medium to high levels of ambition. A benefit of setting average exposure targets is that they can complement limit values, and target background concentrations specifically, rather than limiting focus on pollution hotspots. This is also important for NO_2 as a precursor, including to PM, but less important overall for NO_2 given the more location specific nature of exposure. Costs can be 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. Should an average exposure indicator be introduced, limit values applying in all places would be required to ensure that emissions reductions happen at all hotspots and ensure that the benefits achieved by more and less disadvantaged groups are more proportionate [BCR: Medium]											
R1	0 to +++	0 to +	0 to +++	0 to +	0 to +	0 to --	0 to -	0 to +	+ / -	0	0 to +	0 to --
	Introduce standards for peak-season O_3: The effectiveness of the intervention will scale vary with the level of ambition. However, given high levels of existing exceedance, the benefit to air quality is expected to be high. 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). 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.											

Intervention reference	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
	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 difference 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 Air Quality Guidelines, 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. There are several challenges for implementation (see Section 9.2.2). **[BCR: 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)**]**											
R2	0 to +++	0 to +	0 to ++	0 to +	0 to +	0 to ---	0 to -	0 to +	+ / -	0	0 to +	0 to ---
	Revise standards for 8-hour O_3: 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. 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). Several challenges for implementation have been identified (see Section 9.2.2). **[BCR: 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)**]** 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/m3 standard, and the highest scoring associated with a 100 ug/m3 standard.											
R3	0 to ++	0 to +	0 to ++	0 to +	0 to +	0 to --	0 to -	0 to +	+ / -	0	0 to +	0 to --
	Introduce average exposure standards for O_3: The impact on air quality and ecosystems will vary, notably with the level of ambition, and benefits only become significant with medium to high levels of ambition. A benefit of setting average exposure targets is that they can complement target and limit values, and target background concentrations specifically. Costs can be 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. It is uncertain whether an average exposure standard would offer a useful complement and afford additional management options in the case of O_3, given the specific chemical characteristics of ozone generation and its links with meteorological conditions (resulting in pronounced local and year-to-year variability). **[BCR: Medium - Low]**											
S1	0 to +	0 to +	0 to +	0 to +	0 to +	0 to -	0	0	0	0	0 to +	0 to -
	Revise standards for annual SO_2: Revisions to this standard were not modelled and therefore the balance of costs and benefits is more uncertain. There has been substantial progress around SO_2 emissions and concentrations historically. This may also suggest that a majority of the low-cost											

Intervention reference	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
	actions may have already been captured. Furthermore, the benefits per tonne of pollutant abated are smaller than for other pollutants (e.g. $PM_{2.5}$). The WHO did not include an AQG recommendation around long-term exposure to SO_2 with which an EU standard targeting human health could align. In addition, stakeholders provided limited input regarding the value and level of such a standard **[BCR: Medium]** 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/m3 standard.											
S2	0 to +	0 to +	0 to +	0 to +	0 to +	0 to -	0	0	0	0	0 to +	0 to -
	Revise standards for daily/hourly SO_2: This measure 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 Air Quality Guidelines. Revisions to this standard were not modelled and so the balance of costs and benefits is more uncertain. 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. No monitoring data is available over a 10-minute period, which makes it challenging to draw conclusions around the impact and merit of introducing a new 10-minute standard alongside, or instead of, other short-term standards for SO_2. As described for S1, historical progress for SO_2 may suggest that low-cost actions have already been captured. Stakeholders propose that the WHO standards could be met with limited additional effort. **[BCR: Medium]** 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	0 to +	0 to +	0	0 to +	0	0 to -	0	0	0	0	0 to +	0 to -
	Revise standards for daily/8-hour CO: This measure 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 Air Quality Guidelines. 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. From the modelling performed, a certain level of improvement can be made through abatement measures 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 modelling, thus the costs are uncertain. 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. Health benefits are more commonly associated with $PM_{2.5}$, as such the benefits per tonne of CO reduction are relatively lower. Introducing new standards will introduce additional complexity and administrative burden for public authorities. Stakeholders propose that the existing EU standards can be met with limited additional effort and propose to remain at the existing standard. For the introduction of an additional standard the response to the targeted stakeholder was uncertain. **[BCR: Medium]**											
U1	0 to +	0 to +	0	0	0	0 to -	0	0	0	0	0	0 to -
	Revise standards for annual benzene: Monitoring data suggests there is broad compliance with the existing standard in 2019 and low exceedances relative to the WHO Air Quality Guidelines, not accounting for further improvements in the baseline. The negative impact of benzene is however											

Intervention reference	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
	also lower in relation to other pollutants. **[BCR: Low/medium]** 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	0 to ++	0 to +	0	0 to +	0 to +	0 to -	+/-	0 to +	+/-	+/-	0 to +	0 to --
	Revise standards for annual benzo(a)pyrene: This intervention considers both: (a) changing from target to limit value and (b) aligning the standard with the WHO Guideline. Emissions and concentrations of BaP have been modelled directly and reductions in the baseline are anticipated to be significant compared to the baseline but smaller compared to other pollutants. A moderate number of sites will remain in exceedance in 2030 in the baseline, with high BaP concentrations primarily occurring in specific regions in three Member States. The number of sites exceeding could be minimised through further measures. To 2050, there is broad compliance with the existing EU standard under the baseline already, and further action could achieve a lower one. BaP is mainly associated with detrimental health impacts **[BCR: Medium/Low]** 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/m3 standard, high impacts with a 0.4 ug/m3 standard, and the highest scoring associated with a 0.12 ug/m3 standard.											
W1	0 to +	0 to +	0 to +	0	0 to +	0 to -	0 to -	0	+ / -	0 to -	0 to +	0 to -
	Revise standards for annual lead. The benefits of reducing concentrations would be significant on a per emission basis, but lower overall than for pollutants that are present more widely in concentrations above WHO guideline levels. The costs of a stricter standard depends on the level of ambition. Compliance with the current target value is already very high, also pointing to low costs for a limit value. Costs of a stricter standard 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. There is an important link to L3 regarding monitoring of additional heavy metals to improve the evidence base. **[BCR: Low/Medium]**											
X1	0 to +	0 to +	0 to +	0	0 to +	0 to -	0 to -	0	+ / -	0 to -	0 to +	0 to -
	Revise standards for annual arsenic: 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. The benefits of reducing emissions would be significant on a per emission basis, but lower overall than for pollutants that are present more widely in concentrations above WHO guideline levels. 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. There is an important link to L3 regarding monitoring of additional heavy metals to improve the evidence base. **[BCR: Low/Medium]**											

Intervention reference	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
Y1	0 to +	0 to +	0 to +	0	0 to +	0 to -	0 to -	0	+ / -	0 to -	0 to +	0 to -
	Revise standards for annual cadmium: Costs (and benefits) of implementing the standard as a limit value could be small, but this could help drive compliance at the remaining sites and ensure continued performance at compliant sites. The benefits of reducing emissions would be significant on a per emission basis. There is an important link to L3 regarding monitoring of additional heavy metals to improve the evidence base. **[BCR: Low/Medium]**											
Z1	0 to +	0	0	0	0	0 to -	0 to -	0	+ / -	0 to -	0	0 to -
	Revise standards for annual nickel: 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 and ensure continued performance at compliant sites. The benefits of reducing emissions would be significant on a per emission basis, but lower overall than for pollutants that are present more widely in concentrations above WHO guideline levels. Costs would strongly depend on the specific control measures deployed at an individual site to abate emissions. There is an important link to L3 regarding monitoring of additional heavy metals to improve the evidence base. **[BCR: Low]**											
Ø1	0 to ++	0 to +	0 to +	0 to +	0 to +	0 to --	+/-	0 to +	+ / -	+/-	0 to +	0 to ---
	Introduce standards for additional air pollutants: Setting standards would go beyond latest scientific advice and the extent to which they may reduce negative health impacts is therefore uncertain. A clear benefit of this intervention would be a requirement to monitor concentrations and this information could subsequently be used to gain more scientific evidence about health effects. Therefore this intervention is strongly linked to monitoring interventions (L1 and L2). Administrative burden would vary with ambition (with more air quality plans required in cases of the high ambition variant to account for the greater number of exceedances). There would be costs associated with additional monitoring required (link to L1 and L2). **[BCR: Low]**											

9.2.2 *Discussion*

Policy Area 1 explores long- and short-term limit values as well as average exposure indicators. The Fitness Check of the Ambient Air Quality Directives found that limit values have been more effective than other standards in driving down air pollutant concentrations. However, average exposure indicators can complement limit values by addressing larger areas where air quality needs improvement. In this way, the inclusion of average exposure indicators is expected to help reduce the average exposure of the population to harmful air pollutant concentration levels. Reducing average exposure can also facilitate compliance with limit values.

For setting standards for various pollutants (both long and short term), variants of the intervention consider different levels at which the standard can be set below the existing EU standard, such as interim targets where these have been set in the WHO air quality guidelines. Variants can also consider different timeframes over which a standard should be achieved. For average exposure indicators, variants 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.

Across all interventions reviewed for Policy Area 1, the more ambitious standards can achieve greater improvements in air quality, with corresponding benefits for health and ecosystems. Health benefits are more closely associated with exposure to finer particles $PM_{2.5.}$ Between long- and short-term standards, greater health benefits 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. Short-term standards are reviewed for $PM_{2.5}$, PM_{10}, NO_2, O_3 and SO_2. Generally, positive impacts are found for air quality, health and ecosystems. For benzene, BaP and heavy metals, the revisions are targeted to relatively fewer cases of exceedances, and benefits are significant in those cases but smaller in broader terms.

Administrative burden will also scale with ambition (mainly impacting Member State competent authorities). The costs of abatement measures can only be estimated rather broadly. Depending on the pollutant, past abatement measures taken and technological and other developments since, low-cost abatement measures may already have been adopted in the past. 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. For interventions that review the use of average exposure indicators, there is potential to reduce the administrative burden by taking more coordinated and centralised action, notably coordinating with actions that address limit values.

For interventions relating to heavy metals, there is an important link to interventions under Policy Area 3 (L2), and the need to enhance the evidence base around the source apportionment of sites with high concentrations of heavy metals.

For the intervention to introduce standards for additional pollutants, it is important to note that 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).

9.3 Policy area 2

9.3.1 *Summary of analysis*

Intervention reference	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	11. Policy synergies	12. Administrative Burden
A1	++	(+)	(+)	+	0	0	0	(+)	**0**	0	+	(-)
Introduce review triggered by scientific progress: Introduction of a mechanism that will provide a basis for the alignment of the AAQ Directive with the latest scientific knowledge will directly contribute towards reductions in air quality concentrations. Meeting the direct objective of air quality reduction will subsequently indirectly protect EU population from harmful exposure to air pollution and indirectly benefit ecosystems. Direct costs estimated for this intervention are small administrative costs for the Commission. [BCR: High]												
A2	(+)	(+)	(+)	(+)	0	0	0	0	0	0	(+)	(-)
Introduce review of EU air quality standards triggered by technical progress: This measure introduces a mechanism for adjusting EU air quality standards based on technical progress in air pollution reduction. This intervention would formalise consideration of technological progress 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. However, the process would be driven by technology considerations, not health considerations, and therefore addresses the objective of protecting human health only to some extent. Direct costs estimated for this intervention are small administrative costs for the Commission. [BCR: Low]												
A3	(+)	(+)	(+)	(+)	0	0	0	(+)	0	0	0	(-)
Introduce option to notify stricter standards: This measure introduces a provision to allow 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. This intervention has a potential to have a small indirect impact on reducing air pollution concentrations as it would contribute to sharing of information, including on scientific and technical data that can be used by the EU and other EU Member States. This intervention has been assessed under the assumption that it will enhance the Commission's evidence base regarding Member State policy action at EU level. Direct costs estimated for this intervention are small administrative costs for EU Member State competent authorities. The benefit cost ratio of this measure is considered high as low administrative burden would lead to an improved knowledge base. [BCR: High]												
A4	(+)	(+)	(+)	(+)	0	0	0	0	0	0	0	-
Introduce a list of priority air pollutants: This measure aims to keep and periodically update a list of priority air pollutants with a view to monitoring air pollutants of emerging concern. This intervention is likely to have a small indirect impact on air quality as the monitoring of identified priority pollutants could eventually lead to regulating them in the AAQ Directive. Black carbon, UFP, ammonia, PFAS, dioxins and PCB have been specifically highlighted as possible priority air pollutants. Direct costs estimated for this intervention are small administrative costs for the Commission. 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.[BCR: Low]												

B1	+	0	0	0	0	0	0	0	0	0	0	(-)
Introduce additional short-term standards: 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. This intervention could therefore contribute to improvement in air quality and consequent health benefit alongside others. The extent of impacts is very much dependent on the standards set (interventions under Policy Area 1). Direct costs estimated with this intervention are small administrative costs for the Commission. Implementation may be challenging as there is a lack of consensus over which short term standards best target risks associated with exposure. [BCR: High]												
B2	+	+	(+)	(+)	0	0	0	+	0	0	(+)	(-)
Introduce additional alert/information thresholds: Alert and information thresholds provide a trigger for alerting the public and developing short term action. Short-term action is expected to benefit air quality indirectly to a small extent. Better information (on all relevant air pollutants) for the public would enable citizens, in particular vulnerable groups, to take more targeted and effective personal measures to reduce their exposure to harmful air pollution, thereby having a direct small positive impact on human health. This intervention is expected to have small direct administrative costs for the Commission and competent authorities. [BCR: Medium]												
B3	(+)	(+)	(+)	(+)	(+)	0	0	(+)	0	0	(+)	(-)
Revise definition of average exposure standards: This may improve the way that the average general population exposure reduction is monitored and addressed. The average exposure indicator (AEI) is currently measured in urban background stations, which might not always be reflective of general population exposure. As a result, this measure is likely to provide better targeting of general air pollution exposure reduction measures, thereby contributing to further protection of public health from harmful air pollution and reducing the air quality cost to society. It could also improve the effectiveness of implementing mitigation measures. Direct costs estimated with this intervention are small administrative costs for the Commission and Member States. [BCR: High]												
B4	(+)	(+)	(+)	(+)	0	0	0	0	0	0	(+)	(-)
Introduce guidance on addressing exceedances: While varying circumstances across different EU Member States are a challenge for developing effective guidelines, guidance 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 protecting the general population from harmful air pollution. It is difficult to estimate indirect compliance and potential mitigation costs. Direct costs estimated with this intervention are small administrative costs for the Commission. [BCR: Medium]												
B5	++	+	+	+	+	-	0	+	0	0	0	(-)
Introduce limit values for additional air pollutants: Limit values have proved more effective in reducing air pollutant concentrations than other standards, as evidenced in the Fitness Check of the Ambient Air Quality Directives. Introduction of limit values for all pollutants, where these would prove feasible, would strengthen the AAQ Directive. Direct costs estimated with this intervention are medium administrative costs for the Commission, 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). 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 pollutant). [BCR: Medium]												
C1	(+)	(+)	(+)	(+)	(+)	0	0	0	(+)	0	(+)	--

