European Parliament

EU policy on air quality: Implementation of selected legislation

European Implementation Assessment

STUDY

EPRS | European Parliamentary Research Service

Author: Ekaterina Karamfilova
Ex-Post Evaluation Unit
PE 654.216 – January 2021

EN

EU policy on air quality: Implementation of selected EU legislation

European implementation assessment

Air pollution is a cross-border problem with direct negative effects on health and the environment. It also has indirect but tangible adverse effects on economies and societies.

With the aim of securing good air quality status for its citizens and the environment, the EU has established a policy framework that employs legal regulation as the main policy instrument. This European implementation assessment (EIA) presents findings on the implementation of three major pieces of EU legislation on air quality, namely the two Ambient Air Quality Directives and the Industrial Emissions Directive, and makes recommendations for policy action.

In addition, the research paper annexed to this EIA maps and assesses the local policies designed and implemented by 10 EU agglomerations with the aim of tackling air pollution from relevant sources, and, in particular, from road transport. It also makes recommendations for policy action, some of which are relevant to any other EU zone/agglomeration affected by air pollution exceedances, irrespective of specific local conditions. Furthermore, the research paper studies the effects of the first wave of pandemic lockdown measures implemented in the same 10 EU agglomerations and their effects on concentrations of certain air pollutants (particularly harmful for health), and, on this basis, outlines lessons that could be applied in future policy-making on air quality at all levels of governance.

EPRS | European Parliamentary Research Service

AUTHOR(S)

1. The introductory part of this European implementation assessment has been drawn up by Ekaterina Karamfilova (with Lucia De La Trinidad Salvador Sanz) from the Ex-post Evaluation Unit of the Directorate for Impact Assessment and European Added Value, within the Directorate-General for Parliamentary Research Services (EPRS) of the Secretariat of the European Parliament.

To contact the authors, please email: EPRS-ExPostEvaluation@ep.europa.eu.

2. The research paper published as Annex I to this European Implementation Assessment and entitled 'Mapping and assessing local policies on air quality. What air quality lessons could be learnt from the COVID-19 lockdown?' has been drawn by Wood E&IS GmbH and Milieu Consulting SRL at the request of the Ex-post Evaluation Unit of the Directorate for Impact Assessment and European Added Value, within the Directorate-General for Parliamentary Research Services (EPRS) of the Secretariat of the European Parliament.

ADMINISTRATOR RESPONSIBLE

Ekaterina Karamfilova, Ex-post Evaluation Unit, Directorate for Impact Assessment and European Added Value, within the Directorate-General for Parliamentary Research Services (EPRS) of the Secretariat of the European Parliament

To contact the publisher, please e-mail EPRS-ExPostEvaluation@ep.europa.eu.

LINGUISTIC VERSIONS

Original: EN

Manuscript completed in January 2021.

PE 654.216
ISBN: 978-92-846-7683-5
DOI: 10.2861/808342
CAT: QA-02-21-002-EN-N

eprs@ep.europa.eu
http://www.eprs.ep.parl.union.eu (intranet)
http://www.europarl.europa.eu/thinktank (internet)
http://epthinktank.eu (blog)

Executive summary

This European implementation assessment (EIA) has been prepared in support of an implementation report on air quality drawn up by the European Parliament's Committee on the Environment, Public Health and Food Safety (ENVI).[1] Along with the two Ambient Air Quality Directives, the implementation report will also look at the implementation of the Industrial Emissions Directive and EU type-approval legislation, namely, the two regulations setting emission standards (Euro 5/6 and Euro VI) for light- and heavy-duty vehicles.

Part 1 of this EIA presents the impacts and sources of air pollution and sets the scope of the problem that needs to be addressed by policy measures at all levels of governance. Air pollution is a cross-border problem with direct negative effects on the environment, climate and health, especially as regards the population living in urban areas. Air pollution is considered a major factor for premature death and 'the single largest environmental health risk'[2] in Europe. Furthermore, air pollution also has indirect but tangible adverse effects on economies and societies more generally. Anthropogenic activity, along with natural sources, are the main emitters of air pollutants.

Part 2 of this EIA presents the policy framework established at EU level with the aim of tackling air pollution and ensuring good air quality across the EU. This is implemented at national, regional and local levels in the EU Member States. More specifically, EU policy on air quality is based on three main pillars that employ EU legal regulation as a main policy instrument. The first pillar is composed of the two Ambient Air Quality Directives[3] (AAQDs), which set out standards for a number of air pollutants, harmonised criteria for the monitoring and assessment of air pollution across the Member States and the obligation that measures to avoid, prevent or reduce pollution must be taken by the zones/agglomerations faced with pollution exceedances. The second pillar builds on the directive on the reduction of national emissions of certain atmospheric pollutants, commonly referred to as the 'NEC Directive',[4] which set national emissions reduction commitments for five main air pollutants. The third pillar contains several EU legislative acts regulating air pollution from specific sources in sectors such as industry (for example, the 2010 Industrial Emissions Directive),[5] and transport (for example the environmental performance aspects of EU type-approval legislation, namely the Euro 5/6 Regulation setting emissions standards for light-duty vehicles and the Euro VI regulation setting emissions standards for heavy-duty vehicles).

On the basis of a literature review of publically accessible sources, Part 3 presents findings on the implementation of certain EU legislative acts on which EU air quality policy is based, namely the two Ambient Air Quality Directives (AAQDs) and the Industrial Emissions Directive (IED). The presentation of findings centres on the standard set of five criteria for ex-post evaluation, namely, relevance, effectiveness, efficiency, coherence and EU added value. Finally, Part 4 of this EIA presents the main conclusions and makes recommendations for policy action. Some of the most important

1 The implementation report is entitled 'Implementation of the Ambient Air Quality Directives: Directive 2004/107/EC and Directive 2008/50/EC'.

2 Air quality in Europe – 2020, Report 9/2020, European Environment Agency, 2020 (EEA, 2020).

3 Directive 2008/50/EC of the European Parliament and of the Council of 21 May 2008 on ambient air quality and cleaner air for Europe (the 2008 AAQ directive) and Directive 2004/107/EC of the European Parliament and of the Council of 15 December 2004 relating to arsenic, cadmium, mercury, nickel and polycyclic aromatic hydrocarbons in ambient air (the 2004 AAQ directive).

4 Directive (EU) 2016/2284 of the European Parliament and of the Council of 14 December 2016 on the reduction of national emissions of certain atmospheric pollutants, amending Directive 2003/35/EC and repealing Directive 2001/81/EC.

5 Directive 2010/75/EU of the European Parliament and of the Council of 24 November 2010 on industrial emissions (integrated pollution prevention and control directive, IPPCD).

conclusions and recommendations, which are also pertinent in the context of the scheduled revisions of the AAQDs[6] and the IED[7] under the European Green Deal,[8] are presented briefly below.

Some of the current EU air quality standards established by the two AAQDs are not aligned with the latest scientific knowledge, especially as regards the effects of air pollution on health. The standards concerned with health protection therefore need to be brought up to date. Furthermore, the adaptability of the AAQDs to the most recent science and technology needs to be further enhanced. More specifically, the two AAQDs must include an obligation for a periodic review of the standards against the latest technical and scientific evidence.

The 2008 AAQ Directive suffers from deficiencies ('ambiguities') in its provisions that, in certain cases, have resulted in incorrect siting of pollution sampling and related doubts about the representativeness and comparability of sampled data. Therefore, the legal framework needs to be revised so as to remove all deficiencies that could lead to practical situations where pollution is not sampled correctly, and which could have strong negative effects on the measures taken by the relevant authorities to tackle the problem.

There is a positive trend as regards practical implementation of Member States' obligations under the AAQDs to inform the public of air quality status. However, Member States sometimes take differing approaches, not least because of loopholes in the two AAQDs. One example is the fact that information and alert thresholds are currently missing for some pollutants. This is a problem because some national approaches deliver better public awareness than others, and the citizens of some Member States are not able to monitor and control the policy measures implemented by the authorities of the zone/agglomerations affected by air pollution exceedances effectively. Therefore, it is sensible to suggest that there is a need for EU-level harmonisation of the way air quality data is communicated to the public, not least by filling in the gaps in the two AAQDs. Furthermore, the legal framework must include a provision to guarantee the right of citizens to access justice.

Over the past decade, both the number and the magnitude of exceedances have decreased for most pollutants and in most Member States. Both industry and road transport have played a role in this process.[9] However, despite this general improvement trend, the periods of exceedances have not been kept as short as possible in all instances as required by the two AAQDs. In particular, exceedances for certain pollutants (notably particulate matter, nitrogen dioxide, ozone and benzo(a)pyrene) are still widespread and persistent and lead to harmful effects for the environment and for health, in particular.[10] The assessment made by the Commission's 2019 fitness check of the two AAQDs[11] shows a picture of partially effective implementation of the directives. Non-compliance (with the two AAQDs and beyond, e.g. with the IED) has led to a high number of infringement procedures launched by the Commission against a significant number of Member States. More specifically, at the end of 2019, of the 327 open infringement procedures in the field of environment, 61 concerned failures (including problems with transposition and compliance) under all three pillars of EU air quality policy,[12] and a few more followed in the course of 2020. However, infringement procedures, in addition to being lengthy, do not always succeed in enforcing

6 The Commission proposal for revision of the AAQDs is expected in the third quarter of 2022.

7 The Commission proposal for revision of the IED is expected in the fourth quarter of 2021.

8 Communication on the European Green Deal, SWD(2020)640 final, European Commission, 2019.

9 EEA, 2020.

10 EEA, 2020.

11 The Commission staff working document (SWD(2019) 427 final) and other supporting documents can be found here.

12 Annual report on monitoring the application of EU law (2019), Commission SWD – monitoring of applications by EU policy area, Part 2.

compliance with the EU air quality standards to the extent that, in some cases, Member States do not comply with decisions of the Court of Justice of the European Union (CJEU). Such cases show that both compliance with the current EU air quality standards at national level and, in particular at zone/agglomeration level, and enforcement of compliance at both national and EU levels are a particular challenge.

Zone/agglomeration-specific air quality plans (and/or measures) are a critically important instrument on which the two AAQDs rely for the avoidance, reduction and prevention of air pollution beyond the established values in that zone/agglomeration. However, in certain cases, these plans and their implementation are a factor hampering compliance with EU air quality standards. Action for improvement should focus on the quality of the plans and, more specifically, on the nature of the measures included in the plans, which may compromise their implementation in practice. Such action should, as a priority, be taken at the level of the zone/agglomeration affected by exceedances to ensure that local conditions are taken properly into account when measures are designed and implemented. EU-level guidance could support this process. Furthermore, the implementation of air quality plans (and/or measures) need to be properly monitored and evaluated, as a basis for improvements in their design and implementation commensurate with the pollution problem they have been created to solve.

In some cases, air quality plans (and/or measures) suffer from deficiencies in the EU legal framework, such as for example the absence of an obligation for Member States to report to the Commission on the implementation of their plans (and/or measures), or to update them when new measures are adopted or when progress has not been sufficient. This loophole leads to problems with the monitoring of the implementation of the plans for both the relevant authorities and the Commission. These gaps need to be addressed by means of legislative changes to the legal framework of the AAQDs. This recommendation is also supported by the European Court of Auditors,[13] which adds that the legal framework should feature a requirement that air quality plans be results-oriented and their number per zone/agglomeration limited.

As regards the IED, the following issues should be addressed so as to further enhance positive trends identified in the effectiveness of its implementation. First, national practices of granting derogations to certain installations (also a pertinent coherence issue) should not unduly delay implementation of the respective best available techniques (BATs) and, hence, the reduction of emissions from these installations. Second, the current exclusion from the scope of the IED of some highly polluting installations in the agricultural (livestock) and mining sectors should be reconsidered, and the practice of constructing installations with a capacity just below the IED threshold, which leaves such installations outside the scope of the IED and its requirements, should be prevented. Third, data collected via monitoring should be published in a systematic way by all competent authorities, including by using digital technologies, which would show whether operators are indeed reporting data consistently, would improve the transparency of the approaches followed by the competent authorities when assessing operators' compliance with the IED and would facilitate access to data for the public. Fourth, the release of many emerging air pollutants should be better monitored and reported, which would allow for improved assessment of progress towards overall clean production processes. Fifth, and finally, all permits granted under the IED should be made public, which would improve public access to information and public participation in permit procedures.

There are several examples of EU policies, both in the very area of air quality and in other EU policy areas, whose design and/or implementation undermine the achievement of EU air quality objectives because of coherence-related problems. Such policy areas include the IED, the environmental

13 Air pollution – Our health still insufficiently protected, Special Report 23/2018, European Court of Auditors, 2018.

(emissions) performance aspects of the EU type-approval framework for vehicles with internal combustion engines, climate action (and related energy) policy, and agriculture. The policy coherence issues identified need to be addressed as a matter of priority, so as to ensure that EU policies create synergies, facilitating the achievement of the air quality objectives, rather than inconsistencies and policy failures with detrimental health and environmental effects. Furthermore, EU funding would have stronger positive effects on air quality if EU-funded projects were better targeted and more coherent with the zone- and/or agglomeration-specific policies aimed at tackling pollution in those zones or agglomerations.

Against this backdrop, which paints a picture of only partially effective and coherent implementation of the two AAQDs and related EU legislation across the EU, it is necessary to revisit the need to align certain current EU standards with the latest scientific knowledge. Such an upgrade, while relevant and indeed necessary in terms of health protection, will make sense only if it goes hand in hand with fully effective implementation at all levels of governance of what should be an internally and externally coherent EU policy framework (across all three pillars).

The findings of this EIA show that implementation of air quality measures generates significant compliance costs in the form of direct investments, such as infrastructure projects or deployment of technologies, or indirect costs related, for example, to enforcement by the competent authorities. However, it has also been found that the benefits of implementing EU policies, such as reduced premature death rate, improved health, wellbeing and working capacity, especially as regards the two AAQDs and the Industrial Emissions Directive, far outweigh the compliance- and enforcement-related costs. This proves that EU air quality policies can generate efficiency gains.

Finally, this EIA found that air quality policies and legislation, especially regarding the AAQDs and the IED, should indeed be harmonised at EU level as opposed to a situation where Member States act on their own. Air quality policy-making at EU level also has broad support from stakeholders.

Although this EIA does not present findings on the implementation of the Euro 5/6 and Euro VI Regulations,[14] it does make an original contribution to the ENVI implementation report by delivering new knowledge on a major and very pertinent problem relating to emissions from internal combustion engine vehicles, the legacy of on-road polluting vehicles. In particular, the research paper published as Annex I to this EIA [15] maps and assesses the policy measures applied by a sample of ten agglomerations[16] across the EU with the aim of tackling the 'legacy' issue (along with other pollution sources relevant to each specific agglomeration). It thus also contributes to a better understanding of policy measures taken at agglomeration level, with the aim of complying with EU standards established by the AAQDs (under the first pillar of EU air quality policy). In addition, Section 2.5 of the research paper makes recommendations, some of which are also relevant to any other EU zone/agglomeration affected by air pollution exceedances, regardless of the specific local conditions. The research paper also studies the effects of the first wave of pandemic lockdown measures implemented in the same 10 agglomerations and their effects on concentrations of certain pollutants with harmful effects in particular for health, and on this basis outlines (in Section 3.6) lessons that could be applied to future policy-making on air quality at all levels of governance.

14 The limited timeframe of this EIA research project did not allow for a comprehensive ex-post evaluation of the legal framework to be conducted by the Ex-post Evaluation Unit of EPRS.

15 See the research paper 'Mapping and assessing local policies on air quality. What air quality policy lessons could be learnt from the COVID-19 lockdown?' published as Annex I to this EIA. It was prepared by Wood E&IS GmbH and Milieu Consulting SRL at the request of the Ex-Post Evaluation Unit of the European Parliamentary Research Service in support of the ENVI implementation report referred to above.

16 Namely, Athens, Barcelona, Berlin, Bucharest, Paris, Rome, Madrid, Lisbon, Krakow and Stockholm.

Acknowledgements

EPRS would like to express its gratitude to all actors involved in the data collection exercise of this research project.

Table of contents

Table of figures

Table of tables

1. Air pollution – impacts and sources

1.1. The impacts of air pollution

Outdoor air pollution is a cross-border problem that has direct negative effects on the environment, the climate and health, especially for people living in urban areas. It also has indirect but tangible adverse effects on economies and societies more generally. Although air quality has improved over the last decade,[17] air pollution is still a serious problem for a number of areas across the EU.

According to the World Health Organisation (WHO), ambient air pollution is the biggest environmental risk to human health globally.[18] Air pollution is a major factor for premature death and 'the single largest environmental health risk'[19] in Europe. The most harmful pollutants to human health in Europe are particulate matter (PM), nitrogen dioxide (NO_2) and ground-level ozone (O_3).[20] Heart disease and stroke are the most common factors for premature deaths attributable to poor air quality, together with lung diseases and lung cancer.[21] Although over the last decade the estimated number of premature deaths in Europe has decreased somewhat (especially those attributable to (or associated with) particulate matter with a diameter of 2.5 µm or less (PM2.5) and NO_2), levels remain high. According to EEA estimates,[22] in 2018 alone, long-term exposure to PM2.5 in the EU-28 was responsible for the premature deaths of 379 000 EU citizens. This is a reduction of 13 % (or 60 000) in the premature death rate as compared with 2009. Also in 2018, NO_2 was responsible for approximately 54 000 premature deaths in the EU-28; this is also a reduction (54 %) as compared with 117 000 in 2009. Premature deaths resulting from O_3 pollution, however, increased from 15 700 in the EU-28 in 2009 to 19 400 in the EU-28 in 2018 (an increase of 24 %).[23] Different population groups are affected differently. Groups with lower socio-economic status are more exposed to air pollution, while vulnerable groups such as older people, children and those with pre-existing health conditions tend to be more susceptible to the negative effects of air pollution.[24]

The environment, and in particular vegetation and ecosystems, are also exposed to and impacted by air pollution. In particular, the high concentrations of certain air pollutants directly affect the vegetation and fauna, the quality of water and soil and the ecosystem services they support. The most damaging air pollutants for ecosystems are O_3, sulphur dioxide (SO_2), NO_x (nitrogen oxides, which include nitrogen monoxide (NO) and nitrogen dioxide (NO_2)) and ammonia (NH_3).[25] In particular, O_3 is damaging for crops, forests and other vegetation, impairs their growth and affects biodiversity.[26] Nitrogen (N_2) compounds such as NO, NO_2, and NH_3 lead to eutrophication, which, simply put, is a process of pollution that occurs when a lake or stream becomes over-rich in plant

17 Air quality in Europe - 2020, Report 9/2020, European Environment Agency, 2020 (EEA, 2020).

18 Ambient air pollution: A global assessment of exposure and burden of disease, World Health Organisation, 2016.

19 EEA, 2020.

20 EEA, 2020.

21 EEA, 2020.

22 EEA, 2020.

23 This increase between these two specific years can be attributed to the strong influence of high temperatures on O_3 concentrations in the summer of 2018.

24 EEA, 2020.

25 EEA, 2020.

26 EEA, 2020.

nutrient.[27] Estimates show that, in 2018, exceedances of critical loads for eutrophication occurred in virtually all European countries and over about 65 % of the European ecosystem area, which covers 3 million km^2.[28] The three nitrogen compounds mentioned above and SO_2 also lead to acidification, which involves changes in the pH level of water and soil that are damaging for land and water life (for both animals and plants).[29] Estimates for 2018 show that critical loads for acidification were exceeded over about 6 % of the European ecosystem area.[30]

Even though they differ in nature,[31] air pollution and climate change are linked processes. On the one hand, air pollutants such as O_3 and black carbon are also greenhouse gases (GHGs) and thus warm the atmosphere, while others (for example some PM components) have a cooling effect.[32] On the other hand, changes in weather patterns resulting from climate change may alter the transport, dispersion, deposition and formation of air pollutants in the atmosphere; this is for example, the case of the high O_3 levels registered in 2018, which could be attributed to the high atmosphere temperatures in the summer of 2018.[33] Given that GHGs and air pollutants often have the same main emission sources, limiting the emissions of one or the other could bring potential benefits for both.[34]

As mentioned, air pollution also has indirect adverse effects on economies and societies. These effects result from the combined direct effects of air pollution on health, environment and climate. More specifically, as regards the economy, air pollution results in market and non-market costs.[35] Market costs include reduced labour productivity, increased health expenditure, losses of crop and forest yield and impacts on the tourism sector. Non-market costs include those resulting from increased mortality and morbidity, degradation of air and water quality and consequently the health of ecosystems, and climate change. Furthermore, air pollution (as combined with other factors of the social and physical environment) can also increase inequalities across societies, especially as regards a disproportionate disease burden for more vulnerable sections of society.[36]

1.2. Main air pollutants and their sources

Air pollutants can be broadly defined as primary or secondary. Primary pollutants are those directly emitted into the atmosphere. Secondary pollutants are formed from precursor pollutants via chemical reactions and microphysical processes that take place in the atmosphere.[37]

Some of the main primary air pollutants include particulate matter (PM), black carbon (BC), sulphur oxides (SO_x), nitrogen compounds such as nitrogen oxides (NO_x) (which includes nitrogen monoxide (NO) and nitrogen dioxide (NO_2)) and ammonia (NH_3), carbon monoxide (CO), methane (CH_4),

27 As a result, lakes, rivers, etc. become overgrown with algae and other aquatic plants. The plants die and decompose, in a process where plants rob the water of oxygen and the lake, river or stream becomes lifeless. Source: EEA.

28 EEA, 2020.

29 D. Bourguignon, 2018.

30 EEA, 2020.

31 While climate change is caused by greenhouse gases, which can have very long life spans and are spread almost evenly across the atmosphere, air pollution varies a lot in time and space, with shorter time spans between the moment pollutants are emitted and the moment where significant concentrations can be measured. (D. Bourguignon, 2018).

32 EEA, 2020 report.

33 EEA, 2020 report.

34 EEA, 2020.

35 EEA, 2020.

36 D. Bourguignon, 2018.

37 EEA, 2020.

non-methane volatile organic compounds (NMVOCs), including benzene (C_6H_6), and certain metals and polycyclic aromatic hydrocarbons (PAHs), including benzo[*a*]pyrene (BaP).[38]

Key secondary air pollutants include PM (formed in the atmosphere), O_3, NO_2 and several oxidised volatile organic compounds (VOCs). NO_x, NH_3, SO_2, and VOCs are key precursor gases for secondary PM. Furthermore, gases such as SO_2, NO_x and NH_3 react in the atmosphere to form particulate sulphate (SO_4^{2-}), nitrate (NO_3^-) and ammonium (NH_4^+) compounds. These compounds form new particles in the air or condense onto pre-existing ones and thus lead to the synthesis of secondary inorganic PM. In addition, certain NMVOCs are oxidised in the air and form less volatile compounds, which, in turn, synthesise secondary organic aerosols. Ground-level (tropospheric) O_3 is formed from chemical reactions in the presence of sunlight, following emissions of precursor gases, mainly NO_x, NMVOCs, CO and CH_4.[39]

Air pollutants may be of anthropogenic, natural or mixed origin, depending on their sources or the sources of their precursors.[40] As regards emissions from natural sources, volcanos are the main source of emissions of SO_2; lightning and soils are main sources of emissions of NO_x; oceans and natural vegetation are the main sources of emissions of NH_3 and CO; vegetation is the main source of emissions of VOCs; wind erosion (mainly in deserts) and the release of sea salts through waves are the main sources of emissions of PM.[41] As regards emissions from anthropogenic activity, heating, industry and transport are the main sectors emitting PM; transport and energy production are the main sectors emitting NO_x; energy production and non-road transport are mainly responsible for the anthropogenic emissions of sulphur oxides (SO_x); agriculture is almost the sole source of man-made NH_3; VOCs are mainly the result of 'solvent and product use' (such as paints and chemicals used in manufacturing and maintenance); heating and transport are the main emitters of CO; and the agriculture, waste and energy sectors emit the largest share of CH_4 emissions.[42]

The following processes leading to the release of pollutants are worth mentioning – combustion, volatilisation, mechanical processes and other natural processes.[43] In particular, combustion from both human activities (such as power generation, transport, heating or waste incineration) and natural processes (e.g. forest fires) leads, following chemical reactions with nitrogen (N_2) and oxygen (O_2) in the atmosphere, to the formation of NO_x, carbon dioxide (CO_2) and water vapour (the latter two also being GHGs). Combustion is usually not complete and, therefore, also releases substances such as CO, VOCs, PM, PAHs, dioxins and furans. The process of volatilisation of volatile or semi-volatile compounds, for instance from fossil fuels during storage or from paints and solvents during use, also leads to the release of air pollutants. Mechanical processes from both human activities (for example building, tilling, certain industrial processes or transport) and natural activities (such as the release of dust and sea salt by the wind) also emit air pollutants. Finally, other natural processes such as vegetation metabolism, ruminant digestion and volcanic eruptions also release air pollutants. For example, vegetation metabolism produces organic volatile compounds, while ruminant digestion leads to the production of methane. Figure 1 below shows the contribution made by the relevant sectors between 2000 and 2018.

[38] EEA, 2020.

[39] EEA, 2020.

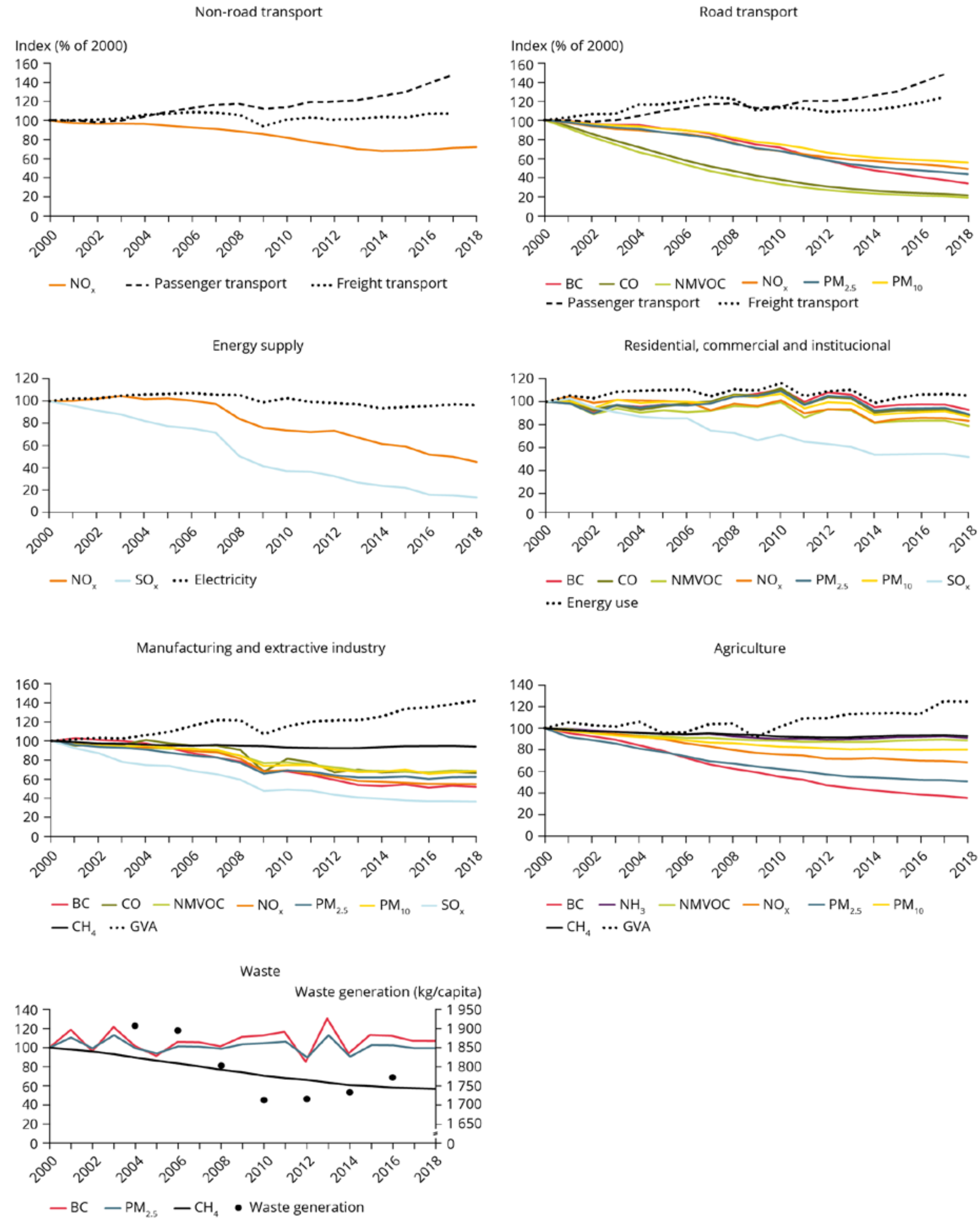
[40] EEA, 2020.

[41] D. Bourguignon, 2018.

[42] D. Bourguignon, 2018.

[43] D. Bourguignon, 2018.

Figure 1 – Development of EU-28 emissions from the main source sectors between 2000 and 2018*



*Note: Development in EU-28 emissions from the main source sectors of NO_x, PM10, PM2.5, SO_x, NMVOC, NH_3, BC, CO and CH_4 between 2000 and 2018 (% 2000 levels). For comparison, key EU-28 sectoral activity statistics are shown (% 2000 levels, except waste (kg per capita). GVA refers to gross value added.

Source: EEA, 2020.

In addition, Table 1 below describes selected outdoor air pollutants, their sources, effects and whether they are precursors to other pollutants.

Table 1 – Brief description of selected outdoor air pollutants

Pollutant	Description and sources	Adverse impacts on *	Precursor to
Particulate matter (PM)	Solid or liquid particles of varying sizes and chemical composition. PM_{10} ($PM_{2.5}$) are 10 (2.5) micrometres or smaller.[44] Primary PM is emitted directly from natural sources (sea salt, naturally suspended dust, pollen and volcanic ash) and anthropogenic sources (from combustion, heating, transport, industry, agriculture, as well as tyres and road wear). Secondary PM is formed from emissions of SO_2, NO_x, NH_3 and NMVOCs, mainly from anthropogenic sources.	**Health** Climate	–
Ozone (O_3)	Not emitted directly in the atmosphere. Ground-level ozone forms on the basis of complex chemical interactions involving sunlight and precursor pollutants, mainly NO_x, CO, NMVOCs and CH_4.	**Health** **Environment** **Climate**	–
Nitrogen oxides (NO_x)	Nitrogen monoxide (NO) and nitrogen dioxide (NO_2). They are emitted during fuel combustion, for instance from industrial facilities and the transport sector (mainly from diesel vehicles).	**Health** **Environment**	ozone PM
Sulphur dioxide (SO_2)	Emitted mainly through the combustion of fuels containing sulphur.	Health Environment	PM
Ammonia (NH_3)	Emitted mainly from the use of manure and nitrogenous fertilisers in agriculture.	Health Environment	PM
Non-methane volatile organic compounds (NMVOCs)	Emitted from anthropogenic sources (mainly paints, solvents, dry-cleaning, road transport) and natural sources (mainly vegetation).	Health	ozone PM
Benzene (C_6H_6)	Volatile organic compound emitted from the combustion of fossil fuels and from industrial processes.	Health	ozone
Carbon monoxide (CO)	Emitted due to incomplete combustion (mainly from road transport, businesses, households and industry).	Health	ozone
Methane (CH_4)	Produced by both anthropogenic sources (mainly from agriculture, waste, coal mining and gas) and natural sources.	**Climate**	ozone
Lead (Pb)	Emitted from the combustion of fossil fuels, the incineration of waste and the production of non-ferrous metal, iron, steel and cement.	**Health** **Environment**	
Cadmium (Cd)	Emitted from non-ferrous metal production, stationary fossil-fuel combustion, waste incineration, and the production of iron, steel and cement.	**Health** **Environment**	
Mercury (Hg)	Mainly emitted from the combustion of coal and other fossil fuels, as well as metal and cement production, waste disposal and cremation.	**Health** **Environment**	
Arsenic (As)	Mainly emitted from metal smelters and fuel combustion.	**Health** **Environment**	
Nickel (Ni)	Emitted from oil and coal combustion, mining, incineration of waste and sewage sludge, and steel production.	**Health** Environment	

[44] For comparison, a human hair has a diameter of 50 to 70 micrometres.

Pollutant	Description and sources	Adverse impacts on *	Precursor to
Persistent organic pollutants (POPs)	Chemicals used as pesticides or emitted through combustion and mechanical processes. POPs persist in the environment and may bioaccumulate through the food web.	**Health** **Environment**	
Benzo(a)pyrene (BaP)	Persistent organic pollutant belonging to polycyclic aromatic hydrocarbons; mainly emitted from domestic heating (in particular wood and coal burning), waste burning, coke production and steel production.	**Health** **Environment**	

Note: high impacts are indicated in bold.
Source: D. Bourguignon, 2018.

Further detailed information on the various pollutants, their sources, annual concentration levels measured across Europe and relevant trends are contained in the series of 'Air quality in Europe' reports published by the European Environment Agency towards the end of each calendar year. The latest report,[45] which is also a main source of information for this part of the EIA, was published in November 2020 and includes air quality data from across Europe[46] for 2018.

Air pollution requires policy action and cooperation at all levels of governance (from global to local). In this context and in line with the scope of the ENVI implementation report, the next part (Part 2) of this EIA presents the policy framework established at EU level, which is then implemented at national, regional and local levels in the EU Member States.

45 EEA, 2020.

46 It is of note that the EEA 2020 air quality report contains data for the 28 EU Member States (as per 2018) as well as for several other non-EU countries part of the EEA network.

2. EU policy on air quality – legal framework

Air quality improvement has been on the EU agenda for decades, not least because of the strong cross-border dimension of air pollution. Currently, the main EU strategic document with a specific focus on air quality is the 2013 clean air programme for Europe.[47] Its main objective is to ensure that by 2030, the number of premature deaths caused by exposure to ground level ozone and fine particulate matter (PM2.5) is reduced by half as compared to 2005 levels. Very recently, the European Green Deal[48] provided for the adoption of a zero pollution action plan,[49] expected to include air quality improvement across the EU among its key objectives.

Legal regulation is a key policy instrument used by the EU and its Member States to achieve the above objectives at operational level and specific action is taken within the framework of three policy pillars.

The first pillar is composed of the two Ambient Air Quality Directives[50] (AAQDs), which set out standards for a number of air pollutants, harmonised criteria for the monitoring and assessment of air pollution across the Member States and an obligation to take measures to avoid, prevent or reduce pollution.

The second pillar builds on the directive on the reduction of national emissions of certain atmospheric pollutants (the NEC Directive),[51] which set up national emission reduction commitments for main pollutants, namely, SO_2, NO_x, VOCs, NH_3 and PM2.5. It translates into EU law the commitments taken by the EU under the updated Gothenburg Protocol.[52]

The third pillar contains several EU legislative acts regulating air pollution from specific sources in sectors such as industry (the 2010 Industrial Emissions Directive;[53] the 2015 Medium Combustion Plants Directive;[54] the 2009 Ecodesign Directive;[55] etc.), and transport (the environmental performance aspects of EU type-approval legislation, for example the Euro 5/6 Regulation setting emission standards for light-duty vehicles and the Euro VI regulation setting emissions standards for heavy-duty vehicles; EU legislation on the storage and distribution of petrol (the 1994 'Stage-I'

---

47 Communication on A Clean Air Programme for Europe, COM/2013/0918 final, European Commission, 2013.

48 Annex to the communication on the European Green Deal, European Commission, COM(2019) 640 final, 2019.

49 Roadmap on EU action plan 'Towards a Zero Pollution Ambition for air, water and soil – building a Healthier Planet for Healthier People', European Commission, 2020. The Commission is expected to adopt the action plan in the second quarter of 2021.

50 Directive 2008/50/EC of the European Parliament and of the Council of 21 May 2008 on ambient air quality and cleaner air for Europe (the 2008 AAQ directive) and Directive 2004/107/EC of the European Parliament and of the Council of 15 December 2004 relating to arsenic, cadmium, mercury, nickel and polycyclic aromatic hydrocarbons in ambient air (the 2004 AAQ directive).

51 Directive (EU) 2016/2284 of the European Parliament and of the Council of 14 December 2016 on the reduction of national emissions of certain atmospheric pollutants, amending Directive 2003/35/EC and repealing Directive 2001/81/EC.