<table>
<tr><td colspan="13">Revise obligations to take measures triggered by exceedances of air quality standards: This measure would specify the ‘type of measures’ that competent authorities must take to ensure that exceedance periods can be kept as short as possible. Since authorities would be provided with a long-list of measures to select from, this would lead to a systematic approach to developing an air quality plan and reduce the time to explore potential measures. The intervention 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 this also depends on funds for implementation of measures and properly trained staff in competent authorities. 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. The success of this intervention relies on the capability (knowledge, skills, competences) of Competent Authorities in charge of designing air quality plans to develop effective plans. This intervention will not result in any additional relevant direct costs for competent authorities as the obligation to develop air quality plans already exists. [BCR: Medium]</td></tr>
<tr><td>C2</td><td>(+)</td><td>(+)</td><td>(+)</td><td>(+)</td><td>(+)</td><td>0</td><td>0</td><td>0</td><td>(+)</td><td>0</td><td>(+)</td><td>--</td></tr>
<tr><td colspan="13">Revise/clarify the term ‘as short as possible’: Specifying a clear time period within which air quality standards have to be respected 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 provide a maximum time span within which results have to be achieved, improving the speed of response rates in many cases. However, as there is no one-size-fits-all timeframe, there is a risk that a fixed timeframe will slow down action in some cases where compliance could be achieved before the end of the fixed term. There may also be effective long-term measures that cannot be fully implemented within the given timeframe. A fixed timeframe may also weaken previous interpretations of the term ‘as short as possible’ by the courts. [BCR: Medium]</td></tr>
<tr><td>C3</td><td>(+)</td><td>(+)</td><td>(+)</td><td>0</td><td>(+)</td><td>0</td><td>0</td><td>0</td><td>(+)</td><td>0</td><td>0</td><td>-</td></tr>
<tr><td colspan="13">Revise short-term action plans and air quality plans: Coordination between short term action plans and air quality plans would lead to synergies among actions and avoid inefficiencies or inconsistencies. Small administrative costs may be incurred for Member State competent authorities related to coordination activities which are expected to be more than off-set by efficiency gains. According to several respondents to the targeted stakeholder survey, the revised Directive could require that short term action plans are included in air quality plans. Also, to facilitate this linkage between the two types of plans, the Ambient Air Quality Directives should include the minimum content that short-term action plans should contain. [BCR: Medium]</td></tr>
<tr><td>C4</td><td>+</td><td>+</td><td>+</td><td>(+)</td><td>(+)</td><td>0 to -</td><td>(-)</td><td>+</td><td>(+)</td><td>(-)</td><td>(+)</td><td>-</td></tr>
<tr><td colspan="13">Introduce additional short-term action plans for other pollutants: 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, thus expected to benefit air quality and protect in particular sensitive groups from immediate health risks. Additional administrative burden is expected from this intervention as it imposes additional requirements (i.e. additional work) to Member State competent authorities. Risks linked to this intervention have to do with time-lag risk and separation of source and pollution. Short term action plans may be effective only to a limited extent where pollution episodes cannot be influenced by local measures or in case of secondary pollutants for which it is not straight forward to identify immediate measures. [BCR: Medium]</td></tr>
<tr><td>C5</td><td>(+)</td><td>(+)</td><td>(+)</td><td>(+)</td><td>(+)</td><td>-</td><td>0</td><td>0</td><td>(+)</td><td>0</td><td>(+)</td><td>---</td></tr>
<tr><td colspan="13">Introduce a requirement to update air quality plans: Requiring regular updates of air quality plans would increase the effectiveness of plans and thus have an ‘indirect’ positive effect on air quality. Mitigation costs and administrative burden are expected to directly impact Member States’ competent authorities responsible</td></tr>
</table>

for the updating of air quality plans and implementation of measures. A risk identified for this measure relates to the fact that the process of drafting air quality plans tends to be long. [BCR: Medium]												
D1	(+)	(+)	(+)	0	0	0 to -	0	0	0	0	0	--
Revise requirements to involve stakeholders: This measure seeks to improve the involvement of all relevant actors in the design and implementation of air quality plans. This may possibly be done by adding a requirement for consulting and involving government authorities at various levels, and by introducing a new 'public participation' clause for the development of air quality plans. [BCR: High]												
D2	0	0	0	0	0	0	0	0	0	0	0	--
Introduce a 'one zone, one plan' requirement: 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. However, the benefits and added value of this intervention are unclear while it would generate some costs (and considerable administrative burden). Overall it is unclear what the added value of this intervention would be and a global approach does not seem helpful as air quality plans and air quality zones are very specific to local conditions. 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. [BCR: Low]												
M1	(+)	(+)	(+)	(+)	0	0 to (+)	0	0	0	0	(+)	--
Introduce methodology to assess transboundary contribution: This measure aims to facilitate and harmonise the used methodology when assessing transboundary air pollution/contributions to local/regional air pollution. The effectiveness of this intervention to improve air quality is impacted by the lack of an agreed methodology between Member States or from expert groups. Implementing this intervention would imply additional costs for Member States who would need to align their methodology to assess transboundary air pollution. A challenge for implementation is that it may be unclear where the responsibility lies for transboundary air pollution assessment and action. In addition, assessment expertise is needed to conduct the modelling and there is a risk of limited expertise at local level. [BCR: High]												
M2	(+)	(+)	(+)	(+)	(+)	-	0	0	0	0	(+)	-
Revise obligations for transboundary cooperation: Requiring joint transboundary cooperation above a specific threshold would foster transboundary cooperation and in turn improve air quality in bordering regions, and benefit health and ecosystems in these areas. Implementing this intervention would imply additional costs for competent authorities, especially in bordering countries were transboundary air pollution is an issue. Implementation challenges include enforcement (where one Member State cannot enforce action in another), lack of funds at local/regional authority level and acceptability of authorities and industry to implement measures to bring air improvements elsewhere. [BCR: Medium]												
E1	(+)	(+)	(+)	(+)	(+)	(-)	0	0	(+)	0	(+)	(-)
Introduce minimum levels for financial penalties: Effective minimum penalty levels should discourage competent authorities and industry or other private entities from breaching provisions of the Directives or measures adopted pursuant to the Directives, thus indirectly benefiting air quality, ecosystems and health. If effective, it would lead to competent authorities and industry implementing more measures to avoid breaches (and therefore avoid high fines). This would indirectly generate additional costs for these actors, though related to achieving compliance. The additional administrative burden of clarifying levels of financial penalties is low and would facilitate their implementation. The risks for implementation have to do with determining penalty levels applicable across the EU and, more indirectly, with difficulties concerning												

enforcement of breaches, as well as with the need for timely action and a faster process in light of breaches [BCR: Medium – High]												
E2	(+)	(+)	(+)	(+)	(+)	-	0	0	(+)	0	(+)	0
Introduce right to health damage compensation: This measure would work as an effective incentive for competent authorities and industry/business to implement more effective measures, which in turn would benefit air quality, health and ecosystems. This measure, if implemented, would require competent authorities and/or industry (polluters) to pay compensation to those who have suffered damage to health from air pollution and would therefore carry mitigation costs for those who are held accountable for breaches of air quality standards. It would also carry administrative burden for competent authorities and/or industry (polluters) as they would need to put in place and manage the compensation scheme and deal with a potentially increasing number in lawsuits by citizens / civil society, though only in case of continued non-compliance. Implementation challenges include the difficulty of proving the causal link between pollution and long-term health effects and the question of accountability (who is held responsible). [BCR: Medium]												
E3	0 to (+)	0 to (+)	0 to (+)	0 to (+)	0	0 to (+)	0	0	(+)	0	0 to (+)	(-)
Introduce a fund to be fed by penalties paid: A dedicated fund would make available funding for compensation for health damage suffered and facilitate access to funding of the implementation of mitigation measures (leading to measures being more readily implemented). However, it could also lead to competent authorities using the fund to finance measures that they would implement in any case, without leading to 'more' (i.e. additional) measures being implemented, which is a risk the governance of the fund would have to address. The effectiveness of this measure requires a solid framework of penalties and procedures (administrative, legal) that ensure that penalties are duly paid. Setting up and administering such a fund will generate additional burden. Risks for implementation include a potential conflict of interest in cases where the authority that has to pay also administers the fund and the alignment with national budgetary rules. The organisation of the fund could provide safeguards to avoid that the budget from which the penalty is paid into the fund is not the one benefiting from it. [BCR: Low]												
E4	(+)	(+)	(+)	(+)	(+)	(-)	0	0	(+)	0	0	0
Introduce an explicit 'access to justice' provision: There is a gap in the AAQ Directives with regard to 'access to justice' and including such a provision in the legislation would be a coherent step, in line with other environmental Directives, Article 47 of the EU Charter on fundamental Rights, the Aarhus Convention and the case law of the Court of Justice of the EU. Public judicial enforcement of the obligations under the AAQ Directives has already led to multiple national rulings (in several Member States) mandating national authorities to take action to improve air quality. Introducing an explicit provision would enable such actions by citizens that are currently unable to do so because of strict national procedural requirements. In turn, this would indirectly benefit air quality and human health as a whole. Additional administrative burden for Member States (probably central / national government) and industry may occur as an increase in lawsuits may be expected; this would largely depend on whether national authorities have already taken the necessary measures to comply with the Aarhus Convention and the relevant case law of the Court of Justice of the EU. The implementation of the intervention carries risks in terms of capacity from Member States to deal with additional legal claims. [BCR: High]												
F1	0	(+)	0	0	0	0	0	(+)	0	0	0	--
Revise provisions related to up-to-date data: 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 benefits of the												

intervention are indirect while its costs are negligible but administrative burden will increase slightly for Member States. There are risks around the accuracy of real-time information. [BCR: Medium/High]												
F2	0	(+)	0	0	0	0	0	0	0	0	0	-
Introduce requirement to provide AQ health data: Information on health (protection) would allow citizens to make decisions that may impact on their health such as deciding not to exercise outdoors or opting for a cleaner transport route. Ensuring that information is provided to 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. [BCR: Medium]												
F3	0	0	0	0	0	0	0	(+/-)	0	0	0	---
Introduce use of specific communication channels: Obliging competent authorities to use a set of information channels would lead to a better, and more consistently informed public with indirect benefits on health. 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. [BCR: Low]												
F4	0	(+)	0	0	0	0	0	(+)	0	0	0	-
Introduce requirements for harmonised AQ index: 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 with indirect benefits for health. However, there are concerns that the European Air Quality Index is not effective (e.g. around its ability to represent multi-pollutant effects), and that complete harmonisation may restrict the ability of Member States to tailor advice and information to the specific situation in each Member State. The intervention will increase administrative burden for competent authorities (regional or national) as it will require these to adapt their index bands. [BCR: Medium]												

9.3.2 *Discussion*

Many of the interventions reviewed for Policy Area 2 do not entail significant direct environmental, social or economic impacts but would form an important means for

- ensuring that more effective and efficient action is taken to achieve the air quality standards (for instance by enabling more targeted action);
- ensuring timely action is taken to achieve air quality standards (for instance through dissuasive penalties)reducing administrative burden (for instance by enabling more synergies between air quality plans and short-term action plans); and
- Future proofing EU standards by ensuring they are reviewed regularly

Thus, the majority of the benefits identified are indirect, derived from expert judgement, and also interpretation of the way in which the interventions will underpin and complement changes to other interventions under review, notably for Policy Area 1.

Direct benefits primarily relate to air quality and have been identified for five of the interventions reviewed for Policy Area 2 (interventions to: introduce review triggered by scientific progress; introduce additional short-term standards; introduce additional alert/information thresholds; introduce limit values for additional air pollutants, and introduce additional short-term action plans for other pollutants). Introducing limit values for additional air pollutants would have the potential for the most significant direct benefits among the interventions assessed for Policy Area 2. It is important to note that the benefits are dependent on the pollutant. For example, in the case of ozone, the use of target values is better suited than limit values due to the specific mechanisms of ozone formation in the atmosphere and the particularly strong role of transboundary sources and annual variations in meteorology for this air pollutant.

Many of the interventions within Policy Area 2 are expected to incur small administrative costs for the Commission, administrative costs for competent authorities, and some abatement costs (identified for 7 of the interventions reviewed). Costs relate to additional monitoring needs, updating of air quality plans and implementation of measures, transboundary cooperation, financial penalties (however only in cases of non-compliance), and the use of specific communication channels. Indirect costs were also identified as a possible result of introducing an explicit ‘access to justice’ clause (however only in cases of non-compliance).

9.4 Policy area 3

9.4.1 *Summary of analysis*

<table>
<tr><th>Intervention reference</th><th>1. Air Quality</th><th>2. Impact on Health</th><th>3. Impacts on Ecosystems</th><th>4. Climate change links</th><th>5. Costs to society</th><th>6. Mitigation costs</th><th>7. Impacts on Competitiveness</th><th>8. Impacts on Sensitive Groups</th><th>9. Societal benefits and burden sharing</th><th>10. Impacts on Employment</th><th>11. Policy synergies</th><th>12. Administrative Burden</th></tr>
<tr><td>G1</td><td>(+)</td><td>(+)</td><td>(+)</td><td>0</td><td>(+)</td><td>0</td><td>0</td><td>0</td><td>(+)</td><td>0</td><td>0</td><td>---</td></tr>
<tr><td colspan="13">Revise rules related to indicative sampling points: When used to supplement (not substitute), fixed monitoring 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. This contributes to an overall improved air quality assessment process with indirect benefits to air quality, health and ecosystems. However, the substitution of fixed monitoring stations by lower quality indicative monitoring devices is seen by many stakeholders as a major risk to degrade an important pillar in air quality management. Administrative burden is dependent on implementation: where used to supplement fixed monitoring, there would be an increase in costs and administrative burden, whereas substitution of fixed monitoring stations by indicative monitoring would result in cost savings. [BCR: High]</td></tr>
<tr><td>G2</td><td>(+)</td><td>(+)</td><td>(+)</td><td>0</td><td>0</td><td>0</td><td>0</td><td>(+)</td><td>(+)</td><td>0</td><td>0</td><td>---</td></tr>
<tr><td colspan="13">Introduce requirements for AQ modelling: Variants relate to the possible use of air quality modelling and include:

(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).