52 Gothenburg Protocol to the Convention on long-range transboundary air pollution, signed in 1979 in the framework of the United Nations Economic Commission for Europe (UNECE). The Protocol was originally signed in 1999 and amended in 2012. Among others, the revised protocol introduced national emission reduction commitments to be achieved by 2020.

53 Directive 2010/75/EU of the European Parliament and of the Council of 24 November 2010 on industrial emissions (integrated pollution prevention and control).

54 Directive (EU) 2015/2193 of the European Parliament and of the Council of 25 November 2015 on the limitation of emissions of certain pollutants into the air from medium combustion plants.

55 Directive 2009/125/EC of the European Parliament and of the Council of 21 October 2009 establishing a framework for the setting of ecodesign requirements for energy-related products (recast).

Directive)[56] and on petrol vapour recovery during refuelling of motor vehicles at service stations (the 2009 Stage-II Directive),[57] etc.).[58]

Part 2 of the EIA presents in more detail the legal acts that fall specifically within the scope of the ENVI implementation report, namely the two AAQDs, the Industrial Emissions Directive and the environmental (emissions) performance aspects of the EU legal framework on type approval.[59]

2.1. First pillar of EU air quality policy – the Ambient Air Quality Directives

The legal framework established under the two AAQDs builds on four main objectives, namely: to define common methods for the monitoring and assessment of air quality; to set standards to be achieved across the EU; to ensure that air quality information is made available to the public; and to maintain good air quality and improve it where it is not good enough. The paragraphs below give more detail on each of these objectives.

Monitoring and assessment of air quality

The AAQDs require Member States to establish a network of measurement stations and sampling points following a set of common criteria on the determination of minimum numbers of sampling points, data quality, unacceptable uncertainty in monitoring and modelling and on microscale and microscale siting of sampling points. The AAQDs thus harmonise common methods and criteria for air quality assessment in all Member States in a comparable and reliable manner.

Member States must establish air quality zones and/or agglomerations across their territories as well as monitor and assess the concentration of air pollutants in all zones and/or agglomerations.[60] Furthermore, Member States must classify the zones and/or agglomerations according to certain assessment thresholds. When assessing air quality, Member States must use reference measurement methods based on international standards or equivalent methods and must ensure the accuracy of measurements.

---

56 Directive 94/63/EC of the European Parliament and of the Council of 20 December 1994 on the control of volatile organic compound (VOC) emissions resulting from the storage of petrol and its distribution from terminals to service stations

57 Directive 2009/126/EC of the European Parliament and of the Council of 21 October 2009 on Stage II petrol vapour recovery during refuelling of motor vehicles at service stations.

58 For an overview of existing EU (and also international) legislation aimed at reducing emissions of air pollutants at specific sources in sectors other than industry and transport, see Chapter 5.3 in D. Bourguignon, 2018.

59 The deadline for the transposition of the 2016 NEC Directive into national law was 1 July 2018 and the deadline for submission of the National Air Pollution Control Programmes, which the directive requires from Member States, was 1 April 2019. The NEC directive has thus not yet been implemented in practice for at least three years and, therefore, at this stage, a comprehensive ex-post evaluation of its implementation would be premature. Nevertheless, and even though this directive is not specifically included in the scope of the ENVI implementation report, it is worth mentioning that cases of non-compliant transposition, failure to submit national programmes as well as non-compliant application of the NEC Directive resulted in infringement procedures launched by the Commission against some Member States.

On 26 June 2020, the Commission published a 'progress' report on the implementation of the NEC directive. The analysis of the submitted national air pollution control programmes takes up much of this report.

60 The European Environment Agency (EEA) maintains an interactive map of all zones and/or agglomerations.

Setting EU air quality standards

Standards are needed to allow the assessment of data derived from air quality monitoring. The EU began setting standards for concentrations of certain air pollutants back in the 1980s. Currently, the two AAQDs define standards to be attained for 13 air pollutants: sulphur dioxide (SO_2), nitrogen dioxide (NO_2) and nitrogen oxides (NO_x), particulate matter (PM10 and PM2.5), ozone (O_3), benzene, lead, carbon monoxide, arsenic, cadmium, nickel, and benzo(a)pyrene.

The two ambient air quality directives set a number of reference values, aimed specifically at protecting health, namely: limit values, target values, information thresholds, alert thresholds, and exposure concentration obligations. More specifically:[61]

- **limit values** are binding standards, defined as the concentration of a pollutant over an averaging period; limit values are set up for particulate matter, sulphur dioxide, nitrogen dioxide, lead, carbon monoxide and benzene;
- **target values** are standards that must be attained where possible, defined as the concentration of a pollutant over an averaging period; target values are set up for ozone, arsenic, cadmium, nickel and benzo(a)pyrene;[62]
- the **information threshold** is a pollutant concentration level beyond which brief exposure is deemed to pose health risks for specific segments of the population; if such a threshold has been reached, authorities are required to inform the public; there is an information threshold set for ozone;
- the **alert threshold** is a pollutant concentration level beyond which brief exposure is deemed to pose health risks for the population as a whole; if such a threshold has been reached, authorities are required to inform the public and draw up short-term action plans; alert thresholds are set for sulphur dioxide, nitrogen dioxide and ozone;
- the **exposure concentration obligation** is a binding standard reflecting human exposure to fine particulate matter at national level (in contrast, limit and target values apply at the level of air quality zones).

A number of exceedances may be allowed over a given period for some of these reference values. For example, the daily limit value of 50 µg/m^3 for PM10 can be exceeded no more than 35 times per year. Table 2 below presents the air quality standards for the protection of health as established by the AAQDs.

Table 2 – Air quality standards for the protection of health as established by the AAQDs

Pollutant	Averaging period	Legal nature and concentration	Comments
PM_{10}	1 day	Limit value: 50 µg/m^3	Not to be exceeded on more than 35 days per year
	Calendar year	Limit value: 40 µg/m^3	
$PM_{2.5}$	Calendar year	Limit value: 25 µg/m^3	

[61] The information presented under the bullets points below follows D. Bourguignon, 2018.

[62] Although the 2004 directive obliges Member States to measure concentrations of mercury, it does not lay down any target value (or any other reference value) for mercury concentration.

		Exposure concentration obligation: 20 µg/m³	Average exposure indicator (AEI) ([a]) in 2015 (2013-2015 average)
		National exposure reduction target: 0-20 % reduction in exposure	AEI ([a]) in 2020, the percentage reduction depends on the initial AEI
O_3	Maximum daily 8-hour mean	Target value: 120 µg/m³	Not to be exceeded on more than 25 days/year, averaged over 3 years ([b])
		Long-term objective: 120 µg/m³	
	1 hour	Information threshold: 180 µg/m³	
		Alert threshold: 240 µg/m³	
NO_2	1 hour	Limit value: 200 µg/m³	Not to be exceeded on more than 18 hours per year
		Alert threshold: 400 µg/m³	To be measured over 3 consecutive hours over 100 km² or an entire zone
	Calendar year	Limit value: 40 µg/m³	
BaP	Calendar year	Target value: 1 ng/m³	Measured as content in PM_{10}
SO_2	1 hour	Limit value: 350 µg/m³	Not to be exceeded on more than 24 hours per year
		Alert threshold: 500 µg/m³	To be measured over 3 consecutive hours over 100 km² or an entire zone
	1 day	Limit value: 125 µg/m³	Not to be exceeded on more than 3 days per year
CO	Maximum daily 8-hour mean	Limit value: 10 mg/m³	
C_6H_6	Calendar year	Limit value: 5 µg/m³	
Pb	Calendar year	Limit value: 0.5 µg/m³	Measured as content in PM_{10}
As	Calendar year	Target value: 6 ng/m³	Measured as content in PM_{10}
Cd	Calendar year	Target value: 5 ng/m³	Measured as content in PM_{10}
Ni	Calendar year	Target value: 20 ng/m³	Measured as content in PM_{10}

Notes:

([a]) AEI: based on measurements in urban background locations established for this purpose by the Member States, assessed as a 3-year running annual mean.

([b]) In the context of this report, only the maximum daily 8-hour means in 1 year are considered, so no average over the 3-year period is presented.

Source: EEA, 2020. Sources used by the EEA: EU (2004, 2008).

In order to protect the environment (especially as regards vegetation), the 2008 directive sets binding 'critical levels' for SO_2 and NO_x as well as a non-binding target value and 'long-term objective' for O_3. Table 3 below presents the air quality standards for the protection of vegetation as established by the 2008 directive and the Convention on Long-range Transboundary Air Pollution.[63]

Table 3 – Air quality standards for the protection of vegetation as established by the 2008 Directive and the Convention on Long-range Transboundary Air Pollution

Pollutant	Averaging period	Legal nature and concentration	Comments
O_3	AOT40 ([a]) accumulated over May to July	Target value, 18 000 µg/m³·hours	Averaged over 5 years ([b])
		Long-term objective, 6 000 µg/m³·hours	
	AOT40 ([a]) accumulated over April to September	Critical level for the protection of forests: 10 000 µg/m³·hours	Defined by the CLRTAP
NO_X	Calendar year	Vegetation critical level: 30 µg/m³	
SO_2	Winter	Vegetation critical level: 20 µg/m³	1 October to 31 March
	Calendar year	Vegetation critical level: 20 µg/m³	

Notes:

([a]) AOT40 is an indication of accumulated O_3 exposure, expressed in µg/m³·hours, over a threshold of 40 parts per billion (ppb). It is the sum of the differences between hourly concentrations > 80 µg/m³ (40 ppb) and 80 µg/m³ accumulated over all hourly values measured between 08.00 and 20.00 (Central European Time).

([b]) In the context of this report, only yearly AOT40 values are considered, so no average over 5 years is presented.

Source: EEA, 2020. Sources used by the EEA: EU (2008); UNECE (2011).

When assessing compliance, pollution from natural sources (such as natural events such as volcanic eruptions, seismic activates, wild-land fires, transport of natural particles from dry regions) may be deducted from the measured concentrations.

Informing on the status of air quality

Under the legal framework, Member States are expected to report to the Commission as well as to inform the general public of the results of air quality assessment on an annual basis and provide 'up-to-date' air quality measurements. Furthermore, Member States must communicate information on their air quality plans and programmes.

Avoidance, prevention and reduction of air pollution

If a given zone/agglomeration does not meet the standards for a certain pollutant, Member States are obliged to adopt air quality plans and/or take appropriate measures (depending on the pollutant). In particular, the plan must contain measures intended to keep the exceedance period

[63] Convention on Long-range Transboundary Air Pollution, United Nations Economic Commission for Europe, 1999

in the zone/agglomeration concerned as short as possible. The AAQDs leave the choice of how to achieve the standards to Member States depending on the specific local conditions they are faced with. Furthermore, air quality plans need to identify the main pollutant(s) emitting sources and outline the reasons for the exceedances, as a basis for the determination of abatement measures to reduce the pollution. Such abatement measures may include, for example, measures aimed at reducing emissions from fixed sources (such as industrial installations) or from mobile sources and vehicles (also by retrofitting with emission control equipment), measures aimed at limiting emissions from transport in general (for example, by means of traffic planning or incentives to shift towards less polluting modes, including congestion pricing or low emission zones), measures promoting the use of low-emission fuels, or measures relying on economic and fiscal instruments discouraging activities with high emissions.

In 2019, the Commission published a fitness check on implementation of the two AAQDs.[64] The fitness check results and the findings of other relevant sources are outlined in Section 3.1. below.

2.2. Third pillar of the EU policy on air quality – legislation on the reduction of emissions of air pollutants at specific sources

The third pillar of EU air quality policy is based on the principle enshrined in the Treaty on the Functioning of the European Union that 'environmental damage should as a priority be rectified at source'.[65] As already explained, emissions of air pollutants from specific sources are regulated by a large number of EU legal acts in various sectors. Reflecting the scope of the ENVI implementation report, two main legal frameworks regulating the emissions from industrial activities and from vehicles with internal combustion engine are presented below.

2.2.1. Industrial Emissions Directive

The 2010 Industrial Emissions Directive (IED) strengthened and combined in one document requirements that had previously been set out in seven different directives.[66] This merging of legislation was motivated by the need to further enhance the control of industrial pollution, while at the same time simplifying the rules, decreasing red tape and improving the enforcement of compliance with the rules. In addition, the merger was meant to enhance innovation and improve coherence with EU law on air, water, soil, waste and the circular economy.

Currently, the IED is the main EU legislative act controlling air polluting emissions from industrial activities. In particular, its main objective is to prevent, reduce and eliminate as far as possible emissions into the air, water and soil and remediate soil pollution arising from industrial activities thus controlling and mitigating the health and environmental impacts of industrial emissions across the EU. The IED also aims at ensuring a level playing field for the operators of installations under the

---

64 The Commission staff working document (SWD(2019) 427 final) and other supporting documents can be found here.

65 Article 191(2) of the Treaty on the Functioning of the European Union

66 Directive 2008/1/EC of the European Parliament and of the Council of 15 January 2008 concerning integrated pollution prevention and control, Directive 2001/80/EC of the European Parliament and of the Council of 23 October 2001 on the limitation of emissions of certain pollutants into the air from large combustion plants, Directive 2000/76/EC of the European Parliament and of the Council of 4 December 2000 on the incineration of waste, Council Directive 1999/13/EC of 11 March 1999 on the limitation of emissions of volatile organic compounds due to the use of organic solvents in certain activities and installations, Council Directive 78/176/EEC on waste from the titanium dioxide industry, Council Directive 82/883/EEC on procedures for the surveillance and monitoring of environments concerned by waste from the titanium dioxide industry and Council Directive 92/112/EEC on procedures for harmonising the programmes for the reduction and eventual elimination of pollution caused by waste from the titanium dioxide industry.

directive. Another important objective of the IED is to ensure access to information and justice for the public and public participation in decision-making on the permitting and performance of the agro-industrial installations falling within the scope of the IED.

Under the IED, emissions should be tackled by taking an integrated approach. In particular, all installations with activities listed in Annex I to the directive must operate in compliance with a permit delivered by the competent authority of the Member State where the activity takes place. The permit extends to all environmental aspects of the activities conducted by the installation, including polluting emissions to air, water and soil, noise, odour, waste generation, resource use, prevention of accidents and restoration of the site after the installation closes. For some installations, such as large combustion plants (i.e. over 50 megawatts), waste incineration and co-incineration plants and installations using organic solvents, the IED sets minimum requirements (for example emission limit values) based on the predecessor legislation.

The conditions laid down in a permit must be based on the use of what are referred to as 'best available techniques' (BATs). BATs are the most environmentally effective of the economically viable techniques available in a given sector. They are presented in detail in the 'best available techniques reference documents' (BREFs). The BREFs for each sector are prepared and reviewed in a process of exchange between Member States, the industry concerned, environmental NGOs and the Commission. Central to each BREF are the 'BAT conclusions', which are adopted by the Commission in the form of implementing decisions following approval by Member States representatives in a standing committee. The 'BAT conclusions' contain binding 'associated emission levels' (BAT-AELs) linked with implemented best available techniques. BAT-AELs are particularly relevant to air quality because they constitute a numerical range of emission levels for specific pollutants, and, thus serve as a mandatory reference for setting permit conditions on air pollutants for the installations covered by the IED.

According to Commission data,[67] around 52 000 of the largest agro-industrial installations fell within the scope of the IED in 2015. These installations operate in sectors such as power plants, refineries, and the production of steel, non-ferrous metals, cement, lime, glass, chemicals, pulp and paper, food and drink as well as waste treatment and incineration and the intensive rearing of pigs and poultry.

In 2020, the Commission published an ex-post evaluation on the IED's implementation.[68] The results from this evaluation and the findings of other relevant sources are presented in Section 3.2. below.

2.2.2. EU type-approval legislation – environmental (emissions) performance of internal combustion engine vehicles

Before a new vehicle model is placed on the EU market, it should be certified that it complies with requirements for safety (e.g. lights, brakes, stability control), noise and environmental performance (such as air pollutant emissions limits) as well as with other production requirements (of individual parts and components, such as seats or steering wheel airbags). If the prototypes of the model meet all relevant requirements, a national authority issues an EU vehicle type approval to the manufacturer authorising the sale of the vehicle type. In accordance with the mutual recognition principle, once approved by the national authority of one EU Member State, the model can be sold in all other EU Member States.

[67] Evaluation of the Industrial Emissions Directive, SWD(2020) 181 final, European Commission, 2020

[68] The Commission staff working document (SWD(2020) 181 final) and other supporting documents can be found here.

Until 31 August 2020, the above process known as 'type approval' was regulated by a 2007 Framework Directive[69] and a number of other legislative acts. As regards the environmental performance of internal combustion engine vehicles, and in particular, the emissions of air pollutants from such vehicles, the EU has been adopting successive (and increasingly stringent) specific rules (Euro standards) since the 1990s. The current Euro emission standards for light-duty vehicles (such as cars and vans) are set out in a regulation from 2007[70] (the 'Euro 5/6 Regulation'), while the current Euro emission standards for heavy-duty vehicles (such as trucks and buses) are set in a regulation from 2009[71] (the 'Euro VI Regulation'). These regulations set standards for several air pollutants, including PM, NO_x and CO. Furthermore, as regards NO_x, the Euro 5/6 Regulation differentiates between petrol and diesel vehicles. Several Commission regulations implement the provisions of the two regulations setting standards for air pollutant emissions, also for testing.

In the second half of this decade, the above legal framework underwent a revision not least as a result of the Volkswagen case.[72] While the reform brought changes to many aspects of the type-approval system (such as for example changes relating to market surveillance), the improvement of the environmental (emissions) performance of internal combustion engine vehicles was one of its central elements.

In particular, the reform aimed at preventing implementation failures such as those revealed by the Volkswagen case and the manipulative strategies used by car manufacturers for their cars to pass the type-approval process. In this respect, under the new rules laboratory tests for measuring nitrogen oxides and particulate number will be complemented by a 'real driving emissions' (RDE) procedure where emissions will be measured by means of a portable emissions measurement system (PEMS). In addition, the reform introduced 'not-to-exceed limits' for nitrogen oxides on the basis of Euro 6 emission limits (80mg/km) multiplied by a 'conformity factor', which allows for a margin of error for higher emissions measured under real driving conditions.[73] The conformity factor will gradually be reduced so as to gradually reduce the gap between type approval and on-road emissions. Since 2017, the conformity factor has been set at 2.1 (which allows up to 168 mg of NO_x per km). From 2020 onwards, it is set at 1.43 (which allows 114 mg of NO_x per km), thus leaving a

---

69 Directive 2007/46/EC of the European Parliament and of the Council of 5 September 2007 establishing a framework for the approval of motor vehicles and their trailers, and of systems, components and separate technical units intended for such vehicles (Framework Directive) which was repealed by Regulation (EU) 2018/858 applying from 1 September 2020.

70 Regulation (EC) No 715/2007 of the European Parliament and of the Council of 20 June 2007 on type approval of motor vehicles with respect to emissions from light passenger and commercial vehicles (Euro 5 and Euro 6).

71 Regulation (EC) No 595/2009 of the European Parliament and of the Council of 18 June 2009 on type-approval of motor vehicles and engines with respect to emissions from heavy duty vehicles (Euro VI) and on access to vehicle repair and maintenance information and amending Regulation (EC) No 715/2007 and Directive 2007/46/EC and repealing Directives 80/1269/EEC, 2005/55/EC and 2005/78/EC.

72 The case, which first broke in the US in September 2015, revealed that the car manufacturer Volkswagen (VW) was manipulating the emission tests of their diesel cars. In particular, VW was using defeat devices that ensured that the vehicle was compliant with the NO_x emissions standards when tested in laboratory conditions. However, outside a laboratory setting, the device would switch off the emissions control system, and the vehicle would produce emissions well above the NO_x limit applicable to the relevant market. Volkswagen admitted that such devices had been used on 11 million vehicles sold globally. Later it became clear that other car manufacturers also used defeat devices. The Volkswagen case only reconfirmed what had already been alerted in 2011 by the Commission's Joint Research Centre, which had pushed the Commission to start looking into ways to address the issue even before the Volkswagen case. However, the Volkswagen case accelerated the reform of the type-approval framework. Source: The EU's response to the Dieselgate scandal, Review 1/2019, Briefing Paper, European Court of Auditors, 2019.

73 This novelty was initially introduced by Commission Regulation (EU) 2016/646 of 20 April 2016 amending Regulation (EC) No 692/2008 as regards emissions from light passenger and commercial vehicles (Euro 6).

margin for errors in the measurement. Following a decision of the CJEU from 2018,[74] which ruled that the Commission had no power to amend the Euro 6 emission limits for the newly introduced RDE tests, the 'conformity factor' system is being discussed by the European Parliament and the Council as part of an ongoing ordinary legislative procedure.[75]

Furthermore, since September 2017, the 'world harmonised light vehicle test procedure' (WLTP) – a driving cycle developed at UNECE level that provides a better reflection of real emissions – has replaced the driving cycle used as a basis for laboratory tests, namely the so-called 'New European driving cycle' (NECD), which was considered to be outdated.

Other elements of the reform aimed at improving the environmental performance of internal combustion engine vehicles include new powers for the Commission to review the work of national type-approval authorities and to test vehicles and withdraw or suspend type-approvals and impose penalties, as well as the possibility for interested third parties to conduct emission tests.

The formal legislative outcome of the reform was a new 2018 regulation,[76] which applies from 1 September 2020 and thus repealed the 2007 framework directive, and several substantial changes in the Euro 5/6 Regulation, the Euro VI Regulation and the set of relevant Commission implementing regulations. The various upgrades have been gradually entering into force since 2017.

The Commission has planned an ex-post evaluation of the two regulations,[77] whose results will feed into the ex-ante impact assessment that will accompany the Commission proposal for a post Euro 6/VI legislation (or Euro 7) for cars, vans, lorries and buses. The proposal is expected in the fourth quarter of 2021 as an initiative under the European Green Deal. At the time of the launch of this EIA research project in June 2020, there was no completed fitness check or evaluation of the two regulations. Furthermore, the rather limited timeframe for this EIA research project did not allow for a comprehensive ex-post evaluation of the legal framework to be conducted by the Ex-post Evaluation Unit of EPRS. At the time of writing this EIA, the results of the Commission ex-post evaluation are not yet available, and, therefore, in contrast to Sections 3.1. and 3.2, which present findings on the implementation of the AAQDs and the Industrial Emissions Directive for which Commission evaluations have been published recently, this EIA does not present findings on the implementation of the Euro 5/6 and Euro VI Regulations.

However, as noted by the European Court of Auditors, despite the reform, many years may pass before air quality in cities is improved 'given the large number of highly-polluting cars already on the roads'.[78] This is a serious issue considering the fact that cities (and urban areas at large) are the sites where most Europeans live and are thus exposed to harmful levels of air pollution to which road transport contributes significantly.[79] Therefore, this EIA, rather than evaluating the implementation of the revised legal framework of the Euro 5 and Euro 6 Regulation and the Euro VI regulation, makes an original contribution to the ENVI implementation report by delivering knowledge on the major problem related to emissions from internal combustion engine vehicles,

74 Judgment of the General Court of 13 December 2018 – Ville de Paris, Ville de Bruxelles and Ayuntamiento de Madrid v Commission (Joined Cases T-339/16, T-352/16 and T-391/16).

75 More information on the ongoing procedure inside the European Parliament can be found here.

76 Regulation (EU) 2018/858 of the European Parliament and of the Council of 30 May 2018 on the approval and market surveillance of motor vehicles and their trailers, and of systems, components and separate technical units intended for such vehicles, amending Regulations (EC) No 715/2007 and (EC) No 595/2009 and repealing Directive 2007/46/EC.

77 As announced by the Commission in March 2020 by means of a so-called 'Combined Evaluation Roadmap / Inception Impact Assessment'.

78 ECA, 2019, p. 5.

79 EEA, 2020.

which is indeed the legacy of on-road polluting vehicles. In particular, the research paper published in Annex I to this EIA[80] maps and assesses the policy measures applied by a sample of 10 agglomerations[81] across the EU with the aim of tackling the 'legacy' issue (along with other pollution sources relevant to each specific agglomeration). It thus also contributes to a better understanding of the policy measures taken at agglomeration level with the aim of complying with the EU standards established by the AAQDs (under the first pillar of the EU air quality policy). In addition, in its Section 2.5, the research paper also makes recommendations, some of which are also relevant to any other EU zone/agglomeration affected by air pollution exceedances, regardless of the specific local conditions. The research paper also studies the effects of the first wave of pandemic lockdown measures implemented in the same 10 agglomerations and their effects on concentrations of certain pollutants with harmful effects in particular for health, and on this basis outlines (in Section 3.6) lessons that could be applied to future policy-making on air quality at all levels of governance.

[80] See the research paper 'Mapping and assessing local policies on air quality. What air quality policy lessons could be learnt from the COVID-19 lockdown?' published under Annex I to this EIA.

[81] Namely, Berlin, Paris, Rome, Madrid, Bucharest, Barcelona, Krakow, Stockholm, Lisbon and Athens.

3. Findings on the implementation of the EU policy on air quality – selected legislation

This section of the EIA does not make an original ex-post evaluation of the implementation of the relevant pieces of legislation (namely, the two Ambient Air Quality Directives and the Industrial Emissions Directive) but rather presents the findings on their implementation based on topical Commission evaluation work and other relevant publicly accessible sources (such as audit reports, EEA reports, and other relevant studies). The five criteria for ex-post evaluation are thus used to only give a structure of the narrative. These criteria are as follows:[82]

- Relevance – Under the relevance criterion, the question is whether, in accordance with evolving scientific knowledge, the objectives and requirements set out in the EU legislation under evaluation are still appropriate with respect to current needs.
- Effectiveness – Under the effectiveness criterion, the question is whether the objectives of the EU legislation under evaluation are being achieved and whether the legislation has contributed to this process.
- Efficiency – Under the efficiency criterion, the question is whether the benefits stemming from implementation of the EU legislation under evaluation justify the costs associated with that implementation.
- Coherence – Under the coherence criterion, the question is whether the EU legislation under evaluation is consistent within itself, with other directly related pieces of EU legislation and with EU policies in other sectors and commitments at international level.
- EU added value – Under the EU added value criterion, the question is whether Member States could have achieved better results had they adopted and implemented their own national legislation in the place of the legislation adopted at EU level.

3.1. Findings on the implementation of the Ambient Air Quality Directives

Relevance

The Commission finds[83] that the 13 pollutants (governed by standards laid down in the two Ambient Air Quality directives) are still relevant to current needs given that their harmful effects on health and the environment are reconfirmed further by what is a growing body of scientific knowledge. On the contrary, for pollutants such as black carbon and ultrafine particulate matter ($PM_{0.1}$), not currently covered by EU standards, the Commission considers that the existing knowledge on their adverse effects on health is inconclusive at this stage and thus does not point to an explicit need to set EU standards. This view is not necessarily shared by stakeholders, who seem to express support for regulation of these pollutants at EU level.[84] While the Commission acknowledges that EU air quality standards are instrumental in decreasing concentrations and reducing exceedance levels, it

82 These are internationally recognised criteria (for example by the OECD) adapted to the EU regulatory context. More specifically, they were taken on board in the Commission's Better Regulation guidelines on evaluation.

83 SWD(2019) 427 final.

84 SWD(2019) 427 final.

Figure 2 – EU-28 population exposure to air pollution against EU standards and WHO guidelines

Pollutant	Year	EU: Reporting stations that registered concentrations above WHO AQG value (2)	WHO: Urban population exposure to concentrations **above** WHO AQG value (2)	EU: Reporting stations that registered concentrations **above** EU AQG value (1)	WHO: Reporting stations that registered concentrations **above** WHO AQG value (2)
PM_{10}	2018	15 %	48 %	19 % 20 EU MS (EU-28) and six other countries	53 % All countries except Estonia, Iceland and Ireland
	2019 (preliminary) for 30 countries	*	*	9 % 13 EU MS and two other countries	37 % All countries except Estonia, Finland, Iceland, Ireland and Luxembourg
$PM_{2.5}$	2018	4 %	74 %	4 % Six EU MS and two other countries	70 % All countries except Estonia, Finland, Iceland and Ireland
	2019 (preliminary) for 27 countries	*	*	2 % 4 EU MS and two other countries	58 % All countries except Estonia, Finland, Iceland, Ireland, Luxembourg, Norway and Sweden
O_3	2018	34 %	99 %	41 % 20 EU MS and five other countries	96 %
	2019 (preliminary) for 32 countries	*	*	27 % 18 EU MS and two other countries	98 %
NO_2	2018	4 % (3)	4 % (3)	8 % 16 EU MS and three other countries (3)	8 % 16 EU MS and three other countries (3)
	2019 (preliminary)	*	*	3 % 12 EU MS and one other country (3)	3 % 12 EU MS and one other country (3)
BaP	2018	15 %	75 %	27 % 14 EU MS	83 % All countries except Cyprus
	2019 (preliminary)	*	*	(4)	(4)
SO_2	2018	<1 %	19 %	<1 % One EU MS and three other countries	33 % 27 countries
	2019 (preliminary) for 32 countries	*	*	28 % 22 countries	28 % 22 countries

Notes: (1) The following EU standards are considered: PM10 daily limit value, PM2.5 annual limit value, O3 target value, NO2 annual limit value, BaP target value and SO2 daily limit value. Please see Table 1.1.
(2) For BaP, reference level. Please see Table 1.3.
(3) For NO2, both the EU annual limit value and the WHO AQG are set at the same.
(4) BaP is not measured automatically and therefore is not included in the UTD data exchange.
(*) Estimates of urban population exposure are not available for 2019.

Source: EEA, 2020.

The less stringent EU standards for certain pollutants are a problem, not only in terms of relevance but also in terms of effectiveness of the implementation of the AAQDs. More specifically, the less demanding EU standards for some pollutants prevent the general objectives of the two AAQDs from being met, in particular as regards the protection of health, because they do not follow the evolving scientific evidence on adverse effects on health. The European Court of Auditors[89] gives further arguments on why the weaker EU standards for certain pollutants have implications for the effectiveness of the implementation of the 2008 directive in particular.[90] For example, zones and/or agglomerations facing SO_2 concentrations significantly higher than WHO guidelines for this pollutant are considered compliant with the much weaker EU standard for SO_2 and could thus set up fewer measuring stations, report data from fewer places, and, most importantly, avoid tackling SO_2 concentrations in their air quality plans (especially as regards the daily values, which are currently six times higher than the limit value recommended by the WHO).[91]

It should be noted that there are substantial differences between the 2005 WHO guidelines and EU standards.[92] The first main difference is that the air quality reference values for a number of pollutants, defined by the WHO, are intended as policy guidance only, while the EU standards, as defined in 2004 and 2008, are mandatory. The second main difference is that the WHO guidelines are based solely on health considerations, while the EU standards reflect broader considerations, such as technical feasibility and the political, economic and social aspects of achieving these standards. This explains why for certain pollutants the EU co-legislators opted for weaker standards than those recommended by the WHO.

The Commission has also recognised[93] the differences between the WHO guidelines and EU standards as an issue, while also noting a dichotomy. More specifically, while for a number of air pollutants the air quality standards, as set by the AAQDs, fall short of scientific recommendations (i.e. the WHO guidelines) and public expectations, the persistent exceedances of the current air quality standards for at least one pollutant in a majority of Member States indicate substantial socio-economic and/or political challenges in reaching the current standards.[94] The introduction of more stringent EU standards, in line with state-of-the-art scientific evidence,[95] will thus be even more difficult to achieve by a number of Member States.

Effectiveness

Monitoring and assessment of air quality

The Commission is positive that the EU-wide monitoring network, which now includes more than 4 000 monitoring stations with more than 16 000 sampling points measuring specific pollutants, 'provides reliable, credible and comparable information on air quality'.[96] Furthermore, the Commission considers that the monitoring and reporting of air quality is broadly compliant with the requirements established in the AAQDs. The Commission also finds that most zones in the Member States have the minimum number of sampling points required by the AAQDs, although (as per 2019)

89 Air pollution – Our health still insufficiently protected, Special Report 23/2018, European Court of Auditors, 2018.

90 The 2018 ECA special report covers only the 2008 Directive.

91 20 µg/m^3 (2005 WHO recommendation) versus 125 µg/m^3 (EU standard under the 2008 AAQ directive).

92 EEA, 2020.

93 SWD(2019) 427 final.

94 SWD(2019) 427 final.

95 It is of note that the WHO guidelines referred to here are currently under revision, while results are expected to be published in 2021.

96 SWD(2019) 427 final, p. 15.

there are cases in specific zones or agglomerations where the monitoring requirements of the AAQDs are not met. Certain non-compliant cases have led to the launch of infringement procedures.

While the EU rules lay down certain minimum criteria on the positioning of monitoring stations, these rules also leave Member States with a certain choice (flexibility) on where exactly to locate the stations in accordance with local specificities. However, this flexibility is limited by the requirement to provide information both for places where the highest concentrations of air pollutants occur and for other areas that are representative of the exposure of the general population. The Commission notes [97] that it is a challenge to verify objectively whether these two conditions are met. It also refers to concerns [98] that the way these criteria are defined gives too much discretion to the competent authorities, and therefore considers that these criteria should be defined more restrictively to ensure 'a higher degree of confidence' in the comparability of data from air quality monitoring. Another challenge identified by the Commission, which affects the quality of monitoring (coverage and quality of data) across Member States, refers to resource constraints such as costs and qualified staff. Despite these challenges, the Commission finds that the air quality information collected and reported delivers data that is robust and of satisfactory quality to allow for further policy action.

Concerns as regards the correct siting of sampling, and the related doubts about the representativeness of sampled data, were also raised by the European Court of Auditors (ECA)[99] and by a topical study published in 2019 at the request of the ENVI Committee of the European Parliament [100]. Both sources consider that the 2008 AAQ Directive suffers from several deficiencies ('ambiguities') whose practical implementation could lead to situations where Member States interpret the requirements differently and do not necessarily measure air pollution concentrations at locations where the highest concentrations of pollutants occur (e.g. near urban roads or industrial sites). This could compromise the protection of human health. Therefore, both sources recommend that the deficiencies identified need to be addressed in a future revision of the 2008 AAQ Directive.

Informing the public about the status of air quality

Informing the public about air pollution levels and their possible health effects in a transparent manner is crucial in terms of empowering citizens to monitor the implementation of local air quality policies and exercise pressure on the relevant authorities, including by initiating court cases. As the EU auditors rightly point out, only sufficiently informed citizens are in a position to intervene in policy matters and act upon the problem, 'including changing their own behaviour'.[101] Public awareness is thus a key factor in terms of increasing the effectiveness of air quality policies implemented at all levels of governance and increasing compliance with EU standards.

According to the Commission assessment,[102] the evidence available suggests that the practices of informing the public on the quality of ambient air are generally going in the desired direction. In particular, the Commission finds that 'the AAQDs have facilitated the availability and accessibility of

97 SWD(2019) 427 final.

98 The Commission notes the observation of some stakeholders who have doubts on whether the data provided by sampling points in different locations could be considered comparable. The reason for this doubt is that spatial representativeness of measurements may vary substantially even on small scales (i.e. tens of meters) for some pollutants, for example for NO_2.

99 ECA, 2018. This ECA special report covers six EU cities.

100 C. Nagl, W. Spangl and I. Buxbaum, Sampling points for air quality – Representativeness and comparability of measurement in accordance with Directive 2008/50/EC on ambient air quality and cleaner air for Europe, Study for the Committee on Environment, Public Health and Food Safety, Policy Department for Economic, Scientific and Quality of Life Policies, European Parliament, Luxembourg, 2019 . The study covers five EU Member States.

101 ECA, 2018, p. 39.

102 SWD(2019) 427 final.

reliable and comparable data on air quality across the EU'.[103] The upgraded air quality e-Reporting database managed by the EEA since 2014 is given as a positive example of a data hub for all reporting requirements under the directives, including official reporting of validated data on air quality and up-to-date data reported by Member States. The air quality data reported by Member States is made public by the EEA, and is thus accessible to citizens, who are showing increasing interest in air quality information. This demand for public information is demonstrated by the fact that the number of visits to the EEA air quality website pages have increased nine-fold since 2008. The Commission also notes that information is also made public by national, regional and local authorities as well as by private operators. It also warns, however, that at these levels the information can be less comparable partly because of the varying approaches and metrics used.

Against this background of positive trends, shortcomings have also been identified. In particular, the Commission refers[104] to a stakeholder view, which even if only a perception, is worth quoting here because it seems to be shared by a significant proportion of the respondents.[105] In particular, almost one in three respondents sees room for improvement, especially as regards the alert thresholds and/or information thresholds applied to inform the public. This perception correlates well with the fact that the AAQDs have not defined information and alert thresholds for some pollutants (e.g. for PM). According to the Commission's assessment, this has led to a non-harmonised approach to informing the public on some pollutants across EU, which in turn, has led to extensive differences in government and/or media coverage of alarming levels of pollution.