Air quality modelling improves air quality monitoring and assessment, thus allowing for a better understanding of air quality concentrations, supporting a more effective and more targeted air quality management. The administrative burden may increase for Competent Authorities (to meet the reporting requirement). The increase is likely to depend on the current modelling capability and practices within each Member State. There are risks for implementation linked to technical capacity and potential lack of modelling guidance and/ or lack of resources for training and capacity building. There is also a risk that</td></tr>
</table>

Intervention reference	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
Member States may view the introduction of a mandatory requirement of modelling as a reason to reduce their monitoring network. 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. [BCR: High/Medium]												
G3	0	0	0	0	0	0	0	0	0	0	0	(-)
Revise rules for regular review of AQ assessment: 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. 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. Administrative burden may be significant if the period for review is annual (stakeholder respondents favored the retention of 5-year reviews). [BCR: Low]												
H1	+	+	+	0	+/-	0	0	0	0	0	0	---
Revise minimum number of sampling points: The intervention would involve changing the minimum number of sampling points per air quality zone for each pollutant should be revised with latest scientific knowledge. Changing the minimum number of sampling points required has potential for an increase or decrease in monitoring for the assessment of air quality (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, while an increase in the minimum number of stations would have a positive impact on air quality, health and ecosystem but increase administrative burden). Costs arising from an increased number of stations would be incurred from greater laboratory analysis, and the additional staff needed for servicing and maintenance and data management. There is little/no support from stakeholders for any decrease in the minimum number of sampling points, while an increase of monitoring stations was favoured for at least some pollutants and with a minimum to measure population exposure. 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. [BCR: Medium for increase in sampling points]												
H2	(+)	(+)	0	0	(+)	0	0	0	0	0	0	---
Simplify combined PM_{10}/$PM_{2.5}$ monitoring: This intervention de-couples the current minimum number of sampling points for PM_{10} and $PM_{2.5}$, which should be set independently and cannot substitute one another. $PM_{2.5}$ is a key pollutant for public health risk assessment. Given its important impacts on mortality and morbidity, it is essential for it to be considered and assessed independently from PM_{10}. Clarifying and giving more focus on the assessment of this pollutant in the revised AAQ 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 as those for new monitoring samplers are often high and comes with on-going maintenance costs. Public Authorities report												

Intervention reference	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
no real increase in administrative burden to monitor PM_{10} and $PM_{2.5}$ separately. There is a time lag associated with this intervention (to establish the new sites) and this may risk air quality in the short term. Additional staff is needed to support sampler operation and data management. [BCR: High]												
H3	0	0	0	0	0	0	0	0	0	0	0	--
Simplify the definitions of sampling points types: Currently station classification includes a number of categories such as Urban, Suburban, Rural, Industrial, traffic, background. Station classification could be simplified to identify sites only as hotspots or background locations. This may enable identifying a key source of pollution currently missing in the classification which is that due to residential combustion. As this intervention is a desk task to reclassify the current sites it is unlikely to have any real impact on administrative burden. To be effectively implemented, this intervention would require guidance. However, a more simplified classification risks loss of clarity and misunderstanding on the site differences and the 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.BCR: Low]												
I1	(+)	(+)	(+)	0	0	0	0	(+)	0	0	0	0
Introduce obligations to maintain sampling points: 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. 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. In most cases this would be a prerequisite for more effective and more targeted air quality management. [BCR: High]												
I2	(+)	(+)	(+)	0	0	0	0	0	0	0	0	(-)
Introduce obligations to monitor long-term trends: 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. Assessing long-term trends in pollution data is important for the assessment and management of air quality. There is significant benefit to scientific understanding and policy development to protect health and the environment to have access to a long-established network of monitors. Costs for this intervention depend on the variant. Administrative burden and costs of monitoring could increase as the amount of fixed monitoring stations would remain the same, but it may be required to increase indicative measurements at all previous fixed measurement locations for long-term trend monitoring and analysis. However, where fixed monitoring stations could be replaced by indicative monitoring or modelling a cost saving is likely. For this intervention to be successful, it is important to align with those proposed interventions with the objective of improving quality of indicative monitoring and modelling. [BCR: Low]												
I3	(+)	0	0	0	0	0	0	(+)	0	0	0	-
Introduce a protocol for relocated sampling points: 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												

<table>
<tr><th>Intervention reference</th><th>1. Air Quality</th><th>2. Impact on Health</th><th>3. Impacts on Ecosystems</th><th>4. Climate change links</th><th>5. Costs to society</th><th>6. Mitigation costs</th><th>7. Impacts on Competitiveness</th><th>8. Impacts on Sensitive Groups</th><th>9. Societal benefits and burden sharing</th><th>10. Impacts on Employment</th><th>11. Policy synergies</th><th>12. Administrative Burden</th></tr>
<tr><td colspan="13">transparency especially when areas are in exceedance. This intervention while helpful for greater assessment harmonisation is likely to have little impact on air quality and other indicators. The costs for this intervention are low. Although, reduced flexibility to relocate samplers when necessary, may risk increased administration burden on Member States to find an alternative monitoring location. [BCR: Medium]</td></tr>
<tr><td>J1</td><td>(+)</td><td>(+)</td><td>(+)</td><td>0</td><td>0</td><td>0</td><td>0</td><td>(+)</td><td>0</td><td>0</td><td>0</td><td>--</td></tr>
<tr><td colspan="13">Revise macro-scale siting of sampling points: 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. 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 in the implementation of the requirements and affect the proportionality of any potential infringement action. This intervention would increase the administrative burden for competent authorities in terms of sampling point evaluation and reporting of the relevant indicators. Most stakeholders support the implementation of this intervention since it will 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. [BCR: Medium]</td></tr>
<tr><td>J2</td><td>(+)</td><td>0</td><td>0</td><td>0</td><td>(+)</td><td>0</td><td>0</td><td>(+)</td><td>0</td><td>0</td><td>0</td><td>--</td></tr>
<tr><td colspan="13">Revise micro-scale siting of sampling points: Variants include:
(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.

Revisions to micro-siting criteria, which also apply to indicative monitoring, may have an indirect benefit to society costs due to an indirect improvement on public health. Where new indicative monitoring is being planned this intervention may give access to a higher quality monitoring dataset to assist air quality assessment, underpinning air quality action. There is a low administrative burden, unless the intervention leads to the disqualification of existing sites (in which case the administrative burden would be high). Costs are relatively low, particularly if this intervention does not result in the disqualification of established long-term sampling locations. The most concern raised by stakeholders about micro-siting criteria for sampling points is related to traffic 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. [BCR: Medium]</td></tr>
<tr><td>J3</td><td>(+)</td><td>(+)</td><td>(+)</td><td>0</td><td>(+)</td><td>0</td><td>0</td><td>(+)</td><td>0</td><td>0</td><td>0</td><td>---</td></tr>
</table>

Intervention reference	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
Introduce obligation for spatial representativeness: 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. The concept of an SR area helps to clarify and harmonise 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. When modelling capacity is available higher Tier methods are rather straightforward to apply. 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 Ambient Air Quality Directives in order to ensure comparability between Member States. [BCR: High to Medium depending on the Tier]												
K1	(+)	(+)	(+)	0	0	0	0	0	0	0	0	-
Revise AQ monitoring data quality objectives: 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). 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. This intervention would improve data quality requirements for sampling points which is likely to increase robustness of data and may supplement evidence for trend analysis and modelling. This may lead to indirect improvements in air quality, health and ecosystems which may indirectly reduce costs to society as clarity is provided over the use of data. The costs for this are low or may even be a cost saving as administrative burden may reduce as modelling is likely to cost less than additional fixed or indicative measurements. [BCR: Medium]												
K2	0	(+)	0	0	0	0	0	0	0	0	0	--
Introduce up-to-date data at all sampling points: This intervention would increase the harmonisation of the reporting of real-time air quality information, which during pollution episodic events, brings benefit to the public. Up to date data also helps to improve the accuracy of air quality forecast modelling. Costs are low and those Member States already publishing real time data are unlikely to be impacted. There are risks to implementation in cases of monitoring sampler or IT system failure as this would inhibit publication of air quality data in real-time. Increased resources may be needed for some Member States to ensure immediate data quality. [BCR: Low]												

Intervention reference	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
K3	(+)	(+)	(+)	0	0	0	0	0	0	0	0	--
Introduce AQ modelling data quality objectives: Modelling Quality Objective (MQO) would need to 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. 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. There would be a small administrative burden as some of the modelling systems would have to be upgraded to meet the quality standards [BCR: High]												
K4	(+)	(+)	(+)	0	0	0	0	0	0	0	0	-
Revise approach to AQ assessment uncertainty: Revised monitoring uncertainty and how this is designed, particularly important particularly when air quality standards are low, could improve the quality of measurement data leading to overall improved air quality and reducing health and ecosystem impacts. While it is unlikely to bring significant benefits to air quality management it is an important aspect to clarify. Changes in the calculation for uncertainty may have a negative impact on existing long-established monitoring datasets should it not comply with uncertainty standards. This would negatively impact data quality and overall assessment of pollutant levels for those in non-compliance. Overall, stakeholders saw benefit in combining uncertainty in both absolute and percentage terms. [BCR: Medium]												
L1	(+)	(+)	(+)	0	(+)	0	0	0	0	0	0	---
Introduce concept of monitoring at 'super-sites': Further establishment of supersites across Europe, particularly for observing emerging pollutant trends would bring large benefits for their future assessment and control. Most benefit would be gained if these sites were established at both urban and rural locations. Monitoring is very costly and there is a significant administrative burden (for capital and maintenance costs as well as more staff and training needs), however some Member States already monitor with a supersite network in operation, i.e. Finland. [BCR: Medium]												
L2	**(+)**	**(+)**	**(+)**	**(+)**	**(+)**	**0**	**0**	**0**	**0**	**0**	**0**	**---**
Introduce obligations to monitor more pollutants: Possibilities for which additional air pollutants should be monitored, include: Ultrafine particles, Ammonia, Fine combustion particles, Oxidative potential, Additional heavy metals, Hydrogen sulphide (H2S) and other reduced sulphur compounds (TRS), Nitro-PAHs and Pesticides. Monitoring of emerging pollutants is essential to advance our understanding of current pollution loads, but also to assess source apportionment and underpin modelling to assess future projected levels. This intervention would facilitate research on these emerging pollutants and support epidemiological studies of pollutants of most concern to health. Monitoring of air pollution is costly, and even more so for pollutants which are not widely monitored. Administrative burden would be high, and likely to include capacity building to train site operators. Monitoring for these pollutants would be essential to setting standards for additional pollutants and the setting up of a priority watchlist (links with Policy Area 1 and intervention Ø1 and Policy Area 2 and intervention A4). [BCR: High]												
L3	(+)	(+)	(+)	0	0	0	0	0	0	0	0	---
Revise list of VOC to monitor: Further elaboration of VOC monitoring is necessary to develop scientific knowledge to support emission control though costs are high (for new analysers to measure more VOCs, and												

Intervention reference	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
additional resources that may be needed to service and maintain sites and manage and report data). However, the merit of monitoring more (or other) VOCs in addition to those regularly monitored is unclear. Further monitoring should be accompanied by data quality and siting specifications with appropriate guidance. [BCR: Low]												
N1	++	+	+	(+)	(+)	-	0	(+)	0	0	+	--
Revise the information in air quality plans: Variants 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/m³ 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). It is expected that this intervention would provide an improved framework for air quality planning which gives rise to better air quality plans and eventually an improved air quality. Additional administrative burden expected to 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. [BCR: High]												

9.4.2 *Discussion*

Policy Area 3 consists of interventions that seek to improve and harmonise monitoring and modelling, as well as extend the monitoring to pollutants of emerging concern, thus strengthening the evidence base and providing the foundation to enable effective and efficient air quality management across all Member States. This policy area also includes the minimum content that air quality plans should contain.

For the majority of the interventions reviewed under Policy Area 3, the impacts have been assessed as small, and more often than not, indirect. Only one intervention is expected to result in direct positive impacts (revise the information in air quality plans). It is expected that this intervention would provide an improved framework for air quality planning which would give rise to better air quality plans and eventually an improved air quality and consequent benefits for health and ecosystems.

It is important to underline that, while the *individual* impact of Policy Area 3 interventions is often assessed as small and/or indirect, they are often important to underpin the effectiveness of air quality standards, air quality plans and governance. Although not presented in the summary table above, linkages with interventions in Policy Areas 1 and 2 are key. This detail is in the accompanying appendix detailing the interventions. Linkages between the interventions are incorporated in Section 10 in the grouping of interventions into policy options and packages.

No mitigation costs have been identified for any of the interventions under Policy Area 3 but administrative burden is significant in four cases, namely where capacity building is needed to train site operators and where additional resources may be needed to service and maintain sites and manage and report data.

9.5 Benefit Cost Ratio Summary

Table 67 summarises the benefit cost ratio for all 69 interventions considered in this impact assessment. These are presented by policy areas, and the most uncertainty lies in those interventions that focus on air quality standards as the variation in the proposed standard has a large impact on the BCR. Priority areas identified in interventions associated with revisions to the legislative framework include:

- Introduction of a review triggered by scientific progress.
- Introduction of stricter standards.
- Introduction of short term standards.
- Introduction of additional short term action plans.
- Revision of the requirements to involve stakeholders.
- Introduction of a method to assess transboundary pollution.
- Introduction of an explicit `access to justice' clause.

Priority areas identified in interventions associated with revisions to air quality monitoring, modelling and air quality plans include:

- Revision of the rules related to indicative sampling points.
- Introduction of requirements for AQ modelling.
- Simplification for combining PM_{10}/$PM_{2.5}$ monitoring.
- Introduction of obligations to maintain sampling points.
- Introduction of obligations for spatial representativeness.
- Introduction for AQ modelling data quality objectives.
- Introduction for obligations to monitor more pollutants.
- Revision of the information required in air quality plans.

Table 67 Benefit Cost Ratio (BCR) for all 69 specific interventions considered in this impact assessment

		Focus on EU air quality standards	BCR	35	C3	Revise short-term action plans & air quality plans	M
1	O1	Revise standards for annual $PM_{2.5}$	H	36	C4	Introduce additional short-term action plans	M
2	O2	Introduce standards for daily $PM_{2.5}$	H	37	C5	Introduce requirement to update air quality plans	M
3	O3	Revise average exposure standards for $PM_{2.5}$	L-H	38	D1	Revise requirements to involve stakeholders	H
4	P1	Revise standards for annual PM_{10}	H	39	D2	Introduce a ‘one zone, one plan’ requirement	L
5	P2	Revise standards for daily PM_{10}	L	40	M1	Introduce methodology to assess transboundary	H
6	P3	Introduce average exposure standards for PM_{10}	L-H	41	M2	Revise obligations for transboundary cooperation	M
7	Q1	Revise standards for annual NO_2	H	42	E1	Introduce minimum levels for financial penalties	M/H
8	Q2	Revise/introduce standards for hourly/daily NO_2	H	43	E2	Introduce right to health damage compensation	M
9	Q3	Introduce average exposure standards for NO_2	L	44	E3	Introduce a fund to be fed by penalties paid	L
10	R1	Introduce standards for peak-season O_3	L/M	45	E4	Introduce an explicit ‘access to justice’ clause	H
11	R2	Revise standards for 8-hour O_3	L/M	46	F1	Revise provisions related to up-to-date data	M/H
12	R3	Introduce average exposure standards for O_3	L/M	47	F2	Introduce requirement to provide AQ health data	M
13	S1	Revise standards for annual SO_2	L	48	F3	Introduce use of specific communication channels	L
14	S2	Revise standards for daily/hourly SO_2	L	49	F4	Introduce requirements for harmonised AQ index	M
15	T1	Revise standards for daily/8-hour CO	L			**Focus on AQ monitoring, modelling, plans**	
16	U1	Revise standards for annual benzene	L/M	50	G1	Revise rules related to indicative sampling points	H
17	V1	Revise standards for annual benzo(a)pyrene	L/M	51	G2	Introduce requirements for AQ modelling	M/H
18	W1	Revise standards for annual lead	L/M	52	G3	Revise rules for regular review of AQ assessment	L
19	X1	Revise standards for annual arsenic	L/M	53	H1	Revise minimum number of sampling points	M
20	Y1	Revise standards for annual cadmium	L/M	54	H2	Simplify combined PM_{10}/$PM_{2.5}$ monitoring	H
21	Z1	Revise standards for annual nickel	L	55	H3	Simplify the definitions of sampling points types	L
22	Ø1	Introduce standards for additional air pollutants	L	56	I1	Introduce obligations to maintain sampling points	H
		Focus on AQ legislative framework		57	I2	Introduce obligations to monitor long-term trends	L
23	-	Merge provision of Directives 2008/50 and 2004/107		58	I3	Introduce a protocol for relocated sampling points	M
24	A1	Introduce review triggered by scientific progress	H	59	J1	Revise macro-scale siting of sampling points	M
25	A2	Introduce review triggered by technical progress	L	60	J2	Revise micro-scale siting of sampling points	M
26	A3	Introduce option to notify stricter standards	H	61	J3	Introduce obligation for spatial representativeness	M
27	A4	Introduce a list of priority pollutants	L	62	K1	Revise AQ monitoring data quality objectives	M
28	B1	Introduce additional short-term standards	H	63	K2	Introduce up-to-date data at all sampling points	L
29	B2	Introduce additional alert/information thresholds	M	64	K3	Introduce AQ modelling data quality objectives	H
30	B3	Revise definition of average exposure standards	H	65	K4	Revise approach to AQ assessment uncertainty	M
31	B4	Introduce guidance on addressing exceedances	M	66	L1	Introduce concept of monitoring at ‘super-sites’	M
32	B5	Introduce limit values for additional air pollutants	M	67	L2	Introduce obligations to monitor more pollutants	H
33	C1	Revise obligations triggered by exceedances	M	68	L3	Revise list of VOC to monitor	L
34	C2	Revise/clarify definition of ‘as short as possible’	M	69	N1	Revise the information in air quality plans	H

10 Analysis of illustrative policy packages

10.1 Shortcoming I

Box I Highlights from Policy Option I (POI)

POI is a package which considers 27 policy interventions in different combinations to address the shortcoming identified in the AAQ Directive fitness check around environment and health protection. Policy options have been developed to tackle four underlying drivers, some of which can be supplemented with further interventions to develop the overall policy package. Three variants are presented around the 'revising air quality objectives' variant, resulting in six options overall. The six options are:

- Revising air quality objectives equivalent to 5 μg/m^3 $PM_{2.5}$
- Revising air quality objectives equivalent to 10 μg/m^3 $PM_{2.5}$
- Revising air quality objectives equivalent to 15 μg/m^3 $PM_{2.5}$
- Establishing air quality objectives for additional air pollutants
- Revising average exposure reduction obligations
- Providing for a regular review of EU air quality standards.

Air quality standards are fundamental to drive action for the protection of human health and the environment. The WHO air quality guidelines (AQGs) published in 2021 provides a new benchmark for the setting of air quality standards for many of pollutants covered by the AAQ Directives. Policy options I-1, I-2 and I-3 consider evidence for 12 air pollutants and proposes new standards for the majority of these with varying levels of ambition.

Setting health based-air quality standards for a number of emerging pollutants (e.g. UFP, Black Carbon and Ammonia) has been considered under option I-4. However, the evidence for this is too weak to support recommendation at this time.

AEI is currently measured in urban background stations, which might not always be reflective of general population exposure. Furthermore, an AEI only exists for $PM_{2.5}$, but could complement other standards to drive concentration reductions in other pollutants. Option I-5 proposes defining standards on a regional basis or including additional stations in the calculation of metrics to improve the approximation of exposure, whilst considering the merits of AEIs for the different pollutants. Likewise requiring that Member States to develop AQ Plans where obligations are not being met, will ensure that action is taken to address exceedances (and/or ensure enforcement action can be taken).

There is currently no mandate for regular reviews of air quality standards. Such a review is introduced within policy option I-6 which would be triggered by scientific progress.

Table 68 Policy Options to address environment and health shortcomings (I)

Policy options	Specific measures included in the respective policy option		(+ specific measures assessed as sub-options)			
Policy option I-1 - air quality objectives equivalent to 5 µg/m^3 $PM_{2.5}$	Revise and/or introduce standards for target year **2030** for **12 air pollutants:** $PM_{2.5}$, PM_{10}, NO_2, O_3, SO_2, CO, BaP, benzene, Pb, As, Cd, Ni		+	I-1a, I-2a, I-3a: Same standards as 'parent' options, with a later target year		
Policy option I-2 - air quality objectives equivalent to 10 µg/m^3 $PM_{2.5}$			+			
Policy option I-3 - air quality objectives equivalent to 15 µg/m^3 $PM_{2.5}$			+			
Policy option I-4 - establish objectives for additional air pollutants	**Ø1**					
Policy option I-5 - revise average exposure reduction obligations	**B3**	**O3**	+	II-3a: **P3**	II-3b: **R3**	II-3c: **Q3**
Policy option I-6 - regular review of EU air quality standards	**A1**	**A3**	+	II-1a: **A2**	II-1b: **A4**	

10.1.1 *Policy options I-1, I-2 and I-3: air quality objectives*

Outline

Policy options I-1, I-2 and I-3 focus on revising or introducing standards for each of the 12 air pollutants: $PM_{2.5}$, PM_{10}, NO_2, O_3, SO_2, CO, BaP, benzene, Pb, As, Cd, Ni. As such they draw on a large number of underpinning interventions: O1, O2, P1, P2, Q1, Q2, R1, R2, S1, S2, T1, U1, V1, W1, X1, Y1 and Z1. The benefits and costs of the different interventions vary depending on the pollutant, and level of ambition. In addition, the impacts will vary depending on the timeline for achievement (the impacts of achieving standards in 2030 is greater than that in 2050) and for short-term standards, on the number of permitted exceedances in a given year.

Three policy options have been defined representing three different levels of ambition:

- Policy option I-1 - air quality objectives equivalent to 5 µg/m^3 $PM_{2.5}$: This option simulates complete alignment with the WHO AQGs.
- Policy option I-2 - air quality objectives equivalent to 10 µg/m^3 $PM_{2.5}$: Implies a moderate improvement over the baseline, with high take up of technical mitigation potential, leaving a moderate number of exceedances to be dealt with at local level.
- Policy option I-3 - air quality objectives equivalent to 15 µg/m^3 $PM_{2.5}$: Implies a small improvement over the baseline, with moderate take up of technical mitigation potential, leaving a small number of exceedances to be dealt with at local level.

The remaining discussion proceeds pollutant by pollutant and standard by standard, providing an illustration of the potential ambition that could be allocated to each policy option.

$PM_{2.5}$ - annual average [O1 - BCR: High[58]]: The modelling suggests that by 2030, there will be broad compliance with both a 20 and 15 µg/m^3 target – for the latter only around 400,000 people will remain living in areas of exceedance under OPT15. Under OPT10, around 11 million people remain living in areas exceeding 10 µg/m^3, implying a moderate level of effort would be needed at local level to meet

[58] As discussed in other sections. The BCR of this and other standards is ranked as high, but is somewhat uncertain. This is because the modelling does not predict complete compliance with the standard is achievable through technical mitigation only. As such the additional costs (and benefits) of full compliance are uncertain.

this ambition. Under OPT5, around 225 million remain in areas of exceedance. Key contributors to remaining exceedances above the WHO AQGs appear to be residential (and some road transport) in those areas remaining with higher concentrations (e.g. above 15 $\mu g/m^3$), and non-anthropogenic sources in areas just exceeding the WHO AQGs (between 5 – 15 $\mu g/m^3$). To 2050, a fairly similar pattern of results holds: with 0.05m, 8.2m and 108m people living in areas exceeding 15 $\mu g/m^3$ (OPT15), 10 $\mu g/m^3$ (OPT10) and 5 $\mu g/m^3$ (OPT5) respectively. Amongst stakeholders who responded to the targeted Stakeholder Survey, a small overall majority favoured moving in line with the WHO AQG to 2050 (majority of NGOs and research), but some (public authorities and industry) still favoured less ambitious standards. Hence even to 2050, full alignment with the WHO AQG appears challenging – as such the standards proposed for 2030 are also retained for the post-2030 option.

$PM_{2.5}$ – short-term target [O2 - BCR: High]: The intervention considers the introduction of a new standard. In isolation, and alongside the annual average standard for $PM_{2.5}$, there is a strong case for a standard managing $PM_{2.5}$ peak concentrations. This is underlined by the opinions provided by stakeholders through the Targeted Stakeholder Survey and the advice of the WHO, the latter make the point that even a small number of extreme peaks could have a significant negative health impact. However, the effectiveness of limiting peak concentration as a safety net (and indeed its additional value over an annual standard) decreases with the number of exceedance days allowed 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). That said, the WHO have introduced a daily AQG alongside the daily AQG for PM_{10}, the more gradated interim targets and guideline for $PM_{2.5}$ offer greater flexibility to increase ambition and the additional cost of monitoring is likely to be small, whilst having a short-term standard for $PM_{2.5}$ recognises it is this fraction that is more commonly associated with detrimental health effects.

Short-term standards for $PM_{2.5}$ were not captured directly in the modelling. Analysis of current monitoring data suggests there are currently broad exceedances of the WHO AQG, but this does not capture further improvements going forward in the baseline. 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 $PM_{2.5}$ (99^{th} percentile) is close to 4. This suggests daily limits of 60 $\mu g/m^3$ and 40 $\mu g/m^3$ respectively under options I-3 and I-2. The majority of public authorities, NGOs and research organisations considered a 25 $\mu g/m^3$ level appropriate for 2030 (although the majority of industry opted for no standard) and aligning with the WHO AQG in 2050 (with the same pattern across stakeholder types as 2030). That said, given that the modelling suggests a similar pattern of results for the long-term standard between 2030 and 2050, the options have the same illustrative numerical standard for both the 2030 and post-2030 options.

PM_{10} – annual average [P1 - BCR: High]: The modelling suggests that by 2030, there will be broad compliance with a 30 $\mu g/m^3$ 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 $\mu g/m^3$, 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 $\mu g/m^3$. This suggests that the WHO AQG for PM_{10} is more achievable than that for $PM_{2.5}$, however it is acknowledged that there is greater uncertainty around the modelling of PM_{10}, which suggests the selection on PM_{10} standards should be more conservative. The analysis chimes well with opinion of stakeholders noted through the targeted Stakeholder Survey: For 2030, the majority favoured some reduction from the current standard (most selecting 30 or 20µg/m^3). To 2050, a fairly similar pattern of results holds: with 0.15m, 2.85m and 13.5m people living in areas exceeding 30 µg/m^3 (OPT15), 20 µg/m^3 (OPT10) and 15 µg/m^3 (OPT5) respectively. Amongst stakeholders who responded to the targeted Stakeholder Survey, 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. However, the modelling suggests alignment with the WHO AQG in 2050 would still be challenging, hence the standards for 2030 are retained for the post-2030 option (also reflecting greater uncertainty in the modelling).

PM_{10} – short-term target [P2 - BCR: Low]: The intervention considers the revision of the existing daily standard. It appears that there is merit in having a standard to manage peak alongside annual average concentrations. However, 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). That said, the WHO have introduced a daily AQG for $PM_{2.5}$ alongside the daily AQG for PM_{10}, and any cost saving of not having a short-term target for PM_{10} is likely to be small.

Short-term standards for PM_{10} were not captured directly in the modelling. Analysis of current monitoring data suggests there are currently a small level of exceedances against the existing EU standard (around 10% of sites), and broad exceedances of the WHO AQG (69% of sites). However, this does not capture further improvements going forward in the baseline. 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, suggesting daily limits above the existing daily limit value of 50µg/m^3. The majority of all stakeholder types except research and academics considered the existing 50 µg/m^3 level appropriate for 2030 (although a sizeable minority of all groups and the majority of researchers felt 45 µg/m^3 was appropriate for 2030). A significant majority of all groups (except industry) opted for alignment with the WHO AQG in 2050, although based on the modelling of average annual pollutants and the statistical multiplier, this may be challenging. As such this is only considered in option I-2 and I-1 for 2050.

NO_2 – annual average [Q1 - BCR: High]: The modelling suggests that by 2030, there will be broad compliance with a 30 µg/m^3 target – only around 500,000 people will remain living in areas of exceedance under OPT15. Under OPT10, around 3.5 million people remain living in areas exceeding 20 µg/m^3, implying a moderate level of effort would be needed at local level to meet this ambition. Under OPT5, 42.5 million remain in areas exceeding 10 µg/m^3. For 2030, the majority of stakeholders favoured some reduction from the current standard, with most selecting a moderate reduction to 30µg/m^3. The remaining exceedances relative to the WHO AQG appear to come from shipping, which would therefore be the focus of any local action to tackle remaining exceedances.

To 2050, there is broad compliance with both 30 and 20 µg/m^3 targets – with only 0.2m and 0.9m people are living in areas exceeding these levels under OPT15 and OPT10 scenarios respectively. Hence 20 µg/3 is proposed for the I-3 option for post 2030. The modelling also generally suggests only moderate non-compliance with the WHO AQGs to 2050: Under OPT5, around 5m people remain living in areas exceeding 10 µg/m^3 – as such this is adopted for both I-1 and I-2 scenarios. Amongst stakeholders, a small overall majority favoured moving in line with the WHO AQG to 2050 (majority of NGOs and research organisations), but some (public authorities and industry) still favoured less ambitious standards. This somewhat matches stakeholder opinion, with a strong overall majority favouring moving in line with the WHO AQG to 2050, driven by the majority of NGOs, public authorities and research that responded in this way.

NO_2 – short-term targets [O2 - BCR: High]: The intervention considers both the revision of an existing standard (1-hour) and the potential introduction of a new (24-hour) standard. The effectiveness of 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. 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. In addition, stakeholders were less positive about introducing a new 24-hour EU standard, in the context of an existing 1-hour standard and noted complexity in having multiple standards for multiple pollutants. 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 steps offered by the 24-hour interim targets and guideline provide the opportunity to increase ambition.

Short-term standards for NO_2 were not captured directly in the modelling. Analysis of current monitoring data suggests 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. Again, assuming the statistical relationship between annual and daily concentrations holds, this suggests a daily limit 3x above the annual (99th percentile), implying standards of 60 and 90 µg/m^3 under options I-2 and I-3 respectively for 2030. This also corresponds with the views of stakeholders: in response to the targeted Stakeholder Survey where the majority of public authorities and research 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 (majority of industry selected 'no standard'). To 2050, the majority of public authorities, NGOs and research organisations opted for full alignment with the WHO AQGs.

Given the options introduce a new 24-hourly limit, no increase in the ambition of the 1-hour standard is included in the options.

O_3 - peak-season [R1 – BCR: Low/Medium]: 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 more ambitious standards for ozone would be feasible in all locations. This is perhaps underlined by the difference 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. Hence existing target values are retained for all options, but there is a link to average exposure indicators under option I-5 and whether such a standard for ozone could help drive progress.

O_3 – short-term targets [R2 – BCR: Low/Medium]: There remains a clear need for a standard to regulate short-term 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, the benefits of such action (at least in economic impact assessment) often rank below action taken around other pollutants. The monitoring data shows there is currently broad exceedances of both the existing EU target value and the WHO AQG. 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). Hence existing target values are retained under all options, but limit values could be considered. Given a change in standard is challenging, there is a link to average exposure indicators under option I-5 and whether such a standard for ozone could help drive progress. Post-2030 there is some continued improvement to 2050, although moderate exceedances of the WHO AQG remain even in 2050 under the baseline (321 sites) and MTFR (185 sites), as such the same standards as for 2030 are again proposed.

SO_2 – annual average [S1 – BCR: Low]: There is no existing EU standard nor WHO AQG. 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. 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. As such, no option has been included in the policy options.