The ECA special report also outlines[106] issues of concern as regards informing the public on the quality of air. In particular, the auditors find that one and the same air quality status could receive different assessments in different Member States, regions and cities, because the air quality indices they use are defined differently. According to the ECA, 'as the damage to human health is not different for the same air pollution, independent of the location, different classifications for the same quality of air compromise the credibility of the information provided'.[107] The Commission fitness check explains[108] this issue by the lack of a common metric used for publicised air quality indices, which allows the same data to be presented in different ways in different locations. Therefore, in 2017, the Commission and the EEA established the European Air Quality Index.

Eurobarometer surveys consistently indicate that a majority of citizens still do not feel informed about air quality issues in their countries.[109] These stakeholders' perceptions correlate with the findings of the study prepared in support of the Commission fitness check,[110] which indicates that the information shared with the public is of mixed quality partly because Member States have taken varied approaches in terms of both dissemination approaches and data collection, assessment and reporting.

As regards Member States' obligation to report data to the Commission, the ECA also raised[111] concerns that the current legal framework has not established adequate provisions to ensure that air quality data is reported early enough. More specifically, according to the ECA assessment, timely

---

103 SWD(2019) 427 final, p. 84.

104 SWD(2019) 427 final.

105 At the open public consultation conducted by the Commission between May and July 2018.

106 It is recalled here that the ECA findings are based on six cities.

107 ECA, 2018, p. 40.

108 SWD(2019) 427 final.

109 Annex X to COM SWD(2019) 427 final 'Evolving public perceptions on air quality'.

110 COWI et al., 2019.

111 ECA, 2018.

air quality data is important both for Member States, which are responsible for taking appropriate action to reduce air pollution, and the Commission, which must act early enough to take enforcement procedures against non-compliant Member States. However, the AAQDs require Member States to provide annual validated data by 30 September of the year following the year when data was collected. The auditors compare the current requirement with previous versions of the directive, which required Member States to report to the Commission within six months of the end of the measuring period. The ECA considers that technological developments over recent years (such as e-reporting) enable earlier reporting.

Finally, yet importantly, the ECA considers problematic the fact that, in contrast to other pieces of EU legislation in the field of the environment, the 2008 directive[112] does not contain explicit provisions guaranteeing access to justice for the public. This would be very pertinent given that national legal orders are different and citizens face barriers when trying to access justice in some Member States,[113] even if this right (together with the rights to access to environmental information and to public participation in environmental decision-making) is guaranteed by a number of EU legislative acts, which have transposed the Aarhus Convention[114] into the EU legal order.

Are the EU Member States meeting the air quality standards set by the AAQDs?

As explained above, one of the main objectives of the AAQDs is to set standards for air quality that Member States should meet. It has also been explained that mandatory standards have indeed been established (although some of them are less stringent than what the WHO recommends). The standards create the legal obligation for Member States to take action to avoid, reduce or prevent air pollution beyond the established values. So, the next pertinent question is whether EU Member States are meeting the EU air quality standards and what is the role of the two AAQDs in this process?

In its fitness check, the Commission concludes that the two AAQDs 'have not ensured that sufficient action is taken throughout the EU to meet air quality standards and keep exceedances as short as possible, resulting in a mixed picture'.[115] The Commission stresses that persistent and widespread exceedances for certain pollutants (notably particulate matter, nitrogen dioxide, ozone and benzo(a)pyrene) still continue.[116] Despite the general improvement in air quality over the past decade,[117] the periods of exceedances have not been kept as short as possible in all instances as required by the directives. Therefore, the Commission concludes that the AAQDs have been partially effective in achieving the EU air quality standards and reducing the adverse effects of air pollution.

The legal framework requires Member States (at the relevant governance level) to prepare air quality plans (and/or take measures) for the zones and/or agglomerations facing exceedances of the

---

112 The same goes also for the 2004 Directive.

113 ECA, 2018.

114 Convention on Access to Information, Public Participation in Decision-making and Access to Justice in Environmental Matters (Aarhus Convention), United Nations Economic Commission for Europe, 1998.

115 SWD(2019) 427 final, p. 38.

116 This trend is also confirmed by the EEA 'Air quality in Europe - 2020 report', which uses data for 2018.

117 In 2019, when the fitness check was published, the Commission reported (based on data for 2017) that both the number and magnitude of exceedances have decreased for most pollutants and in most Member States. Hence, the observed decrease also means that the percentage of urban population exposed to air pollution above the EU air quality standards is lower now than a decade ago. Source: COM SWD(2019) 427 final.

This trend of decreasing pollution is also reconfirmed by the latest EEA 'Air quality in Europe - 2020 report', which uses data for 2018.

standards for the various pollutants covered by the two directives.[118] Air quality plans (and/or measures) are thus a key policy instrument aimed at ensuring that the effects of poor air quality are avoided, reduced, or prevented. Member States are given the discretion to design and implement measures that best fit their local conditions. Air quality plans (and/or measures) must be communicated no later than two years after the end of the year when the first exceedance was registered. These considerations need to be carefully factored in by the competent authorities in order to ensure exceedance periods are kept as short as possible, and not delayed unduly.

However, air quality plans and their implementation have been identified as a factor hampering Member States' compliance with EU air quality standards in certain cases. In particular, the Commission finds[119] that, in several instances, air quality plans and their implementation were not able to keep the exceedance periods as short as possible, as required by the legal regulation. The Commission notes that the success of each individual air quality plan depends on the political commitment and coordination between the levels of governance involved in their design and implementation. Furthermore, for the Commission, the ultimate test for the success of a plan is whether the measures implemented have led to reductions in the concentration levels of the air pollutants targeted, and indeed kept the exceedance period as short as possible. Eventually, against the metric of reduced concentration levels (and reduced exposure to concentration levels above EU air quality standards), the Commission concludes that there have been both successes and shortcomings. However, as indicated by the original findings of the research paper annexed to this EIA,[120] such a causal link is difficult to establish because, in addition to the very design and implementation of the policy measures (included in plans or not), other factors also have an impact on their effectiveness, and, in addition, policy implementation and its effectiveness is not well monitored, which makes it difficult to judge the actual success or lack of success of the policy measure. This is a significant regulatory problem of the effectiveness of the implementation of the legislation, because, if the implementation of the local policy measures and their effects cannot be plausibly evaluated, improvements to their design and subsequent implementation commensurate with the pollution problem also becomes difficult, which ultimately means that meeting the EU standard(s) for the specific pollutant(s), which has/have seen exceedance(s), is rather challenging, if possible at all.

The Commission also underlines[121] that the 2008 AAQ directive allows for delays in the start of the implementation of the measures included in the air quality plans. In particular, more than two years can elapse from the moment the pollutant exceedance was first observed until the measures are implemented in practice. Furthermore, if these measures involve large-scale infrastructure projects, their practical implementation can take even longer to start, which, however, does not bring air quality improvements as quickly as possible as required by the EU legislation.

The Commission states[122] that it has acted upon the problems identified, in particular by launching several infringement procedures. More specifically, as per 2019 when the fitness check was published, there were infringement procedures against 20 Member States open on grounds of air

[118] Air quality plans must be reported to the Commission no later than two years after the exceedance occurred. Between 2013 and 2017, almost 300 air quality plans were reported by 20 Member States. EEA analysis indicates that, in terms of pollutants, the measures tend to focus on particulate matter and nitrogen dioxide (Source: Improving Europe's air quality – measures reported by countries, Briefing 9/2018, European Environment Agency, 2018).

[119] SWD(2019) 427 final.

[120] Its findings are based on a sample of ten agglomerations across the EU. See the Research paper 'Mapping and assessing local policies on air quality. What air quality policy lessons could be learnt from the COVID-19 lockdown?' published under Annex I to this EIA.

[121] SWD(2019) 427 final.

[122] SWD(2019) 427 final.

pollution concentration exceedances but also because the measures taken were found to be insufficient.[123]

The European Court of Auditors also finds that 'Member States are not taking enough effective actions to improve air quality as quickly as possible',[124] as required by the EU standards. It is particularly critical of the air quality plans their audit work was able to check[125] and considers that their quality is insufficient. The auditors highlight three main points, relating to the nature of the measures included in the studied plans, that compromise the plans' effective implementation. First, the measures are not targeted and could not be implemented quickly for the areas where the highest concentrations were measured. Second, the measures could not deliver significant results in the short term because they go beyond the powers of the local authorities responsible for implementing them or because they are designed for the long-term. Third, the measures are not supported by cost estimates or are not funded.

The ECA also notes as a shortcoming of the legal framework the fact that Member States are not obliged to report back the Commission on the implementation of their air quality plans, or to update the plans when new measures are adopted or when progress is visibly insufficient. It is of note that Member States need to update their plans only at the end of the respective implementation period, provided air quality in the respective zone/agglomeration still does not meet EU standards. Furthermore, Member States tend to draft a high number of plans, which reflects the fact that air pollution exceedances are a widespread problem. In addition to being voluminous, some of the plans covered by the ECA special report did not contain all the relevant air quality measures planned or taken. The auditors concur with the Commission finding that drafting air quality plans take time and, as explained, this is due (not least) to the directive itself. All these aspects of the preparation of air quality plans make the monitoring of national actions a complicated task for the Commission. In particular, according to the ECA, the Commission's work on monitoring Member States' compliance has been slowed down.

The above assessment on compliance monitoring ties in with another important finding of the ECA special report, namely that the Commission faces limitations as regards the enforcement of compliance. The auditors declare[126] that the Commission has pursued Member States at the Court of Justice of the EU (CJEU) when it has found sufficient evidence for serious breaches of the 2008 AAQ directive but also considers that these enforcement actions are lengthy and despite the several Court decisions in favour of the Commission (as per 2018 when the ECA report was published), air quality standards continue to be frequently breached. This finding is further supported by recent cases from the Commission's December 2020 infringement package. In the first case, the Commission took a Member State[127] to the CJEU because it had failed to comply fully with a decision of the Court from 2017 in the context of PM_{10} exceedances. In the second case, the Commission

[123] Based on the information available in the latest Commission annual report on monitoring the application of EU law, at the end of 2019, out of the 327 open infringement procedures in the field of environment, 61 concerned failures (including both problems with transposition and compliance) under the three pillars of the EU air quality policy (see SWD – Part II Policy Areas). In the course of 2020, several new procedures were launched or advanced further phases of the infringement procedure.

[124] ECA, 2018, p. 44.

This finding is also supported by the 2019 Joint report on air quality issued by the EUROSAI working group on environmental auditing at the beginning of 2019, which covers eight EU Member States and other European countries.

[125] It is recalled that the 2018 ECA special report covers six cities.

[126] ECA, 2018.

[127] Bulgaria - See the details here.

called on a Member State[128] to comply with a 2019 decision of the CJEU in the context of NO_2 exceedances. Both cases illustrate that the infringement process indeed suffers from delays and, ultimately, is not effective in enforcing compliance even when it comes to the use of the very last enforcement resort, which is the CJEU.

The research paper annexed to this EIA gives a detailed overview and assessment of policy measures (those included in air quality plans and others) implemented by 10 agglomerations across the EU with the aim of abating emissions from relevant pollution sources, including from transport for each of the studied agglomerations, and, in particular, measures aimed at tackling the issue with 'on-road polluting vehicles legacy'. Although the overview is very specific for each of the 10 agglomerations, it contains findings relevant to the effectiveness of the implementation of the two AAQDs.

Efficiency

The Commission points out[129] that analysis should not rely solely on quantification of measures directly targeting air quality improvements but should also take account of policies that could benefit air quality indirectly.[130] More specifically, the Commission considers that many of the more expensive measures included in the relevant air quality plans are indeed designed to deliver on the objectives of other EU policies, for example, improving mobility or reducing congestion and greenhouse gas emissions.

The Commission notes in particular that aggregate estimates of the overall costs and benefits of air quality policies, and of the AAQDs specifically, do exist even though they are sometimes based on different assumptions. However, the Commission specifically warns that such estimates might be useful for giving a flavour of the order of magnitude of costs and benefits, but using them for comparison purposes or as precise data is not sufficiently plausible.

The Commission uses the findings of a 2017 study[131] to illustrate this order of magnitude. According to this study, the cost of all measures – not necessarily having air quality as their primary consideration but resulting in air quality improvements – amounts to €70 to 80 billion per year. The benefits aspect is exemplified by the findings of a Commission ex-ante impact assessment from 2013,[132] which shows that the cost of air pollution to society, health and economic activities – i.e. the harm done – amounts to between €330 and 940 billion per year for the EU as a whole. The two figures give a clear illustration of the order of magnitude of what is a relatively low cost for action (involving various policy measures) when compared to the cost of inaction (harmful impacts of air pollution) on citizens' health, the economy and society.

The latest EEA annual report on air quality[133] also elaborates on the link between air pollution and cost. The EEA refers to the findings of a study on the impacts of air pollution on market economic activity in Europe published by the Organisation for Economic Co-operation and Development (OECD) in 2019.[134] The study estimates that a decrease of 1 µg/m3 in annual mean PM2.5

128 France - See the details here.

129 SWD(2019) 427 final.

130 See more on this under 'coherence' in the context of the two AAQ directives further down in this section of the EIA.

131 'Costs, benefits and economic impacts of the EU clean air strategy and their implications on innovation and competitiveness', Report, International Institute for Applied Systems Analysis, 2017.

132 The Commission refers to the impact assessment contained in SWD(2013)531, which in 2013 accompanied several policy and legislative proposals submitted by the Commission in the context of the clean air programme for Europe.

133 EEA, 2020(a).

134 The economic cost of air pollution: Evidence from Europe, Economics Department Working Paper No 1584, Organisation for Economic Co-operation and Development, 2019.

concentration would increase Europe's gross domestic product (GDP) by 0.8 %, representing around €200 per capita per year (for 2017). Ninety-five per cent of this increase in GDP is the result of increases in output by individual workers, through lower absenteeism at work or increased labour productivity, due to lower air pollution. The OECD study thus concludes that more stringent air quality regulations could be justified based on economic reasons alone, as the direct economic benefits from air quality policies are much greater than the abatement costs, even when ignoring the major benefits in terms of averted mortality. The OECD study also find that, if all Member States were to meet their national exposure reduction targets for PM2.5 in 2020, EU GDP would grow by 1.28 % between 2010 and 2020, accounting for the costs of abatement of around 0.01 % of GDP. Poland, with the highest reduction target, would increase its GDP by up to 2.9 % and Bulgaria by 1.7 %. The impact is around 1.5 % for Austria, Belgium, Czechia, France and Italy; 1.2 % for Germany, and even for countries with low PM2.5 concentrations, such as Ireland, the increases in GDP would still be substantial at around 0.8 %.

The Commission also highlights[135] that the costs and benefits of taking air quality measures can vary significantly between Member States, namely, by a factor of two or more, depending on national specificities and the types of measures taken. Finally, as regards the costs incurred by the obligation on Member States to monitor and report pollution levels, the Commission notes that the burden per capita is relatively low (less than one euro per person per year based on a sample of Member States) and that there is room for improvement, especially as regards the differing governance approaches followed by Member States.

Coherence

Policy coherence is a key factor that could support or hamper the achievement of air quality objectives. The following coherence aspects impact the achievement of the air quality objectives: internal coherence (i.e. coherence among the provisions of the AAQDs and coherence between the AAQDs and other EU policies and/or legislation on air quality), external coherence (i.e. coherence between the AAQDs and other EU sectoral policies and/or legislation with effects on air quality, and coherence of the AAQDs with EU commitments taken at international level), as well as policy funding of projects with direct or indirect positive impacts on air quality.

The Commission makes[136] a positive assessment of both aspects of internal coherence. In particular, it concluded that the two AAQDs together constitute a 'coherent regulatory system' for air quality improvement and that they are also coherent with the general EU clean air policy framework and, more specifically, the updated NEC Directive.

However, the Commission does point[137] to certain gaps as regards internal coherence. More specifically, on coherence within the directives it notes 'minor' inconsistencies that 'may have a limited impact' on the monitoring elements of the regulatory system. These inconsistencies have already been discussed under effectiveness above, and given the impact they were shown to have on the quality of monitoring, the Commission's assessment appears too mild. In contrast, this EIA would support the view of the EU auditors[138] that the deficiencies identified in the monitoring-related provisions of the 2008 AAQ Directive affect the quality of measurement of air pollution significantly (i.e. leading to situations where air pollution is not measured at the most appropriate

135 SWD(2019) 427 final.

136 SWD(2019) 427 final.

137 SWD(2019) 427 final.

138 ECA, 2018.

site), which in turn has far reaching consequences for the adequacy and effectiveness of the policy measures taken by the zones/agglomerations concerned to address pollution.

The environmental (emissions) performance aspects of the EU type-approval framework are an essential part of the EU air quality policy because their primary objective is to prevent air polluting emissions at a specific source (in this case pollution from on-road transport). However, it is an example of EU legislation whose implementation hampers the achievement of the air quality objectives set by the two AAQDs, especially as regards light-duty vehicles.[139] The EU auditors[140] note that the Euro standards for emissions from internal combustion engine vehicles and the technological developments that these standards stimulated, have reduced CO_2 and PM emissions[141] significantly but have not been as successful in reducing NO_x emissions, especially from diesel-fuelled vehicles. In particular, as already explained in Part 2 of this EIA, in several cases real NO_x emissions from diesel vehicles were found to be higher than those produced under test conditions. This issue was already well documented before the Volkswagen case (September 2015), which further revealed the scale and the root causes of the problem. The European Commission had already started developing a more realistic EU test procedure in real driving conditions at the beginning of the decade. The EU type-approval framework was recently upgraded and it will take some time before the effects of the reform become visible.[142] However, one element of the upgraded policy, namely the 'conformity factor' system, is worth noting because it might have negative effects on NO_x emissions. In particular, following the reform, the Euro 6 emission target of 80 mg NO_x emissions per km for light-duty vehicles (which was supposed to be applied as of 2014) will be delayed further and will thus not have to be met for the real driving emissions test before 2023.[143] As explained in Part 2 of this EIA, the conformity factor system is subject to an ongoing ordinary legislative procedure. It is of note that the European Parliament is advocating that the Commission must continuously review the conformity factor in the light of technical progress and review it downwards each year on the basis of assessments by the Joint Research Centre (JRC). Furthermore, the Parliament insists that, after an immediate reduction from 1.43 to 1.32, the conformity factor must cease applying by 30 September 2022.[144]

The Industrial Emissions Directive, which falls firmly within the scope of the ENVI implementation report, is another example of an EU air quality policy because it is designed to prevent air pollution[145] at source. However, according to the assessment of the European Court of Auditors,[146] the directive and its implementation could hamper the achievement of air quality objectives (established by the AAQDs) on account of several possibilities for exemptions available to Member States and the relevant installations. In particular, as mentioned above, the IED leaves the possibility for Member States to set less stringent emission limit values if the application of best available techniques (BATs) would lead to 'disproportionately higher costs' compared with the environmental benefits. The IED also allows certain 'flexibility instruments' by way of exemption from the limits set for large

[139] SWD(2019) 427 final.

[140] ECA, 2018.

[141] The reductions in $PM_{2.5}$ emissions are also confirmed by this EPRS briefing. In particular, the EPRS publication refers to an article published in 2016, which found that the Euro standards cut $PM_{2.5}$ emissions from road transport exhausts by 50 % globally, and that the implementation of Euro standards by EU car-makers on global markets lowered $PM_{2.5}$ concentrations and thus extended life expectancy by 5 months in Europe.

[142] ECA, 2019.

[143] ECA, 2018.

[144] The mandate given (in September 2020) by the EP plenary for negotiations at first reading could be found here.

[145] Along with pollution to water and soil.

[146] ECA, 2018.

combustion plants. For example, according to the ECA's findings,[147] 15 Member States adopted 'transitional national plans' that allowed higher emission ceilings until 2020; some district heating plants were granted a special derogation until 2023; other installations do not need to apply BATs, if ever they limit their operations and close by 2024. This means that in all these cases the application of the BATs to their full potential has been delayed, which means that the reduction of emissions from these installations has also been delayed and thus hampered the achievement of the objectives of the two AAQDs.

When it comes to external coherence, there is a need to check the coherence between the AAQDs and EU policies and/or legislation in other sectors and international commitments made by the EU on air quality. The Commission is again positive[148] about the 'mutually supportive relationship' between environmental, sectoral and other relevant EU policies and legislation such as climate, energy, transport and agriculture. Furthermore, the Commission states that the two AAQDs have helped Member States in their efforts to comply with international law requirements, especially as regards the Convention on long-range transboundary air pollution and the Convention for the prevention of pollution from ships.[149]

However, incoherencies between the AAQDs and other EU policies and legislation do exist. These concern both the design and the implementation of the policies, for example, in the fields of agriculture and climate action (and the related measures in the field of energy), and undermine the achievement of the objectives of the AAQDs. A few examples are presented below.

While EU climate action policies and air quality policies are usually mutually beneficial, some EU climate action (and related energy) policy measures may come at the expense of air quality. In particular, according to the Commission,[150] the promotion of biomass combustion for the production of renewable energy is such a measure because it releases harmful air pollutants. Another example of a climate-related measure hampering the achievement of air quality objectives is the practice of some Member States that promote diesel over petrol cars with the aim of reducing greenhouse gas emissions.[151] The promotion of diesel-fuelled vehicles is also possible thanks to EU legislation on taxation of fuels, which allows Member States to tax diesel at lower rates than petrol fuels. The EEA notes specifically that EU Member States' measures to cut the emissions of air pollutants would benefit from stronger links with climate action policy.[152]

EU agricultural policies are another example identified by the ECA[153] as affecting the achievement of air quality objectives. Very similar to previous years, in 2018, agricultural activities were responsible for the vast majority of NH_3 emissions (around 93 %).[154] Ammonia is problematic because it is a precursor of PM generally, and PM2.5 in particular, which, as already explained in Part 1 of this EIA, is the top cause of high rates of premature deaths attributable to air pollution in

147 ECA, 2018.

148 SWD(2019) 427 final.

149 International Convention for the Prevention of Pollution from Ships (MARPOL) adopted in 1973 under the auspices of the International Maritime Organisation.

150 SWD(2019) 427 final.

151 It is of note that diesel-fuelled vehicles produce fewer CO_2 emissions than petrol cars.

152 Measures to reduce emissions of air pollutants and greenhouse gases: the potential for synergies, Briefing, European Environment Agency, 2020 (EEA, 2020).

153 ECA, 2018.

154 European Union Emission Inventory Report 1990-2018 – under the UNECE Convention on Long-range Transboundary Air Pollution (LRTAP), Report 5/2020, European Environment Agency, 2020.

It is of note that the AAQ directives do not set standards for ammonia. However, the NEC Directive does set limits.

Europe. The ECA notes further that despite the existence of technically and economically viable measures such as agronomic, livestock or energy measures, they have yet to be adopted at the scale and intensity necessary to deliver significant emission reductions. Furthermore, the external study supporting the Commission fitness check notes[155] that, while the second pillar of the CAP provides a funding opportunity for the implementation of air quality measures and thus supports the achievement of the two AAQDs, the coherence of the first pillar is assessed as 'less strong'. In particular, in terms of objectives, there is no specific focus on air quality, and no specific measures to tackle ammonia emissions directly are included as air pollutant emissions in cross-compliance.

Finally yet importantly, funding is an important aspect of coherence. While the Commission finds that substantial funding has been made available to support air quality improvements directly in the 2014-2020 period, the EU auditors consider (based on the concrete projects they examined)[156] that, although useful, EU funding is not always targeted.

According to the figures quoted by the Commission,[157] in the 2014-2020 period Member States allocated approximately €2 billion to air quality projects. Furthermore, cohesion policy funds supported projects with indirect positive effects on air quality, namely projects on the low-carbon economy (€45 billion), environmental protection and resource efficiency (€63 billion) and network infrastructure (€58 billion). In the same vein, the ECA notes[158] that funding for air quality measures under the ERDF and the Cohesion Fund increased from €880 million in the 2007-2013 programming period to €1.8 billion in the 2014-2020 period but also warns that this amounted to less than 1 % of total EU cohesion policy funding. Three of the Member States that are major beneficiaries from the EU cohesion policy (and that were visited by the auditors) used these funds. However, only in Poland did the respective amounts increase significantly (by more than 160 %) between the earlier and later programming periods. In the Czech Republic, funding in the two periods was kept at almost the same level, while in Bulgaria it fell significantly (by almost 60 %). Furthermore, the auditors found cases where Member States did not prioritise this funding on projects to target the main sources and pollutants identified in the air quality zones visited. This was, for example, the case of Sofia, where no projects targeted emission reductions from domestic heating, which is a major source of pollution with PM. Discrepancies between measures supported by EU funds and local air quality agendas were also identified. The ECA gives the example of Krakow where the replacement of boilers funded by EU money was not supported by a parallel process of restricting access to inefficient boilers and low quality coal.

On a more positive note, the ECA also found practices of well-targeted EU-funded projects that were able to contribute directly to reductions in local emissions, as identified in Member States' air quality plans. This was the case of Ostrava where boilers were replaced as were old diesel buses (by buses running on compressed natural gas). The modernisation of inefficient household heating systems (in Krakow) and public transport (in both Krakow and Sofia) were also assessed as good examples.

EU added value

155 COWI et al., Supporting the fitness check of the EU Ambient Air Quality Directives (2008/50/EC, 2004/107/EC), Appendix G to the Final Report: Detailed evidence on coherence, 2019.

156 It is noted that the ECA special report, referred to here, covered six cities across the EU, and, therefore, its findings on funding are based on the projects implemented by these six cities funded by the LIFE programme, the European Regional Development Fund and the Cohesion Fund with the aim of improving air quality.

157 SWD(2019) 427 final.

158 ECA, 2018.

According to the Commission,[159] the implementation of the two AAQDs has demonstrated that the establishment of air quality standards and of a common monitoring and assessment framework should indeed be done at EU rather than at national level. This view seems to be also supported by stakeholders who 'overwhelmingly' agree that the two directives have been instrumental in motivating and framing action in the Member States and achieving better air quality.

As regards EU air quality standards, the two directives established new and reinforced existing standards thus leading to a harmonised approach across Member States and contributing to a declining trend in the concentrations of most regulated pollutants. The Commission warns that it is difficult to attribute the observed trend only to the standards set by the two AAQDs, because this trend is very likely also the result of the implementation of legislation on pollution sources (e.g. the Industrial Emissions Directive), the National Emission Ceilings Directive, national legislation already in place, and the prevalence of activity in certain sectors in specific Member States). Nevertheless, the Commission is confident that the establishment of air quality standards at EU level had the added value of setting an equal level of ambition across the EU in terms of both health protection and the single market.

The Commission is equally positive regarding the added value of the common framework for air quality assessment and monitoring. In particular, the Commission considers that this framework has provided reliable and comparable air quality data across Member States, which, in turn, has led to increased public awareness and supported implementation and enforcement of air quality standards. However, as already explained, the legal framework on monitoring and assessment suffers from deficiencies that have had a negative impact on its effective implementation in several cases. This clearly calls for improvements to the already established EU-level approach to monitoring and assessment of air quality status.

3.2. Findings on the implementation of the Industrial Emissions Directive

This section presents the findings of publicly available sources on the implementation of the Industrials Emissions Directive with a specific focus on air pollution.[160]

Relevance

When it comes to industrial processes as a source of air pollution, and more specifically the agro-industrial installations covered by the Industrial Emissions Directive (IED), the Commission finds[161] that the directive's objectives and requirements remain relevant because the problem they are meant to solve is still there. In particular, the industrial activities falling in the scope of the IED still contribute significantly to pollution (including air pollution) thus resulting in significant health and environmental impacts. Furthermore, the steady decline in pollution from industrial processes (especially as regards air pollution[162]) shows the IED (and its predecessor legislation) are having positive impacts. The Commission has thus concluded that the objectives and requirements of the IED remain relevant to the problem.

[159] SWD(2019) 427 final.

[160] It is noted that along with air, the IED addresses water and soil pollution; these not however covered by this EIA.

[161] SWD(2020)181 final.

[162] EEA, 2020.

Also in the context of relevance, the Commission notes[163] that the BREF process is the main IED instrument, which ensures that the legal framework is able to respond to new or emerging environmental issues. The Commission finds however that the specificities of the BREF process may hamper this process. In particular, the length of the BREF process and the time between BREF reviews, combined with the BREF process requirement for monitoring data on pollutants lead to a greater focus on existing pollutants than on emerging ones, hampering a swift response to emerging environmental challenges as required by the directive.

[163] SWD(2020)181 final.

Effectiveness

The Commission's overall assessment of the effectiveness of the directive is positive.[164] In particular, the implementation of the directive has contributed to the reduction of polluting emissions and their impacts on health and the environment, which is the main objective of the IED. As regards air quality, a significant reduction in pollution from the industrial activities covered by the IED has been registered. The EEA notes[165] that the air emissions from industry decreased for all key air pollutants in the respective industrial sectors between 2007 and 2017. As a general trend, SO_x emissions declined by 54 %, NO_x decreased by more than one third, and NMVOC emissions also declined although less significantly. The EEA also confirms that the decarbonisation of industry is expected to be a major driver of air pollutant emission reductions.

The Commission is confident[166] in linking the reduction of air pollution from large combustion agro-industrial installations to the implementation of the IED in particular, although other factors might have had a positive impact as well. It is, however, noted that the reduction of emissions of certain large combustion plants has been slowed down owing to the delayed application of BATs in certain Member States that have applied the time-restricted flexibilities allowed by the directive. As explained under 'Coherence' in the context of the two AAQDs, this assessment is also shared (and detailed further) by the EU auditors.[167]

The BREF process, which involves Member States, industry and environmental organisations, is an essential instrument of the IED, which is also assessed positively by the Commission evaluation.[168] Under the IED, 17 BAT conclusions have already been adopted and six more are under revision. Furthermore, BAT-based permitting has significantly increased under the IED. Of the 17 BAT conclusions adopted, eight have already been implemented by Member States in an estimated 2 500 installation permits. The remaining nine BAT conclusions are implemented in permits for around 36 000 additional installations. More specifically, the IED requires that permit conditions must be updated within four years of the BAT conclusions' publication in the Official Journal of the EU. Practice shows that permits are generally updated within the required deadline and the permit emission limit values (ELVs) are largely set within the BAT-associated emission limit (BAT-AEL) range, but most frequently towards its least stringent end. The EEA also gives[169] a positive assessment of the BREF process taking place under the IED. In particular, according to the EEA assessment, there is continued progress on establishing a regulatory push to improve uptake of BATs by issuing permits to installations, at least within the scope of industrial activities covered by the IED.

The Commission highlights[170] as a challenge pertinent to the effective implementation of the IED the fact that a number of highly polluting activities in the mining and intensive livestock sectors (e.g. (cattle, aquaculture, mixed farms, poultry farms below IED activity thresholds) are not currently covered explicitly by the IED. Some of these intensive livestock activities (such as cattle and poultry) emit pollutants such as ammonia (a precursor to $PM_{2.5}$) and thus have a negative impact on air quality. The Commission also explains that these activities were not included in the scope of the

---

164 SWD(2020)181 final.

165 SOER - The European environment — State and outlook 2020, Chapter 12 on industrial pollution, European Environment Agency, 2019 (SOER – 2020, EEA, 2019).

166 SWD(2020)181 final.

167 ECA, 2018.

168 SWD(2020)181 final.

169 SOER – 2020, EEA, 2019.

170 SWD(2020)181 final.

directive because of a 'previous impact assessment',[171] which found that that the full IED permitting process was not appropriate for some of these activities (e.g. cattle) because of the red tape it would involve. In the same scope-related context, the Commission underlines another issue of concern relevant to the effectiveness of the directive's implementation. It refers specifically to the practice of constructing new industrial installations with a capacity just below the IED threshold. Such installations are thus left outside the scope of the directive, which means that they are not obliged to comply with its requirements, despite that air pollutants they emit.

The monitoring and reporting of emissions by operators of IED installations to the competent authorities is crucial to the assessment of compliance. Furthermore, the monitoring and reporting of emissions is essential for keeping track of the quantities of pollutants released. The Commission notes[172] that all recent BAT conclusions contain consistent BATs on emissions monitoring. Data reported by Member States to the Commission show that monitoring frequencies in permit conditions are consistent with the frequencies included in the BAT conclusions. Therefore, the Commission considers that the transparency and consistency of the requirements across Member States have generally improved. However, it is less certain whether compliance has also improved. In particular, in many Member States, data collected via monitoring is not published in a systematic way, and it could not, therefore, be judged whether operators were indeed reporting data consistently and whether competent authorities were using the information to assess compliance. Furthermore, the Commission notes that the limited information available on the various approaches used by competent authorities for compliance assessment points to divergences in practices. Such variations, and especially presumed variations in the levels of compliance from one Member State to another, would put the functioning of the internal market at risk.

Another deficiency in terms of monitoring and reporting is that the releases of many emerging air pollutants are currently not monitored. In particular, according to the EEA's assessment,[173] this is a problem because the lack of robust data does not allow assessment of progress towards overall clean production processes.

As regards the accessibility of emissions data, the Commission notes[174] that, even though as a rule this information (held by competent authorities) is public, it remains uncertain how easily accessible it is. More specifically, emissions data, including real-time data, are rarely made available via the internet. However, the Commission states that there are certain EU-based installations that publish the results of emission measurements online, including in real time (in the case of continuous measurements). For the Commission, such examples prove that digital technologies could help to improve emissions reporting, facilitate compliance checks and enhance public access to information. This assessment seems to be also supported by stakeholders. Another challenge highlighted by the Commission in the context of public access to information is that not all permits are publicly available online, and information available online is sometimes very difficult to locate. The Commission has noted that the authorities of at least one Member State initially applied fees to requests for access to permits.

Public participation in the permitting procedure and access to justice also show a mixed picture of some improvements and limitations. As regards improvements, the Commission considers[175] that public access to justice seems to work, mostly when it comes to new permits. As regards limitations,

[171] It could not be deduced from the text which impact assessment the Commission is specifically referring to.

[172] SWD(2020)181 final.

[173] SOER – 2020, EEA, 2019.

[174] SWD(2020)181 final.

[175] SWD(2020)181 final.

based on the experience of some Member States, the Commission has outlined two main issues: first, with the capacity of the public or environmental organisations to challenge revisions of existing permits, and, second, in the interpretation of the wording 'substantial change' used by Article 24 of the IED ('in combination with uncertainty over whether the public can challenge a decision if the change is declared to be non-substantial'). Other issues relate to the ability of the public and environmental organisations to file legal proceedings against competent authorities that have omitted to act, for example, where a competent authority has not issued the permit for a given agro-industrial installation. Furthermore, the Commission highlights the ongoing case against the EU,[176] in which the Aarhus Convention Compliance Committee considers that the IED provisions on public participation in permitting do not cover all cases where the Convention requires such participation, and therefore, are not fully compliant with the provisions of the Aarhus Convention.

Last but not least in terms of effectiveness, the Commission makes an important observation[177] on the knowledge available regarding how Member States are actually implementing the provisions of the IED, which is considered to be 'limited'. The possible reasons for this include the complexity caused by the large number of installations covered by the directive and the permits that require revisions to the volume and complexity of technical documentation, and the differing tiers of Member State administration (e.g. regional, local) in charge of writing permits, and their expertise and language capacities. The Commission also considers that enforcement has been strengthened at least to some extent.

Efficiency

The Commission underlines[178] that this analysis is challenging for this particular directive, because it is hard to estimate compliance costs owing to the implementation of the BAT conclusions by competent authorities and in individual processes and installations. However, the Commission considers (although with only a medium level of certainty) that the overall benefits of implementing the BAT conclusions have been shown to substantially outweigh all the costs, and this is especially true for the benefit 'reduced emissions to the air'. The Commission evaluation illustrates its finding with the example of the iron and steel sector where the benefits to society of reduced emissions to air (€932 million annually) that result from compliance with the BAT conclusions for this sector are around 10 times higher than the investment costs (€90 million annually). If other non-investment costs (such as those of monitoring and inspection in the same sector) are added to the primary costs invested in the techniques required for compliance with BAT conclusions, the benefits are still found to exceed the costs significantly.