SO_2 – short-term targets [S2 – BCR: Low]: 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 24-hour and 1-hour EU standards in 2019. In fact, there is currently broad compliance with the WHO AQG (only 49 or 3.7% sites exceeded in 2019). Again, 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 propose that the WHO AQG standards could be met with limited additional effort, and there is even some appetite to move beyond the existing 1-hour standard (and hence also beyond the WHO AQG). Hence the WHO AQGs are adopted across all options. Introducing a new 10-minute standard will introduce additional complexity and administrative burden for public authorities, and as such is not included in the options.

CO – short-term targets [T1 – BCR: Low]: 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 daily maximum 8-hour EU standard in 2019, which matches the WHO AQG. 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 and this would go beyond the WHO AQG. Introducing new standards will introduce additional complexity and administrative burden for public authorities. Furthermore, monitoring data highlights the same stations at risk under an 8-hour maximum, 24 or 1-hour average, suggesting there would be some overlap in the effects of different standards. But there is a larger 'non-zero' data return available for both the 24 and 1-hour standards, perhaps suggesting that these are simpler to monitor, report and understand. Given CO is harmful when inhaled in large amounts over a short space of time, a 1-hour standard, in line with the WHO AQG, may support better enforcement and better target risks of CO than a 24-hour standard.

Benzene – annual average [U1 – BCR: Low/Medium]: 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 (11%), not accounting for further improvements in the baseline.

BaP – annual average [V1 – BCR: Low/Medium]: This intervention considers both: (a) changing from target to limit value and (b) aligning the standard with the WHO Guideline. Based on the modelling, a moderate number (62/334) of sites) or 16m people) will remain in exceedance in 2030 in the baseline. However, this does not capture further ambition possible under the policy scenarios – MTFR demonstrates the number of sites exceeding could reduce to 10 (or to 3.3m people exposed). Hence even setting the existing standard as a limit value (alongside standards for other pollutants) implies moderate ambition (I-2). For option I-3, a target value is retained and the standard changed to 1.0. To 2050, there is broad compliance with the existing EU standard. Furthermore, additional abatement potential can be adopted to achieve even broad compliance with a lower standard: under MTFR only 4 sites (or around 16m people exposed) remain non-compliant against a 0.4 ng/m^3 standard in the baseline.

Lead – annual average [W1 – BCR: Low/Medium]: 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, no sites currently exceed the EU standard and only a very limited number of sites would fall into exceedance under a lower limit value (8 sites against a 0.15 µg/m^3 standard). 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).

Arsenic – annual average [X1 – BCR: Low/Medium]: The existing EU standard is already below the current WHO AQG. 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 and even a large increase in ambition would only bring fairly few sites into exceedance (e.g.

under a 3 ng/m^3 standard, the number of exceedances rises from 8 to 24). Indeed, setting a lower target value may drive further improvements at sites which subsequently fall 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).

Cadmium – annual average [Y1 – BCR: Low/Medium]: The existing EU standard is already consistent with the current WHO AQG. 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 and even a large increase in ambition would only bring fairly few sites into exceedance (e.g. under a 2.5 ng/m^3 standard, the number of exceedances rises from 1 to 11). Indeed, setting a lower target value may drive further improvements at sites which subsequently fall 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).

Nickel – annual average [Z1 – BCR: Low]: The existing EU standard is already below the current WHO AQG. 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 and even a large increase in ambition would only bring fairly few sites into exceedance (e.g. under a 10 ng/m^3 standard, the number of exceedances rises from 3 to 12). Indeed, setting a lower target value may drive further improvements at sites which subsequently fall 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).

Summary

The tables below summarise the illustrative options for 2030 and post-2030.

Table 69 - Illustrative air pollutant standards for the three policy options - 2030

	Baseline (current)			Policy option I-1 (2030)		Policy option I-2 (2030)		Policy option I-3 (2030)	
$PM_{2.5}$ (annual) [µg/m³]	**25 / 20**	LV	O1	**5**	**LV**	**10**	LV	15	LV
$PM_{2.5}$ (daily) [µg/m³]	-	-	O2	(99%) **15**	LV	40 (99%)	LV	60 (99%)	LV
PM_{10} (annual) [µg/m³]	**40**	LV	P1	**15**	LV	20	LV	30	LV
PM_{10} (daily) [µg/m³]	(35 days) **50**	LV	P2	(99%) **45**	LV	50 (99%)	LV	50 (90th)	LV
NO_2 (annual) [µg/m³]	**40**	LV	LV	**10**	LV	20	LV	30	LV
NO_2 (daily) [µg/m³]	-	-	Q2	(99%) **25**	LV	60 (99%)	LV	90 (99%)	LV
NO_2 (hourly) [µg/m³]	(18 hours) **200**	LV	Q2	(99.98%) **200**	LV	200	LV	200	LV
O_3 (peak-season) [AOT40 µg/m³]	18,000	TV	R1	60*	LV	18,000	TV	18,000	TV
O_3 (8-hour mean) [µg/m³]	(25 days) **120**	TV	R2	(99%) **100**	LV	120 (25 days)	TV	120 (25 days)	TV
SO_2 (annual) [µg/m³]	**-**	-	S1	**-**	-	-	-	-	-
SO_2 (daily) [µg/m³]	(3 days) **125**	LV	S2	(99%) **40**	LV	40	LV	40	LV
SO_2 (hourly) [µg/m³]	(24 hours) **350**	LV	S2	(99.98%) **350**	LV	350	LV	350	LV
CO (1-hour) [mg/m³]	-	-	T1	35	LV	35	LV	35	LV
CO (8-hour) [mg/m³]	**10**	LV	T1	**10**	**LV**	**10**	**LV**	**10**	**LV**
Benzene (annual) [µg/m³]	**5**	LV	U1	**1.7**	LV	1.7	LV	3	LV
BaP (annual) [ng/m³]	**1**	TV	V1	**0.12**	LV	1.0	LV	1.0	TV
Lead (annual) [µg/m³]	**0.5**	LV	W1	**0.5**	**LV**	**0.5**	**LV**	**0.5**	**LV**
Arsenic (annual) [ng/m³]	**6**	TV	X1	**6.0**	**LV**	**6.0**	**LV**	**6.0**	**LV**
Cadmium (annual) [ng/m³]	**5**	TV	Y1	**5.0**	**LV**	**5.0**	**LV**	**5.0**	**LV**
Nickel (annual) [ng/m³]	**20**	TV	Z1	**20**	**LV**	**20**	**LV**	**20**	**LV**

Note: * figure expressed according to WHO AQG metric of 'average daily maximum 8-hour mean O3 concentrations of 60 µg/m³, in the six consecutive months with the highest six-month running-average O3 concentration'.

Table 70- Illustrative air pollutant standards for the three policy options - post 2030

	Baseline (current)			Policy option I-1 (post-2030)*		Policy option I-2 (post-2030)*		Policy option I-3 (post-2030)*	
$PM_{2.5}$ (annual) [$\mu g/m^3$]	25 / 20	LV	O1	5	LV	10	LV	15	LV
$PM_{2.5}$ (daily) [$\mu g/m^3$]	-	LV	O2	(99%) 15	LV	40 (99%)	LV	60 (99%)	LV
PM_{10} (annual) [$\mu g/m^3$]	40	LV	P1	15	LV	20	LV	30	LV
PM_{10} (daily) [$\mu g/m^3$]	(35 days) 50	LV	P2	(99%) 45	LV	45 (99%)	LV	50 (99%)	LV
NO_2 (annual) [$\mu g/m^3$]	40	LV	Q1	10	LV	10	LV	20	LV
NO_2 (daily) [$\mu g/m^3$]	-	-	Q2	(99%) 25	LV	25 (99%)	LV	40 (99%)	LV
NO_2 (hourly) [$\mu g/m^3$]	(18 hours) 200	LV	Q2	(99.98%) 200	LV	200	LV	200	LV
O_3 (peak-season) [AOT40 $\mu g/m^3$]	18,000	TV	R1	60**	LV	18,000	TV	18,000	TV
O_3 (8-hour mean) [$\mu g/m^3$]	(25 days) 120	TV	R2	(99%) 100	LV	100	TV	120	TV
SO_2 (annual) [$\mu g/m^3$]	-	-	S1	-	-	-	-	-	-
SO2 (daily) [$\mu g/m^3$]	(3 days) 125	LV	S2	(99%) 40	LV	40	LV	40	LV
SO2 (hourly) [$\mu g/m^3$]	(24 hours) 350	LV	S2	(99.98%) 350	LV	350	LV	350	LV
CO (1-hour) [mg/m^3]	-	-	T1	35	LV	35	LV	35	LV
CO (8-hour) [mg/m^3]	10	LV	T1	10	LV	10	LV	10	LV
Benzene (annual) [$\mu g/m^3$]	5	LV	U1	1.7	LV	1.7	LV	1.7	LV
BaP (annual) [ng/m^3]	1	TV	V1	0.12	LV	0.4	LV	0.7	LV
Lead (annual) [$\mu g/m^3$]	0.5	LV	W1	0.5	LV	0.5	LV	0.5	LV
Arsenic (annual) [ng/m^3]	6	TV	X1	6.0	LV	6.0	LV	6.0	LV
Cadmium (annual) [ng/m^3]	5	TV	Y1	5.0	LV	5.0	LV	5.0	LV
Nickel (annual) [ng/m^3]	20	TV	Z1	20	LV	20	LV	20	LV

Note: * 2050 is defined as an illustrative target year post 2030 – in practice, standards can be set for any year post 2030 (although this will have a consequent impact on the benefits and costs of achieving such standards); **figure expressed according to WHO AQG metric of 'average daily maximum 8-hour mean O3 concentrations of 60 $\mu g/m^3$, in the six consecutive months with the highest six-month running-average O3 concentration'.

The overall benefit-cost ratio of all options is high. As demonstrated by the modelling, both the costs and benefits increase with ambition, with the most ambitious options delivering significant benefits (namely in terms of human health improvements) which significantly outweigh the costs. These are summarised for the different modelling scenarios in the following tables.

Table 71 presents and aggregates the monetised benefits associated with each scenario, relative to the baseline. Table 72 presents the total gross benefits relative to the mitigation costs, and the resulting total net benefit of the scenarios. Note these estimates do not include the administrative burden, which will scale with the ambition of the standards and the number of new exceedances that need to be tackled. But overall, given the costs are in the EUR millions, any new administrative burden is considered unlikely to change the overall, net positive balance of costs and benefits.

Table 71 - Benefits of policy options, relative to the baseline (EURm, 2015)[59]

Impact			2030				2050		
			OPT20	OPT15	OPT10	OPT5	OPT15	OPT10	OPT5
Human health	Mortality (VOLY)		9,505	25,182	32,394	34,734	2,897	16,287	16,935
	Mortality (VSL)		33,486	85,697	110,517	118,764	11,097	63,194	65,804
	Morbidity		2,343	6,141	7,992	8,610	529	3,121	3,310
Environmental health	Material		29	181	196	204	12	156	160
	Crops		67	188	254	276	44	259	258
	Forests	Low	69	222	287	316	52	292	293
		High	69	222	287	316	127	712	716
	Ecosystems	Low	101	448	706	863	83	790	931
		High	302	1,345	2,117	2,588	250	2,370	2,794
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

Note: In some cases, summing the individual impacts in the table does not exactly equate to the totals presented. All totals presented are correct, and the variance is due to rounding of individual impacts for presentation in the table.

Table 72 - Costs and net benefit of the policy options, relative to the baseline (EURm, 2015)

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

Note: In some cases, summing the individual impacts in the table does not exactly equate to the totals presented. All totals presented are correct, and the variance is due to rounding of individual impacts for presentation in the table.

Alongside the core cost-benefits analysis results presented in the above two tables, two further sets of sensitivity results have been produced for illustration, as presented in the following two tables.

[59] Macro-economic impact, including productivity impacts, are not included here.

The core set of results presented above focus on the valuation of the health and ecosystem impacts (indicators 2, 3 and 5), in comparison to the mitigation costs (indicator 6). As such, this follows the approach adopted in previous studies, for example, Clean Air Outlook 2. These results do not take into account the wider macro-economic effects, as modelled under Indicator 7, in part due to the potential for overlap with impacts modelled under Indicators 2, 3 and 5. As part of this study, the extent of these overlaps has further been considered, with a view to combining the results from the core cost-benefit and macro-economic analysis into a single compiled set of cost-benefit analysis results.

Indicator 7 captures the impact of air pollution on labour productivity, using an aggregate relationship based on recent OECD work (Dechezleprêtre et al. 2019) - the coarse nature of this relationship makes it challenging to accurately identify what underlying effects are or are not captured (i.e. how the change in air pollution manifests into a change in productivity). Given the direct link to labour force participation, expert judgement suggests that at least this would capture work-days lost (WDL). In theory the OECD relationship may also capture other effects, e.g. wider morbidity effects where the change in health may also affect labour market participation and on-the-job productivity. However, the other morbidity health pathways in this study (i.e. other than WDL, such as RADs) are valued predominantly considering the direct health care costs only, and do not assess the potential for lost wages – as such the potential for the assessment to capture impacts on labour productivity for these wider morbidity effects is much lower.

This uncertainty aside, Table 73 presents an illustration of the potential effect of including the much broader assessment of productivity (in place of the quantification of work days lost). As presented below, the productivity effect is significantly greater than the estimate of WDL, and hence further increases the net benefit of the policy options. Furthermore, the assessment of productivity effects is significantly greater than the overall assessment of morbidity effects, hence even where the overlap is greater than that accounted for here, this alternative approach to assessing labour market effects would still likely increase the net benefit of the scenarios relative to the core cost-benefit analysis. Due to the magnitude, taking up and further exploring this channel in future research would be a worthwhile endeavour.

Table 73 - Costs and net benefit of the policy options, relative to the baseline (EURm, 2015) - sensitivity around productivity impacts

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
WDL[1]		481	1,318	1,705	1,854	98	622	663
Productivity[2]		14,998	42,998	63,067	74,020	5,330	48,106	59,617

Notes: 1. Included in total gross benefit. 2. Not included in total gross benefit, but presenting an alternative approach of estimating productivity impacts (‘high’ case compared to WDL).

Linkages

This problem has important links to all other policy options.

10.1.2 *Policy option I-4: establish objectives for additional air pollutants*

Outline

This policy option contains one option: 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. There was a clear preference amongst stakeholders that annual targets were favoured over peak targets for these pollutants.

These pollutants are not in scope of the WHO guidelines as they concluded that 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.

More monitoring and evidence are needed before standards can be set for these additional pollutants, both around existing pollution levels and health effects, to understand the scale of the problem before standards can be set. At the same time, introducing standards can be a driver for additional monitoring. The extent to which it contributes to air quality improvements and ecosystems is dependent on the level of ambition. Setting standards would go beyond the latest scientific advice and the extent to which they may reduce negative health impacts is uncertain. However, 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).

Sub-options

There are no sub-options for policy option I-4.

Linkages

There are important linkages with a number of other policy options:

- Policy options I-1 to I-3: action to tackle other air pollutants will also somewhat reduce emissions and concentrations of emerging pollutants
- Policy option I-6: Introducing a mechanism for adjusting EU air quality standards (based on scientific advice, technical progress or maintaining a list of priority air pollutants for emerging pollutants).
- Policy option III-3: 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.