On a less positive note though, the Commission mentions[179] that EU competitiveness in the global economy has experienced certain negative effects from the implementation of the IED. These effects stem, for example, from the additional compliance costs paid by EU companies compared to the costs made by competitors located outside the EU where less stringent standards are applied. However, the Commission says there is no evidence that these negative impacts are significant and it even outlines positive effects on EU competitiveness (relevant also in terms of the EU added value of the directive presented below) – namely the export of EU sustainability expertise. In particular, the Commission highlights that several non-EU countries are borrowing from the BREFs to design their own national industrial measures or to decide on emission limits.

---

[176] Case ACCC/C/2014/121 Aarhus Convention Compliance Committee, United Nations Economic Commission for Europe.

[177] SWD(2020)181 final.

[178] SWD(2020)181 final.

[179] SWD(2020)181 final.

Coherence

On internal coherence, the Commission finds[180] that the IED does not suffer from major deficiencies. However, it is also noted that there are issues of concern. These are best illustrated via stakeholders' feedback. In particular, a number of stakeholders consider that the IED is like a 'juxtaposition' of several previous directives, rather than a piece of coherent legislation that would otherwise integrate parts of these directives in a coherent manner. For example, inconsistencies are also claimed to exist between the relevant BAT conclusions and the requirements of Chapter III on large combustion plants and Chapter IV on waste incineration and co-incineration plants.

Also in terms of internal coherence, the Commission notes[181] that there are several inconsistencies between the IED and the European pollutant release and transfer register (E-PRTR) that are of concern in terms of air quality.[182] This Commission finding is also supported by the EEA.[183] In particular, there are differences between the sectors covered by each of the two pieces of EU law. Furthermore, the value of the reported data is reduced because the E-PRTR's sets up high emission thresholds. In addition, the scope of the E-PRTR is limited to the pollutants listed in its own annexes, which, however, have not been adapted to technological innovation. This is for example the case of emerging environmental issues, such as per- and poly-fluoroalkyl substances (PFAS), an issue also highlighted by the EEA.[184]

As regards the coherence of the IED and the AAQDs, the EU auditors[185] point out that the derogations allowed by the IED, and in particular their practical implementation, have a negative effect on the achievement of the EU air quality standards set by the two AAQDs.

As regards external coherence, and as far as air quality is concerned, the Commission evaluation does not refer to major incoherencies between the IED and other relevant EU environmental or other sectoral policies. In terms of coherence between the IED and EU commitments at international level, as shown above, the alignment of the directive with the Aarhus convention has been questioned. In particular, the question is whether the implementation of the relevant IED provisions is good enough to give full effect to the rights of access to information and public participation in decision making. The Aarhus Convention Compliance Committee finds that there is a lack of public participation with regard to reconsiderations and updates of permits under Article 21 (3), (4), (5)(b) and (5)(c) of the IED, and thus that there are cases of non-compliance with Article 6(10) of the Aarhus Convention.

EU added value

The Commission underlines[186] that there are a number of important benefits of this policy intervention being implemented at EU level as compared to a situation where Member States were to act on their own. This confirms the EU added value of the IED. In particular, EU action has secured a more consistent approach in the adoption of environmentally effective standards for industrial emissions, with relatively limited deviation across Member States. It has also ensured a more

180 SWD(2020)181 final.

181 SWD(2020)181 final.

182 Incoherencies between the IED and the 2017 regulation that established the E-PRTR were identified back in 2017 by the Commission REFIT evaluation of this regulation. The Commission notes that several initiatives aimed at improving the situation have been launched.

183 SOER – 2020, EEA, 2019.

184 SOER – 2020, EEA, 2019.

185 ECA, 2018.

186 SWD(2020)181 final.

consistent approach in the monitoring and enforcement of the requirements across the EU. All these positive results of the implementation of the directive have also contributed to a level playing field, which is key for the good functioning of the internal market.

It is also noted by the Commission evaluation[187] that Member States alone could not replicate the BREF process to the degree that it is performed at EU level, not least because identifying BATs at national level would be considerably more expensive as compared to the ongoing BREF process at EU level. Furthermore, in some Member States there would not be enough installations in one or all sectors to allow for proper comparison of techniques and environmental performance levels, which is at the very heart of the BREF process. On the basis of the evidence available, the Commission suggests that without EU action – previously under the IPPCD and currently under then the IED – environmental standards would have remained less demanding in many Member States. This would have resulted in higher levels of pollutant emissions and hence stronger adverse impacts on health and the environment than it is currently the case. The Commission concludes, therefore, that action at EU level has likely led to stricter requirements.

Another aspect underlying the added value of the IED and its implementation is its above-mentioned potential to export EU environmental sustainability expertise and thus environmental standards globally. The examples noted by the Commission include BRIC countries such as the Russian Federation, China and India, and also South Korea, which seem to be developing concepts based on the EU BAT system.

[187] SWD(2020)181 final.

4. Conclusions and recommendations

Some of the current EU air quality standards established by the two AAQDs are not aligned with the latest scientific knowledge, especially as regards the effects of air pollution on health. Therefore, to remain relevant, the standards should be updated by means of legislative changes to the two AAQDs. The Commission has scheduled their revision for the third quarter of 2022.[188] More specifically, the ECA considers that the PM, SO_2 and O_3 standards need to be aligned with the latest WHO guidance and that the number of times that concentrations can exceed standards (for PM, NO_2, SO_2 and O_3) must be reduced. Furthermore, the EU auditors are in favour of establishing a short-term limit value for PM2.5 and alert thresholds for PM.

Furthermore, the AAQDs are not fit for swift adaptation to scientific developments. Therefore, the adaptability of the AAQDs to state-of-the-art science and technology needs to be further enhanced. More specifically, there should be a requirement in the two AAQDs for a periodic review of the standards against the latest technical and scientific evidence.[189]

The 2008 AAQ Directive suffers from deficiencies ('ambiguities') in its provisions that in certain cases have resulted in incorrect siting of pollution sampling and related doubts as to the representativeness and comparability of sampled data. This has a negative effect on the implementation of the directives. In particular, non-representative data can lead to situations where action is not taken in the relevant zone/agglomeration because the pollution levels measured are within the limits and thus do not show the need for such an action to be taken. Furthermore, if action indeed needs to be taken because exceedances have been registered, then there is a risk that the action is not adequate because the magnitude of the pollution problem (that this measure would aim to solve) has not been correctly identified and hence is not fully known. Therefore, the legal framework needs to be revised so as to remove all deficiencies that could lead to practical situations where pollution is not sampled correctly, which, as explained, has strong negative effects on the measures taken by the relevant authorities to tackle the problem. In this context, the ECA considers[190] that the Commission proposal for a revision of the AAQ legal framework should address this issue. In particular, the requirements for locating industrial and traffic measuring stations should be revised in such a way as to ensure better measurement of the highest exposure of the population to air pollution. In addition, the auditors consider that the legal framework should set up a minimum number of measurement stations per type (i.e. traffic, industrial or background) as well as the possibility for the Commission to require additional monitoring points to be placed where it finds necessary to ensure better measurement of air pollution. Further recommendations are suggested by the study on sampling points prepared at the request of the European Parliament's ENVI Committee.[191] In particular, the study suggests that the directive should be revised in such a way as to: introduce clear provisions for the identification of highest concentrations, including the obligation for regular updates, modelling and / or passive sampling campaigns; clarify the ambiguities in the provisions regarding the microscale and macroscale siting criteria, as well as the number and distribution of monitoring stations;[192] clarify the ambiguous criteria in the guidance documents, e.g. concerning the classification of monitoring sites; introduce provisions for the delivery of documentation (and regular update) of monitoring site selection, comprising requirements for a complete, thorough assessment, including modelling; develop definitions for

188 Roadmap on the inception impact assessment for the revision of the Ambient Air Quality Directives.

189 COWI et al., 2019.

190 ECA, 2018.

191 Nagl, C. et al., 2019.

192 In particular, any changes to the siting criteria should be substantiated by modelling and / or monitoring exercises.

imprecise but crucial concepts, such as 'general population exposure' and provisions for the representativeness of monitoring sites; make NO_2 assessment obligatory by a combination of fixed monitoring and modelling (with suitable spatial resolution), optionally accompanied by passive sampling, because the high variability of NO_2 levels is difficult to grasp with fixed monitoring sites; and increase the required minimum number of PM2.5 sites, since it is considerably lower compared with PM10, and does not reflect the potential impact of PM2.5 on human health.

There is a positive trend as regards the practical implementation of Member States' obligations under the AAQDs to inform the public of air quality status. However, in doing so, Member States are sometimes following differing approaches, not least because of loopholes in the two AAQDs, as is for example in the case of the currently missing information and alert thresholds for some pollutants. This is a problem because some national approaches deliver better public awareness than others, and the citizens of some Member States could not effectively monitor and control the policy measures implemented by the authorities of the zones/agglomerations affected by air pollution exceedances. Therefore, it is sensible to suggest that EU-level harmonisation of the way air quality data is communicated to the public is necessary, including by filling in gaps in the two AAQDs. Furthermore, the ECA considers that the revised legal framework should advance the date for the reporting of validated data to six rather than nine months after the end of the measuring periods and should explicitly require Member States to provide up-to-date (real time) data. The EU auditors make several other recommendations [193] aimed at improving the quality of information for citizens and hence their involvement in air quality matters. These include measures that need to be taken by the Commission as follows: to identify and compile, with the help of health professionals, the most critical information that the Commission and Member States authorities should make available to citizens (including health impacts and behavioural recommendations); to support the Member States in adopting best practices to communicate with and involve citizens in air quality matters; to publish rankings of air quality zones with the best and worst progress achieved each year and share the best practices applied by the most successful locations; to develop an online tool that allows citizens to report on air quality violations and provide feedback to the Commission on issues related to Member States' actions on air quality; to support the Member States in developing user-friendly tools for the access of the public to air quality information and monitoring (for example, smartphone apps and/or social media dedicated pages); and to seek an agreement on harmonising air quality indices in cooperation with Member States. The ECA also considers that the revision of the 2008 directive [194] should introduce a provision to guarantee the right of citizens to access justice.

The evidence available suggests that over the last decade both the number and magnitude of exceedances have decreased for most pollutants and in most Member States and both industry and road transport have played a role in this process. However, despite this general improvement trend, the periods of exceedances have not been kept as short as possible in all instances as required by the two AAQDs. In particular, exceedances for certain pollutants (notably PM, NO_2, O_3 and benzo(a)pyrene) are still widespread and persistent and lead to harmful effects for the environment and for health, in particular.[195] This shows a picture of a partially effective implementation of the two AAQDs. Non-compliance (with the two AAQDs and beyond, e.g. with the IED) have led to a high number of infringement procedures launched by the Commission against a significant number of Member States. More specifically, at the end of 2019, of the 327 infringement procedures open in the field of environment, 61 concerned failures (including problems with transposition and

193 ECA, 2018.

194 The same could be also recommended for the 2004 directive.

195 This trend is also confirmed by the EEA 'Air quality in Europe - 2020 report', which uses data for 2018.

compliance) under all three pillars of EU air quality policy,[196] and a few more followed in the course of 2020. However, infringement procedures do not always succeed in enforcing compliance with EU air quality standards to the extent that, in some cases, Member States do not comply with decisions of the CJEU. Such cases show that both compliance with the current EU air quality standards at national and, in particular, at zone/agglomeration level, and enforcement of compliance at both national and EU levels are a particular challenge. The ECA report,[197] which finds that enforcement procedures at EU level are lengthy, considers that the Commission should 'actively manage' infringement procedures at each step to ensure that the period from the launch of each procedure until the issue is resolved or submitted to the CJEU is kept as short as possible.

Zone/agglomeration-specific air quality plans (and/or measures) are a critically important instrument on which the two AAQDs rely for the avoidance, reduction and prevention of air pollution beyond the established values in that zone/agglomeration. However, in certain cases, these plans and their implementation are a factor hampering compliance with EU air quality standards. Action for improvement should focus on the quality of the plans, and more specifically on the nature of the measures included in the plans that may compromise their implementation in practice. Such action should as a priority be taken at the level of the zone/agglomeration affected by exceedances to ensure that local conditions are properly taken into account when measures are designed and implemented. EU-level guidance could support this process. In particular, the EU auditors recommend[198] that the Commission should share best practices from Member States that have successfully reflected the requirements of the AAQ Directives in their air quality plans, including on issues such as information relevant for monitoring purposes; targeted, budgeted and short-term measures to improve air quality; and planned reductions in concentration levels at specific locations. Furthermore, the implementation of air quality plans (and/or measures) need to be properly monitored and evaluated, as a basis for improvements in their design and implementation commensurate to the pollution problem they are meant to solve.

It has been established that, in some cases, air quality plans (and/or measures) suffer from certain deficiencies in the EU legal framework, such as for example the lack of an obligation for Member States to report to the Commission on the implementation of their plans (and/or measures), or to update them when new measures are adopted or when progress has not been sufficient. This loophole leads to problems with monitoring the implementation of the plans for both the relevant authorities and for the Commission. These gaps need to be addressed by means of legislative changes to the legal framework of the AAQDs. This recommendation is also supported by the ECA, which adds that the legal framework should feature a requirement that air quality plans be result-oriented and their number per zone/agglomeration be limited.

As regards the IED, which is also scheduled for revision in the fourth quarter of 2021,[199] the following issues should be addressed with a view to further enhancing the positive trends identified in the effectiveness of its implementation: the national practices of granting derogations to certain installations (which is also a pertinent coherence issue) should not cause undue delay to the implementation of the respective BATs and, hence, the reduction of emissions from these installations; the current exclusion from the scope of the IED of some highly polluting installations in the agricultural (livestock) and mining sectors should be reconsidered and the practice of

[196] Annual report on monitoring the application of EU law (2019), Commission SWD – monitoring of applications by EU policy area, Part 2.

[197] ECA, 2018.

[198] ECA, 2018.

[199] Roadmap on the inception impact assessment for the revision of the Industrial Emissions Directive, European Commission, 2020.

constructing installations with a capacity just below the IED threshold, which leaves such installations outside the scope of the IED and its requirements, should be prevented; data collected via monitoring should be published in a systematic way by all competent authorities, also using digital technologies, which would show whether operators are indeed reporting data consistently, would improve the transparency of the approaches followed by the competent authorities when assessing operators' compliance with the IED and would facilitate public access to data; the release of many emerging air pollutants should be better monitored and reported, so as to improve assessment of progress towards overall clean production processes; and all permits granted under the IED should be made public, which would also improve public access to information and public participation in the permitting procedures.

As mentioned above, the research paper annexed to this EIA [200] contains original findings on the design and implementation of policies adopted in a sample of 10 agglomerations across the EU (as part of the relevant air quality plans or existing as separate policy initiatives) and recommends actions for improvements. The research paper makes recommendations, some of which are also relevant to any other EU zone/agglomeration affected by air pollution exceedances, regardless of the specific local conditions. In addition, in Section 3.6, the research paper elaborates on the policy lessons that could be learnt from the pandemic-related lockdown measures, which indeed led to reductions of certain air pollutants, and that could be applied in future policy-making.

As regards coherence, this EIA found several examples of EU policies, both in the very area of air quality and in other EU policy areas, whose design and/or implementation undermine the achievement of the EU air quality objectives. More specifically, these policy areas include the IED, the environmental (emissions) performance aspects of the EU type-approval framework for internal combustion engine vehicles, climate action (and related energy) policy, agriculture. The policy coherence issues identified need to be addressed as a matter of priority, thus ensuring that EU policies create synergies facilitating the achievement of the air quality objectives, rather than inconsistencies and policy failures with detrimental health and environmental effects. The ECA suggests further that air quality would benefit from better targeted projects (funded by the EU) and projects that are more coherent with the zone- and/or agglomeration-specific policies aimed at tackling pollution in that zone/agglomeration.

Against the above backdrop, which paints a picture of partially effective and coherent implementation of the two AAQDs and related EU legislation across the EU, it is necessary to revisit the need to align some current EU standards with latest scientific knowledge. An upgrade of this kind, while relevant and indeed necessary in terms of health protection, will make sense only if it goes hand in hand with fully effective implementation at all levels of governance of what should be an internally and externally coherent EU policy framework (across all three pillars).

The findings of this EIA show that implementation of air quality measures generates significant compliance costs in the form of direct investments, such as infrastructure projects or deployment of technologies, and indirect costs relating, for example, to enforcement by the competent authorities. However, it has also been found that the benefits of implementing EU policies, such as reduced premature death rate, improved health, wellbeing and working capacity, especially as regards the two AAQDs and the Industrial Emissions Directive, outweigh by far compliance- and enforcement-related costs. This proves that EU air quality policies can generate efficiency gains.

Last but not least, it has been shown that air quality policies and legislation – especially as far as the AAQDs and the IED are concerned – should indeed be harmonised at EU level as opposed to a

[200] See the research paper 'Mapping and assessing local policies on air quality. What air quality policy lessons could be learnt from the Covid-19 lockdown?' published as Annex I to this EIA.

situation where Member States act on their own. Air quality policy-making at EU level also has broad support from stakeholders.

REFERENCES

Air quality guidelines. Global update 2005. Particulate matter, ozone, nitrogen dioxide and sulphur dioxide, World Health Organisation, 2006

Air quality in Europe – 2020, Report 9/2020, European Environment Agency, 2020 (EEA, 2020).

Air quality – revision of EU rules, European Commission webpage, 2020.

Air pollution – Our health still insufficiently protected, Special Report 23/2018, European Court of Auditors, 2018.

Ambient air pollution: A global assessment of exposure and burden of disease, World Health Organisation, 2016.

Analysing on-road emissions of light-duty vehicles with Portable mission Measurement Systems (PEMS), Study, Joint Research Centre, European Commission, 2011.

Annual report on monitoring the application of EU law - 2019, European Commission, 2020.

Better Regulation guidelines on evaluation, European Commission, 2017.

Bourguignon D., Air quality - pollution sources and impacts, EU legislation and international agreements, Study, European Parliamentary Research Service, European Parliament, 2018.

Bourguignon D., Motor vehicles: new approval and market surveillance rules, Briefing, European Parliamentary Research Service, European Parliament, 2018.

Bourguignon D., Vehicle Emission Tests: beyond the VW case, At-a-glance, European Parliamentary Research Service, European Parliament, 2015.

Case ACCC/C/2014/121, Aarhus Convention Compliance Committee, United Nations Economic Commission for Europe.

Combined Evaluation Roadmap / Inception Impact Assessment – Development of post Euro6/VI emission standards for cars, vans, lorries and buses, European Commission, 2020.

Communication on A Clean Air Programme for Europe, COM/2013/0918 final, European Commission, 2013

Communication on the European Green Deal, SWD(2020)640 final, European Commission, 2019.

Costs, benefits and economic impacts of the EU Clean Air Strategy and their implications on innovation and competitiveness', Report, International Institute for Applied Systems Analysis, 2017.

COWI et al., Supporting the fitness check of the EU Ambient Air Quality Directives (2008/50/EC, 2004/107/EC), Final Report, 2019

COWI et al., Supporting the fitness check of the EU Ambient Air Quality Directives (2008/50/EC, 2004/107/EC), Appendix G to the Final Report: Detailed evidence on coherence, 2019.

Crippa M., Janssens-Maenhout G., Dentener F., Guizzardi D., Sindelarova K., Muntean M., Van Dingenen R., and Granier C., 'Forty years of improvements in European air quality: regional policy-industry interactions with global impacts', *Atmospheric Chemistry and Physics*, Vol. 16, pp. 3825–3841, https://doi.org/10.5194/acp-16-3825-2016, 2016.

Evaluation criteria, Organisation for Economic Co-operation and Development webpage, 2020.

Evaluation of the Industrial Emissions Directive, SWD(2020)181 final, European Commission, 2020.

European Union Emission Inventory Report 1990-2018 – under the UNECE Convention on Long-range Transboundary Air Pollution (LRTAP), Report 5/2020, European Environment Agency, 2020.

Fitness check of the Ambient Air Quality Directives Directive 2004/107/EC relating to arsenic, cadmium, mercury, nickel and polycyclic aromatic hydrocarbons in ambient air and Directive 2008/50/EC on ambient air quality and cleaner air for Europe, SWD(2019) 427 final, European Commission, 2019.

Impact assessment accompanying the communication on A Clean Air Programme for Europe, the Proposal for a Directive of the European Parliament and of the Council on the limitation of emissions of certain pollutants into the air from medium combustion plants, the Proposal for a Directive of the

European Parliament and of the Council on the reduction of national emissions of certain atmospheric pollutants and amending Directive 2003/35/EC, and the Proposal for a Council Decision on the acceptance of the Amendment to the 1999 Protocol to the 1979 Convention on Long-Range Transboundary Air Pollution to Abate Acidification, Eutrophication and Ground-level Ozone, SWD(2013) 531 final, European Commission, 2013.

Improving Europe's air quality – measures reported by countries, Briefing 9/2018, European Environment Agency, 2018.

Interactive map of all zones and/or agglomerations, European Environment Agency.

Joint report on air quality, EUROSAI Working group on environmental auditing, 2019.

Judgment of the General Court of 13 December 2018 – *Ville de Paris, Ville de Bruxelles and Ayuntamiento de Madrid* v *Commission* (Joined Cases T-339/16, T-352/16 and T-391/16).

Measures to reduce emissions of air pollutants and greenhouse gases: the potential for synergies, Briefing, European Environment Agency, 2020.

Motor vehicles: type approval with respect to emissions from light passenger and commercial vehicles (Euro 5 and Euro 6) and access to repair and maintenance information, 2019/0101(COD) Legislative Observatory, European Parliament, 2020.

Nagl C., Spangl W. and Buxbaum I., Sampling points for air quality - Representativeness and comparability of measurement in accordance with Directive 2008/50/EC on ambient air quality and cleaner air for Europe, Study for the Committee on Environment, Public Health and Food Safety, Policy Department for Economic, Scientific and Quality of Life Policies, European Parliament, Luxembourg, 2019.

REFIT evaluation of Regulation (EC) No 166/2006 concerning the establishment of a European Pollutant Release and Transfer Register (E-PRTR), SWD(2017) 710 final, European Commission, 2017.

Report on the progress made on the implementation of Directive (EU) 2016/2284 on the reduction of national emissions of certain atmospheric pollutants, COM(2020) 266 final, European Commission, 2020.

Review of evidence on health aspects of air pollution — REVIHAAP Project, Final Technical Report, World Health Organization, Regional Office for Europe, 2013.

Roadmap on EU action plan 'Towards a Zero Pollution Ambition for air, water and soil – building a Healthier Planet for Healthier People', European Commission, 2020.

Roadmap on the inception impact assessment for the revision of the Industrial Emissions Directive, European Commission, 2020.

Roadmap on the inception impact assessment for the revision of the Ambient Air Quality Directives, European Commission, January 2021.

SOER - The European environment — State and outlook 2020, Chapter 12 on industrial pollution, European Environment Agency, 2019 (SOER – 2020, EEA, 2019).

The economic cost of air pollution: Evidence from Europe, Economics Department Working Paper No 1584, Organisation for Economic Co-operation and Development, 2019.

The EU's response to the Dieselgate scandal, Review 1/2019, Briefing Paper, European Court of Auditors, 2019.

Wood et al., Mapping and assessing local policies on air quality. What policy lessons could be learnt from the COVID-19 lockdown?, Research paper published under Annex I to the European Implementation Assessment on Air Quality, European Parliamentary Research Service, 2020.

Legislation

Commission Regulation (EU) 2016/646 of 20 April 2016 amending Regulation (EC) No 692/2008 as regards emissions from light passenger and commercial vehicles (Euro 6).

Convention on Access to Information, Public Participation in Decision-making and Access to Justice in Environmental Matters (Aarhus Convention), United Nations Economic Commission for Europe, 1998

Convention on Long-range Transboundary Air Pollution, United Nations Economic Commission for Europe, 1999

Council Directive 1999/13/EC of 11 March 1999 on the limitation of emissions of volatile organic compounds due to the use of organic solvents in certain activities and installations.

Council Directive 92/112/EEC on procedures for harmonising the programmes for the reduction and eventual elimination of pollution caused by waste from the titanium dioxide industry.

Council Directive 82/883/EEC on procedures for the surveillance and monitoring of environments concerned by waste from the titanium dioxide industry.

Council Directive 78/176/EEC on waste from the titanium dioxide industry.

Directive (EU) 2016/2284 of the European Parliament and of the Council of 14 December 2016 on the reduction of national emissions of certain atmospheric pollutants, amending Directive 2003/35/EC and repealing Directive 2001/81/EC.

Directive (EU) 2015/2193 of the European Parliament and of the Council of 25 November 2015 on the limitation of emissions of certain pollutants into the air from medium combustion plants.

Directive 2010/75/EU of the European Parliament and of the Council of 24 November 2010 on industrial emissions (integrated pollution prevention and control directive).

Directive 2009/126/EC of the European Parliament and of the Council of 21 October 2009 on Stage II petrol vapour recovery during refuelling of motor vehicles at service stations (known as the 'Stage-II' Directive).

Directive 2009/125/EC of the European Parliament and of the Council of 21 October 2009 establishing a framework for the setting of ecodesign requirements for energy-related products (recast).

Directive 2008/50/EC of the European Parliament and of the Council of 21 May 2008 on ambient air quality and cleaner air for Europe (2008 AAQ directive).

Directive 2008/1/EC of the European Parliament and of the Council of 15 January 2008 concerning integrated pollution prevention and control.

Directive 2007/46/EC of the European Parliament and of the Council of 5 September 2007 establishing a framework for the approval of motor vehicles and their trailers, and of systems, components and separate technical units intended for such vehicles (Framework Directive) as repealed by Regulation (EU) 2018/858.

Directive 2004/107/EC of the European Parliament and of the Council of 15 December 2004 relating to arsenic, cadmium, mercury, nickel and polycyclic aromatic hydrocarbons in ambient air (2004 AAQ directive).

Directive 2001/80/EC of the European Parliament and of the Council of 23 October 2001 on the limitation of emissions of certain pollutants into the air from large combustion plants.

Directive 2000/76/EC of the European Parliament and of the Council of 4 December 2000 on the incineration of waste.

Directive 94/63/EC of the European Parliament and of the Council of 20 December 1994 on the control of volatile organic compound (VOC) emissions resulting from the storage of petrol and its distribution from terminals to service stations (known as the 'Stage-I' Directive).

Gothenburg Protocol to the Convention on long-range transboundary air pollution, United Nations Economic Commission for Europe, 1999 (as amended in 2012).

International Convention for the Prevention of Pollution from Ships (MARPOL), International Maritime Organisation, 1973.

Regulation (EU) 2018/858 of the European Parliament and of the Council of 30 May 2018 on the approval and market surveillance of motor vehicles and their trailers, and of systems, components and separate technical units intended for such vehicles, amending Regulations (EC) No 715/2007 and (EC) No 595/2009 and repealing Directive 2007/46/EC.

Regulation (EC) No 595/2009 of the European Parliament and of the Council of 18 June 2009 on type-approval of motor vehicles and engines with respect to emissions from heavy duty vehicles (Euro VI) and on access to vehicle repair and maintenance information and amending Regulation (EC) No 715/2007 and Directive 2007/46/EC and repealing Directives 80/1269/EEC, 2005/55/EC and 2005/78/EC.

Regulation (EC) No 715/2007 of the European Parliament and of the Council of 20 June 2007 on type approval of motor vehicles with respect to emissions from light passenger and commercial vehicles (Euro 5 and Euro 6).

Treaty on the Functioning of the European Union.

Mapping and assessing local policies on air quality – What air quality policy lessons could be learned from the Covid-19 lockdown?

Research paper

EPRS | European Parliamentary Research Service

Glossary

AIDE-G	Dataset combining reports on attainment of air quality objectives delivered by countries for each pollutant within individual zones and agglomerations.
Airparif	Non-profit organisation accredited by the French Ministry of Environment to monitor the air quality in Paris and in the Île de France region.
DPF	A diesel particulate filter is a device designed to remove diesel particulate matter or soot from the exhaust gas of a diesel engine.
EEV	The Enhanced Environmentally-friendly Vehicle is a vehicle propelled by an engine that complies with the permissive emission limit values set out by Regulation (EC) No 715/2007 of the European Parliament and of the Council of 20 June 2007
SCR	Selective catalytic reduction is an advanced active emissions control technology system
$PM_{0.2}$ – $PM_{2.5}$	Particulate matter with a median diameter in the range of 0.2 to 2.5 µm are considered fine particles, to differentiate them from ultrafine particles ($PM_{<0.2}$) and coarse particles ($PM_{2.5}$ to PM_{10})
Soot emissions	Soot forms part of the particulate matter emissions of combustion engines. Diesel soot particles consist of elemental carbon and other substances such as organic carbon compounds.

Abbreviations

ACE-2	Angiotensin-converting enzyme 2
ADEME	*Agence de la transition écologique*
AMB	Barcelona Metropolitan Area
APU	Auxiliary Power Units
AQ	Air quality
ARDS	Acute Respiratory Distress Syndrome
BC	Black carbon
BSG	Blavatnik School of Government
cc	Cubic centimetres (engine displacement)
CNG	Compressed natural gas
CO	Carbon monoxide
CO_2	Carbon dioxide
COVID-19	Coronavirus disease 2019
CRTM	Madrid Regional Transport Consortium (*Consorcio Regional de Transportes de Madrid*)

DPM	Diesel particulate matter
DRIEE	*Direction Régionale et Interdépartementale de l'Environnement et de l'Energie*
EBC	Exhaled breath condensate
EEA	European Environment Agency
EEV	Enhanced Environmentally friendly Vehicle
EIA	European Implementation Assessment
EMT	*Empresa Municipal de Transportes de Madrid*
ENVI	European Parliament Committee on the Environment, Public Health and Food Safety
EU	European Union
HC	Hydrocarbon
HGV	Heavy goods vehicle
H_2O_2	Hydrogen peroxide
ICU	Intensive Care Unit
LEZ	Low Emission Zone
LNG	Liquefied Natural Gas
LPG	Liquefied Petroleum Gas
NCESD	National Centre for the Environment & Sustainable Development
NH_3	Ammonia
NO	Nitrogen oxide
NO_2	Nitrogen dioxide
NO_x	Nitrogen oxides
NRMM	Non-Road Mobile Machinery
NTUA	National Technical University of Athens
ONS	Office for National Statistics
PM	Particulate Matter
RNA	Ribonucleic acid
SARS-Cov-2	Severe Acute Respiratory Syndrome Coronavirus 2

SER	Servicio de Estacionamiento Regulado (Regulated Parking Service (*Servicio de Estacionamiento Regulado* - Madrid)
SCR	Selective Catalytic Reduction
SO_2	Sulphur dioxide
SRF	Solid Recovered Fuel
SUMP	Sustainable Urban Mobility Plan (Bucharest)
TSP	Total Suspended Particles
UVAR	Urban vehicle access regulations
ZERO	*Associação de Sistema Terrestre Sustentável*

1. Introduction and objectives

1.1. Context of this research paper

This is the final research paper for the project titled 'Mapping and assessing local policies on air quality. What air quality policy lessons could be learnt from the COVID-19 lockdown?' (Services Order Form EPRS/EVAL/SER/20/021, issued under Framework Contract EPRS/DIRC/SIR/19/002/Lot1/C1).

Milieu Consulting SRL together with Wood E&IS GmbH (hereafter 'Milieu' and 'Wood', respectively) have been contracted to provide the requested expertise.

1.2. Project objectives

The European Parliament's Directorate for Impact Assessment and European Added Value has commissioned this research paper to inform a European Implementation Assessment (EIA), which in turn will support the implementation report on air quality (AQ) to be prepared by the European Parliament's Committee on the Environment, Public Health and Food Safety (ENVI). The implementation report will focus on the implementation of the European Union (EU) Ambient Air Quality Directives (Directive 2004/107/EC and Directive 2008/50/EC) and relevant EU legislation on sources of pollution.

The core objective of the research project is to produce a clear and high-quality research paper to provide the ENVI Committee with insights into the implementation of AQ policies, drawing, among others, on lessons learned from the 2020 novel coronavirus disease (COVID-19), which presents an unprecedented opportunity to consider the effect of reduced activity (e.g. road traffic and industrial output) on AQ.

1.3. Report structure

The sections below provide the approach and findings of each of the project tasks as follows:

- Section 2 presents the methodology applied and findings from Task 1 - the mapping and assessment of local AQ policies, including the methodology for defining the scope and the (primary and secondary) data collection and analysis;
- Section 3 sets out the results from Task 2 - covering the links between AQ policies and the COVID-19 lockdown;
- Section 4 provides the list of references.

2. Mapping and assessment of local air quality policies

2.1. Introduction

This section presents the methodology and results from Task 1, the aim of which was to map and assess local policies addressing air pollution in selected agglomerations across the EU so as to identify:

- •recommendations for improvements in the design of AQ policies and their implementation in each of the selected agglomerations; and
- •practices to tackle pollution from transport and other sources that have the potential to work well regardless of the specific local conditions.

The methodology applied for the selection of agglomerations and for the collection and review of information is presented in section 2.2. The results are presented in sections 2.3.1 to 2.3.10, with an overview of policies identified in each agglomeration followed by a cross-city analysis of the policy design and implementation features (2.4), recommendations and best practices (2.5) and, finally, an indication of the limitations and gaps in the analysis (2.6).

2.2. Methodology

2.2.1. Selection of agglomerations

Given the predominantly urban nature of air pollution issues, the research focused on urban agglomerations or cities.[1] In total, 10 agglomerations were selected for the work under both research tasks. Using the same set of agglomerations for both tasks enables the COVID-19-related research to be considered together with the long-term trends in pollution in each city, as well as the policies identified.

In addition to the five largest cities in the EU in terms of population (Berlin, Bucharest, Madrid, Paris and Rome), five other European cities (Athens, Barcelona, Krakow, Lisbon and Stockholm) were selected based on certain criteria.

- **Availability of AQ data** from the European Environment Agency (EEA) European Air Quality Portal[2] (number of monitoring stations in the urban area), as well as exceedance statistics provided by the EEA in AQ attainments (AIDE G).[3] The latter details whether or not EU limit values have been achieved and the population exposed to exceedances. Priority has been given to nitrogen dioxide (NO_2) pollution as the main indicator of urban traffic pollution. Particulate matter (PM) with a median diameter of 2.5 µm or less ($PM_{2.5}$) exceedances have also been considered as it is the regulated pollutant most associated with health effects in urban areas.

[1] Air pollution is not necessarily limited to the area of the agglomeration but can extend beyond the borders and cover a larger area. Similarly, agglomerations can be affected by air pollution from surrounding areas.

[2] European Environment Agency (EEA). European Air Quality Portal. Available at: https://aqportal.discomap.eea.europa.eu/products/data-download/download-e1a-e2a-for-previous-year/

[3] European Environment Agency (EEA). Dataset combining reports on attainment of AQ objectives delivered by countries for each pollutant within individual zones and agglomerations. Available at: https://www.eea.europa.eu/data-and-maps/data/aqereporting-8/attainments-of-air-quality-environmental/air-quality-attainments-aide-g

- **COVID-19 Stringency Index** (per country) produced by the University of Oxford Blavatnik School of Government (BSG).[4] These data consider the degree of lockdown, which can be related to changes in AQ (Task 2). The index reports a number between 1 and 100 to reflect the level of government action and is based on indicators related to the number and strictness of government policies.
- Whether or not a **Low Emission Zone** (LEZ) has been declared, as taken from the Urban Access Regulations website.[5]
- The **geographical balance** of the agglomerations, to ensure a good variation in typical sources and meteorological conditions for the study.
- Preference was given to agglomerations not studied extensively by previous sources. Several review studies exist on the implementation and effectiveness of LEZ in European cities.[6,7] These often cover the biggest cities or cities whose LEZ has been implemented for many years.

The mapping of the agglomerations against these selection criteria is presented in the table below.

Table 2.1 List of selected agglomerations against the selection criteria

	AQ data and exceedance statistics ***						COVID-19 Stringency Index[4]	LEZ[5]	Location in EU
Agglomeration	NO_2 short-term exc.	NO_2 annual exc.	Top 5 NO_2 pop. Exp.	$PM_{2.5}$ annual exc.	Top 5 $PM_{2.5}$ pop. Exp.	No. of monitors			
Berlin*		x				16	73.15	Y	Central
Madrid*	x	x	x			23	85.19	Y	Southern
Rome*		x	x			10	93.52	Y	Southern
Paris*		x				23	90.74	Y	Western
Bucharest*		x	x			6	87.04	N**	Eastern
Lisbon	x	x				6	87.96	Y	Southern
Barcelona		x	x			11	85.19	Y	Southern
Athens		x				8	84.26	Y	Southern
Krakow		x		x	x	4	83.33	Y	Eastern
Stockholm						6	51.85	Y	Northern

[4] University of Oxford Blavatnik School of Government, COVID-19 Stringency Index, 2020. Available at: https://www.bsg.ox.ac.uk/research/research-projects/coronavirus-government-response-tracker

[5] Urban Access Regulations website available at : https://urbanaccessregulations.eu/ (previously www.lowemissionzones.eu).

[6] Air, R., Pouponneau, M., Forestier, B and Cape, F., Les zones à faibles émissions (Low Emission Zones) à travers l'Europe : déploiement, retours d'expériences, évaluation d'impacts et efficacité du système – Rapport. ADEME, 2019. Retrieved from https://www.ademe.fr/sites/default/files/assets/documents/rapport-zones-faibles-emissions-lez-europe-ademe-2018.pdf

[7] Transport & Environment, Low-Emission Zones are a success - but they must now move to zero-emission mobility, 2019. Retrieved from https://www.transportenvironment.org/sites/te/files/publications/2019_09_Briefing_LEZ-ZEZ_final.pdf

** Five largest cities in the EU (in terms of population)*
*** Information on an LEZ in Bucharest was identified under Task 1 based on other sources (LEZ in Bucharest was established in October 2019 and annulled in March 2020)*
**** EEA data on whether the EU limit values are exceeded and the highest agglomerations for population exposure to that pollutant*

2.2.2. Information requirements

To guide the mapping and assessment of local AQ policies in each of the agglomerations, a set of research questions was identified in the Technical Specifications. The set of research questions is presented in Table 2.2 and applies to:

(i) local policies aiming to reduce **air pollution from the most relevant sources**,

(ii) air pollution from **road transport** (in particular local measures related to the issue of **'on-road polluting vehicle legacy'** – see text box below Table 2.2), and

(iii) the introduction of an **'LEZ'**.

The set of research questions is addressed to each of these types of measures or policies. The table below presents the data needs against each of the research questions and the main sources of information used in the study.

Table 2.2 Research questions, data needs and indication of source of information for Task 1

Research question*	Data needs and parameters	Source of information
Q1. What policy measures have been designed and implemented by the relevant authorities in each of the selected agglomerations in the sample: - with the aim of reducing air pollution from sources - such as industry, waste management, agriculture, heating, transport - relevant for this agglomeration? - with the aim to tackle the issue of 'on-road polluting vehicle legacy'? What is **the design of the 'low emission area/zone'** policy measure of each agglomeration (included in the sample)?	Identification of policy measure: - Regulation / practice / policy / technology - Existing / emerging - Technical / behavioural - Scope of policy Applicability: - Emission sources - Uptake – current, future, potential - Location / scale Other design elements: - Voluntary / mandatory - Cost efficiency	Secondary data – information from local authorities, government reports, technical studies, policy impact assessments describing local AQ measures.
Q2. In a comparative perspective, what **features** in the design of the policy measures (including 'low emission area/zone' and 'on-road polluting vehicle legacy') are **common** to the agglomerations and what features are **specific to each agglomeration**? Are there any common trends (across the agglomerations included in the sample) **in the factors underlying the specific policy choices** of the authorities?	- Common and specific features - Synergies - Barriers	Assessment of compiled information Primary data - expert insights and judgement
Q3. Have the implemented policy measures (including 'low emission area/zone' and 'on-	Impacts on emissions:	Data / evidence on emission trends during

Research question*	Data needs and parameters	Source of information
road polluting vehicle legacy') led to the intended **decrease in air pollution** from the relevant pollution source(s) in the agglomerations or not?	- Emission trends (short, medium and long term) - Matching trends against initial targets Impacts on pollutant concentrations Knock-on impacts or co-benefits (air, climate, water, land, noise)	and/or after implementation. Assessment of compiled data
Q4. What has worked well in each zone and/or agglomeration and why? What has **not worked well** in each agglomeration and **why?**	Design and implementation elements: - Incentives, subsidies, fines, etc. - Distribution impacts (inequalities, competitiveness) - Speed of effect (timescale, phased approach, short/long term) - Voluntary / mandatory - Compliance levels	Assessment of compiled information Primary data - insights and judgement of interviewed experts
Q5. In a comparative perspective, are there any **common trends** (across the agglomerations included in the sample) in the identified **good and bad implementation practices** and their **underlying factors**?	Pros and cons	Assessment of information and internal expert judgement

* Research questions are taken from the study's Technical Specifications.

Following from the analysis of these research questions, the aim was to outline recommendations for improvements in the design of AQ policies and their implementation in each agglomeration in the sample. As per the Technical Specifications, the research intended to outline practices (if any) aimed at tackling pollution from transport and other sources that have the potential to work well regardless of the specific local conditions.

The focus of the research was on the most important urban air pollutants, NO_2 and PM ($PM_{2.5}$ and PM_{10}), which arise mainly from road traffic but also from other relevant sources. The main focus was $PM_{2.5}$, a component of PM_{10} associated with emissions from combustion, as this size fraction can penetrate more deeply into the lungs and is most strongly associated with adverse health effects. PM_{10} is also discussed where it was specifically referred to in the literature or during interviews. Sulphur dioxide (SO_2) was also considered for the agglomerations in which it is a priority pollutant due to specific local emission sources. Ozone (O_3) was not considered in reference to human health effects as pollution episodes typically occur in areas away from cities as chemical reactions in the air produce O_3 from NO_2. Conversely, the NO_X emissions in cities mean that O_3 levels are typically low (see section 3.5.3, which discusses this seemingly paradoxical relationship).

The identification of the local AQ policies under Task 1 was guided by the main source(s) of air pollution in each of the 10 agglomerations. A detailed source apportionment of air pollution in each city is provided under Task 2 and indicates the main sources of air pollution (and related pollutants).

On-road polluting vehicle legacy

According to the Technical Specifications, 'on-road polluting vehicle legacy' includes light and heavy-duty vehicles from all European emission standards and fuel types, which:

- have been put on the market under the rules preceding the reform of the type-approval legal framework and that are still in force, and,
- have higher exhaust emissions in real driving conditions than their laboratory type approval performance, also due to an installation of a defeat device (as revealed, among others, by the Dieselgate scandal in September 2015), and
- are still in circulation.

2.2.3. Information collection and review

The approach to the collection and review of information to address the Task 1 research questions comprised several steps:

- Collection and review of evidence (secondary data);
- Identification of information gaps and gap filling (primary data); and
- Identification of recommendations and best practices.

The collection of evidence through the literature search (secondary data) was performed systematically, guided by the selection of agglomerations and the data needs related to the research questions. The literature review started with EU-wide sources (e.g. Fitness Check of the Ambient Air Quality Directives and other references provided in the Technical Specifications), followed by a review of local sources for each of the agglomerations (e.g. AQ plans, AQ websites or technical (transport) studies). The list of sources reviewed for each of the agglomerations is presented in section 4.

A template was used to extract the relevant information from each source, ensuring consistency in the information gathered for each agglomeration and policy. The template included fields to identify the data needs. An overview of the policies and summary of the findings are presented in section 2.3. The compiled database of policies can be made available upon request[8].

Some of the information needed to effectively address all the research questions was expected to be lacking on completion of the literature review (specific insights into what did/did not work well and why; linking a trend in air pollution to specific local policies, etc.). As this information is typically not available in published reports, papers or on websites, interviews were undertaken with relevant stakeholders to address those information gaps (primary data). Interviews provided expert input and/or judgement but also aimed to validate the data compiled from the literature review. The stakeholders for the follow-up interviews were identified during the literature review and included local authorities, authors of local AQ plans, academics and non-governmental organisations (NGOs). Experts from the organisations listed in the table below were interviewed for the purposes of this research project.

[8] Requests could be sent to: EPRS-expostevaluation@ep.europa.eu

Table 2.3 List of organisations whose experts were interviewed on local AQ policies.

City	Organisation
Athens	National Technical University of Athens (NTUA)
Barcelona	Barcelona city council (*Departament de Qualitat Ambiental*)
Barcelona	Barcelona Provincial Council (*Diputació de Barcelona*)
Berlin	Senate Department for the Environment, Transport and Climate Protection
Bucharest	National Environmental Protection Agency (*Agentia pentru Protectia Mediului Bucuresti*)
Krakow	Krakow - Department of Air Quality
Lisbon	*Associação de Sistema Terrestre Sustentável* (ZERO)
Lisbon	Lisbon City Council - *Departamento de Ambiente, Energia e Alterações Climáticas*
Madrid	City Council (Directorate General for sustainability and environmental control)
Madrid	Community of Madrid
Paris	Paris - *Direction des Espaces Verts et de l'Environnement*
Paris	AIRPARIF – *l'Observatoire de l'air en Île-de-France*
Rome	Regional Environmental Protection Agency of Lazio (*Agenzia Regionale per la Protezione Ambientale del Lazio*, ARPA)
Rome	Directorate Mobility service (*Roma Mobilita*)
Stockholm	*Stockholms Stad*

The general interview topics and questions are presented in Appendix 5. However, the discussion points and questions for the individual interviews were tailored to each city and/or expert.

The outcomes of the interviews have been used to complement the information from the literature review: together, these sources form the basis for responding to the research questions and informing the recommendations and conclusions. The recommendations indicate areas for improvement in the design of AQ policies and in their implementation. Practices were also identified that aimed to tackle pollution from transport and other sources and that have the potential to work well regardless of the specific local conditions. The limitations of the approach and data gaps from the analysis are presented in section 2.5.

2.2.4. Long-term trend analysis of pollutant concentrations

Data collection

Many assessments and policy documents focus on total emissions for different sources and how policy measures might change these. Given that EU limit values relate to concentrations of pollutants in the air, it is also necessary to consider actual changes in pollutant concentrations over time as measures are implemented. Long-term trends in NO_2 and $PM_{2.5}$ concentrations in each of the agglomerations studied have been considered. Hourly-mean NO_2 and $PM_{2.5}$ concentrations were obtained from the EEA European Air Quality Portal[9] from 2013 (or earliest year available for newer stations) up to 2019 (inclusive) for each of the agglomerations. Trends were calculated for individual sites, with trends across the sites within an agglomeration then considered. Three monitoring sites were selected within each agglomeration to provide an indication of the change in pollutant concentrations over time. Where the data capture for the available period or first/last year was under 75 % (fewer than 6 570 hours of usable data in the year), results were flagged for a data quality warning.

Monitoring stations selected

Monitoring sites were selected to provide a representative view of AQ in the agglomeration based on a good geographical spread across the city. Where possible, at least one urban background and one roadside monitoring site was selected in each agglomeration. Selected stations are presented in Appendix 1.

Data analysis

The Openair open-source software package of tools for analysing AQ data[10] was used for the data obtained from the European Air Quality Portal to determine long-term trends in air pollutant concentrations. The trends were then assessed against the measures implemented in each city.

Two Openair tools were used, a smooth-trend fit to the data and a statistical Theil-Sen linear fit. These analyses calculate monthly mean data, with the mean for the month only calculated when the 1-hour mean data capture is greater than 75 %. The smooth-trend function establishes the linearity of a trend. The Generalised Additive Model finds the appropriate level of smoothing for monthly averages. The plots produced show the smoothed trend line, along with a 95 % confidence interval. The Theil-Sen function provides an analysis of the significance of trends. The percentage change in the pollutant concentration per year (%/yr) was determined as the key output (rather than change in concentration per year, which makes comparison between sites' concentrations difficult).

Results are summarised in the next section in relation to each city in this report, and full results are provided in Appendix 2.

2.3. City analysis

The sections below present, for each agglomeration: (i) an overview of the policies identified covering different pollution sources; (ii) a factsheet on the city's LEZ; (iii) a description of the policies related to 'on-road polluting vehicle legacy'; and (iv) a description of other policies, i.e. those policies (in addition to the policies aimed at tackling pollution from transport) that have been selected for more in-depth assessment, including through the interviews with experts. The group of other policies was selected based on the importance of the related air pollution sources in the city (in addition to road transport) and therefore relate to emissions from other sources, specifically domestic heating, non-road transport or construction. The source apportionment details for each agglomeration are provided in section 3.

[9] EEA (2020) Download of air quality data Download service for E1a and E2a data. Available at: https://discomap.eea.europa.eu/map/fme/AirQualityExport.htm

[10] Carslaw, D. C. and K. Ropkins, (2012) openair - an R package for air quality data analysis. Environmental Modelling & Software. Available at: https://davidcarslaw.github.io/openair/

Road transport related policies were the majority of policies identified and were further divided to differentiate between their type or rationale. Four groups of road transport policies were identified:

1. Reduce demand for more polluting forms of transport – such as promoting cycling and walking, modal shifts in public transport, new taxi schemes, school buses, etc.
2. Reduce emissions from existing vehicles – including speed limitations, other driving restrictions, emissions tests and abatement retrofit. This category includes policies addressing the issue of 'on-road polluting vehicle legacy'.
3. Promote vehicles with low emissions – including LEZs, development of electric vehicle charging infrastructure, cleaner public transport and public procurement.
4. Displace pollutant sources outside hotspots and populated areas – such as the use of logistics or freight consolidation centres or the use of newer buses on the most polluted routes.

The categorisation and labelling of measures is similar to previous studies' approaches to AQ interventions[11] and can be linked to the EEA list of AQ measures.[12]

Where available, a summary of the impacts of identified policies on air pollution is provided as a final section for each of the agglomerations.

2.3.1. Athens

Overview of local AQ policies

The city of Athens has designed and implemented AQ policies addressing various sources of air pollution, including pollution from road transport, non-road transport, and heating. An overview of the policies identified for Athens is presented in Table 2.4.

Table 2.4 Overview of AQ policies identified for Athens.

AQ policies - ATHENS		
Sector	Category	Policies and measures
ROAD TRANSPORT	Reduce demand for more polluting forms of transport	Investments in public transport by cutting fares and increasing financial incentives Promotion of alternative means of transport such as walking and cycling, e.g. by increasing cycling lanes, pedestrianising the centre of Athens ('the Great Walk')
	Reduce emissions from existing vehicles	Financial incentives to replace old vehicles with low-polluting ones (monetary incentive for discarding old vehicles, dependent on the engine size) Vehicle emission checks (determination of measurement methods for harmful pollutants in exhaust gases of road vehicles) Annual vehicle emissions tests, requiring annual inspections of private vehicles once a year and taxis and light trucks twice a year. Development of dedicated bus lanes (to increase the reliability and speed of buses, the use of public transport and to reduce emissions)

[11] Public Health England (2019). Review of interventions to improve outdoor air quality and public health. Available at: https://www.gov.uk/government/publications/improving-outdoor-air-quality-and-health-review-of-interventions

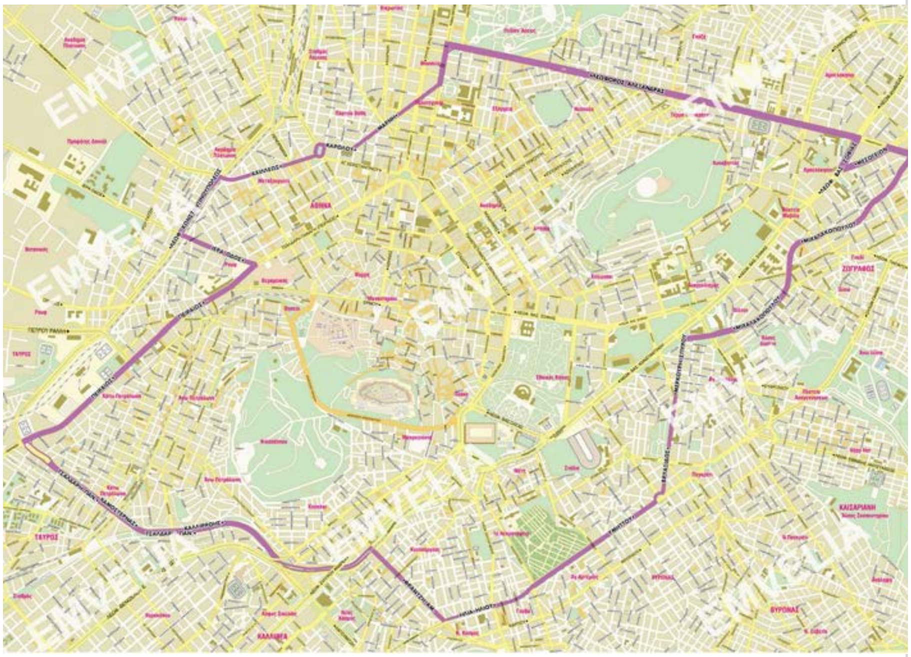
[12] EEA Air quality measures (data flow K). Available at: http://aidek.apps.eea.europa.eu/

AQ policies - ATHENS		
Sector	Category	Policies and measures
	Promote vehicles with low emissions	Athens LEZ (Small Ring and Big Ring) Scrappage schemes and fiscal incentives for low emissions vehicles (tax relief measures for the purchase of new vehicles) Replacement of old diesel buses with buses using natural gas Development of plans for the installation of charging points/ development of a charging network for electric vehicles
NON-ROAD TRANSPORT	Aviation sector	Relocation of the international airport servicing Athens from Elliniko (located in a suburb of greater Athens) to Spata (an area outside greater Athens) in 2001 with the underlying aim of addressing air pollution in the more densely populated area. Plans for a large development in Elliniko will likely involve parks and sustainable development, which could improve the AQ of the area
HEATING		Introduction of quality standards for biomass used for household heating (non-industrial purposes) Provision of free electricity to low-income households Minimum performance requirements for new hot water boilers powered by liquid or gaseous fuels Feed-in tariff for the generation of electricity using solar panels from households

LEZ

The table below presents the information on the Athens LEZ.

Table 2.5 Overview of Athens LEZ

Athens LEZ	
Map of LEZ	

Athens LEZ	
	Figure: Athens LEZ. The area marked by the purple line represents the LEZ (Small Ring). Source: https://urbanaccessregulations.eu/
Description and scope	The Athens LEZ, represented by the area marked by the purple line in figure above, is a restriction system regulating the entry of vehicles, with the aim of removing diesel vehicles - and their contribution to local air pollution – by 2025. Two different schemes are currently implemented in Athens: - A small area ('Small Ring') represented by the city centre (purple line in figure above) where only private-use cars and light trucks are allowed to enter on alternating days. There are no entry restrictions for low emission vehicles, such as electric and hybrid vehicles and those meeting specific emission standards - A bigger area that represents the whole Athens area ('Big Ring' or *Megalo Daktylio*) where only private-use cars and light trucks and buses registered after a specified date are allowed
Enforcement mechanism	The LEZ is enforced through cameras and number plate recognition. Vehicles must display coloured signs according to their vehicle emission category and carry appropriate documentation. In case of non-compliance, a penalty fee of €200 applies.[13]
Exemptions	Electric and hybrid vehicles and vehicles that emit carbon dioxide (CO_2) emissions of less than 140g/km are allowed to access the LEZ. This measure does not apply on Saturdays, Sundays, public holidays and days of 24-hour strikes of public transport. In addition, rental cars for the first 40 days and foreign vehicles are not affected. Within the Small Ring, there is unrestricted movement of electric vehicles and trucks under 2.2 tonnes and private cars from Euro 5 and Euro 6 standards (or later), regardless of the fuel they use (petrol, diesel, LPG, or compressed natural gas).

ON-ROAD POLLUTING VEHICLES

Several measures have been implemented in Athens that directly or indirectly address the issue of on-road polluting vehicles.

- Vehicle emission checks: a law was passed in 1994 with the objective to reduce emissions from existing vehicles. The law addressed the determination of measurement methods and permissible limits of carbon monoxide (CO) and hydrocarbons (HCs) in the exhaust gases of petrol and Liquefied Petroleum Gas (LPG) road vehicles. The law was updated in 2007 to include the determination of measurement methods and permissible turbidity limits in the exhaust gases of diesel road vehicles.

  In addition, a national inspection programme for the control of emissions from motor vehicles was transcribed into law in 1992, which requires inspections of private vehicles once each year and of taxis and light trucks twice each year. An 'Exhaust Control Card' is issued to each vehicle inspected, detailing the vehicle emissions. Owners of vehicles with higher than allowed emissions are fined or prosecuted.

- Scrappage schemes and fiscal incentives to replace high-emitting vehicles with low emission vehicles: a retirement plan for old vehicles was introduced in 1991, aiming to replace old polluting vehicles with vehicles equipped with catalytic converters (passenger or private vehicles and trucks of up to 2.5 tonnes gross weight). The plan included tax relief measures for

[13] Urban Access Regulations in Europe (Athens). Available at: https://urbanaccessregulations.eu/countries-mainmenu-147/greece/athens

the purchase of new vehicles costing between €500 and €2000, depending on the vehicle type.

- Road tax scheme: the road tax was revisited and updated in 2016, with vehicles of higher engine capacity and polluting potential incurring a higher tax, and hybrid, electric and hydrogen vehicles under 1,929 cubic centimetres (cc) incurring zero road tax.

OTHER POLICIES

Since 2014, the city of Athens provides free electricity to low-income households once they are registered in the 'Social Housing Invoice' programme. The measure targets low-income households and neighbourhoods and, while aimed at tackling energy poverty, has clear knock-on impacts on air pollution and AQ. The provision of free electricity, as well as low electricity prices, reduces the need to burn fuels or waste, especially on days when weather conditions favour the creation of smog, and thus improve AQ.

Impacts of policies on air pollution and AQ

A 2010 report on the Athens metro reported that as a result of the investment in public transport, approximately 650 000 passengers used the two metro lines each day.[14] It was estimated that the development of the metro system had reduced the number of cars entering the city centre by 70 000 or, similarly, vehicular traffic had fallen by 335 000 vehicle kilometres travelled on a daily basis. At the same time, it reduced the number of buses in the centre of Athens due to the re-organisation of other public transport modes.

The analysis for this research paper indicates that NO_2 concentrations have increased over the study period, with a mixed pattern for $PM_{2.5}$. There was an average increase in NO_2 concentrations of 5.0 μgm^{-3} per year at the traffic station, which is 15 % of the 2013 concentration. There was an average increase of 0.9 μgm^{-3} per year (11 % of the 2013 concentration) at one of the background monitoring stations and an average reduction of 0.3 μgm^{-3} per year (1 % of the 2013 concentration) at the other. The analysis shows an average reduction in $PM_{2.5}$ concentrations of 0.2 μgm^{-3} per year at the traffic station, corresponding to less than 5 % of the 2013 concentration. It shows an average increase of 0.1 μgm^{-3} per year at each background station, corresponding to less than 1 % of the 2013 concentration.

2.3.2. Barcelona

Overview of local AQ policies

The city of Barcelona has designed and implemented AQ policies addressing various sources of air pollution, including pollution from road transport, non-road transport (shipping), and non-road mobile machinery (NRMM). An overview of the policies identified for Barcelona is presented in Table 2.6.

Table 2.6 Overview of AQ policies identified for Barcelona

AQ policies - BARCELONA		
Sector	Category	Policies and measures
ROAD TRANSPORT	Reduce demand for more	Support and promote electric public transport with low emissions

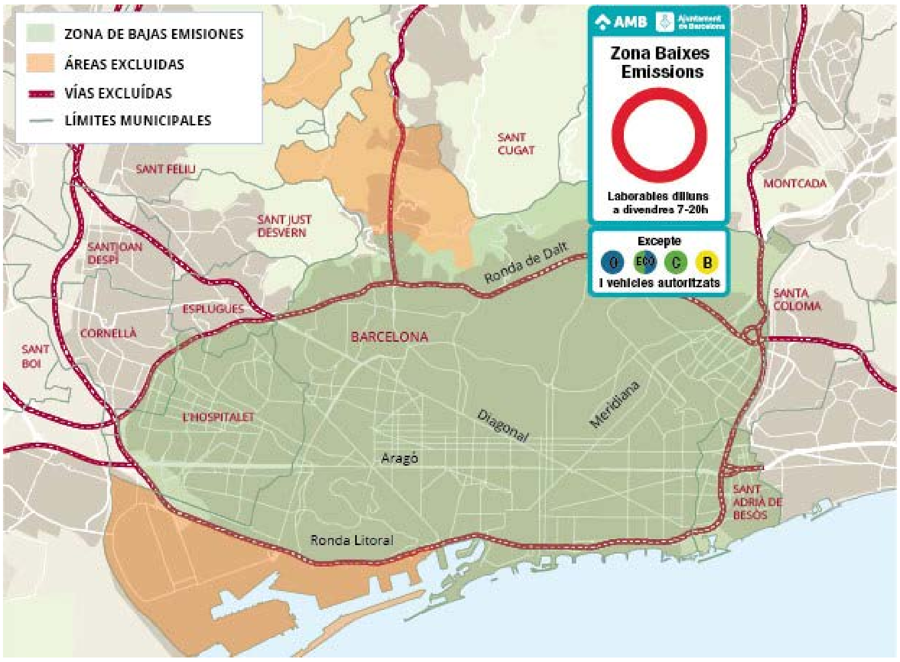
[14] Bartlett School of Planning, Greece - Athens Metro, University of Thessaly, 2010. Available at: http://www.omegacentre.bartlett.ucl.ac.uk/wp-content/uploads/2014/12/GREECE_ATHENSMETRO_PROFILE.pdf

AQ policies - BARCELONA		
Sector	Category	Policies and measures
	polluting forms of transport	Encouragement to shift to public transport and the use of public bicycles through initiatives such as Bicivia (bicycle lane network), Biciempresa (e-bikes to business), Bicibox (free parking for bikes), Bicing (electric bicycles) The RENOVE programme promotes car-sharing and clean vehicles, and imposes parking regulations and vehicle taxes The Terrassa Old Town Integral Plan defines streets and squares where traffic and parking are only allowed during loading and unloading times The Green Area parking scheme reduced parking supply, in combination with parking fees The T-aire promotes public transport in periods of traffic restriction
	Reduce emissions from existing vehicles	Vehicle restrictions in the Old City through local traffic ban for non-residential vehicles at certain hours of the day, and through speed and weight limits The T-verda programme grants free public transport for vehicles out of circulation Definition of special environmental intervention areas and changes in the urban model, creating spaces that reduce traffic and allow access only to residents
	Promote vehicles with low emissions	*Zona de Baixes Emissions Rondes* - Barcelona Ring Road Low emission (LEZ) Investments in procurement for public 'electromobility' and clean cars Renewal of the urban freight fleet New charging points for electric vehicles Replacement of the bus fleet with clean vehicles
NON-ROAD TRANSPORT	Shipping sector	Electrification of mooring points at the port Promotion of LNG as an alternative combustible to conventional fuel Implementation of a maritime sector emissions reduction plan
	NRMM	Introduction of emissions standards for the port fleet
COMMUNICATION AND OUTREACH		Raise awareness of climate change and pollution effects Share an actuation protocol against pollution events

LEZ

The table below presents the information on the Barcelona LEZ.

Table 2.7 Overview of Barcelona LEZ

Barcelona LEZ	
Map of LEZ	 *Figure: LEZ in Barcelona. The green area represents the LEZ. Source: https://urbanaccessregulations.eu/*
Description and scope	Barcelona implemented an LEZ on 1 January 2020: *Zona de Baixes Emissions Rondes* - Barcelona Ring Road LEZ To be allowed to enter the LEZ, certain standards apply. More specifically, vehicles classified as B, C, ECO or Zero (vehicle categories reflecting the potential for pollutant emissions)[15] and certified by an environmental label have access to the LEZ. The measure takes effect from Monday to Friday 07:00 – 20:00
Enforcement mechanism	Vehicles are checked automatically using cameras that check licence plates against the appropriate environmental label, and with the metropolitan register of foreign vehicles and other authorised vehicles. The automatic monitoring system has over 100 licence plate-reading cameras at various points in the metropolitan area. In case of non-compliance, fines range between €200 and €1 800. For repeat offenders, the penalties may be increased by 30 % compared to the minimum amounts
Exemptions	Vehicles for people with reduced mobility and vehicles used by emergency services are allowed to access the LEZ. In addition, the most polluting private cars, motorcycles and mopeds that do not have an environmental label can apply for single-day permits to drive in the LEZ, with a cap of 10 permits per year.

[15] Categories of vehicles are set out on the city's website: https://ajuntament.barcelona.cat/qualitataire/en/afectacions-la-mobilitat/dgt-environmental-label

ON-ROAD POLLUTING VEHICLES

Policies that could be linked to the issue of on-road polluting vehicle legacy in Barcelona also promote the use of public transport:

- The T-verda is a metropolitan area green card that offers free public transport for up to three years, renewed annually. The card is personal and non-transferable, offered to people who have withdrawn a vehicle from circulation and who are registered inhabitants of the metropolitan area.
- With a budget of €1 741 700, the RENOVE programme implemented measures to support car-sharing, change vehicles taxes, support lower emission vehicles, improve the transport of goods and people, improve communication efficiency, promote clean vehicles, and implement parking regulations so that the parking tariffs reflect the level of pollution of the car.

OTHER POLICIES

From 2016 to 2020, the city of Barcelona implemented the **maritime sector emissions reduction plan,** which consists of a group of actions focused on reducing the emissions in Barcelona Maritime Port.

Impacts of policies on air pollution and AQ

The impact on air pollution of policies related to on-road polluting vehicles has yet to be evaluated.

The analysis for this research paper shows a mixed pattern.

There is an average reduction of 0.6 μgm^{-3} in NO_2 concentrations per year at the traffic station, corresponding to 1 % of the 2013 concentration. It shows an average increase of 0.3 μgm^{-3} per year at one background station and an average reduction of 0.5 μgm^{-3} per year at the other, corresponding to 1 % and 2 % of the respective 2013 concentrations.

The analysis shows an average reduction in $PM_{2.5}$ concentrations of 0.2 μgm^{-3} per year at the traffic station, corresponding to less than 0.1 % of the 2013 concentration. It shows an average increase of 0.2 μgm^{-3} per year at one background site and an average reduction of 0.3 μgm^{-3} per year at the other background station, corresponding to less than 0.1 % of the respective 2013 concentrations.

2.3.3. Berlin

Overview of local AQ policies

The city of Berlin has designed and implemented AQ policies addressing various sources of air pollution, including pollution from road transport, non-road transport, heating, industry and construction sites, and urban planning. An overview of the policies identified for Berlin is presented in Table 2.8.

Table 2.8 Overview of AQ policies identified for Berlin

AQ policies - BERLIN		
Sector	Category	Policies and measures
ROAD TRANSPORT	Reduce demand for more polluting forms of transport	Modal shift to clean transport (e.g. electric buses) Promotion of public transport by extending infrastructure and adjusting tariffs Promotion of alternative means of transport such as walking and cycling, by implementing a digital cycling atlas and improving existing cycling facilities, streets and intersections to make them safer, and promoting programmes for cargo bikes Management of parking space and establishment of mobility stations for parking Centralisation of logistics for large construction works, including the planning of transport as much as possible to rail and water (e.g. construction of Potsdamer Platz) Digitalisation of the mobility platform – optimising transport data processing from the main transport providers in Berlin Provision of mobility advice for businesses, including information campaigns on mobility management
	Reduce emissions from existing vehicles	Implementation of a road transport retrofitting programme for municipal heavy-duty vehicles Ban on heavily NO_2 polluting diesel cars Lower speed limits on main roads (speed limit of 30 km/h instead of 50 km/h) iQmobility programme for an environmentally sensitive traffic management (fixed-time control systems and traffic-related control programmes) Bus retrofitting (equipping buses with selective catalytic reduction (SCR) systems) Cleaning of municipal vehicles (retrofitting vehicles and procurement of light commercial vehicles with electric drives) Emission reduction for city tour buses (SCR systems or electric drive) Information campaigns about retrofitting and alternative drives and establishing AQ partnerships with companies
	Promote vehicles with low emissions	Berlin LEZ Support natural gas vehicles (financial support in the form of fuel vouchers in the amount of €111 to €1 500) Implementation of a campaign for cleaning the vehicle fleet Investment in electric public buses Expansion of the charging infrastructure for electric vehicles
	Displace pollutant sources outside of populated areas	Traffic ban on trucks in some areas (*Berlin-Neukölln*) Transit ban for diesel vehicles - drive-through ban for all diesel vehicles up to and including Euro 5 / V

AQ policies - BERLIN		
Sector	**Category**	**Policies and measures**
		Micro-hubs for delivery traffic - construction of micro-depots in areas with high population density and high levels of air pollution
NON-ROAD TRANSPORT	Shipping sector	Cleaning of passenger ships (e.g. retrofitting ships with SCR and particle filters, improving the use of shore power) Test for particulate filter retrofitting for passenger ships
	Rail sector	Environmental standards for diesel-powered trains
HEATING		Emission limits for domestic heating in the inner city and for wood-fired small combustion systems Reduction of the heat demand of buildings (renovation of buildings owned by the state of Berlin and municipal housing associations) Development of information campaigns for the correct heating with wood (e.g. correct handling, such as layering of wood, air supply and quality of wood) Avoidance of new stress points from new buildings (including recommendations for the preservation of wide street spaces and developing specifications for modelling AQ in land-use planning)
INDUSTRY AND CONSTRUCTION	Construction sites	Control of dust emissions by promoting the use of particulate filters in construction equipment
	Other industry	Environmental requirements for mobile machines and devices, and mobile power generators Requirements for diesel engines in approval notices for systems
URBAN PLANNING		Biotope Area Factor - a nature conservation measure used in spatial planning, measuring the proportion of green space for the entire development Urban climatology and air exchange – planning measures for the preservation and, if possible, improvement of the current diffusion conditions for air exchange

LEZ

The table below presents information on the Berlin LEZ.

Table 2.9 Overview of Berlin LEZ

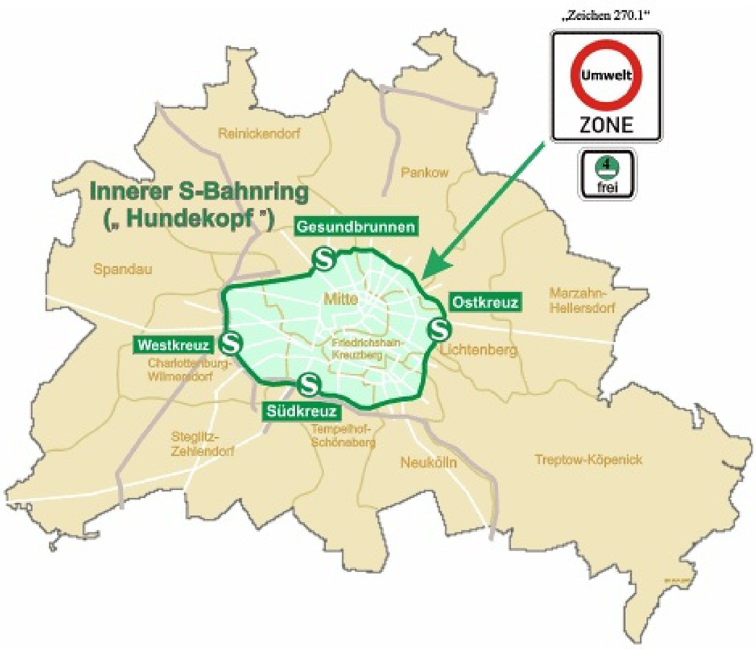
<table>
<tr><th colspan="2">Berlin LEZ</th></tr>
<tr><td>Map of LEZ</td><td>


Figure: LEZ in Berlin. The green area represents the LEZ. Source: https://urbanaccessregulations.eu/
</td></tr>
<tr><td>Description and scope</td><td>
The LEZ came into force on 1 January 2008. Stricter standards were introduced in January 2010, demanding Euro 4 standard or better. The four established pollutant classes apply to cars and trucks and follow the Euro standards for vehicles with diesel engines. For vehicles with petrol engines there are two classes:

- Pollutant class 1 without a windscreen sticker, for vehicles that do not meet the Euro 1 standard
- Pollutant class 4, for all vehicles meeting or exceeding the requirements of Euro 1

The LEZ covers about 88 km^2 of a very densely built-up area of one million residents. The following requirements are effective for the whole area of the environmental zone:

- Stage 1 from 1 January 2008: vehicles must at least be up to the standards of the emission group 2. Vehicles of emission groups 2, 3 and 4 are allowed to drive in the LEZ
- Stage 2 from 1 January 2010: only vehicles of emission group 4 (or better) are allowed to drive in the LEZ
</td></tr>
<tr><td>Enforcement mechanism</td><td>It is mandatory to have a sticker on the windshield showing the emission group to which the vehicle belongs</td></tr>
<tr><td>Exemptions</td><td>Vehicles that are specially adapted to transport people with disabilities</td></tr>
</table>

Berlin LEZ	
Effectiveness in reducing air pollution[16]	Impact of stage 1 after one year: • emissions of diesel exhaust particulates decreased by 24 % (62 tonnes); • emissions of NO decreased by 14 % (960 tonnes); • pollution of annual PM_{10} decreased by 3 %; and • pollution of NO_2 decreased by 7-10 %. Impact of stage 2 after one year: • emissions of diesel exhaust particulates decreased by 50 % (170 tonnes); • emissions of NO decreased by 20 % (1500 tonnes); • pollution of annual PM_{10} decreased by 3 %; and • pollution of annual NO_2 decreased by 7-10 %. Overall: • Black carbon (BC) concentrations measured along busy roads in the LEZ are 50 % lower since the LEZ was launched

ON-ROAD POLLUTING VEHICLES

Several measures have been implemented in Berlin to reduce emissions from existing vehicles.