10.1.3 *Policy option I-5: Revise average exposure reduction obligations*

Outline

This policy package contains 5 potential options: B3 which considers how average exposure standards could be expressed, and O3, P3, Q3 and R3 which consider whether standards should be set for $PM_{2.5}$,

PM_{10}, NO_2 and Ozone respectively (with existing standards being revised in the case of $PM_{2.5}$). These measures go hand-in-hand as one should consider the most appropriate form of target, alongside for which pollutants, and what level they should be set.

The analysis suggests there may be benefit in changing the way in which average exposure standards are expressed (B3). AEI is currently measured in urban background stations, which might not always be reflective of the general population exposure. The general consensus amongst stakeholders is that defining standards on a regional basis or including additional stations in the calculation of metrics would improve the approximation of exposure. Likewise requiring that Member States develop AQ Plans where obligations are not being met, will ensure that action is taken to address exceedances (and/or ensure enforcement action can be taken) [BCR B3: high].

Average exposure standards can offer an effective complement to absolute limit values especially where absolute limits are more conservative. Likewise, there will be interactions between standards set for different pollutants. Hence their effectiveness and impact are critically linked to short and long-term limit values defined for different pollutants. Average exposure standards, where an obligation is set at a lower level than the overall standard, can drive further improvement in areas where exposure is higher. Where these are defined as relative reductions, they can drive further progress where limit values have already been reached. Finally, they can also stimulate (and ensure) action on national or regional pollution sources is taken to help tackle exceedances at hotspots (although it is noted there is overlap with other regulation especially the NECD). Given its regional nature, the high ambition set by the updated WHO AQG, and as it is the key pollutant associated with health effects, maintaining an average exposure standard for $PM_{2.5}$ forms an important part of the policy option [BCR O3: high].

Sub-options

Under the existing AAQ Directives, average exposure standards only exist for $PM_{2.5}$.

Policy Sub-Option I-5a inclusion of intervention P3: *Introduce average exposure obligations and reduction targets*. The merits of introducing an average exposure standard for PM_{10} (P3) will critically depend on the outcome of the interventions considering changes to long and short-term absolute standards (P1 and P2), and other average exposure standards ($PM_{2.5}$). The additional value of an average exposure standard for PM_{10} would increase to the extent that peaks are not correlated with $PM_{2.5}$ peaks, and any unique sources driving peaks in PM_{10} can be controlled (i.e. are not from natural sources). Both PM_{10} and $PM_{2.5}$ share similar sources and control strategies, hence this option is likely to deliver very limited additional value over I-5, whilst increasing administrative costs [BCR P3: Low/High].

Policy Sub-Option I-5b inclusion of intervention R3: *Introduce average exposure obligations and reduction targets*. The merits of introducing an average exposure standard for Ozone (Q3) will critically depend on the outcome of the interventions considering changes to long and short-term absolute standards (R1, R2 and B5). Existing target value standards for ozone are not widely complied with, perhaps in part drive by the fact they are target values. However, the feasibility of setting limit values for ozone (B5) is questionable given the importance of transboundary sources and natural factors, and relative limitations around control options. To that end, average exposure standards for ozone could help drive some improvement where target values do not drive air quality improvement and absolute limit values are not feasible and could provide another metric of understanding. However, the ability to control concentration levels that pose a challenge to absolute limit values could also pose a challenge to average exposure standards, and the mitigation options are similarly more uncertain (relative to other pollutants) [BCR R3: Low/Medium].

Policy Sub-Option I-5c inclusion of intervention Q3: The merits of introducing an average exposure standard for NO_2 (Q3) will critically depend on the outcome of the interventions considering changes to long and short-term absolute standards (Q1 and Q2), and other average exposure standards ($PM_{2.5}$) given NO_2 is a precursor of $PM_{2.5}$. As for I-5a, 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. Given NO_2 is a precursor or $PM_{2.5}$, to a certain extent Option I-5 alone will drive similar action to reduce NO_2 concentrations in a step-wise fashion. Furthermore, given NO_2 is less of a 'regional' pollutant relative to PM, and is more concentrated in hotspots, this reduces the additional value that Q3 could deliver over and above a limit value applying everything (Q1). But such a measure can complement absolute limit values to support easing pressure at hotspots [BCR Q3: Low].

Box – Level of ambition for average exposure targets
Alongside the selection of for which pollutants should average exposure indicators and targets be defined, there are a number of other parameters associated with the policy options, in particular: the level of reduction to be achieved, the geographical disaggregation of the regions to which targets apply, and the baseline against which reduction targets are set.

Additional analysis around AEIs is presented in Appendix 4 – 'Average exposure and percentage reductions in concentrations'. This presents analysis undertaken using the results of the central modelling. This compares the relative concentration reductions for $PM_{2.5}$ and NO_2, between the 2020 baseline and the OPT10 scenario in 2030, on the basis of NUTS1 regions, factoring in all pollution sources (i.e. anthropogenic and non-anthropogenic).

The results of the analysis show that for $PM_{2.5}$:

- Those regions with higher concentrations in 2020 tend to achieve larger relative reductions to 2030 under the OPT10 scenario
- There is a wide range in the relative reductions achieved: the reduction at the 5th percentile is estimated to be 13.1%, relative to a 46.6% estimated at the 95th percentile
- 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.
- The ability of some regions to achieve large relative reductions may be affected by significant non-anthropogenic sources which are more difficult to tackle (and indeed are not targeted in the GAINS model).

For NO_2:

- There is a wide range in the relative reductions achieved: the reduction at the 5th percentile is estimated to be 21.4%, relative to a 52.6% estimated at the 95th percentile
- 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 NO2 concentrations of 35% or more, with 3 achieving a reduction of over 50%.
- The ability of some regions to achieve large relative reductions may be affected by sources which may not be significant in 2020, but become more significant over time – in particular those areas which are susceptible to emissions from shipping.

Linkages

There are important linkages with a number of other policy options:

- I-1 to I-3 will define absolute standards for the same, or linked pollutants
- I-6 will define the frequency of revision of standards
- II-2 will define the requirements for other standards.

10.1.4 *Policy option I-6: regular review of EU air quality standards*

Outline

There is currently no mandate for regular reviews of air quality standards. Intervention A1 (BCR: High) introduces a review triggered by scientific progress. This policy option contains three possible variants, as follows:

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 of 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.

To complement the mandate for regular reviews of air quality standards, this policy option would include a provision to allow Member States to notify the European Commission should they adopt more stringent standards in light of the new technical and scientific progress (intervention A3). This would enable the European Commission to collect information on technical and scientific knowledge and to identify where national/local standards surpass the EU standard, enabling information sharing across Member States.

Direct costs estimated with this policy option are small administrative costs, while direct benefits could be large. Poor air quality imposes a high cost on society, so this intervention has potentially large indirect benefits. It is difficult to estimate indirect compliance costs.

Sub-options

Two sub-options are also under consideration to complement policy option I-6.

Sub-Option I-6a inclusion of intervention Policy A2: *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). Direct costs estimated are small administrative costs. Direct benefits are difficult to estimate. Health benefits are likely to be indirect. As poor air quality imposes a high cost on society, indirect benefits of this intervention are potentially large. It is difficult to estimate indirect compliance costs. We would argue for a medium rating primarily as technological progress is indirectly already taken into account when revising the AAQ Directive (e.g. via underlying modelling analysis). This intervention would allow this process to be made formal and enable links to be drawn between technology progress and health benefits [BCR A2: Low].

Sub-Option I-6b inclusion of intervention Policy A4: *Keep and periodically update a list of priority air pollutants to ensure air pollutants of emerging concern are monitored*. The Commission would be required 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 part of the latest technical and scientific review and to demand monitoring of such at Member State level. This sub-option 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. Direct costs estimated are small administrative costs. It is not possible to estimate eventual indirect compliance costs. Direct benefits are difficult to estimate, given that this measure will not directly 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 [BCR A4: Low].

Linkages

There are important linkages with a number of other policy options as introducing a review mechanism may facilitate revisions to the AAQ Directives by providing the evidence base and legal grounds for amending certain provisions (depending on the outcome of the review), in particular:

- Policy option I-5 – it may facilitate the option of expanding exposure reduction targets
- Policy option II-2 – it may facilitate revisions to limit values
- Policy option II-5 – it may facilitate revisions to alert/ information thresholds and action plans.

In addition, this policy option (namely sub-option II-1b) is expected to complement policy option III-1 and the introduction of a regular review mechanism of the assessment regime following clear criteria defined in the Directive.

10.2 Shortcoming II

Box II Highlights from Policy Option II

POII explores 19 policy interventions (and 2 policy interventions assessed as sub-options) with relevant contributions to addressing shortcomings identified in the AAQ Directive fitness check around the provision to address governance and enforcement. Policy options have been developed to tackle six underlying drivers, some of which can be supplemented with further interventions to develop the overall policy package. The six specific drivers are:

- Revising the approach to addressing exceedances and establishing air quality plans
- Revising the number of air pollutants subject to `limit values’
- Revising the implementation timeline for measures
- Revising the legal tools available in case of non-compliance
- Revising the alert/information thresholds and action plans
- Revising the approach to exceedances due to transboundary air pollution.

Policy option II-1 offers significant benefit and is key to addressing all exceedance situations and delivering action to improve air quality. It should help clarify the obligation to develop effective air quality plans and is highly important to the overall objective of the AAQ Directives to provide clean air for everyone.

Limit values better aid the implementation and enforcement of the Directives, a widespread opinion also held by stakeholders. Policy option II-2 includes interventions to replace target values with limit values, although most benefit would be gained for pollutants where current compliance with target values is low e.g. PaH and ozone.

The purpose of policy option II-3 is to prompt competent authorities to take measures to reduce air pollution to a safe level in a timely manner. Policy option II-4 clarifies the penalties to be applied to competent authorities where their level of ambition to improve air quality is not sufficient. It also clarifies how citizens can rely on legal provisions should they suffer as a result of exceedance situations. Furthermore, citizens would benefit from policy option II-5 which would help to drive action during episodes of high pollution and help inform the public of such, so they are better informed to take action to protect their health.

Finally, policy option II-6 would provide for a common methodology to assess transboundary contributions which would help competent authorities to assess the relevance of transboundary transport of air pollution. This in turn would enhance co-operation between neighbouring countries, help reduce disagreements on the evidence and magnitude of transboundary pollution, and in turn facilitate bilateral discussions.

Table 74 Policy options to address governance and enforcement shortcomings (II)

Policy options	Specific measures included in the respective policy option								
Policy option II-1 - revise approach to addressing exceedances and establishing AQ Plans	**B4**	**C1**	**C3**	D1	N1	+	II-1a: **D2**		
Policy option II-2 - revise number of air pollutants subject to 'limit values'	**B1**	**B5**							
Policy option II-3 - revise implementation timeline for measures	**C2**	**C5**							
Policy option II-4 - revise legal tools available in case of non-compliance	**C1**	**E1**	**E2**	**E4**		+	II-4a: **E3**		
Policy option II-5 - revise alert/information thresholds and action plans	**B2**	**C4**	**F2**	**F4**					
Policy option II-6 - revise approach to transboundary air pollution	**M1**	**M2**							

10.2.1 *Policy option II-1: revise approach to addressing exceedances and establishing AQ plans*

Outline

This policy option contains five interventions in the core package, covering different actions related to the exceedance of limit values and the development of air quality plans: B4 introduces guidance on how to address exceedances and on the actions to be taken in case of exceedance of different types of standards. Guidance is provided in terms of suitable response measures and on the type of plans to be used [BCR B4: Medium]. This intervention is complemented by intervention C1 which further specifies the obligation on taking measures to keep exceedance periods as short as possible [BCR C1: Medium] and C3 focussing on clearer coordination between short-term action plans and air quality plans. Such coordination between short-term action plans and air quality plans would lead to synergies between actions, and possibly competent authorities, and the avoidance of inefficiencies [BCR C3: Medium]. To guarantee effectiveness and efficiency in the setup and implementation of the air quality plan, intervention D1 revises the requirements to involve all relevant stakeholders in the design of the plan. This also contributes to the required governance structures for effective policy implementation [BCR D1: High]. Finally, the policy option includes intervention N1 which refines the minimum information to be included in an air quality plan. This latter intervention prescribes the methodological framework of an air quality plan and how the effectiveness of the plan is evaluated. This N1 intervention comes with variants emphasising various aspects of the planning process [BCR N1: High].

The benefit gained via this policy option is significant and is key to addressing all exceedance situations and delivering action to improve air quality. This policy option should clarify the obligation to develop effective air quality plans and consequently costs to achieve compliance in as short a time as possible are likely to be relatively low. Overall, this policy option is extremely important to the overall objective of the AAQ Directives to provide clean air for everyone.

Sub-options

Policy Option II-1 could be enhanced by the inclusion of a further intervention presented below:

Policy Sub-Option II-1a inclusion of intervention D2: *Introduce a requirement for Member States to harmonise air quality plans and air quality zones (and require a 'one zone, one plan' approach)*. As a sub-option to this policy option, D2 could be added, introducing a requirement for Member States to harmonise air quality plans and air quality zones (and require a 'one zone, one plan' approach). This intervention aims to increase the effectiveness of the Ambient Air Quality Directives by tackling the current mismatch between the zones used for assessment and the areas covered by air quality management and planning practices. A better alignment of these geographical zones could improve the overall efficiency of the AAQ Directives' implementation. However, this could also interfere with Member State competence on internal administrative organisation of the state.

Linkages

There are important linkages with other policy options:

- II-3: revise implementation timeline for measures
- II-6: revise approach to exceedances due to transboundary air pollution
- III-5: introduce requirements for modelling quality
- IV-2: revise requirements for air quality health data.

10.2.2 *Policy option II-2: revise number of air pollutants subject to 'limit values'*

Outline

This policy option contains two potential interventions: B1 which considers the implementation of new short-term standards for pollutants to achieve greater alignment with the latest WHO AQGs, and B5 which considers switching to limit values for those pollutants where standards are currently set as target values, namely for:

- air pollutants that tend to depend on transboundary precursors and /or annual variations in meteorology (i.e. ozone).
- air pollutants that tend to correspond to specific point source emissions (i.e. most heavy metals).
- air pollutants that tend to correspond to emissions from specific widespread practices (e.g. as is the case for most polycyclic-aromatic hydrocarbons (PaH)).

This policy option provides the facilitating legal basis for such standards to be set, and hence it is an important component of a wider solution that could be effective in improving air quality and thereby improving health protection. 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). As such this measure has only low direct costs, but the potential for high benefits [BCR B1: high].

Limit values better aid the implementation and enforcement of the Directives, a widespread opinion also held by stakeholders. Where there is widespread compliance with existing target values (i.e. heavy metals), the impacts of this measure would be small and only affect a limited number of sites but could help maintain this positive performance going forward. For PaH and ozone, where current compliance with target values is much lower, the impacts would be higher. Although there is likely to be further improvement in compliance with existing target values going forward in the baseline, the feasibility of setting limit values for ozone is questionable given the importance of transboundary sources and natural factors in its formation, feeding into challenges around control options. Where target values are changed to limit values, the impacts and risks will critically depend on the standard set, hence there is a key interaction with interventions under policy area 1. Depending on the accompanying levels set, this intervention could have a small direct effect on improving air quality and thereby improving health protection as well as impacting on sensitive groups. [BCR B5: Medium]

Together, this option is critical for facilitating enforcement of the AAQ Directives. That said, this option alone will deliver only small additional administrative burden whilst providing the basis for large, indirect benefits.