- Bus retrofitting: progressive measures have been enforced to reduce emissions for the bus fleet. In particular:
  - By the end of 2019, all Euro IV double-deckers were to be retrofitted with SCR systems.[17]
  - By mid-2020, all buses were to be upgraded or equipped with SCR systems or meet the Euro VI emissions standard. The function of the SCR systems in real life traffic has been proven.
  - By mid-2020, the Euro V / Enhanced Environmentally friendly vehicles (EEV) single-deck vehicles were to be replaced by electric buses and diesel buses complying with the Euro VI standard.
- Support for retrofitting vehicles in commercial transport. In particular:
  - Retrofitting 10 % of diesel cars with the Euro 4 emissions standard used in commercial transport, 50 % of diesel cars with Euro 5 and 10 % of diesel cars with Euro 6 by 2021.
  - Retrofitting 50 % of the light commercial vehicles used in commercial transport with the Euro 4 emissions standard and 50 % of the light commercial vehicles with Euro 5 by 2021.
  - Retrofitting 30 % of the heavy commercial vehicles used in commercial transport of the Euro IV emissions standard, 70 % of heavy commercial vehicles up to 7.5 tonnes with Euro V and 30 % of heavy commercial vehicles over 7.5 tonnes with Euro V by 2021.
- Information campaigns to promote retrofitting and lower emissions from driving. This included:
  - Development of a communication and cooperation concept.
  - Creation of a website for vehicle procurement and retrofitting.
  - Banning high-emitting diesel cars and trucks: heavily NO2 polluting diesel cars and trucks are banned in certain parts and streets of the city.

[16] *Senatsverwaltung für umwelt verkehr und klimaschutz*, *Luftreinhalteplan für Berlin 2. Fortschreibung*, 2019. Retrieved from https://www.berlin.de/senuvk/umwelt/luft/luftreinhaltung/luftreinhalteplan_2025/download/Luftreinhalteplan.pdf

[17] SCR is an advanced active emissions control technology system.

OTHER POLICIES

The city of Berlin has implemented other AQ policies addressing important sources of air pollution – domestic heating:

- Emission limit values for domestic heating in the inner city (about 100 km^2). All new buildings are required to emit no more than the levels of oil-fired heating systems. This prohibits the use of individual biomass heating systems or stoves.
- Emission limits for wood-fired small combustion systems. A solid fuel ordinance with the definition of emission limit values for solid fuel firing applies to all small combustion comfort stoves and chimney stoves. The emission limits for wood-fired small combustion systems led to an estimated reduction of around 128 tonnes of PM10 emissions per year.
- Information campaigns for the use of wood for heating, as the emissions from small combustion systems that are not operated automatically depend very much on their handling.

Impacts of policies on air pollution and AQ

The LEZ was very successful initially as it is relatively large and required that almost 25 % of the diesel fleet be retrofitted with a diesel particulate filter (DPF).[18] As a result, the introduction of green windscreen stickers in 2010 reduced soot pollution by half and is considered very successful for PM.

The LEZ was not initially successful for NO_2 since at the time there was no retrofit technology available and NO_2 reduction could only be achieved through rapid fleet renewal. However, real NO_2 driving emissions increased with newer vehicles (partly because soot particle filters increase NO_2 direct emissions).

In addition to the reduction in air pollutants such as PM and BC due to the introduction of the LEZ, vehicle retrofitting has had positive effects on AQ. More specifically, it is estimated that bus retrofitting led to a reduction of 274 tonnes of NO_x emissions per year, while retrofitting in commercial transport led to a 10 % NO_2 emission reduction, corresponding to a reduction of approximately 1 $\mu g/m^3$ in ambient concentrations.[19]

The analysis carried out for this research paper shows sustained reductions in NO_2 and $PM_{2.5}$ concentrations over the study period.

For NO_2, results show an average reduction of 0.9 μgm^{-3} per year at the traffic station between 2013 and 2019. This corresponds to 2 % of the 2013 NO_2 concentration. There is an average reduction of 0.8 μgm^{-3} and 0.7 μgm^{-3} per year at the background stations, corresponding to 3 % of the 2013 NO_2 concentration at each background station.

There has been an average reduction in $PM_{2.5}$ of 0.2 μgm^{-3} per year at the traffic station, corresponding to 1 % of the 2013 concentration, together with an average reduction of 0.4 μgm^{-3} and 0.3 μgm^{-3} per year at the background stations. This corresponds to 1 % and 2 % of the 2013 concentrations at each background station.

[18] Source: interview with representative of the Senate Department for the Environment, Transport and Climate Protection Berlin, October 2020.

[19] *Senatsverwaltung für umwelt verkehr und klimaschutz, Luftreinhalteplan für Berlin 2. Fortschreibung*, 2019. Retrieved from https://www.berlin.de/senuvk/umwelt/luft/luftreinhaltung/luftreinhalteplan_2025/download/Luftreinhalteplan.pdf

2.3.4. Bucharest

Overview of local AQ policies

The city of Bucharest has designed and implemented AQ policies addressing various sources of air pollution, including pollution from road transport, heating, industry and construction sites, urban planning, waste management and agriculture. An overview of the policies identified for Bucharest is presented in Table 2.10. However, in November 2020, the Bucharest Municipal Court annulled the Air Quality Plan developed by the Bucharest City Hall.[20] The court decision was handed down following a lawsuit initiated by a group of NGOs and residents of Bucharest, who complained that the Plan did not comply with national rules and the European Air Pollution Directive and that it had been adopted without public consultation.

The applicant NGOs argued that the Plan adopted by the Bucharest administration to improve AQ did not include measures to achieve legal levels of pollution in 'the shortest possible time', as required by law, nor did it include a detailed timetable for implementing the measures or assessing their impact. In addition, the plan was not carried out on the basis of an updated study to determine the sources of pollution, instead using a study from 2013. The law requires the study be carried out no more than one year before the adoption of the Plan.

The court's decision means that the local administration in Bucharest must prepare a new Air Quality Plan.

Table 2.10 Overview of AQ policies identified for Bucharest

AQ policies - BUCHAREST		
Sector	Category	Policies and measures
ROAD TRANSPORT	Reduce demand for more polluting forms of transport	Development of the first Sustainable Urban Mobility Plan (SUMP), that includes a group to discuss critical aspects of Bucharest's transport system. The SUMP for Bucharest was adopted on 29 March 2017
		The Active Access three-year Intelligent Energy Europe-funded project promoted walking and cycling (August 2009 – July 2012)
		Development of the *Cicloteque*, the first bike rental centre (initiated in 2008) and Bikes with Ties, a free bike-sharing programme for business centres. Creation of bicycle lanes, including in recreational areas. Introduction of a public transport system by bicycle
		Development of pedestrian areas like Bucharest's Historic Centre, by widening footpaths and rationalising their use for other purposes (2018-2022)
		Improvement of the quality of public transport and promotion of its use (2016-2020)
		Increase the share of the use of public electric transport by modernising, rehabilitating and expanding the transmission network (2016-2018)
		Development of facilities for companies to encourage the use of public transport by employees (2018-2022)
		Discouraging ownership of several cars per person or family (2018-2022)

[20] Aerlive project (2020). Platform for measuring air quality in Bucharest. Available at: https://aerlive.ro/victorie-in-instanta-pentru-cetatenii-capitalei/

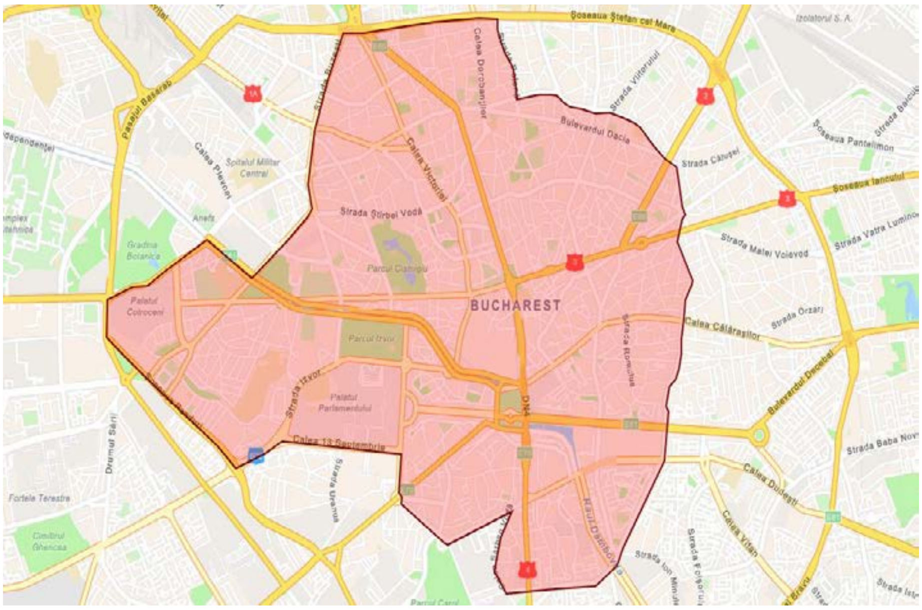
AQ policies - BUCHAREST		
Sector	Category	Policies and measures
	Reduce emissions from existing vehicles	Programme for the disposal of old vehicles owned by inhabitants (2018-2022) Completing the traffic management system that will lead to the improvement of traffic conditions Modernisation and expansion (where possible) of roads in Bucharest Urban sanitation (washing and cleaning streets) Stimulation to use certain routes only if there are at least four people in the car
	Promote vehicles with low emissions	ZSE – Low Emission Zone (2019-2020) Modernisation of the fleets of legal entities and institutions (2018-2022) Stimulating the purchase of hybrid or electric cars (2018-2022)
	Displace pollutant sources outside of populated areas	Construction of park-and-ride facilities at key public transport stations and intermodal train, bus, metro transport stations (2017-2022) Extension of the mandatory parking payment regime to the entire territory of Bucharest in conjunction with the application of additional sanctions for illegal parking (2018-2022) Construction of underground car parks with a sufficient number of spaces for new residential or office buildings, in accordance with the legal provisions in force (2018-2022)
HEATING		Continuation of the modernisation of district heating plants and equipping them with boilers with burners with low pollutant emissions Continuation of the thermal rehabilitation programme of residential and public buildings Heat efficiency through the rehabilitation of primary and secondary heat distribution networks
INDUSTRY AND CONSTRUCTION	Construction sites	Development of a good practice guide for AQ management in the perimeters of construction sites (2019) Development of the 'Anti-dust solutions in Bucharest' project to test, establish and promote a methodology for the application of anti-dust solutions on construction sites that would lead to the reduction of suspended dust concentrations
URBAN PLANNING		Conservation, improvement and expansion of public green spaces (2016-2020) Development of programmes to provide facilities for buildings that have landscaped green terraces Reforestation of certain areas around Bucharest Expansion of green spaces by rehabilitation of land subject to wind erosion

AQ policies - BUCHAREST		
Sector	Category	Policies and measures
WASTE MANAGEMENT AND AGRICULTURE		Prohibition of burning vegetable and household waste in back gardens or on private land
GENERAL / COMMUNICATION		Development of Aerlive.ro network, a platform that measures AQ through 10 sensors located in key points of the city (2020, ongoing) Development and implementation of a guide for the monitoring of the Integrated Plan of Air Quality for Bucharest (2018-2019) Informing and warning citizens about AQ by raising awareness of the real level of AQ and the implications for human health (2018-2020) Involvement of citizens in the observance of good practices in respect of air pollution at urban level (2018-2022)

LEZ

The table below presents the information on the Bucharest LEZ.

Table 2.11 Overview of Bucharest LEZ

Bucharest LEZ	
Map of LEZ (Action area for AQ)	 *Figure: Action area for AQ in Bucharest. The area marked in red represents the restricted access area. Source: https://playtech.ro/2020/ce-e-zaca-bucuresti-masini-interzise/*
Description and scope	Bucharest Local Council issued Decision no. 539 in October 2019 establishing the so-called 'Action area for air quality in Bucharest', i.e. an LEZ in the centre of Bucharest According to that decision, from January 2020, access is prohibited for vehicles with emissions standards non-Euro, Euro 1 and Euro 2. Vehicles with emission standard Euro 3 must purchase a sticker to enter the LEZ. Starting in 2021, vehicles with Euro 4 emissions standards must purchase

Bucharest LEZ	
	a sticker as well. Vehicles with emissions standards Euro 5 and Euro 6, electrical and hybrid vehicles, motorbikes and scooters have free access to the LEZ[21] The restrictions are valid from Monday to Friday, from 7:00 to 22:00, except on holidays However, Decision no. 539/2019 of the Bucharest Local Council was in place for only a few months. It was annulled at the end of March 2020 at the initiative of the then-mayor. City Hall stated that the annulment followed a public consultation initiated after the LEZ was already functional, whose results showed that 85 % of the participants voted against the creation of the LEZ and the enforcement of the corresponding stickers.[22] The results of the public consultation were disputed, however, as it came in the form of a referendum initiated by the mayor on her Facebook account[23]
Enforcement mechanism	Decision no. 539/2019 established that following the issuance of the sticker, a vehicle is registered in an information system dedicated to the issuance, management, monitoring and control of stickers. The information system is managed by Bucharest municipality. Collection of revenues obtained from the sale of the stickers would be done by the Bucharest municipality, which would use the money to fund priority investments in environmental protection and mobility Non-compliance with the rules of Decision no. 539 / 2018 was punishable with fines ranging from RON 1 500 to 2 000 (approx. €300-€400)
Exemptions	• Vehicles with emissions standards Euro 5 and Euro 6, electrical and hybrid vehicles, motorbikes and scooters • Public transport vehicles • Other vehicles of public utility (ambulances, vehicles belonging to the army, etc.) • Vehicles that function with LPG, LNG, CNG, if they have emissions standards of at least Euro 3
Participation and communication	This measure is part of the Bucharest Air Quality Plan 2018-2022, for which public consultation and debates were organised.[24] Several stakeholders were involved in the adoption of the plan. There is no information available on whether the public was involved in the subsequent adoption of the Bucharest Local Council Decision no. 539 / 2019, which transposed the measures of the Air Quality Plan and established the 'Action area for air quality in Bucharest'
Implementation costs	According to the Bucharest Air Quality Action Plan 2018-2022, no implementation costs were foreseen
Implementation barriers	Decision no. 539/2019 of the Bucharest Local Council was in place for only a few months, being annulled at the end of March 2020 at the initiative of the then-mayor In addition to the negative results of the public consultation, 441 preliminary complaints were registered by citizens or organisations, requesting courts to annul the decision on the introduction of the sticker. Complaints included the fact that the measure does not take into account the capacity of a car's engine, nor the fuel used. No exceptions were created for residents of the LEZ[25] However, Bucharest Environmental Protection Agency disagreed with the annulment of the Decision no. 539 / 2019, which established the LEZ. In the 2019 yearly monitoring report on the

[21] See the full text of the Decision no. 539/2019 in original language here: http://acteinterne.pmb.ro/legis/acteinterne/AtachInt/H539_19.pdf

[22] For details see here https://www2.pmb.ro/pmb/comunicate/presa_com.php?msj=7748

[23] https://www.digi24.ro/stiri/actualitate/gabriela-firea-ii-intreaba-pe-bucuresteni-pe-facebook-daca-sunt-sau-nu-de-acord-cu-taxa-oxigen-1263566

[24] Source: interview with the representatives of the National Environmental Protection Agency, October 2020.

[25] For more information, see: https://romania.europalibera.org/a/tot-ce-trebuie-sa-stii-taxa-oxigen-/30366927.html

Bucharest LEZ	
	Bucharest Air Quality Action Plan, the Agency requested that Bucharest City Hall reinstate this Decision, given the estimated reductions in traffic that it would generate[26]
Effectiveness in reducing air pollution	Bucharest Air Quality Plan 2018-2022 estimates show that the establishment of an LEZ in Bucharest city centre would reduce traffic by 40 % in the centre and by 25 % in the middle ring

ON-ROAD POLLUTING VEHICLES

In order to reduce emissions from existing vehicles, the Environmental Fund has established a programme to collect and dispose of old vehicles belonging to residents. The Rabla Programme contributes through non-reimbursable financing, in the form of a scrapping premium, for the purchase of new, less polluting vehicles. The used vehicle must be handed over in exchange.

The programme has the following environmental protection objectives:

- Reduction of air pollution impacts on the environment and health of the population, related to the emissions of exhaust gases from used vehicles.
- Reduction of the effects of soil and water pollution caused by spills of hazardous substances from used vehicles.
- Prevention of waste and achieving objectives regarding the recovery of waste from end-of-life vehicles.

In parallel to the Rabla Programme (designed by the central administration and implemented nationwide, including in Bucharest), the municipality of Bucharest implemented its own 'Rabla' programme. The programme was implemented between 2018 and 2019, on the basis of Bucharest Local Council Decision no. 377/2018, which granted vouchers to the value of RON 9 000 (approx. €2 000) to physical and legal person owners of old vehicles from Bucharest, with the purpose of buying new cars. According to the 2019 yearly report on the implementation of the measures from the Bucharest Air Quality Plan 2018-2022,[27] 4 194 old vehicles were decommissioned under the programme. The implementation cost for this measure was RON 37.75 million (approx. €8.39 million).

OTHER POLICIES

The city of Bucharest has implemented other AQ policies addressing important sources of air pollution – **domestic heating:**

- In 2017-2018, facing an enforcement cost of about €1.6 million, the city modernised 11 district heating plants, equipping them with low emission boilers.
- In 2017-2018, the city implemented a thermal rehabilitation programme for residential buildings and institutional buildings, reaching a total of 481 198 apartments and 221 institutional buildings.

[26] For more information, the Monitoring Report is available at: http://www.anpm.ro/documents/16241/38124058/RAPORT+PICA+2019+APMB+v.4.docx/49e92fb2-5b3d-4d01-b5dc-3d67be67b3b3

[27] https://doc.pmb.ro/institutii/primaria/directii/directia_mediu/planuri_de_calitate_aer/docs/plan_integrat_calitate_aer_buc/raport_anual_privind_stadiul_realizarii_masurilor_PICA_2019.pdf

- Between 2018 and 2023, facing an enforcement cost of about €58 million, the city promoted heat efficiency through the rehabilitation of all primary and secondary heat distribution networks, a total of 205.7 km.

Impacts of policies on air pollution and AQ

Bucharest Air Quality Plan 2018-2022 estimates show that the establishment of an LEZ in Bucharest city centre would reduce traffic by 40 % in the centre and by 25 % in the middle ring.

The impact of the Rabla Programme on air pollution has not been quantified.

Equipping district heating plants with boilers with low NO_x burners is expected to reduce NO_x emissions from these boilers by 40 %.

The rehabilitation of the heat distribution network is expected to reduce heat losses by 30 % (from 40 % to 10 % of energy distributed), with a proportional reduction in NO_x emissions.

Data availability for Bucharest was limited. Data are only consistently available for the monitoring stations since 2016 and no clear trends can be determined for NO_2 or $PM_{2.5}$ for this research paper. It will be possible to determine long-term trends when a longer, more consistent data series is available.

2.3.5. Krakow

Overview of local AQ policies

The city of Krakow has designed and implemented AQ policies addressing various sources of air pollution, including pollution from road transport, heating, and industry. An overview of the policies identified for Krakow is presented in Table 2.12.

Table 2.12 Overview of AQ policies identified for Krakow

AQ policies - KRAKOW		
Sector	**Category**	**Policies and measures**
ROAD TRANSPORT	Reduce demand for more polluting forms of transport	'Integrated public transport in Krakow', including: - Implementation of safe and passenger-friendly bus and tram stops (modernised bus and tram stops with an adjusted platform) to encourage the use of public transport - Improved pedestrian environment to reduce the use of private vehicles - Improving the public transport service and enlarging the transport system - TELE-BUS: new dedicated innovative services Renewal of the public transport fleet (purchasing modern trams and buses) Promotion of cycling
	Reduce emissions from existing vehicles	Strengthening inspections at vehicle diagnostic stations (as part of the air protection programme for *Małopolskie* Province – see below) Reconstructing streets to improve traffic flow in Krakow and reduce traffic in specific streets

AQ policies - KRAKOW		
Sector	**Category**	**Policies and measures**
		Access regulated - paid parking zone (11 different paid parking zones marked with different colours and numbers)
	Promote vehicles with low emissions	Krakow LEZ Improvement of public transport services and infrastructure Implementation of energy-saving and low emission solutions in public transport
HEATING		Low emission fuels: anti-smog resolution for Krakow – regulating the combustion of wet wood and coal Provision of financial support for more environmentally friendly solid fuels
INDUSTRY AND CONSTRUCTION	Other industry	Municipal low emission reduction programs (PONE) - elimination of low-efficiency solid fuel devices Plan for low emission economy for Krakow municipality – concept of activities to increase the use of low-carbon energy sources (in particular renewable energy sources), reducing energy consumption and improving energy efficiency in the city
INDUSTRY AND CONSTRUCTION	Other industry	Municipal low emission reduction programs (PONE) - elimination of low-efficiency solid fuel devices Plan for low emission economy for Krakow municipality – concept of activities to increase the use of low-carbon energy sources (in particular renewable energy sources), reducing energy consumption and improving energy efficiency in the city

LEZ

The table below presents the information on the Krakow LEZ.

Table 2.13 Overview of Krakow LEZ

Krakow LEZ	
Map of LEZ	 Figure: LEZ in Krakow. The green streets represent the LEZ. Source: https://urbanaccessregulations.eu/
Description and scope	The LEZ was first implemented in January 2019 and was then amended and stalled in March 2019. The LEZ in Krakow was considered a six-month pilot project. Due to increased concerns from local businesses and following a local councillor vote in March 2019, it was no longer effective. A new clean transport zone (LEZ) will be introduced in Krakow (2020/2021) The pilot LEZ applied to all vehicles Electric vehicles, hydrogen powered vehicles, CNG-fuelled vehicles and bicycles could enter the LEZ
Exemptions	The following exemptions were included and allowed to access the pilot LEZ: › clients for any businesses within the LEZ › taxis (until end of 2025) › all residents' vehicles › vehicles for people with disabilities › funeral and wedding procession vehicles › municipal services vehicles, road maintenance and police vehicles › vehicles for doctors, nurses and midwives › low-speed vehicles with an electric motor Loading and unloading could be done in the LEZ on: › Monday to Friday from 06:00 - 07:00, 09:00-11:00 and 17:00-19:00, excluding holidays › Saturday and public holidays from 06:00-08:00, 14:00-16:00 and 18:00-20:00

ON-ROAD POLLUTING VEHICLES

To reduce emissions from existing vehicles, the city of Krakow implemented an **air protection programme** with several elements:

- Extension of the restricted traffic zone and limited paid parking, together with a park-and-ride type system;

- Improving the organisation of car traffic in the city;
- Maintaining roads so to reduce secondary emissions of pollutants, through regular washing, repairs and improving the condition of road surfaces;
- Development of public transport and implementation of energy-saving and low emission solutions in public transport;
- Development of bicycle infrastructure and communication campaigns;
- Strengthening inspections at vehicle diagnostic stations.

The implementation of the **inspections at vehicle diagnostic stations** created some challenges.[28] Although the stations in Krakow are regularly inspected (once a year), those in the villages surrounding Krakow are not subject to such strict controls. This led to a decrease in the effectiveness of the policy. Legislation will be amended to improve the inspections at diagnostic stations and provide higher penalties to those stations not meeting the requirements.

To reduce the demand for more polluting forms of transport, the city of Krakow **has renewed the public transport fleet**, exchanging the old fleet with modern, less polluting trams and buses.

OTHER POLICIES

In Krakow, additional heating and industry-related policies have been implemented, addressing major sources of air pollution:

Since 1 September 2019, Krakow **regulates the burning of solid fuels** (coal and wood) in boilers, stoves or fireplaces. It restricts the following:

- Fuels in which the mass of coal or lignite of particle size 0-5 mm is more than 5 %;
- Fuels containing coal or lignite meeting at least one of the following parameters during operation: calorific value below 26 MJ/kg, ash content greater than 10 %, sulphur content greater than 0.8 %;
- Fuels containing biomass with moisture content greater than 20 %.

Residents have been supported through:

- Subsidies for the replacement of heating for solid fuels;
- A programme for those who incur increased costs of heating their premises;
- Assistance in obtaining information.

Since 2017, Krakow has taken action to eliminate low-efficiency solid fuel devices. This applies to combustion sources with a capacity of up to 1 MWth in apartment buildings and in the service and trade sector, as well as in small and medium-sized enterprises (SMEs).

Implementation costs included:

- Introduction of restrictions on the use of solid fuel installations (about €22 million);
- Additional cost of purchasing new boilers that meet the requirements of the resolution (about €60 million);
- Implementation of elimination of low-efficiency solid fuel devices (about €22 million);
- Use of renewable energy sources to reduce the operating costs of low emission heating (about €7 million);
- Improving energy efficiency of buildings and supporting energy-saving construction in housing construction (about €44 million).

[28] Source: interview with representative of the Department of Air Quality, Krakow, October 2020.

Impacts of policies on air pollution and AQ

According to the implementation summary of the regional air protection programme, in recent years the level of PM_{10} pollution in the Małopolska Region has been consistently decreasing.[29] The average concentration of PM_{10} between the winter season 2014-2015 and 2019-2020 decreased in Małopolska by 30 %, and in Kraków by as much as 45 %.

The data analysis for this research paper showed a mixed pattern for NO_2, with evidence of sustained improvements in $PM_{2.5}$. In particular, the analysis shows an average increase in NO_2 concentrations of 0.7 μgm^{-3} per year at the background station, corresponding to 3 % of the 2013 concentration. It shows an average reduction of 1.2 μgm^{-3} per year and an average increase of 0.3 μgm^{-3} per year at each traffic station, corresponding to 1 % and 2 % of the respective 2013 concentrations. The analysis shows an average $PM_{2.5}$ reduction of 2.3 μgm^{-3} and 1.9 μgm^{-3} per year at each traffic station, corresponding to 5 % of the respective 2013 concentrations. Reductions in $PM_{2.5}$ concentrations at these traffic sites reduced by 30-40 % between 2013 and 2019, reflecting the PM_{10} results. An average reduction in concentrations of 0.4 μgm^{-3} per year at the background station is evident, corresponding to 1 % of the 2016 concentration (earliest year of monitoring).

2.3.6. Lisbon

Overview of local AQ policies

The city of Lisbon has designed and implemented AQ policies addressing various sources of air pollution, including pollution from road and non-road transport, and heating. An overview of the policies identified for Lisbon is presented in Table 2.14.

Table 2.14 Overview of AQ policies identified for Lisbon

AQ policies - LISBON		
Sector	Category	Policies and measures
ROAD TRANSPORT	Reduce demand for more polluting forms of transport	Promotion of the 'One Car Less' campaign to reduce the use of private cars and encourage the use of public transport Development of the MOBIL.T (Mobility and Ticketing for Multimodal Transport) scheme, an integrated ticketing system that harmonises different systems towards a central one, supports mobile tickets and bank cards, and strengthens multimodal ticketing delivery Promotion of car-sharing Promotion of cycling through a programme for financing new bikes for urban use, three public bike and scooter-sharing systems (GIRA, Jump by Uber and Hive by Free Now), and increasing the total length of cycling lanes
	Reduce emissions from existing vehicles	Development of integrated parking management to improve safety, mobility, commercial interests and promote the local living conditions Increase the number of paid parking zones Implementation of fiscal incentives for low emission vehicles through a green taxation reform that provides incentives for the purchase of electric vehicles and plug-in hybrids

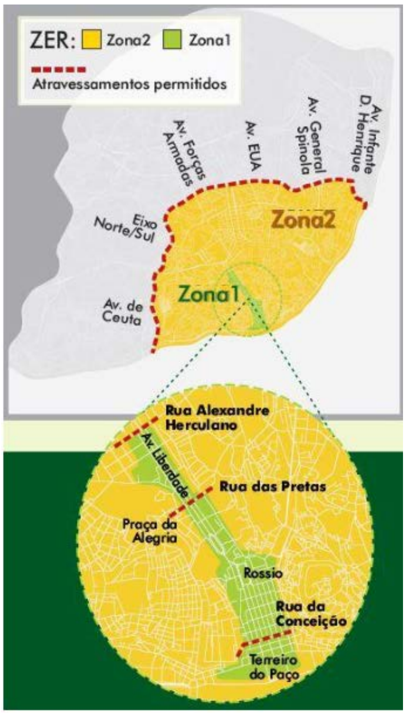
[29] Malopolska Region, Department of the Environment - Air quality in Małopolska. Available at: https://powietrze.malopolska.pl/program-ochrony-powietrza/

AQ policies - LISBON		
		Public procurement of clean cars
	Promote vehicles with low emissions	Lisbon LEZ Development of electric vehicle charging infrastructure Fleet recognition schemes that promote low emission vehicles Fiscal incentives for low emission vehicles Implementation of public procurement of clean cars by replacing the bus fleet with less polluting vehicles
NON-ROAD TRANSPORT	Shipping	Reduce emissions from cruise ships moored in Lisbon Port
HEATING		Improvement of energy efficiency of domestic heating equipment Implementation of mandatory energy efficiency certifications for domestic heating

LEZ

The table below presents the information on the Lisbon LEZ.

Table 2.15 Overview of Lisbon LEZ

Lisbon LEZ	
Map of LEZ	 Figure: LEZ in Lisbon. The yellow area represents the LEZ. Source: https://urbanaccessregulations.eu/
Description and scope	The LEZ in Lisbon affects all vehicles – light and heavy, petrol and diesel. It comprises two sub-zones and currently covers 33 % of the whole city. The LEZ area has been expanded and further restrictions have been implemented in three phases: - First phase July 2011 to January 2012: applied from Monday to Saturday, 08:00-20:00: - Zone 1 only, prohibits vehicles manufactured before 1992 (usually Euro 1) - Second phase January 2012 – January 2015: applied from Monday to Saturday, 07:00-21:00: - Zone 1 prohibits vehicles manufactured before 1996 (Euro 2) and - Zone 2 prohibits vehicles manufactured before 1992 (Euro 1) - Third phase in place since 15 January 2015: applied from Monday to Saturday, 07:00-21:00: - Zone 1: prohibits vehicles manufactured before 2000 (Euro 3) and - Zone 2: prohibits vehicles manufactured before 1996 (Euro 2) Public information campaigns have been set up by Lisbon municipality to raise awareness and acceptance of the LEZ
Enforcement mechanism	Access to Zones 1 and 2 requires a badge valid for 12 months. Initially, the enforcement was limited, with only random traffic police checks and no penalties applied. The city then evaluated the introduction of an automatic number plate recognition to facilitate enforcement

Lisbon LEZ	
	Currently, it is enforced through closed-circuit television cameras and number plate recognition, and penalty fees are applied. It was noted, however, that the cameras are currently not in operation
Exemptions	Emergency, special and historic vehicles, as well as residents
Implementation barriers	Key barriers or areas of improvement are: - need for further enforcement - better integration of the different public transport systems - contingency/emergency plan should be set up to cover temporary periods of high air pollutant concentrations associated with weather conditions - AQ monitoring should be expanded
Effectiveness in reducing air pollution	Data from Zone 1 show the following trends in emissions:[30] - Drop in annual average PM_{10} concentrations from about 50 µg/m^3 in 2007 to about 30 µg/m^3 in 2013 - Drop in annual average NO_2 concentrations from about 70 µg/m^3 in 2007 to about 50 µg/m^3 in 2013

ON-ROAD POLLUTING VEHICLES

The city of Lisbon has promoted low emission buses by replacing the city bus fleet with less polluting vehicles. The 'Clean Buses 2020' programme aims to remove all diesel buses from its fleet by 2030 and to have 100 % electric buses by 2040.

OTHER POLICIES

Lisbon has also implemented other AQ policies addressing important sources of air pollution. In the **shipping sector**, the city of Lisbon will reduce emissions from cruise ships moored in Lisbon Port through a regulation to be implemented in 2022, requiring the use of electric power when docked, via infrastructure to be provided in the port. This will allow ships to use grid electricity for their activities in the port, such as hospitality or (un)loading. Typically, ships' auxiliary engines are used for these activities, using fossil fuels and leading to emissions of air pollutants (PM, NOx, SO_2).

Impacts of policies on air pollution and AQ

Trends in pollutant concentrations following the implementation of the LEZ are reported in the table above. No data are available evaluating the expected impacts of low emission buses or the shipping regulation in Lisbon.

The data analysis for this research paper shows a mixed pattern, with some moderate reductions in NO_2 over the study period and increases in $PM_{2.5}$ concentrations.

The analysis shows an average reduction in NO_2 concentrations of less than 0.1 µgm^{-3} per year at the traffic station, corresponding to 0.1 % of the 2013 concentration. It shows an average reduction of 0.2 µgm^{-3} per year at one background station and an average increase of 0.1 µgm^{-3} per year at the other background station, corresponding to 1 % and 0.2 % of the 2013 concentrations.

The analysis shows an average $PM_{2.5}$ increase of 0.3 µgm^{-3} per year at the traffic site, corresponding to 3 % of the 2013 concentration. It shows an average increase of 0.3 µgm^{-3} per year and an average

[30] Associação de Sistema Terrestre Sustentável (ZERO). Available at: https://zero.ong/quatro-anos-apos-o-inicio-da-3a-fase-zero-quer-zer-de-lisboa-com-maior-exigencia-e-medidas-complementares/

reduction of 0.4 $\mu g m^{-3}$ per year at the background sites, corresponding to 3 % of the respective 2013 concentrations.

2.3.7. Madrid

Overview of local AQ policies

The city of Madrid has designed and implemented AQ policies addressing various sources of air pollution, including pollution from road and non-road transport, heating, industry and construction sites, urban planning, waste management and agriculture. An overview of the policies identified for Madrid is presented in Table 2.16.