Sub-options

There are no sub-options for policy option II-2.

Linkages

There are important linkages with a number of other policy options:

- I-1 to I-3: impacts will be critically determined by standards set for each pollutant
- I-5: indirect link to average exposure indicators, which will also interact with achievement of short and long-term standards
- I-6: any standards may need to be updated in the future depending on changes to the underlying evidence base.
- II-4: limit values better support enforcement of the AAQ Directives, which links to the legal tools available in case of non-compliance
- III-1: changes to the range and type of standards may have implications for monitoring requirements placed on MS.

10.2.3 *Policy option II-3: revise implementation timeline for measures*

Outline

This policy option would amend the legal text to include specific timeframes in which exceedance periods must be addressed and for which air quality plans must be updated. The purpose of this policy option is to prompt competent authorities to take measures to reduce air pollution to a safe level in a timely manner. Regular updates to air quality plans would help the effectiveness of measures and would therefore lead to faster action to address exceedances of air quality standards.

This would involve replacing the current “as short as possible” wording with a specific time period within which competent authorities must bring an end to the exceedance of the limit values (amending Article 23(1) of Directive 2008/50/EC) [C2 BCR: Medium]. This current provision is open to interpretation and risks exceedances remaining systematic and persistent.

This policy option would also entail introducing a legal duty for competent authorities to update air quality plans at regular intervals to keep exceedance periods as short as possible [C5 BCR: Medium]. The 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[60]. 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 an air quality plan address new challenges for air quality). It would be important to define to what extent air quality plans should be updated.

[60] Based on responses to Targeted Stakeholder Survey where replied ranges from requiring revisions yearly to every 10 years, with a few stakeholders – including national and regional authorities - mentioning three (3) years as adequate.

On the one hand, this intervention could bring high indirect benefits resulting from more effective air quality plans. On the other hand, for countries (regions and municipalities) which face exceedances, this measure will result in additional costs from having to update plans regularly.

Sub-options

There are no sub-options for policy option II-3.

Linkages

There are important linkages with a number of other policy options:

- II-1: This includes revisions to further specify the obligation to take measures to keep exceedance periods as short as possible. By clarifying the measures needed to keep exceedance periods as short as possible, it will complement policy option II-3 which seeks to prompt competent authorities to take measures to reduce air pollution to a safe level in a timely manner. This also includes revisions to establish a requirement for Member States to involve all relevant stakeholders in air quality plan development and to specify coordination arrangements for the development and implementation of air quality plans. In doing so, it will complement policy option II-3 which seeks to prompt competent authorities to take measures to reduce air pollution to a safe level in a timely manner.
- II-4: This will include provisions to revise the legal tools available in case of non-compliance, thus strengthening enforcement (which in turn will prompt competent authorities to take measures to reduce air pollution to a safe level in a timely manner, as is the intention of policy option II-3).

10.2.4 *Policy option II-4: revise legal tools available in case of non-compliance*

Outline

This policy option sets out interventions, which, taken together, will strengthen the legal tools available to the public when Member States fail to comply with the Directives. It contains four interventions. The first C1 BCR: Medium, further specifies the obligation to take measures to keep exceedance periods as short as possible. This sets a benchmark by which Member States should consider measures to improve air quality. If a Member State still fails to comply with limit values, intervention E1 (BCR: Medium/High) sets out minimum financial penalties that could be levied on competent authorities failing to establish effective air quality plans or polluters failing to respect measures under air quality plans. The two remaining interventions (E2 BCR: Medium and E4 BCR: High) are directed to those suffering damage as a result of failure to comply with the provisions in the Directive. E2 supports a right to compensation for damage suffered due to air pollution while E4 proposes an explicit provision on access to justice for citizens. Together this policy option clarifies the level of ambition needed and the penalties to be applied if this is not taken up by competent authorities. It also clarifies how citizens can rely on legal provisions should they suffer as a result of exceedance situations

Sub-options

Policy Option II-4 could be enhanced by the inclusion of a further interventions presented below:

Policy Sub-Option II-4a inclusion of intervention E3: *Set up a fund to be fed by the payment of penalties and which can be used to compensate damage to health or finance air quality measures*. While such a fund would be useful to highlight that air quality is an issue that should be addressed and it may provide ready access to funds by which competent authorities can take action, it remains uncertain which air quality measures would be eligible for funding and who would manage such a fund. Moreover, there is also a risk of interfering with Member States' national funding responsibilities.

Linkages

- II-2 – revision of the number of air pollutants subject to 'limit values' may result in more exceedances which in turn will impact the penalties that p may be levied and the number of compensation damage claims and access to justice court proceedings.
- II-3 - revise implementation timeline for measures. Penalties and access to justice are impacted on when measures are required to be implemented.

10.2.5 *Policy option II-5: revise alert/information thresholds and action plans*

Outline

This policy option aims to revise alert and information thresholds and short-term action plans with four interventions. B2 introduces additional alert/information thresholds which do not currently address PM concentrations. This intervention is likely to have a small positive impact on human health and societal costs associated with reduction of healthcare costs via enhanced protection during air pollution episodes (e.g. via reduced hospital admissions) [BCR B2: Medium]. This is linked to intervention C4 which introduces additional short-term action plans for each pollutant to tackle episodic pollution events. While this may be beneficial, 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 [BCR C4: Medium]. F2 introduces a requirement to provide AQ health data which is beneficial to individuals, particularly those sensitive to air quality during periods of high pollution. It only has a small additional cost as many Member States already have the capability to publicise air quality in real time [F2 BCR: Medium]. In addition to this, intervention F4 introduces requirements for harmonised AQ index across Europe to make air pollution information more readily accessible to members of the public, which will help inform citizens of their health risk to air pollution. [BCR F4: Medium].

This policy option is not particularly costly to implement but it does bring good benefits to drive action during episodes of high pollution and help inform the public of such, so they are better informed to take action to protect their health.

Sub-options

There are no sub-options for policy option II-5.

Linkages

- II-1 on revisions for the obligations on how to establish AQ plans. Short term action plans are similar to air quality plans developed to address long term exceedances of limit values and there should be co-ordination in the approach.

10.2.6 *Policy option II-6: Revise approach to transboundary air pollution*

Outline

This option contains two interventions which focus on assessing and addressing transboundary air pollution in local/regional air quality management: M1 would require the use of an agreed methodology when assessing transboundary air pollution/contributions to local/regional air pollution; and M2 would require transboundary cooperation and joint action on air quality where the air pollution contribution from transboundary sources are above certain thresholds.

A common methodology to assess transboundary contributions would help competent authorities to assess the relevance of transboundary transport of air pollution. This in turn would enhance co-operation between neighbouring countries, help reduce disagreements on the evidence and magnitude of transboundary pollution, and in turn facilitate bilateral discussions. A 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 a common methodology is impacted by the willingness of Member States to co-operate and implement mitigation measures within a joint air quality plan. 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. In addition, there could be additional mitigation costs for Member States where transboundary pollution is an issue for having to adapt their air quality plans and implement further measures to reduce transboundary pollution. Coherence with the methodology used in the EMEP (European Monitoring and Evaluation Programme) for international co-operation to solve transboundary air pollution problems under the Convention on Long Range Transboundary Air Pollution (CLRTAP) should be taken into account. Although there are likely to be additional costs incurred by many Members States dealing with transboundary issues the benefits are anticipated to outweigh the costs [BCR M1: High].

Intra- and inter-EU transboundary air pollution cannot be reduced by one country alone. Article 25 of Directive 2008/50/EC 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, the provision limits the obligation to cooperate to exceedances ‘due to significant transboundary transport’ which, in practice, results in a lack of cooperation. This intervention would imply additional costs for competent authorities in bordering countries were transboundary pollution is an issue, through the need to design joint air quality plans. Coherence with the NEC Directive and Convention on Long Range Transboundary Air Pollution (CLRTAP) Gothenburg Protocol are also important considerations. But requiring joint transboundary cooperation above a specific threshold would foster transboundary cooperation and in turn improve air quality in bordering regions and could also lead to a more efficient (lower cost) response to reducing concentrations at exceedance points. This will become increasingly important going forward as transboundary sources become a proportionately higher contributor to overall air pollutant concentrations [BCR M2: medium].

Interventions M1 and M2 complement each other, as M1 would remove a potentially important stumbling block to the effectiveness of M2.

Sub-options

There are no sub-options for policy option II-6.

Linkages

- II-1a: where intervention D2 is included (‘one plan one zone’), this could present a barrier to transboundary co-operation between countries.

10.3 Shortcoming III

Box III Highlights from Policy Option III

POIII considers 14 policy interventions with relevant contributions to address shortcomings identified in the AAQ Directives fitness check around monitoring and assessment of air quality. Policy options have been developed to tackle five underlying drivers, and each of these can be supplemented with further interventions to develop the overall policy package. The five specific drivers are:

- Improving air quality assessment;
- Require monitoring continuity;
- Require monitoring of other pollutants;
- Improve monitoring quality;
- Introduce modelling quality requirements.

Although all five policy options could make relevant contributions, Option III-1 presents a particularly significant opportunity to enhance the effectiveness of (and the environmental benefits that flow from) the AAQ Directives' implementation and would make a significant contribution to the overall impacts of this policy package. This policy option seeks to increase the use of key tools for the assessment of air quality, which have historically been limited by an approach reliant on fixed monitoring at a minimum number of sampling points. This option mandates the use of models, which could deliver wider spatial coverage for air quality assessment purposes. Use of models should be supported with sufficient monitoring sites. This policy option also focuses on the improved use of monitoring both spatially and temporally to assess air quality.

To support the enhanced assessment that can be derived from increased monitoring and binding use of models under Policy option III-1, Policy options III-4 and III-5 offer more rigorous quality levels in both monitoring and modelling. These quality standards could greatly improve air quality management and the harmonisation across all Member States.

With developing knowledge and understanding of the science of air pollution both on health and ecosystem impacts, the research community requires monitoring of emerging pollutants of concern. Policy option III-3 offers the opportunity to ensure monitoring networks are in place and of good quality to support this research.

It is also important to track and evaluate how emission reduction and air quality management policy is shaping air quality over the longer term to ensure health and environmental impacts are reduced. Policy option III-2 offers a good opportunity to establish monitoring protocols to assess air pollution levels over the longer term and ensures that any relocation of a sampling point is done following clear rules and a protocol.

Table 75 Policy options to address monitoring & assessment shortcomings (III)

Policy options	Specific measures included in the respective policy option						(+ specific measures assessed as sub-options)			
Policy option III-1 - revise requirements for air quality assessment	**G1**	**G2**	**H1**	**H2**	**L1**	+	III-1a: **G3**	III-1b: **H3**	III-1c: **K2**	III-1d: **J3**
Policy option III-2 - revise requirements for monitoring continuity	**I1**	**I3**				+	III-2a: **I2**			
Policy option III-3 - expand requirements to monitor other air pollutants	**L1**	**L2**				+	III-3a: **L3**			
Policy option III-4 - revise requirements for monitoring quality	**J1**	**J2**	**K1**			+	III-4a: **K4**			
Policy option III-5 - introduce requirements for modelling quality	**G2**	**K3**								

10.3.1 *Policy Option III-1: Revise requirements for air quality assessment*

Policy option III-1 includes interventions which aim to widen the scope for air quality assessment, improve the minimum number and type of sampling points and expand monitoring requirements. It is made up of five interventions and includes four sub-options. G1(BCR: High) on encouraging the use of indicative monitoring and G2 (BCR: Medium/High) mandating the use of models in certain circumstances. These interventions offer a far wider spatial assessment, and, importantly, enable comprehensive source apportionment and future projections of air quality. These techniques go hand in hand and should be part of all responsible air quality managers' toolkits. In addition this policy option includes two further interventions which are likely to result in an increase in the minimum number of sampling points (H1 change the minimum number of sampling points (H1 BCR: Medium) and H2 the minimum number of sampling points for PM_{10} and PM2.5 to be considered independently (H2 BCR: High)). These likely additional sampling points could be further used to support air quality model validation and ensure a broader coverage of monitoring in specific situations. In addition, this policy option includes the establishment of "supersites" which monitor a suite of pollutants and help underpin the scientific understanding of air quality.

This policy option is viewed (by the project team) as the most critical revision required to enhance the current air quality assessment regime, and at least partly address the identified shortcoming.
The cost of this policy option is likely to be relatively low, as many of the interventions are already in place. The benefits gained from further monitoring and widespread modelling to support certain aspects of air quality assessment and management are high. The approach and rigour given to the assessment of air quality is fundamental to underpinning effective planning and mitigation, and subsequently to the overall objectives of the AAQ Directives. This policy option is viewed as the basic level to support that assessment and resolve the identified shortcomings.

Sub-options

Policy Option III-1 could be enhanced by the inclusion of further interventions. These are presented below:

Policy Sub-Option III-1a inclusion of intervention G3: Require a regular review of the assessment regime following clear criteria defined in the Directive. This intervention builds in a time-based review point of the assessment regime. As our data knowledge and understanding increases, which includes new monitoring techniques, advances in modelling, our concern of pollutants develops or dissipates, it is important to capture such developments in our air quality assessment approach. However, many of these scientific developments already get incorporated into best assessment processes and are supported by expert communities such as AQUILA on monitoring and FAIRMODE on modelling (G3 BCR: Low).

Policy Sub-Option III-1b inclusion of intervention 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 addition of this intervention to policy option III-1 brings clarity on where monitoring stations are placed, which in turn is important to support any mandatory modelling and assessment. While on the face this intervention is a monitoring site reclassification system, it does offer a re-focus to monitor, and hence assess, in areas of high emissions where populations are exposed (hotspots) other than roadside and industrial sites. For example, it could help address the issue that residential combustion emissions are not a focus of the assessment process but yet are a public health concern. In particular, residential combustion is a key source of $PM_{2.5}$, which has been highlighted by WHO as a major health risk, this intervention could result in a more robust assessment regime. This intervention, however, is unlikely to make much difference to monitoring networks as areas with residential combustion sources of emission are most likely already being assessed. In addition, stakeholders reported that this intervention could result in an over simplification of the current monitoring site categorisation (H3 BCR: Low).

Policy Sub-Option III-1c inclusion of 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 addition of this intervention to Policy Option III-1 is focussed on timely access to available monitoring data. This brings the advantage of tracking air quality closely, which is important to support air quality forecasters and all air quality managers who are implementing measures to achieve compliance with limit values. These data also underpin wider assessment of air quality across Europe including the assessment of transboundary pollution. However, as many Member States already provide access to their monitoring data in real-time, albeit the data are provisional, this intervention is unlikely to bring significant benefits across Europe (K2 BCR: Low)

Policy Sub-Option III-1b inclusion of 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 estimation of spatial representativeness that this intervention brings has the benefit of assessing the monitoring network and identifying any gaps for assessment purposes. A proper 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 and the exceedance indicators. It has the potential to have high benefits especially to those countries whose monitoring networks just meet minimum numbers of stations. However, for others, monitoring networks are typically adequate especially in urban areas.(J3 BCR: Medium)

Links with other options

- III-2 Revise requirements for monitoring continuity where I1 ensures monitoring continues to support assessment purposes;

- III-3 Expand the requirements to monitor other pollutants where both L1 and L2 support the monitoring of additional pollutants. Where limit and target values are set for such additional pollutants their assessment against such will be required;
- III-4 Revise the requirements for monitoring quality which increases the robustness of monitoring data that is needed for air quality assessment;
- III-5 Introduce requirements for modelling quality which sets out standards to support the mandatory introduction of modelling under certain circumstances.