Table 2.16 Overview of AQ policies identified for Madrid

AQ policies - MADRID		
Sector	Category	Policies and measures
ROAD TRANSPORT	Reduce demand for more polluting forms of transport	Development of the Regulated Parking Service (*Servicio de Estacionamiento Regulado* - SER) within the LEZ. Parking restrictions and fares are linked to the vehicle labels (see LEZ below)
		Development of a SUMP, a plan that suggests specific measures to reduce traffic in favour of pedestrian mobility, bicycle use and public transport
		Development of strategies and plans for shared spaces, with the aim of freeing the city of cars
		Development of the connection of the International Airport of Madrid-Barajas to the suburban train network of Madrid
		Completion of the transversal line network to improve public transport in outer neighbourhoods
		Improvement of bus stop infrastructure and increase of the number of conventional bus lanes, with separator/dedicated lanes
		New payment systems for public transport
		Improvement of travel information for passengers
		Promotion of the use of bicycles through the improvement of the cycle network and cycling mobility, the extension of the public bicycle system and coordination with the Madrid Regional Transport Consortium (CRTM)
		Promotion of walking and prioritisation of pedestrian mobility
		Promotion of the use of motorcycles
		Promotion of alternative school mobility
		Promotion of the use of public transport for mobility work through the Work Centre Transport programme that creates additional bus routes in business parks or industrial areas
		Promotion of municipal action on regulated parking and parking for residents
		Redesign of the main traffic distribution channels and periphery-centre connections
		Functional redistribution of the road network to establish roads giving effective priority to *Empresa Municipal de Transportes de Madrid* (EMT)

AQ policies - MADRID		
Sector	Category	Policies and measures
		buses through the use of bus-only lanes and the introduction of traffic-light priority systems Development of sustainable mobility plans in companies and in public administrations, drawing up a municipal sustainable mobility plan Promotion of shared mobility initiatives to improve and diversify transport supply
	Reduce emissions from existing vehicles	Development of the global system for sustainable traffic emissions management, able to continuously monitor emissions in real driving conditions in order to identify high-emitting vehicles and require them to be repaired Replacement of city diesel buses with CNG buses Retrofitting of trucks and buses with DPFs Emissions-based parking LEZ Prohibition on keeping motors running in parked vehicles Development of a new taxi schedule regime that limits the maximum amount of time taxis offer services Development of an Emissions Emergency Scheme with different levels of warning linked to levels of air pollution, that matches the entry requirements for vehicles Promotion of best practice and use of new technologies for more efficient use of city buses Promotion of carpooling and car-sharing Development of specific studies, technical reports and technical standards and specifications for sustainable road surfacing Setting of speed limits on metropolitan accesses and the M-30 Optimisation of the taxi service using environmental criteria Renewal of the vehicle pool through a gradual replacement of motor vehicles with the objective of restricting the circulation of the most polluting ones.
	Promote vehicles with low emissions	Madrid LEZ Promotion of electric mobility Consolidation and expansion of government measures to promote the use of cleaner technologies and cleaner fuels Renewal of the municipal fleet of vehicles to cleaner technology Renewal of taxi fleet with cleaner technology and cleaner fuels Incorporation of clean technology in the EMT City Bus Fleet serving the LEZ Expansion of the number of alternative supply points at EMT centres, extension and renewal of the EMT fleet of buses towards a 100 % low emission fleet Voluntary agreements with the private sector to encourage renewal of commercial and delivery fleets to cleaner technologies

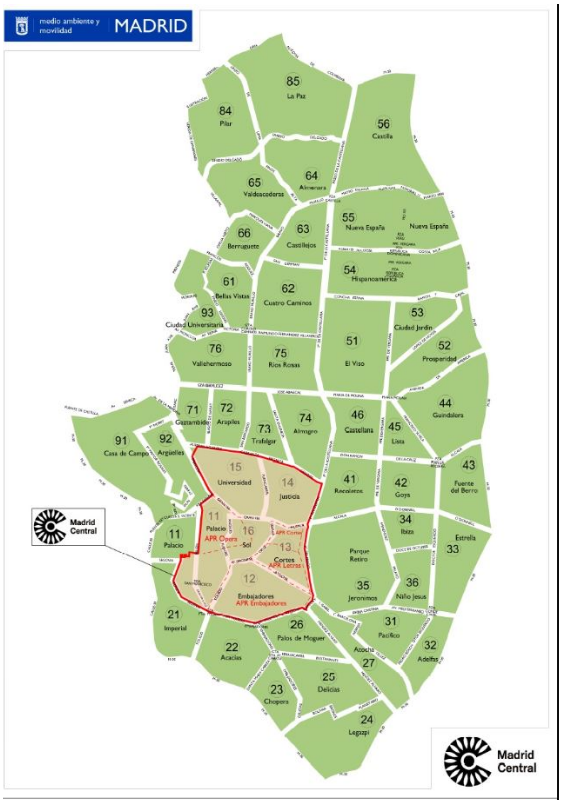
AQ policies - MADRID		
Sector	**Category**	**Policies and measures**
		Mobility advantages for commercial and delivery vehicles with cleaner technology Technological renewal of municipal solid waste collection and city cleaning services fleet vehicles and machinery Use of cleaner vehicles in the maintenance of green areas Urban distribution of goods using low emission vehicles Charging network for electric vehicles and supply of alternative fuels
	Displace pollutant sources outside of populated areas	Weight restriction in LEZ Specific measures for the environment in areas with records of high pollution (e.g. studies to understand correlations between type of road traffic and emissions, restriction of heavy goods vehicles (HGVs), implementation of the 'Clean lines' programme for less contaminating public transport buses) Roadway system review and development Network of intermodal car parks in the metropolitan ring
NON-ROAD TRANSPORT	NRMM	AQ information campaigns
HEATING		Municipal subsidies for renewal of centralised diesel boilers Promotion of housing energy renovation Energy optimisation plan of facilities and buildings owned by Madrid City Council Promotion of energy efficiency practices through voluntary agreements with the private sector Promotion of efficient low emission heating and cooling systems
INDUSTRY AND CONSTRUCTION	Construction sites	Information brochures about AQ issues in construction, maintenance and demolition of buildings Best practice guides for reducing air pollution during the construction and demolition of buildings
URBAN PLANNING		Development of eco neighbourhoods through internal organisation and orientation of buildings to take advantage of natural light, prevailing windows and cross-ventilation, for neighbourhood regeneration and rehabilitation Reduction of pollution via street cleaning Conservation and development of green areas Promotion of best practice in mobility infrastructure projects
WASTE MANAGEMENT AND AGRICULTURE		Installation of central waste collection systems in new construction areas within the city Renewal of wastewater purification equipment engines to new technology

AQ policies - MADRID		
Sector	Category	Policies and measures
		Implementation and optimisation of the waste management processes at the *Valdemingómez* technological complex, a biomethane plant, with the aim of reducing the emissions it produces
GENERAL / COMMUNICATION		Improvement of AQ monitoring, forecasting and information system Environmental awareness-raising and cooperation with public authorities

LEZ

The table below presents the information on the Madrid LEZ.

Table 2.17 Overview of Madrid LEZ

Madrid LEZ	
Map of LEZ	 Figure: LEZ in Madrid. The area marked by the red area represents the LEZ. Source: https://urbanaccessregulations.eu/
Description and scope	It is mandatory for Spanish vehicles to have the sticker *'Distintivo Ambiental'* – that can be permanent, temporary or for a single day – to be able to circulate and park in the municipal area of Madrid. In the LEZ, new pedestrianised areas have been completed and reduced road capacity is in place

Madrid LEZ	
	Vehicles allowed into the LEZ include:[31] - Residents and vehicles with the 'zero emission' sticker can circulate and park without time restrictions (vehicle labels and categories are the same as those applicable to Barcelona, other cities in Spain might follow and use the same approach) - Vehicles with the ECO sticker can enter and park for a maximum time period of two hours - Vehicles with the stickers 'C' or 'B' are only allowed to park in a public car park, a private garage or a private parking space If a resident buys a new vehicle, it needs to meet the minimum standards of petrol Euro 3 and diesel Euro 4 The LEZ policy started on 30 November 2018. From 2020, vehicles of residents' guests without a sticker are no longer allowed to park in the LEZ. From 2025, vehicles without a sticker will no longer be permitted to drive in the LEZ
Enforcement mechanism	There is no specific information about the enforcement mechanism, although fines are possibly in place
Exemptions	Exceptions to the restrictions include cranes and other types of delivery vehicles
Implementation costs	Pedestrianisation: €600 000 (2013-2015) Reducing road capacity: €1 400 000
Implementation barriers	Government has altered the scope of the geographical area covered by the LEZ, which now excludes an area where many fines were issued There are reports of claims from businesses in the city centre against the LEZ, which impacted the implementation
Effectiveness in reducing air pollution	According to City Hall, the LEZ has so far reduced 40 % of NOx[32]

ON-ROAD POLLUTING VEHICLES

To reduce emissions from existing vehicles, the city of Madrid has implemented two main policies:

- GySTRA LIFE project - a Global System for Sustainable TRAffic emissions management. Run from 2017 to 2020, it aims to create an innovative remote-sensing device (RSD) able to continuously monitor emissions of NO, CO, CO2, PM and NO2 in real driving conditions. It is thus able to identify high-emitting vehicles and require them to be repaired as part of a highly replicable urban AQ management model. 700 000 vehicles per year were to be monitored with two RSD+ devices, enabling the government to notify high emitters and requiring them to repair their vehicle or face a fine;
- Emissions-based parking LEZ started in 2019. This regulated parking service (Servicio de Estacionamiento Regulado, SER) combines regulated parking with emissions criteria for parking fees. It is considered an effective mobility management tool and a particular deterrent to the use of cars. The parking spots are marked in two different colours. Green parking spots

[31] Categories of vehicles are set out on the city's website: https://ajuntament.barcelona.cat/qualitataire/en/afectacions-la-mobilitat/dgt-environmental-label

[32] Madrid.es. Plan A: Air quality and climate change plan for the city of Madrid. Retrieved from https://www.madrid.es/UnidadesDescentralizadas/Sostenibilidad/CalidadAire/Ficheros/PlanAire&CC_Eng.pdf

are for residents with a proper permit who can park without time limitations in their neighbourhood and for non-residents, who can park for a maximum of two hours. Blue parking spots are for those with a proper permit, who can park for a maximum of four hours.

OTHER POLICIES

The city of Madrid has promoted efficient low emission heating and cooling systems, addressing an important source of air pollution, through technological improvements of heating, air conditioning and sanitary hot water.

The Plan's time frame has two deadlines:

- By 2020, the Plan calls for the implementation of specific structural and technological measures resulting in a significant reduction of emissions, as required by AQ regulations;
- By 2030, the necessary urban regeneration, energy transition, and renewal of the vehicle pool is envisaged.

Impacts of policies on air pollution and AQ

In addition to the reduction in air pollution due to the LEZ within the GySTRA project, it is expected that 5 % of the 700 000 vehicles monitored in the Madrid pilot will be identified as high emitters. Their repair should achieve the following annual emissions reductions:

- CO – 617 tonnes per year (14.8 %);
- HC – 89 tonnes per year (2.8 %); and
- NO – 518 tonnes per year (22.7 %).

It is expected that the SER will reduce traffic and, consequently, air pollution.

The data analysis for this research paper shows an inconsistent pattern between monitoring sites.

It shows an average reduction in NO2 concentrations of 0.9 µgm-3 per year at one traffic site, and an average increase of 1.7 µgm-3 at the other, corresponding to 2 % and 4 % of the respective 2013 concentrations. It shows an average increase of 0.7 µgm-3 per year at the background site, corresponding to 2 % of the 2013 concentration.

PM2.5 concentrations trends observed show an average of 0.3 µgm-3 and 0.4 µgm-3 reduction per year at each traffic site, corresponding to 3 % of the 2013 concentrations. No change was observed at the background site between 2013 and 2019.

2.3.8. Paris

Overview of local AQ policies

The city of Paris has designed and implemented AQ policies addressing various sources of air pollution, including pollution from road and non-road transport, heating, industry and construction sites, urban planning, waste management and agriculture. An overview of the policies identified for Paris is presented in Table 2.18.

Table 2.18 Overview of AQ policies identified for Paris

AQ policies - PARIS		
Sector	Category	Policies and measures
ROAD TRANSPORT	Reduce demand for more polluting	Seine riverbanks traffic closure Implementation of comprehensive parking management scheme

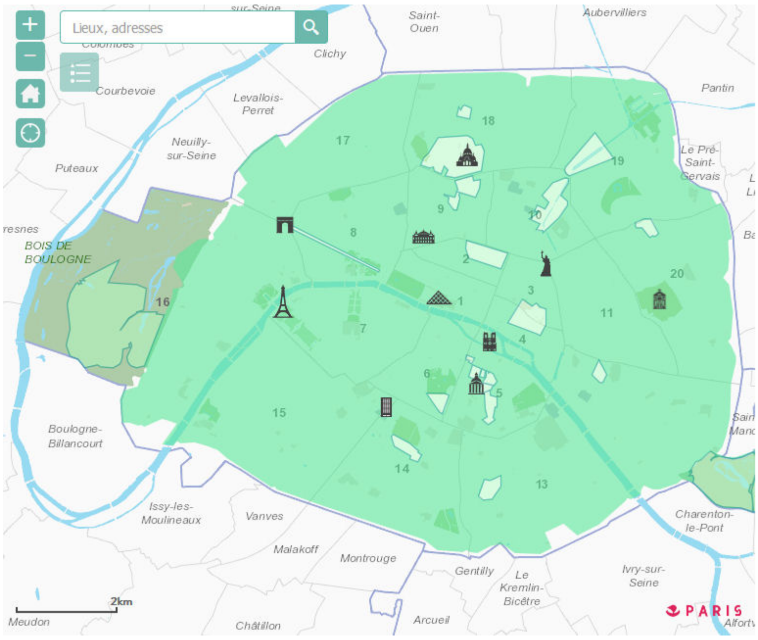
AQ policies - PARIS		
Sector	**Category**	**Policies and measures**
	forms of transport	Promotion of walking and cycling
		Implementation of bicycle rental scheme
		Implementation of car free days – 'Paris Respire' zones
		Implementation of a car-sharing scheme
		Creation of 600 km network of bicycle lanes
		Development of collective bike parks
		Extension and introduction of tram lines
		Promotion of public transport
	Reduce emissions from existing vehicles	Economic initiatives for use of electric cars and giving up old diesel cars
		Implementation of Distripolis, a new city logistics solution where delivery rounds are organised and optimised by a new information system
		Differentiated circulation in the event of air pollution episodes
		Speed limit reduced to 30 km/h on one-third of the roads in the city
	Promote vehicles with low emissions	LEZ (Zone à faible émission, ZFE)
		Public procurement of clean cars
		Sustainable deliveries of goods in Paris through Monoprix, a major French retailer that has reduced its reliance on lorry deliveries and begun to dispatch goods to its stores in Paris using trains and LNG vehicles for last-mile deliveries
NON-ROAD TRANSPORT	Aviation	Reduction of emissions from Auxiliary Power Units (APUs), the engines used to power lighting and air conditioning while aircraft are on stand
		Reduction of emissions from taxiing through the use of N-1 motors (engine design to withstand failure of components)
		Improve aircraft emissions knowledge
HEATING		Encourage switch from old wood-burning heating systems to newer, lower emitting ones
		Restriction on wood-burning heating
INDUSTRY AND CONSTRUCTION	Construction sites	Development of good practices in management of construction sites
		Reduction of NO_x and Total Suspended Particles (TSP) emissions from combustion installations with a power of 2 to 50 MWth
		Reduce particulates emissions from biomass and solid recovered fuel (SRF) combustion facilities
		Reduction of NO_x emissions from house waste and SRF combustion facilities
		Reduction of NO_x emissions on new biomass installations from 2 MWth
URBAN PLANNING		Urban planning innovation through public places like AirLab
WASTE MANAGEMENT		Development of good practices in the use of urea to limit ammonia (NH_3) emissions

AQ policies - PARIS		
Sector	Category	Policies and measures
AND AGRICULTURE		

LEZ

The table below presents the information on the Paris LEZ.

Table 2.19 Overview of Paris LEZ

Paris LEZ	
Map of LEZ	 Figure: LEZ in Paris. The green area represents the LEZ. Source: https://urbanaccessregulations.eu/
Description and scope	- First implemented in 2015 (phase 1), the LEZ banned HGVs manufactured before 2001 and encompassed Paris up to the A86 motorway - Since 2017 (phase 2), AQ certificates are mandatory for vehicles driving in the LEZ. The certificate makes it possible to differentiate vehicles according to their emissions of air pollutants. The higher the number of the certificate (one to six), the higher the level of pollutants produced by the vehicle. Older vehicles covered by less stringent emissions standards are not eligible for a certificate. The AQ certificate applies to all road vehicles: two-wheel, three-wheel, quadricycles, cars, vans and HGVs, including buses and coaches. The certificate takes into account local air pollutant emissions, principally PM and NO_x emitted from vehicle exhaust pipes - Since July 2019 (phase 3), diesel Euro 1, 2, 3 and petrol Euro 1 are not eligible for a certificate - The rule applies to all vehicles during weekdays (HGVs all week) from 08:00 to 20:00 - Further bans are planned for 2022 and 2024 (full ban on diesel cars in Paris LEZ) The information above applies to the LEZ in the city of Paris. More recently (2019), an LEZ for Greater Paris (Metropole of Grand Paris) has been implemented in some of the municipalities. There was opposition by several mayors, although around 50 have now agreed to be part of a Greater Paris LEZ. In 2019, a new law (*loi d'orientation des mobilités*) came into force, which states that areas exceeding AQ limits have to implement an LEZ and it is expected that the

Paris LEZ	
	mayors of Greater Paris will have to enforce the LEZ. Current restrictions for the Greater Paris LEZ (banning diesel Euro 1 and 2) are less strict compared to the Paris LEZ (see above), but discussions are ongoing to apply the same restrictions from 2021
Enforcement mechanism	Travelling with a non-authorised vehicle or without an AQ certificate is subject to fines of €68 for light vehicles and €135 for HGVs Random inspections are undertaken by the authorities. Between January and April 2018, 3 705 vehicles were fined There are plans to implement automatic vehicle inspections
Exemptions	See above
Implementation costs	The price of the certificate is intended only to cover the costs of issuing it (€3.11 plus postage)
Effectiveness in reducing air pollution	In 2018,[33] the reduction in emissions associated with phase 3 in Paris city centre (compared to a 2018 scenario without the implementation of phase 3) was modelled at -23 % for NO_x and -17 % for $PM_{2.5}$. The associated reduction in pollutant concentrations was predicted to be an average of -5 µg/m^3 for NO_2 (up to -10 µg/m^3 along roads) and an average of -0.5 µg/m^3 for PM_{10} and $PM_{2.5}$. These modelled results assume 100 % implementation of the LEZ It is difficult to attribute the implementation of the LEZ to a specific decrease in concentrations of pollutants. Overall, however, there is a reduction in NOx and PM concentrations (not for O_3) in Paris and this reduction is larger in the city compared to the Île-de-France region[34]

ON-ROAD POLLUTING VEHICLES

The city of Paris has implemented a set of policies to promote vehicles with low emissions and address the issue of on-road polluting vehicle legacy.

- It has provided two economic initiatives – the Ecological Bonus (Bonus Ecologique) and the Conversion Bonus (Prime à la conversion) – for using electric cars and giving up old diesel cars. Eligible cars must have a CO2 emission rate below 50g/km.
- The anti-air-pollution plan envisages a municipal fleet that is completely electric or hybrid. The objective is to replace old buses and have 100 % Euro VI buses by 2025. Before then, 80 % of 4 500 buses will be electric and 20 % will be powered by biogas (‘Plan Bus 2025’).
- **Differentiated circulation** in the event of air pollution episodes restricts access to the LEZ to only the least polluting vehicles. In such cases, the prefecture can issue a notice stating that:
  - differentiated circulation is in place for a limited time and that only Crit'Air 0, 1, 2 vehicles are allowed inside Paris (vehicle AQ certificates as for the LEZ – see description in the table above);
  - the maximum speed limit is reduced on motorways and high-speed roads;
  - free residential parking is implemented to encourage people to take public transport.
- Vélib was a successful bike-sharing scheme initiated in 2007 and replaced by Vélib Métropole in 2018. The scheme has provided Paris and some surrounding municipalities with 18 000

[33] Airparif (2018). Zone à faibles émissions dans l’agglomération parisienne. Available at: https://www.airparif.asso.fr/_pdf/publications/Rapport_ZFE_agglo_synthese_20190401.pdf

[34] Airparif (2019). Surveillance et information sur la qualité de l’air. Available at: https://www.airparif.fr/_pdf/publications/Rbilan75_2019.pdf

bicycles and 1 200 bicycle stations. As a result, bicycle traffic has increased and bicycle infrastructure has improved.[35]

OTHER POLICIES

The city of Paris has implemented additional policies for the reduction of emissions from wood burning for heating, identified as an important source of air pollution in the city (in particular $PM_{2.5}$).

- It has encouraged the switch from old wood-burning heating systems to newer, lower emitting ones. This has been done through communication campaigns by local authorities and heating professionals, detailing all existing financial grants for the renewal of individual wood heating systems.
- It imposed restrictions on wood burning for heating. Open wood fireplaces are only allowed as an extra heating source (not main heating). Closed wood stoves are allowed as an extra and main heating source if they comply with emissions regulations (less than 16 mg/m3 of PM2.5). For an extra heating source, a minimum efficiency of 65 % is required.

Impacts on air pollution

Other than the projected reductions in air pollution due to the LEZ described above, no data are available on pollution reductions due to on-road polluting vehicles policies in Paris. In the interviews it was noted that the replacement of vehicles with less polluting ones between 2002 and 2012 had a strong effect on the reduction of PM concentrations, mainly due to newer PM filters.

If all measures in the *Plan de Protection de l'Atmosphère* (PPA) are in place, including the implementation of heating measures, a 24 % average reduction in NO_2 concentrations and a 11 % fall in $PM_{2.5}$ is projected for 2020.[36]

The data analysis for this research paper shows sustained reductions in both NO_2 and $PM_{2.5}$ over the study period.

The analysis shows an average reduction in NO_2 concentrations of 0.8 μgm^{-3} (2 % of the 2013 concentration) and 1.7 μgm^{-3} (2 % of the 2014 concentration, the first year of data available for this site) per year at each traffic site. It shows an average reduction of 0.6 μgm^{-3} at the background site, corresponding to 2 % of the 2014 concentration.

The analysis shows an average $PM_{2.5}$ reduction of 0.2 μgm^{-3} and 1.0 μgm^{-3} per year at each traffic sites, corresponding to 1 % and 5 % of the 2016 and 2014 concentrations, respectively (first years of data available). It shows an average reduction of 0.4 μgm^{-3} per year at the background site, corresponding to 3 % of the 2014 concentration.

2.3.9. Rome

Overview of local AQ policies

The city of Rome has designed and implemented AQ policies addressing various sources of air pollution, including pollution from road transport, heating, waste management and agriculture. An overview of the policies identified for Rome is presented in Table 2.20.

[35] Citycle, Conseils et actualités vélo de ville et cyclotourisme. Available at: https://www.citycle.com/43306-le-velo-acteur-majeur-des-grandes-metropoles/

[36] Airparif, 2017.

Table 2.20 Overview of AQ policies identified for Rome

AQ policies - ROME		
Sector	Category	Policies and measures
ROAD TRANSPORT	Reduce demand for more polluting forms of transport	Promotion of public transport (including for school children)
		Promotion of walking and cycling (bike on public transport, 90 km of new cycle lanes, economic incentives, creation of pedestrian areas, connection hubs between the main stations, creation of 200 bike spaces)
		Development of bike-sharing
		Development of SUMP (*Piano Urbano della Mobilità Sostenibile*)
		Implementation of paid parking spaces
	Reduce emissions from existing vehicles	Regulation of entry of tour buses based on emissions standards
		Limitation of the circulation of diesel vehicles
		Control of exhaust gases in all vehicles
		Implementation of pollution-absorbing wall paint. The pollution-eating paint works with the sunlight and is able to reduce the concentration of harmful pollutants
		Renewal of the bus fleet
		Development of a carpool function in the Moovit app
	Promote vehicles with low emissions	LEZ (*Zona a Traffico Limitato*)
		Cleaning of public transport by increasing the number of electric buses and their transport capacity
		Electric car-sharing - Share'ngo
		Limitation of the circulation of diesel vehicles
HEATING		Reduction of emissions from combustion systems and air pollution abatement (ABA) systems
		Ban on domestic heating using wood biomass for specific categories
		Transformation of heating with non-gaseous fuels into methane or LPG
WASTE MANAGEMENT AND AGRICULTURE		Prohibition of open-air combustion
		Reduction of diffuse emissions through biogas capture and reuse

LEZ

The table below presents the information on the Rome LEZ.

Table 2.21 Overview of Rome LEZ

Rome LEZ	
Map of LEZ	 Figure: LEZ in Rome. The coloured areas represent the main LEZ. Source: https://urbanaccessregulations.eu/
Description and scope	The city centre is divided into various levels of LEZ and tariffs for access are in place for each level, based on the Euro category of the vehicle: - ring rail zone – less restrictive; - green zone – less restrictive; - main LEZ in operation in an area of about 5.5 km^2 – most restrictive Vehicles affected: - All vehicles except electric vehicles, which are allowed to circulate in all LEZs at any time - Cars with Euro 0 emissions standards are not allowed in the city centre at all - Euro 1-6 cars are not allowed on workdays during the day and on Saturdays in the afternoon unless they have a resident or delivery permit - Some areas in the city centre are closed at night-time - HGVs without permits have different, very restrictive access times, depending on their emission class
Enforcement mechanism	Electronic gates/signs (ring rail zone) and cameras control (green zone) access to the city centre LEZ The penalty fee is €70, plus an additional €70 if there was no valid annual emissions test sticker

ON-ROAD POLLUTING VEHICLES

The city of Rome has implemented several policies to reduce emissions from existing vehicles.

- Regulation of entry of tour buses into the city centre via a pass and an emission standard requirement. Coaches must meet either Euro 3 with particulate filter, Euro 4 or a later emission standard. From January 2021, the minimum Euro standard will be Euro 4 with particulate filter. This policy is enforced through cameras and Roma Servizi per la Mobilità carries out random checks on tour buses coming to Rome. The fine for entering without a valid permit is €500. Further suspensions are possible.
- The bus fleet is being renewed to phase out older and more polluting buses. By 2020, 328 new buses will be integrated into Rome's bus fleet.
- All vehicles must undergo a yearly check of exhaust gases to ensure that they comply with legislation. Vehicles that pass the regular check are given a blue mark. Circulation is forbidden for all vehicles without this blue mark (or when it expires). Fines from €59 to €639 are in place.
- To promote vehicles with low emissions, an occasional ban on circulation of private diesel vehicles below Euro 6 is in place ('smog alarm'). The limitation affects the 'Fascia Verde' (green stripe) of the city and is split into two timeframes: 07:30-10:30 and 16:30-20:30.

OTHER POLICIES

The city of Rome has implemented additional policies to reduce emissions from heating, identified as an important source of air pollution:

To reduce emissions from **combustion systems for domestic use**:

- wood biomass-based stoves must have an energy performance of ≥ 75 %;
- a replacement boiler must be a high energy performance one;
- new buildings must be equipped with the latest insulation technologies;
- limit of both domestic and commercial spaces average heating to 19°C – with a 2°C tolerance.

These measures were to be applied by the end of 2011. The Plan for Remediation of Air Quality was approved in 2009. A reviewed version will be released in September 2020.

Impacts of policies on air pollution and AQ

No data are available on the reduction in air pollution resulting from the LEZ or from on-road polluting vehicles and heating-related policies.

The data analysis for this research paper shows consistent reductions in both NO_2 and $PM_{2.5}$ over the study period.

The analysis shows an average reduction in NO_2 concentrations of 2.9 μgm^{-3} per year at the traffic site, corresponding to 4 % of the 2013 concentration. It also shows an average reduction of 0.2 μgm^{-3} and 1.1 μgm^{-3} per year at the two background sites, corresponding to 0.4 % and 2 % of the 2013 concentrations, respectively.

The analysis shows an average $PM_{2.5}$ reduction of 0.8 μgm^{-3} per year at the traffic site, corresponding to a 4 % reduction per year between 2013 and 2019. It shows an average reduction of 0.4 μgm^{-3} and 0.3 μgm^{-3} per year at each background site, corresponding to 2 % of the 2013 concentrations.

2.3.10. Stockholm

Overview of local AQ policies

The city of Stockholm has designed and implemented AQ policies addressing various sources of air pollution, including pollution from road and non-road transport. An overview of the policies identified for Stockholm is presented in Table 2.22.

Table 2.22 Overview of AQ policies identified for Stockholm

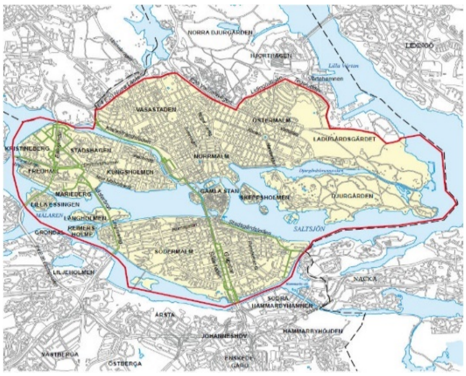
AQ policies - STOCKHOLM		
Sector	Category	Policies and measures
ROAD TRANSPORT	Reduce demand for more polluting forms of transport	Congestion charge – charging a fee on certain vehicles for passage in and out of Stockholm inner city from 06:30 to 18.:30 Monday to Friday
		Strategy aiming to shift from on-street parking to private off-street car parks by implementing parking fees and parking time limits
		Promotion of walking and cycling (campaigns, cycling maps, 24-hour service depots, etc.)
		Promotion of safe and enjoyable routes to and from school (use of travel barometers, campaigns, transport checklist for development areas)
		Promotion of public transport - large-scale developments (e.g. new tram lines and metro extensions)
		Promoting freight modal shift by including environmental criteria for publicly procured transport
		Promoting fuel efficiency by demanding climate-efficient heavy transport in public procurement and environmental differentiation of congestion charges
	Reduce emissions from existing vehicles	Promoting sustainable freight by establishing an urban consolidation centre (UCC) and conducting an off-peak delivery project
		Development of the logistics centre for the Old Town, leading to a decrease in the number of small direct deliveries to restaurants and shops, and essentially less traffic during delivery hours
		Speed limit of 30km/h on the majority of roads in the city centre
		Night-time HGV ban prohibiting the circulation of HGV in the city between 22:00 and 06:00. Permits are required in case of circulation between those hours and in case of weight above 3.5 tonnes
		Studded tyre ban - no studded tyres can be used in certain streets of Stockholm
		Using dust binding agents (e.g. calcium magnesium acetate) to coat roads and reduce dust particles
		Cleaning heavily affected streets (mainly *Hornsgatan* and *Sveavägen*) with hosing and more powerful cleaning machines
	Promote vehicles with low emissions	LEZ
		Public procurement of clean cars – shift towards a fleet with alternative fuels and electric vehicles
		Use of economic incentives for electric vehicles (exempt from both the congestion charge and parking fees)
		Increase of charging/fuelling infrastructure for renewably fuelled transport
NON-ROAD TRANSPORT	Shipping	Electrical connection of ships - enabling access to grid electricity while in port for their activities such as hospitality or (un)loading (instead of the use of auxiliary engines and fossil fuels)
		Environmentally differentiated harbour fees - fees with a focus on reducing emissions of hydrogen peroxide (H_2O_2), NOx, SO_2 and particles
		Reduced emissions in the work of the harbour company by reducing transport and travel by its employees and by installing solar power stations

AQ policies - STOCKHOLM		
Sector	Category	Policies and measures
		Reduction in idling by vehicles and ships, for example by installing electric charging poles at a number of places in the harbour
	NRMM	Programme to reduce emissions of off-road engines, e.g. the inclusion of environmental requirements for contractors

LEZ

The table below presents the information on the Stockholm LEZ.

Table 2.23 Overview of Stockholm LEZ

Stockholm LEZ	
Map of LEZ	 Figure: LEZ 1 in Stockholm. The red street is an LEZ. Source: https://urbanaccessregulations.eu/  Figure: LEZ 2 in Stockholm. The area marked by the red line represents the LEZ. Source: https://urbanaccessregulations.eu/
Description and scope	The LEZs operate 24 hours a day, 365 days a year There are two emission zones: - LEZ *Hornsgatan* (LEZ 1 in figure above) permits access for passenger cars, minibuses and vans depending on Euro class: - From 15 January 2020: minimum standard Euro 5 - From 1 July 2022: minimum standard Euro 6 - LEZ national (LEZ 2 in figure above) permits access to HGVs and buses that are less than six years from the date of first registration

Stockholm LEZ	
	Euro 5 and EEV vehicles can be driven until the end of 2020 or eight years from first registration Euro 6 or better has no time limit for driving in the LEZ
Enforcement mechanism	A penalty fee of SEK 1 000 (about €96) is applied through manual police enforcement (checking the registration number of the vehicle). Vehicles are inspected against relevant registers to see if they have exemption from the rule
Implementation barriers	The effect of the LEZ is dampened by background levels, i.e. the transport of emissions from outside to central Stockholm. These represent a relatively large source of both $PM_{0.2}$ and NO_2 levels[37] There is a widespread misconception that the new LEZ is concerned with all forms of light diesel cars
Effectiveness in reducing air pollution	In Stockholm, the environmental zone (LEZ 2 in figure above) was calculated to reduce emissions of NO_x by 3-4 %, hydrocarbons by 16-21 % and PM by 13-19 %. Ex-post analysis after four years of implementation revealed that the emissions of particles (PM) decreased by 0.5-9 % at roof level (12 % if compliance had been 100 %), depending on the measurement station (highest levels found in *Norrmalm* and *Östermalm*). The largest decrease for NO_2 was 1.5 %, in the same areas NO_x emissions are projected to fall from 41 μg/m³ to 29 μg/m³ between 2017 and a hypothetical 2022 scenario without the addition of the LEZ *Hornsgatan* in central Stockholm (LEZ 1 in figure above). Implementation of the zone is expected to further lower to 26 μg/m³ in 2020 by a marginal difference
Co-benefits	Information not available

ON-ROAD POLLUTING VEHICLES

The city of Stockholm has four key mechanisms in place to reduce demand for more polluting forms of transport and address the issue of on-road polluting vehicle legacy:

- LEZ (described in Table 2.23);
- A congestion charge along main access routes which extends beyond the LEZ limits (described below);
- Additional access regulations on large and heavy vehicles in Stockholm that vary by vehicle (type, weight, height and length) and the time of day;
- Tighter regulations on vehicles in the Old Town, alongside a total ban on motorised traffic in the historical centre except between 06:00 and 11:00.

Since 2007, a **congestion charge** has been imposed on certain vehicles for passage in and out of Stockholm inner city. It operates from 06:30 to 18:30, Monday to Friday. The tax does not apply overnight or weekends, or in July (after the first five weekdays). It is enforced through cameras that use an automatic number plate recognition (ANPR) system and a penalty fee of SEK 500 (about €50). In order to reduce emissions from existing vehicles, the **urban vehicle access regulations** (UVAR) mandate that vehicles entering the congestion charging zone must pass one of 20 inspection points, where ANPR cameras record details of all vehicular traffic entering the city.

[37] SLB Analysis. Available at: http://slb.nu/slb/rapporter/pdf8/slb2001_004.pdf

OTHER POLICIES

A series of actions have been taken to reduce the impact from ships and activities in the harbour on air pollution and environment (identified as an important source of air pollution):

- Electrical connection of ships. Grants of up to SEK 1 000 000 (about €9 600) are available to adapt ships to enable electrical connection when moored;
- Environmentally differentiated harbour fees (taking into account the environmental impact of vessels);
- Fossil-free harbour companies;
- Reduction of idling by vehicles and ships.

Impacts of policies on air pollution and AQ

Other than the impacts of the LEZ on air pollution described above, the road transport policies have led to the following reductions:[38]

- The congestion charge led to a decrease of 8.5 % in NOx and 13 % in PM10 concentrations in the inner city. The annual average levels of NOx and PM10 are estimated to have fallen by up to 2 µg/m3.
- The UVAR led to reductions in CO2 emissions of 14 %, PM10 of 13 % and volatile organic compounds of 13 %.

No data are available on the impact of shipment regulations or measures on air pollution.

The data analysis for this research paper shows evidence of sustained improvements in NO_2. It shows an average reduction in NO_2 concentrations of 2.2 μgm^{-3} and 2.0 μgm^{-3} per year at each traffic station, corresponding to 5 % of the respective 2013 concentrations. It shows an average reduction of 0.5 μgm^{-3} per year at the background station, corresponding to 3 % of the 2013 concentration.

The analysis shows an average $PM_{2.5}$ increase of 0.3 μgm^{-3} at one traffic station and an average reduction of 0.1 μgm^{-3} per year at the other, corresponding to 6 % and 2 % of the 2015 and 2013 concentrations (the first years of data available). It also shows an average reduction of 0.1 μgm^{-3} per year at the background station, corresponding to 3 % of the 2013 concentration.

2.4. Cross-city assessment of the policy measures

Overview

This section provides a summary of the mapping and assessment of AQ policies from responses to the Task 1 research questions. This section thus presents a cross-city assessment of the specific policies addressed in this research paper (i.e. LEZ, on-road polluting vehicle legacy policies and other local AQ policies).

[38] JRC, Catalogue of Air Quality Measures. Available at: https://fairmode.jrc.ec.europa.eu/measure-catalogue/

Research question 1

What policy measures have been designed and implemented by the relevant authorities in each of the selected agglomerations (included in the sample) (i) with the aim of reducing air pollution from sources - such as industry, waste management, agriculture, heating, transport - relevant for this agglomeration? And (ii) with the aim to tackle the issue with 'on-road' polluting vehicle legacy?

What is the design of the 'low emission area/zone' policy measure of each agglomeration (included in the sample)?

Overviews of AQ policies identified in each of the 10 agglomerations are presented in sections 2.3.1 to 2.3.10. As noted above, the focus of the research was the most important urban air pollutants, NO_2 and PM, derived mainly from road traffic but also from other relevant sources in each case. The identification of the local AQ policies under Task 1 was therefore guided by the main source(s) of emissions of these air pollutants in each of the 10 agglomerations.