10.3.2 *Policy Option III-2: Revise requirements for monitoring continuity*

To improve the effectiveness of the AAQ Directives, enhance air quality assessment procedures and clarify and update the existing legal requirements, POIII-2 comprises two policy interventions (I1 BCR: High) 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 and (I3 BCR: Medium) 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 policy option provides clarity on the requirements to continue to monitor, which removes the flexibility for competent authorities to close a monitoring site without due consideration for all pollutants. This risk is of particular concern where limit values are exceeded. This supports the development of an air quality plan and is used to assess the impact of the plan following implementation. Public access to information on air quality, particularly where an exceedance has been recorded, is important for the protection of health.

This policy option also provides limited flexibility to competent authorities where changes occur to affect the performance of a sampling point, such as infrastructure changes. The introduction of a monitoring site relocation protocol will help ensure consistency in pollution trend datasets which are invaluable over the longer term to assess by how far policy and measures are improving air quality.
I1 is an important intervention and brings significant benefit to support action to improve air quality in known hotspots and has little additional cost. While I3 supports the longer-term evaluation of air pollution where sites are relocated the benefit is high but as a small number of sites are relocated, for different reasons, it brings medium overall benefits to air quality across Europe.

Policy Option III-2 could be enhanced by the inclusion of a further intervention.

Sub-options

Policy Sub-Option III-2a inclusion of intervention 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 assessment of long-term trends in pollution brings merit, in that it allows an overall assessment of emissions and air quality used in many monitoring and evaluation studies. This intervention builds in a requirement to continue to monitor in a location where a competent authority wishes to cease monitoring with a reference sampler. Assessment of long-term trends in concentrations would be replaced with indicative samplers or modelling. However, both of these have higher uncertainties compared to a reference sampler, so care should be taken overall data quality may decrease. This intervention is not expected to bring significant benefits across Europe

Links with other options

- PO III-1 Revise requirements for air quality assessment where the continuity of monitoring is important to enable assessment of air quality over the longer term.

10.3.3 *Policy Option III-3: Expand the requirements to monitor other pollutants*

To improve the effectiveness of the AAQ Directives, enhance air quality assessment procedures and clarify and update the existing legal requirements, POIII-3 comprises two policy interventions (L1) Require monitoring stations that measure continuously certain emerging air pollutants (e.g. called "supersites" across the Member States) and (L2) Require monitoring of additional air pollutants at a minimum number of sampling points and with relevant data quality requirements. The assessment of air quality cannot be robustly carried out without ambient monitoring of the pollutants of concern.

Equally, as the scientific knowledge advances, and to underpin that scientific research, monitoring of pollutants that are suspected to be of concern is also fundamental. A basic monitoring network of emerging pollutants to support such research is key for developing understanding and assessment of overall air quality. These interventions are complementary as L1 enables the comparison of emerging pollutants and their trends with already monitored pollutants e.g. NOx and PM. Monitoring at supersites enables the study of pollutant interactions. However, the number of supersites will be limited and therefore L2 which requires a minimum number of sites will help inform of the overall spatial concentration coverage of emerging pollutants to be mapped.

While the establishment of supersites brings high benefit to our overall understanding of air quality and emerging pollutants their installation costs are high (L1 BCR: Medium). L2, setting a minimum number of sites, has lower comparative costs (L2 BCR: High).

Sub-options

Policy Option III-3 could be enhanced by the inclusion of a further intervention. This is presented below:

Policy Sub-Option III-3a inclusion of intervention L3: *Expand the list of required and/or recommended volatile organic compounds (VOCs) to measure*. VOCs are a large group of chemicals that are found in many products used for the construction and maintenance of buildings. While there is a requirement to monitor some of these substances already in Annex X of Directive 2008/50/EC, this intervention requires measurement of additional VOCs which would support the further understanding of levels of these diverse group of chemicals in the atmosphere. In the future it is expected that a reduction of automotive emissions will be observed as well as solvent emissions from regulated industrial activities. This may relatively increase the contribution of other ozone precursors related to biogenic sources and emerging emission sources for example, solvent use, architectural emissions, new industrial processes, agricultural activities, wastewater and indoor environments. However, the list of potential VOCs is extensive and without further analysis into the merits of additional (mandatory) monitoring the costs for this intervention are high (L3 BCR: Low).

Links with other options

- PO III-1 Revise requirements for air quality assessment to include emerging pollutants.

10.3.4 *Policy Option III-4: Revise requirements for monitoring quality*

To improve the effectiveness of the AAQ Directives, enhance air quality assessment procedures and clarify and update the existing legal requirements, POIII-4 comprises three policy interventions (J1 BCR: Medium) Further clarify (and reduce flexibilities related to) the macro-siting criteria for sampling points and (J2 BCR: Medium) Further clarify (and reduce flexibilities related to) the micro-siting criteria for sampling points. These offer clarity on specific issues regarding siting criteria to help harmonise air quality monitoring across all Member States. In addition, (K1 BCR: Medium) which further defines the data quality requirements for sampling points / measurements used for air quality assessments, sets new rules for air quality data management as part of quality assurance/control processes. Therefore, this policy option provides support to enhance the quality of monitoring across Europe. As air pollution can vary across a short spatial scale, clarity on the detailed macro and micro-siting criteria which influences concentrations observed is important to ensure harmonisation to enhance the comparability of data. Overall, this policy option sets out the key interventions to increase and clarify the quality of monitoring data. While clarity within the provisions to increase monitoring quality brings benefit, competent authorities still require some flexibility in siting their monitoring stations. Changes to aspects of J2 on micro-siting criteria should not risk what has been deemed as acceptable quality of long term datasets from long established sites. Overall, further harmonisation of monitoring quality offers high benefit for the comparability of data but any sites which would require to be relocated comes with a medium cost, albeit these are not expected to be large in number.

Sub-options

Policy Option III-4 could be enhanced by the inclusion of further interventions. These are presented below:

Policy Sub-Option III-4a inclusion of intervention K4: *Modify the definition of measurement uncertainty by defining it in absolute values and not in percentage values (or a combination of both)*. Confidence in the use of air quality data comes with an understanding of measurement uncertainty. This intervention offers a definition of uncertainty both as an absolute and percentage value. This is important as for lower limit values uncertainty is better defined in absolute terms ensuring data quality. However, feedback from stakeholders supported a combination of both values to be used. While the costs for implementing this intervention are low, the benefits to the wider suite of pollutants that are measured are also relatively low.

Links with other options

- PO III-1 Revise requirements for air quality assessment where this policy option to improve monitoring quality is important to ensure a robust evidence base for assessment purposes.

10.3.5 *Policy Option III-5: Introduce requirements for modelling quality*

To improve the effectiveness of the AAQ Directives, enhance air quality assessment procedures and clarify and update the existing legal requirements, POIII-5 comprises two policy interventions - (G2) Make the use of air quality modelling mandatory as part of air quality assessment (in some circumstances) and (K3) Introduce a standardized 'modelling quality objective' as a quality control mechanism to assess whether a modelling-based assessment is fit-for-purpose. Air quality models are used extensively across Europe, with many support networks available to Member States e.g. EMEP, FAIRMODE. Many binding activities, e.g. reporting of short term forecasts, assessing and reporting the impacts of air quality plans, are not possible to reliably do without the use of models. The mandatory use of models in some circumstances, supported by further monitoring, will lead to more robust assessment of air quality over wider spatial areas.

Therefore, this policy option provides support to enhance the quality of modelling across Europe. However, unlike in the measurement of air pollution concentrations, there are no legal requirements to direct their use or to meet a certain standard in model techniques (besides setting a level of uncertainty not to be exceeded, see Annex I of Directive 2008/50). This policy option sets out the circumstances where modelling is required (G2) and the expected level of quality to be met (K3).

This policy option offers significant support to the identification of air quality problems and assessing measures to help drive action to improve air quality as part of air quality planning. Models are viewed as essential tools for all air quality managers. The benefits are significant and as most Member States already have a modelling system in place the costs for implementing this policy option are relatively low.

Links with other options

- III-1 Revise requirements for air quality assessment where this policy option to introduce mandatory modelling is important to ensure a robust evidence base for assessment purposes.

10.4 Shortcoming IV

Box IV Highlights from Policy Option IV

POIV considers 4 policy interventions with relevant contributions to addressing shortcomings identified in the AAQ Directive fitness check around the provision of air quality information to the public. Policy options have been developed to tackle three underlying drivers, and each of these can be supplemented with further interventions to develop the overall policy package. The three specific drivers are:

- Revising requirements for up-to-date data;
- Revising requirements for air quality health data;
- Revising requirements for a harmonised air quality indices.

To deliver cleaner air action is needed at all levels. While governments can implement measures to reduce emissions it is essential that the public has ready access to information on air quality to support decisions at the individual level. It could help protect sensitive individuals, particularly during episodic events of high concentrations, to take necessary steps to reduce their personal exposure. In addition, access to information on air quality raises public awareness and brings benefits of encouraging uptake of lower emission activities such as use of cleaner transport.

This policy option offers some indirect benefits to air quality, but these are likely small, but benefits to public health are likely higher. The additional costs to inform the public are relatively small as most Member States already have systems in place.

Table 76 Policy options to address information and communication shortcomings (IV)

Policy options	Specific measures included in the respective policy option					(+ specific measures assessed as sub-options)			
Policy option IV-1 - revise requirements for up-to-date data	**F1**	**K2**							
Policy option IV-2 - revise requirements for air quality health data	**F2**					+	IV-2a: **F3**		
Policy option IV-3 - revise requirements of a harmonised air quality indices	**F4**								

10.4.1 *Policy option IV-1: revise requirements for up-to-date air quality data*

Outline

This option contains two interventions: F1 which would specify: the timeframe for reporting, the data/information to be reported; and K2 which would 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.

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 data and appropriate information, which is publicly accessible. Having such information / data would be particularly important for vulnerable groups. There would be some additional administrative burden for Member States, furthermore no single communication channel would achieve universal coverage and to achieve the benefits would rely on citizens paying attention to, understanding, and acting in response to information provided. Where action is taken, the indirect benefits would likely outweigh the costs [F1 BCR: Medium].

It is also important to highlight there are around the accuracy of real-time information. K2 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. There are risks to implementation in cases of monitoring sampler or IT system failure as this would inhibit publication of air quality data in real-time. Increased resources may be needed for some Member States to ensure immediate data quality. [K2 BCR: Low]

Linkages

- IV-2 and IV-3 - would influence the information to be provided.
- III-4 - 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.

10.4.2 *Policy option IV-2: revise requirements for air quality health data*

Outline

This policy option comprises of one intervention: F2 which would require Member States to provide information to the public around the health effects of exposure as soon as exceedances of alert thresholds occur. Ensuring that information is provided at the moment it is most relevant and can allow citizens to take timely action would increase the effectiveness of information provided. However, initial set up costs may be high and this intervention would require closer interaction between health practitioners and policy makers (F2 BCR: Medium). This option had a high level of support from stakeholders.

Sub-options

Policy Option IV-2 could be enhanced by the inclusion of a further intervention as presented below:

Policy Sub-Option IV-2a inclusion of intervention F3: *Mandate specific communication channels with citizens including user-friendly tools for public access to air quality and health risks information and monitoring their use (for example, smartphone apps and/or social media dedicated pages).* 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 (F3 BCR: Low).

Linkages

- PO IV-1 and IV-3 - would influence how and what information is provided.

10.4.3 *Policy option IV-3: revise requirements of a harmonised air quality indices*

Outline

This policy option comprises one intervention: F4 which would require Member States to use harmonised air quality index bands. 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 European Air Quality Index (from the EEA) in full, to adopting consistent bands. Some stakeholders have expressed doubts around the effectiveness of the European Air Quality Index generally (e.g. around its ability to represent multi-pollutant effects), and that complete harmonization may restrict the ability of Member States to tailor advice and information to the specific situation in each Member State. In any case it seems that any harmonisation in terms of bands would be a positive step forward and could go alongside a review of the European Air Quality Index itself in order to tackle its flaws (F4 BCR: Medium).

Linkages

- IV-1 and IV-2 - would influence how and what information is provided.

11 Summary of policy options

Four policy options have been proposed to address the four identified shortcomings of the AAQ Directives on:

1. Environment and Health
2. Governance and enforcement
3. Monitoring and assessment
4. Information and communication.

Within each policy option there are a number of sub-options, each of which has a set of proposed interventions to improve the Directives. Assessing air quality, addressing exceedances of standards, providing timely information to the public and ensuring all stakeholders play their part to establish clean air for all, are complex processes with many interlinkages between these activities. Overall, each of these activities have substantial importance and each should be addressed for a successful improvement to the delivery of clean air across Europe. In reaching such policy decisions it is important to recognise the synergies between the various policy options and all of the policy sub-options.

The cost-benefit analysis conducted suggests there are significant benefits to be gained from setting more ambitious air quality standards, and that the benefits gained are likely to significantly outweigh the costs. In setting revised objectives for pollutants of concern, consideration should be given not only to the value to gained for human health and the environment, but also to how such objectives could be met and at what cost, how revisions in monitoring and assessment may impact on these and how such information can be readily communicated to the public. Furthermore, even if objectives for pollutants are not revised, should changes be made to aspects of monitoring and assessment, then this may impact on the pollution burden. For example, should the use of more monitoring, such as indicative monitoring and/or modelling be encouraged through policy sub-options, then the understanding of pollutant levels across a wider spatial area may increase and impact on where action should be taken.

The improvement of air quality plans is seen as a key success factor of a revised Directive. This is required to bring transparency to the measures Member States are to implement in cases of non-compliance. Improvement is needed on the effectiveness and efficiency of air quality plans. For any revised air quality objectives set for pollutants it is important that a pathway to compliance can be set out within an updated air quality planning process. Key milestones on this pathway to compliance should be transparent and policy sub-options to address the governance and enforcement of the directive should be considered crucial to achieve revised air quality objectives in the near term.

Some policy sub-options proposed consider the longer term air quality across Europe. While air quality modelling of pollutants to 2030 and 2050 have been presented to support this impact assessment, other longer term issues such as the importance of pollutants of emerging concern have also been considered. In addition, the consideration of a regular review of EU air quality standards is also proposed. Gathering data and information on current levels of such emerging pollutants to support research will be key to inform how we should deal with such pollutants over the longer term as the scientific evidence increases.

All 69 interventions have been assessed against 12 indicators which cover environmental, societal, economic and cost consequences/impacts and all offer benefits to the improvement of air quality for human health and the environment. While these have been amalgamated into policy options to address the four shortcomings of the AAQ Directive, some of the interventions offer lower benefits when assessed in isolation. However, many of these are likely to bring more benefits when assessed synergistically with other interventions. For example, many interventions under the policy option for monitoring and assessment are a prerequisite to determine levels of pollution and how these compare to any revised air quality standards. These interlinkages between and within policy options are therefore an important aspect of bringing these together into an integrated policy package for further consideration by decision makers to deliver a clear pathway for cleaner air for all.

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