The main sources of information for the identification of policy measures were local AQ plans, policy evaluation reports, and insights gathered through stakeholder interviews.

The majority of policies identified in all agglomerations relate to **road transport**. Such measures have been designed and implemented to **control traffic**, as well as to **prevent and reduce air pollution**. The most prevalent groups of policy measures identified were the promotion of walking and cycling, public transport and cleaner vehicles (i.e. measures reducing the demand for more polluting forms of transport and those promoting vehicles with low emissions). An LEZ has been designed and declared in all agglomerations. An LEZ is in operation in eight of the 10 agglomerations included in the sample. Of the remaining two, Bucharest established an LEZ in October 2019 but annulled it in March 2020, while Krakow piloted an LEZ but progress has stalled since March 2019. A new LEZ is planned for Krakow in the near future (2020/2021). The design of the LEZ is described in the sections above for each of the agglomerations included in the sample. A cross-city assessment of the design and implementation of the LEZ is provided below under research question 2.

Other important sources of air pollution for which policies have been designed and implemented in the 10 agglomerations include **domestic heating, industry and construction sites, as well as non-road transport** (shipping, NRMM). Emissions from these sources are important contributors to local air pollution in some cases.

Although individual policy measures can have significant impacts on local AQ, it has been reported by stakeholders in the interviews that a package of policy measures is often required for sustained improvements in AQ. Coherence in the design and implementation of local AQ policies is thus very important (see LEZ assessment below).

Research question 2

In a comparative perspective, what features in the design of the policy measures (including 'low emission area/zone' and measures addressing 'on-road polluting vehicle legacy') are common for the agglomerations and what features are specific for each agglomeration?

Are there any common trends (across the agglomerations included in the sample) in the factors underlying the specific policy choices of the authorities?

The literature review and interviews undertaken for this research paper identified several features in the design of local AQ policy measures that are common to the agglomerations included in the sample (with some specific to each agglomeration). Similarly, there are common underlying factors for the choices of policies. These features are summarised below and address policies on road traffic, the importance of promoting walking, cycling and public transport, the issue of 'on-road polluting vehicle legacy', climatic and environmental conditions, enforcement and compliance, as well as the legal basis for designing policy measures.

Policies targeting a **reduction in road traffic** are common across all agglomerations. While these policies are expected to have positive impacts on AQ, they are often driven by policy goals other than the improvement of local AQ, for example by the need to reduce road traffic in certain areas of cities. This is an important distinction, as a certain policy might be effective in reducing road traffic in a specific area in the city but have little or no impact on the local AQ (e.g. establishing an LEZ in one or two main streets). Similarly, driving restrictions on individual roads are considered ineffective in health protection as they have no impact on the overall vehicle fleet or city-wide emissions from road vehicles. These limitations can be addressed by broader policies: for example, they were one of the underlying factors in the decision to declare the whole city centre of Berlin an LEZ. By encompassing a wider area, the measure impacted the vehicle fleet in the whole city (one million people living within the LEZ).

The policy intention to **promote walking, cycling and public transport,** together with cleaner public transport, is very common across the examined cities. The policy measures chosen in the 10 agglomerations varied however, ranging from public awareness campaigns, large-scale traffic planning measures, driving restrictions, parking management and road pricing or congestion charges.

Policies addressing the issue of **on-road polluting vehicle legacy** vary between cities, with each implementing a unique set of measures. These include different combinations of the following measures: vehicle emission tests; retrofitting; taxation; and scrappage schemes. The aim of these policy measures is to control and reduce emissions from existing vehicles in circulation.

As the agglomerations included in the sample are geographically balanced in the EU, their **climatic, meteorological and environmental conditions** are significantly different. This has an impact on the design and implementation of the local AQ policies and is an important underlying factor. For example, the measure to ban studded tyres during winter months is an effective policy in Stockholm but would be of little use in southern European cities. The location of the cities compared to surrounding regions (and pollution from these regions) also affects the types of local measures designed and implemented, as the supra-regional emissions could be too high for limit values to be achieved by purely local measures.

Differences have been observed in the type of **enforcement and resulting compliance levels** of policy measures across the agglomerations. In the case of an LEZ, the enforcement approach (including level and number of exceptions) is key to its success and effectiveness. It has been reported, for example, that although policies routinely lead to a reduction in road traffic or air pollution, there is often potential for a high level of individual vehicle compliance (and potentially higher impacts on AQ and road traffic levels). Enforcement is performed by various means, such as police inspections, cameras or electronic gates. However, the capacity of the local authorities to enforce measures significantly impacts uptake and compliance levels. The interviews found, for example, that a lack of capacity and resources available meant that measures implemented often focus on campaigns and awareness raising as less resource-intensive options.

Another underlying factor in the design of local AQ policies is the applicable limit values (e.g. for $PM_{2.5}$) and the **legal basis for local action**. One interviewee noted that local measures are often hindered by a lack of legal basis in the respective national law, which makes it difficult to justify the (design of) the policy measure and ensure sufficient support. An example was the proposal for a provision in German vehicle labelling regulation to provide a 'blue' sticker for vehicles meeting Euro 6 standards. The blue sticker would likely have further improved local AQ by providing an easy way to identify and restrict entry of diesel cars. However, there was no agreement on this proposal and it has yet to be implemented.

One interviewee expressed that uniform absolute limit values for $PM_{2.5}$ at EU level are viewed as an unrealistic goal because different local conditions (e.g. meteorology, orography[39], economy) result in non-compliance with the relevant legally binding EU standards despite the local abatement policy measures. A relative exposure reduction target at local level could be a more reasonable objective as it could drive measures in all regions with unhealthy air quality.

Research question 3

Have the implemented policy measures (including 'low emission area/zone' and 'on measures addressing 'on-road polluting vehicle legacy') led to the intended decrease in air pollution from the relevant pollution source(s) in the agglomerations, or not?

The implementation of a (package of) local policy measures is expected to have reduced air pollution from the relevant sources. However, the level of impact is dependent on a range of factors, including the importance of the source of air pollution in the agglomeration, the links between the policy measure and other measures (targeting the same source) and the geographical scope of the measure (see below).

Evidence on the impact of policy measures on air pollution, including from LEZs, is often scattered and rather limited information was available in the literature reviewed. Some evidence suggests a decrease of diesel exhaust particulates by 50 % after implementation of the LEZ stage 2 in Berlin[40] and a decrease of pollution of annual PM_{10} by 3 %. Similarly, emissions of PM decreased by 0.5-9 % in Stockholm following the implementation of the LEZ. The information (where available) is reported in the overview of each city in sections 2.3.1 to 2.3.10. In the case of an LEZ, literature indicates that the magnitude of the effect also depends on the contribution of road traffic to pollution levels.[41] More specifically, an LEZ could have be of greater benefit when road traffic is the major source of pollution.[42]

Generally, it is difficult to directly link a trend in air pollution (increase, decrease or no change) with a specific policy measure, as many other factors have an influence at the same time, including other measures and wider changes in the city (e.g. increasing population (density), urban developments). Often, individual policies have no clear target. Rather, specific goals for reducing air pollution are linked to a package of measures or to an entire AQ plan or programme (for example, Plan A in Madrid and the Air Protection Programme in Krakow).

Available data suggest that clear decreasing trends in air pollution can be observed mainly when policies are implemented in combination. This finding also highlights the importance of a **coherent approach** in the design and implementation of policies.

[39] The topography or elevation of a terrain and region

[40] Stage 2 - from 1 January 2010: Only vehicles of emission group 4 are allowed to drive.

[41] Transport & Environment, Low-Emission Zones are a success - but they must now move to zero-emission mobility, 2019. Retrieved from https://www.transportenvironment.org/sites/te/files/publications/2019_09_Briefing_LEZ-ZEZ_final.pdf

[42] Amundsen, A. H. and Sundvor, I., Low Emission Zones in Europe: Requirements, enforcement and air quality. Institute of Transport Economics, 2018. Retrieved from https://www.toi.no/getfile.php?mmfileid=49204

The interviews found that an approach that is likely to be effective in decreasing traffic and the associated air pollution is switching to more sustainable forms of transport, such as promoting public transport, cycling, pedestrianisation (and not solely through the implementation of an LEZ). A **city-wide policy measure**, such as parking management and congestion charges is likely to be more effective in reducing air pollution and improving AQ than more locally targeted measures such as driving restrictions in specific streets.

Research question 4

What has worked well in each agglomeration and why?

What has not worked well in each agglomeration and why?

The review of information from the literature and in particular from discussions with experts from the local AQ authorities in each of the agglomerations revealed a number of policy design and implementation aspects that contributed to the effectiveness and success of the policies. Similarly, several aspects were highlighted as ineffective or in need of improvement. An illustrative overview of these aspects across the agglomerations and groups of policies is provided in the table below.

Table 2.24 Overview of policy design and implementation aspects that did/did not work well in the 10 agglomerations

	(+) Elements that worked well	(-) Elements that did not work well
LEZ	LEZ proved successful with regard to PM in the early years, stage 1 (2008 onwards) due to the relatively large size of the zone, requiring almost 25 % of the diesel fleet to be retrofitted with DPF (Berlin). Extensive media communication to raise awareness of the new measures, including installation of AQ display boards on busy roads (Stockholm). Use of city-wide traffic planning to avoid confusion about restrictions in specific streets and areas (Stockholm). Degree of flexibility in initial design and implementation is considered fundamental to good policy functioning (Rome). Use of a national vehicle classification system (stickers) (Barcelona, Madrid, Berlin). Integration of the LEZ with the Regulated Parking Service (*Servicio de Estacionamiento Regulado*, SER) policy (Madrid).	High number of exemptions (types of vehicles allowed to enter the city) following local business protests (Krakow). LEZ unsuccessful in stage 1 (2008 onwards) with regards to NO_2, since there was no retrofit technology available to reduce NO_2 (Berlin). Lack of capacity to ensure compliance and enforcement (Athens, Stockholm). Lack of efficient enforcement (random controls rather than automatic vehicle controls) (Paris). Insufficient and unclear LEZ road signs (now improved) (Lisbon). Opposition from municipalities to extend the scope of the LEZ (Paris). Short transition time for the implementation of the LEZ, with claims and opposition by economic actors (Madrid).
On-road polluting vehicle legacy	Use of automatic scanning of vehicle registration on entry to the inner city to ensure compliance with the congestion charge - Automatic Number Plate Recognition (ANPR) (Stockholm). Monitoring real-time emissions from buses (Paris).	Lack of coherence between approach for inspections of vehicle diagnostic stations in the city centre (strict controls) vs the regions surrounding the city (less strict controls) (Krakow).

	(+) Elements that worked well	(-) Elements that did not work well
	Use of economic incentives in parking management scheme, i.e. different parking fees for green, orange and red parking areas (Lisbon). Evaluation of the direct impact of the implementation of differentiated circulation and other measures on air pollution (Paris). Intensive consultation process before approval of the Regulated Parking Service (*Servicio de Estacionamiento Regulado*, SER) (Madrid). Implementation of a funding scheme for catalytic converters for older, more polluting taxis (Lisbon).	Complex and lengthy contractual process for acquiring electric buses compared to natural gas buses (Lisbon).
Other policies (in addition to the policies aimed at tackling pollution from transport, selected for more in-depth assessment)	Highlighting the environmental benefits vs cost of implementation and support from local residents and local politicians (Krakow).	Interaction with authorities at regional and national level to address emissions from heating, industry and agriculture (Paris).
General aspects	Production of interactive maps showing concentrations and emissions of air pollutants in the city (Paris). Combining measures promoting the switch to less polluting vehicles with those to reduce vehicle uptake to address both exhaust and non-exhaust emissions (Paris). Coordination of the relevant bodies and authorities at different administrative levels for effective implementation of AQ policies (Madrid).	The supra-regional emissions (originating from surrounding regions) can be too high for limit values to be achieved by local measures alone (Berlin). Reported lack of legal basis in national law, hindering local measures. An improved legal basis for local action could assist in justifying the (design of) the policy measure and ensure sufficient support (Berlin). Consultations with stakeholders taking place after measures have been adopted by the local authorities (Great Walk - Athens). Understaffing of services/departments/ ministries who approve plans and enforce the policies (Athens).

Note: this is based on the data collection and review and is not an exhaustive list of elements; not all agglomerations are featured in each of the categories in the table.

Research question 5

In a comparative perspective, are there any common trends (across the agglomerations included in the sample) in the identified good and bad implementation practices and their underlying factors?

Common trends identified in good and bad practices are reported and categorised below: (i) LEZ; (ii) on-road polluting vehicle legacy; (iii) other local AQ policies. The trends in their underlying factors are then described.

LEZ

Many cities around the EU have implemented an LEZ with the objectives of reducing road traffic and, in most cases, the resulting pollution as well, in particular concentrations of PM (PM_{10} and $PM_{2.5}$) and NO_2. In the agglomerations studied, each LEZ has characteristics specific to its local context. The dimensions, vehicles affected, exemptions, types of surveillance, progressive implementation and financial support all vary depending on the city. Some common practices and conclusions are evident, however.

There is statistically significant evidence that an LEZ can reduce air pollution, based on both the information for the agglomerations under the scope of this research paper and the findings of previous studies. However, the magnitude of their effect depends, *inter alia*, on the contribution of road traffic to pollution levels.[43] More specifically, an LEZ has a greater beneficial impact on AQ when road traffic is the major source of pollution.[44]

The literature and interviews carried out for this research paper have indicated that the **design** of an LEZ is the main factor affecting its effectiveness and the achievement of its objective to change the vehicle fleet of a city.

- The dimension of the urban territory covered by the LEZ is an important factor to be considered in its design as it determines the percentage of residents and the number of vehicles directly involved. Berlin uses a city-wide approach, for example, while the LEZs in Krakow and Athens apply to smaller areas within the city.
- There are different mechanisms to assess vehicle compliance with LEZ rules. The method chosen affects the total implementation cost, as well as its relative effectiveness. Currently available control mechanisms are:
    - automatic control through a camera that reads the licence plate (e.g. Athens, Barcelona, Lisbon);
    - manual control through a scanner (e.g. Paris);
    - manual control performed by a police agent (e.g. Stockholm).

  There appears to be little consistency in the control mechanism, penalty amounts, and signs used to flag the LEZ area. However, evidence suggests that proper enforcement is key and both local and visitor vehicles should be inspected. This finding is based on previous studies44 and on the analysis of the 10 agglomerations studied here.
- It has been proven that more stringent policies that allow access only to the cleanest vehicles and make few exceptions are the most effective.[45] A counterpoint is seen in the high number of exemptions in Krakow (as well as its relative small size), which led to the low effectiveness of the LEZ there.
- From a social feasibility perspective, effective communication of the policy to the population and public participation in the process seems to be one of the first steps to guarantee its effectiveness. The objective should be clearly stated, together with its benefits and expected

[43] Transport & Environment, 2019.

[44] Amundsen and Sundvor, 2018.

[45] Gehrsitz, M., The effect of low emission zones on air pollution and infant health. Journal of Environmental Economics and Management, 2016. Retrieved from https://strathprints.strath.ac.uk/59756/1/Gehrsitz_JEEM_2017_effect_of_low_emission_zones_on_air_pollution_and_infant_health.pdf

consequences, as outlined in the Clean Air project.[46] Traffic restrictions are more likely to be accepted if the population is informed of the policy, its health benefits, alternatives and supporting measures, it tends to more likely accept the restriction to the circulation.[47] Some flexibility in the early stages of the LEZ in Rome proved crucial to acceptance by the residents (rather than strict enforcement from the start). In Stockholm, AQ display boards are used to inform residents and raise awareness, which can lead to greater compliance.

When considering the **costs and benefits** of an LEZ, evidence[42] suggests that the overall cost – implementation, operation and adaptation – is largely offset by the reduced health costs associated with an improvement in AQ. The reduction in air pollutants due to decreased road traffic is generally significant, although its impact differs depending on the LEZ. Significant reduction in emissions of PM_{10} and $PM_{2.5}$ (and NOx to some extent) have been reported for several of the agglomerations included in the sample (see sections 2.3.1-2.3.10). Similarly, a comparative study found a reduction of up to 29 % in NO_2, up to 12 % in PM_{10}, up to 15 % in $PM_{2.5}$, and up to 52 % in BC.[48] These results were confirmed by a recent study that found that NO_2 is reduced more effectively when LEZs are combined with interventions that promote the use of the highest European standards for all duty vehicles (Euro 6/VI).[49] In general, more significant effects are seen in reductions in $PM_{2.5}$ and BC, as the most polluting vehicles mainly emit these pollutants. Even if the implementation of LEZs does not significantly reduce the number of vehicles circulating in the urban area, it does, however, contribute to the vehicle fleet renovation.[50, 51]

The use of LEZs has the capacity to promote sustainable development in urban areas and in densely populated cities. However, an LEZ cannot be considered as a stand-alone solution to air pollution in agglomerations but must, rather, be part of a grander policy scheme.

On-road polluting vehicle legacy

Road traffic is the major source responsible for air pollution in urban areas because of the emissions from vehicles with internal combustion engines (including the soot from diesel cars), plus brake and tyre wear. In addition to the use of LEZs to remove older vehicles from circulation, **congestion charges** and **retrofitting cars** with Diesel Particulate Filters (DPF) have also been shown to be effective.[52] Such measures have been identified for some of the agglomerations in the sample for this research paper. It has been reported that a major disadvantage of DPFs is an increase in NO_2

[46] Clean Air Europe is a project consisting of a unique Advanced Oxidation Process providing safe and friendly oxidisers able to revert microbes and odours back to CO_2 and water. These oxidisers are very effective often achieving a 99 % reduction within 24 hours http://www.cleanair-europe.org/en/home/

[47] Air, R., Pouponneau, M., Forestier, B. and Cape, F., Les zones à faibles émissions (Low Emission Zones) à travers l'Europe: déploiement, retours d'expériences, évaluation d'impacts et efficacité du système – Rapport, ADEME, 2019. Retrieved from https://www.ademe.fr/sites/default/files/assets/documents/rapport-zones-faibles-emissions-lez-europe-ademe-2018.pdf

[48] Air, R., Pouponneau, M., Forestier, B, and Cape, F., Les zones à faibles émissions (Low Emission Zones) à travers l'Europe: déploiement, retours d'expériences, évaluation d'impacts et efficacité du système, 2020. Retrieved from https://www.ademe.fr/sites/default/files/assets/documents/rapport-zones-faibles-emissions-lez-europe-ademe-2020.pdf

[49] Public Health England, Review of interventions to improve outdoor air quality and public health, 2019. Retrieved from https://www.gov.uk/government/publications/improving-outdoor-air-quality-and-health-review-of-interventions

[50] Air et al., 2020.

[51] Source: interview with representative of the Senate Department for the Environment, Transport and Climate Protection Berlin, October 2020.

[52] Layman, Clean air for European cities, 2016. Retrieved from http://www.cleanair-europe.org/fileadmin/user_upload/redaktion/downloads/Clean_Air_Publikationen/83_D4_Laymans_Report_EN.pdf

emissions, especially for light and heavy goods vehicles, although less so for private cars. While DPFs reduced PM in Berlin, NO_2 increased as a result of this abatement technology.

Driving restrictions, such as the number and type of vehicles allowed in a certain area at selected times (e.g. Athens), have proven effective in producing consistent reductions in air pollution levels. [53] In general, however, driving restrictions on individual roads are ineffective in health protection as they have little effect on the vehicle fleet or on city-wide emissions.

Other local AQ policies

The literature and interviews highlighted that complementing policies to improve AQ include the promotion of clean alternatives like walking and cycling, and the electrification of all means of transport.[54] Investment is needed for cycle paths and the shift to electric vehicles, as well as communication and public awareness campaigns. Structural measures that promote green infrastructure not only improve AQ but reduce health inequalities in urban areas and deal with the consequences of urban heat islands and flooding.[55]

An important source of air pollution in many of the agglomerations studied is **heating and domestic combustion.** The introduction of wood-fired combustion for heating, for example, is considered a climate-conscious choice (carbon neutral). However, as wood combustion emits significant amounts of PM and BC emissions, it will cause air pollution (as well as a greenhouse gas effect due to the BC). Although policies such as fuel restrictions were identified in some of the agglomerations, these reportedly can require large investments or require amendments to national legislation.

Port cities must deal with shipping if they are to improve their AQ, as **ship emissions** are typically significantly higher than those of road vehicles. In addition to other sources such as road transport or heating, port cities also face pollution from shipping, cranes, cruises and various transportation vehicles. There are examples of practices voluntarily adopted to reduce the environmental impacts of ports while keeping their economic benefits.[56] In Stockholm, for example, a series of measures was identified to reduce emissions from cruise ships and port operations. These include taxing specific pollutants (much like urban vehicles), switching to electric mobility using renewable sources, or alternative technologies like LNG.

Several **common factors** were identified in the design and implementation of local AQ policy measures in the agglomerations studied.

- The approaches and time taken to inform and engage with stakeholders on the design and implementation of local AQ policies varied across the agglomerations included in the sample. However, a structured approach for raising awareness and communicating the policies that will affect local residents and businesses is key to increasing compliance. Engagement should take place early in the process and policies should allow some flexibility to account for stakeholder feedback and concerns.
- Although individual policies, such as an LEZ, could be effective in reducing air pollution, it is clear that coherence in the design and implementation of local policies is key to their success.

[53] Public Health England, 2019.

[54] Transport & Environment, 2019.

[55] Public Health England, 2019.

[56] Layman, 2016.

A holistic approach avoids confusion and will increase compliance. Achieving coherence often requires collaboration across various city departments and different authorities.

- A common trend across the policies and agglomerations is the need for enforcement capacity. A lack of capacity in the local authority or police was often reported to be the main factor influencing compliance and success of a policy.

2.5. Recommendations and best practice

Based on the review of information on local AQ policies in the agglomerations included in the sample, the following **recommendations** have been defined to improve the design and implementation of local AQ policies. The agglomerations included in the sample for which these recommendations are likely most relevant are indicated; however, it is expected that these recommendations are also valid for other EU agglomerations.

- Ensure a coherent approach in the design and implementation of local policies addressing the same source of air pollution, such as congestion charges, driving restrictions and LEZ. Ensure coherence between the measure(s) taken in the city and those in the surrounding areas (e.g. enforcement, inspection of vehicle diagnostic stations) (relevant for all agglomerations in the sample).
- Alongside reducing emissions from vehicles in circulation, provide good alternatives to the use of private vehicles, such as promoting public transport, pedestrianisation, cycling networks (all agglomerations).
- Establish a flexible approach that allows for revisions to the scope or approach of the LEZ over time, taking into account changes in vehicle emission performance, technology and need for stricter enforcement (relevant for Bucharest and Krakow).
- Provide for sufficient awareness raising and engagement with stakeholders in the design and implementation of AQ policies directly affecting stakeholders. Highlighting the expected benefits of the policies (e.g. longer-term environmental and health benefits) for stakeholders such as residents and businesses can improve compliance (Athens, Bucharest, Paris, Rome, Stockholm).
- Ensure sufficient capacity for effective enforcement of local AQ policies (Athens, Bucharest, Krakow, Rome, Stockholm).
- Focus on city-wide measures where possible, which are likely to be more effective than measures focused on specific streets or areas to improve AQ. Driving restrictions for individual streets (or small areas) might be effective in reducing traffic at the very local scale but will have little or no impact on the city's AQ or health, as such measures often lead to a diversion of traffic (Krakow, Rome, Stockholm).
- Arrange for an efficient monitoring and evaluation of the effectiveness of local AQ policies (all agglomerations).

The following **practices aimed at tackling pollution from transport and other sources** have the potential to work well regardless of the specific local conditions. They are based on the data collection and analysis in this research paper:

- Design local AQ policies for road transport to prioritise a modal shift, i.e. measures promoting walking, cycling and public transport.
- Focus on measures addressing exhaust emissions (i.e. from engines) as well as those addressing non-exhaust emissions (i.e. resulting from abrasion or re-suspension) to more effectively reduce air pollution from road transport.
- Involve and inform citizens and businesses through information campaigns that will increase uptake and acceptance of the measures. This is an important practice in the design and

implementation of local AQ policies. Examples of relevant tools include the use of interactive maps of air pollution in the city and estimates of the expected health and environmental benefits arising from the implementation of the measures.

- Ensure effective implementation of an LEZ via the use of automatic vehicle controls (instead of more random, ad hoc, manual controls).
- Carry out regular monitoring of emissions and air pollutant concentrations, in particular regular analysis of the effects of individual policies. Analysing the effects of individual policy measures identifies areas for improvement, is relevant to all local AQ policy measures, and works well regardless of local conditions.

2.6. Limitations and gaps

The collection and review of information for this research paper allowed an assessment of the policies employed across the agglomerations included in the sample. This enabled conclusions to be drawn and recommendations to be made for the design and implementation of local AQ policies. Several limitations and data gaps were encountered during the analysis:

- Although the views of experts gathered through interviews were very useful in complementing the analysis, the study relied heavily on publicly available documents for much of its information. Relevant information was not always easy to find, however, and (up-to-date) details about specific policies were often lacking.
- The study provides an overview of the most important policies covering the air pollution sources that were the focus of the study, and this overview was confirmed through the expert interviews. However, the list of policies is not exhaustive. With plans and policies in development in many of the agglomerations, the overview should be considered a snapshot at the time of reporting.
- In assessing the impacts of local AQ policies on the reduction of air pollution, linking a specific policy to precise trends in air pollution is often very challenging. Many other factors also have an impact and/or the effectiveness of the policies is not well monitored.
- The recommendations and conclusions are based on the information reviewed for a sample of 10 agglomerations. Each individual city or agglomeration has specific conditions that need to be considered in the design and implementation of policies. However, common trends could be identified and these trends are also likely relevant for other cities and agglomerations not included in the sample, making the recommendations and conclusions also relevant more broadly.

3. COVID-19 and air pollution

3.1. Introduction

The COVID-19 pandemic, declared by the World Health Organization (WHO) on 11 March 2020, has greatly impacted the way people live, patterns of mobility around cities, and many sectors of the economy. There has been much discussion regarding the effect of exposure to air pollution on the health outcomes of the disease, and the effect of the lockdown measures employed by governments around the world on air pollution levels.

To guide the research into the interactions of COVID-19 and AQ, a set of research questions was identified in the Technical Specifications for this research paper. These are presented in Table 3.1. This table shows the data needs for each of the research questions and the main sources of information used under Task 2.

Table 3.1 Research questions, data needs and sources of information for Task 2

Research question*	Data needs and parameters	Source of information
Q1. What does state-of-the-art research tell us about **air pollution as a factor increasing COVID-19 mortality**?	Considered through a review of the available literature related to three key questions defined in an initial review of the available information: - Does PM play a role in the transmission of the SARS-Cov-2 virus? - Are there feasible mechanisms by which air pollution could worsen COVID-19 health outcomes? - Does exposure to pollution worsen COVID-19 health outcomes?	Academic (including peer reviewed and non-peer reviewed articles), governmental and other technical literature produced up to November 2020
Q2. Have the COVID-19 **lockdown policies affected air pollution levels** - in the zones and/or agglomerations included in the sample under this research task and, possibly (subject to data availability), across the EU as a whole - and how (in terms of pollutants most common for urban areas)?	- Details of the lockdown period in each agglomeration - Monitored AQ data in each of the 10 agglomerations - Monitoring data analysis produced for each agglomeration	- University of Oxford Coronavirus Government Response Tracker - EEA European Air Quality Portal - European Commission Copernicus Atmosphere Monitoring Service (CAMS) - Assessments produced by academic and governmental organisations
Q3. If decreases in air pollution levels resulting from the COVID-19-related lockdown policies have been identified (in the answer to the previous research question), which **air pollution sources contributed to these decreases** in each zone and/or agglomeration included in the	- Source apportionment studies for the 10 agglomerations - Activity data during lockdown	- Academic and governmental literature - Apple mobility trends reports

Research question*	Data needs and parameters	Source of information
sample under this research task and, possibly (subject to data availability), across the EU as a whole?		- Eurostat short-term business statistics
Q4. If decreases in air pollution levels resulting from the COVID-19-related lockdown policies have been identified (in the answer to the second research question under Research Task 2), and if the identified decreases in the levels of air pollution - in the zones and/or agglomerations included in the sample under this research task and, possibly (subject to data availability), across the EU as a whole - are extrapolated to a period of a few years in the future, what would be the effects of those decreased air pollution levels on health (including on premature death rate) and the environment?	- Baseline air pollution and health assessments - Changes in pollutant concentration identified in Question 2 - Literature on effects of lockdown policies on the environment	- EEA Air Quality in Europe - Academic literature
Q5. Are there lessons to be drawn from the COVID-19 lockdown in terms of policy measures to be applied in the future to the various sources of pollution with the aim to reduce air pollution from those sources?	- Conclusions based on the findings of the previous four research questions	- Information sources as above

* The research questions are taken from the study's Technical Specifications.

3.2. Research Question 1: Air pollution as a factor increasing COVID-19 mortality

This section provides a synthesis of the review of the relevant sources of information identified. The full review is provided in Appendix 3. Given the timescales of the pandemic and subsequent research, the majority of the literature reviewed is preliminary in nature and somewhat speculative. However, conclusions have been drawn where the literature studied indicates general agreement on different factors and recommendations are made for further work.

3.2.1. Does PM play a role in the transmission of the SARS-Cov-2 virus?

Literature was identified discussing the role of PM in the transmission of the SARS-Cov-2 virus. The potential for the virus to be present on PM and therefore travelling significant distances and infecting individuals via this route has been discussed. Several conclusions can be drawn from the literature reviewed.

- There is growing evidence that SARS-Cov-2 is likely to be spread in aerosols (including PM) through the air.
- There is some evidence that PM is a potential carrier of the virus, although virus viability and duration has yet to be established.
- The aerosol route of transmission is likely to be more important in internal environments, where ventilation is reduced or air is recirculated. Dispersion due to turbulence and resultant dilution is more limited than is typically seen in external environments.

- The aerosol route of transmission is likely to be of less importance in external environments, where air movements and air volumes available for dilution are greater than those in internal environments.
- As aerosol transmission is likely to be more important in internal environments, room ventilation, open space, sanitisation of protective apparel, and proper use and disinfection of toilet areas can effectively limit the concentration of SARS-CoV-2 in aerosols.
- Initial research suggests that because droplet and aerosol transmission are important modes of transmission of the virus when people are gathered in enclosed spaces, face coverings are the most effective means to prevent inter-human transmission.

To confirm these conclusions and refine strategies to limit transmission of SARS-CoV-2, further evidence is required, as follows:

- SARS-CoV-2 genetic material present on PM in sufficient loads to cause infection;
- SARS-CoV-2 collected from aerosol and/or PM replicating under laboratory conditions;
- SARS-CoV-2 collected from aerosol and/or PM after several hours in outdoor air replicating under laboratory conditions;
- Correlation of wide-scale air sampling and high infection rates where SARS-Cov-2 genetic material has been found on PM in outdoor air.

If further studies confirm these points, this would be a reason to redouble efforts to manage PM.

3.2.2. Are there feasible mechanisms by which air pollution could worsen COVID-19 health outcomes?

Literature discussed the role that exposure to pollution could play in affecting the health outcomes for individuals suffering from COVID-19. For health outcomes to be affected, feasible physiological mechanisms are required by which pollution exposure could change the response of the body to infection. Several feasible mechanisms by which air pollution can affect COVID-19 outcomes were identified in the literature reviewed. These include:

- Non-specific impacts on host immunity (oxidative stress and inflammation);
- Specific impacts of pollutants on receptors such as angiotensin-converting enzyme 2 (ACE-2) by which SARS-CoV-2 enters cells;
- Contribution of air pollution to cytokine production during infection, making a potential contribution to the cytokine storm that is a feature of Acute Respiratory Distress Syndrome (ARDS) seen in severe COVID-19 disease.

Further work will need to focus on specific interactions within the body. In particular, experimental and epidemiological studies are needed to consider factors such as age, obesity and the presence of pre-existing and background diseases. They will also need to consider the impact of pre-exposure to PM and NO_2, and to evaluate the role of the atmospheric pollution in levels of inflammatory cytokines, which have been associated with a poorer prognosis. Part of this work could include follow-up analysis of infected individuals to determine the effects of exposure to short-term elevated NO_2 concentrations.

3.2.3. Does exposure to pollution worsen COVID-19 health outcomes?

Literature discussed the role that exposure to pollution has played in affecting the health outcomes for individuals suffering from COVID-19. This section focuses on the literature that considers whether COVID-19 health outcomes have been worse where exposure to pollution has been higher. The following conclusions have been drawn from that literature:

- Many studies carried out using data in the initial phases of the pandemic showed a statistically significant relationship between long-term (annual data or longer) pollution levels (particularly PM2.5) and COVID-19 health outcomes;
- This relationship appears less significant in later stages of the pandemic as more data becomes available. This is likely to reflect the community response to COVID-19 and the pandemic's spread away from more polluted urban areas.

While a causal effect is not ruled out, further work is required to determine whether or not exposure to pollution does in fact worsen COVID-19 health outcomes.

- As spatial coincidence alone cannot be taken as causality, more detailed epidemiological analysis is needed to develop a comprehensive understanding of the reasons for differences in severity of SARS-CoV-2 between different areas;
- This could include analysis to identify population cohorts as a function of short-term (1-24 hours) and past long-term (multi-year) personal exposure to PM at various locations (home, workplace, etc.) rather than just place of residence, and determine any potential correlation with COVID-19 outcomes;
- Obesity appears to be a key confounding factor, as there are suggested links between obesity and COVID-19 health outcomes. Some research has also suggested a strong link between socioeconomic status and COVID-19 transmission rates and health outcomes. This is likely to be related to personal exposure to air pollution and COV-Sars-2 at work and home, as well as pre-infection health status.

3.3. Research Question 2: The effect of COVID-19 lockdown policies on air pollution levels

3.3.1. Methodology

The long-term trend analysis from Task 1 was used and supplemented by EEA portal data for 2020 from the E2a dataset (preliminary data). The lockdown period in each agglomeration was defined using the COVID-19 Stringency Index (per country) produced by the University of Oxford Blavatnik School of Government (BSG).[57] For the purposes of the analysis, lockdown has been defined as the period when 'stay at home' measures required citizens 'not to leave their houses with exceptions for daily exercise, grocery shopping, and "essential" trips'.

Pollutant concentrations were calculated for this period at the sample monitoring sites within each agglomeration. The analysis was carried out for NO_2 (the pollutant most frequently found at concentrations exceeding the EU limit values) and $PM_{2.5}$ (the PM fraction most strongly associated with adverse health effects). Analysis of changes in $PM_{2.5}$ concentrations is considered to be more likely to respond to changes in activity, such as driving, than coarser particles ($PM_{2.5\text{-}10}$) as $PM_{2.5}$ concentrations are more influenced by combustion sources. The analysis was carried out using the Openair software.

To determine the effect of lockdown, the pollutant concentrations in that period have been compared with historic data processed in several different ways. AQ varies significantly, depending on the prevailing meteorological conditions. The NO_2 and $PM_{2.5}$ concentrations during lockdown

[57] https://www.bsg.ox.ac.uk/research/research-projects/coronavirus-government-response-tracker

have been compared with the following actual and predicted concentrations in the 10 agglomerations:

- The period immediately preceding lockdown (of the same duration of lockdown in each country);
- The average concentrations for the same dates as the lockdown period in the years 2013-2019; and
- The 'predicted concentration' if there had been no lockdown based on a TheilSen trend analysis of concentrations in the years 2013-2019 and a TheilSen trend analysis of concentrations during spring (March-May) in the years 2013-2019.

The use of these different time periods demonstrates both the variability of AQ because of the weather, and the effect that lockdown measures had on AQ.

The analysis of data from the sample monitoring stations selected in each city is supplemented by information from published literature and by the two following data sources, which monitor changes in pollutant concentrations in multiple cities and across Europe:

- European Commission Copernicus Atmosphere Monitoring Service (CAMS) regional data based on satellite and ground-based observations and advanced numerical models;[58]
- Centre of Research on Energy and Clean Air (CREA) report, 'Air pollution returns to European capitals: Paris faces largest rebound'.[59]

3.3.2. Data analysis

Table 3.2 presents a summary of changes in NO_2 and $PM_{2.5}$ concentrations during the lockdown period in each of the 10 cities. The full analysis for all monitoring stations selected is presented in Appendix 4.

[58] https://atmosphere.copernicus.eu/european-air-quality-information-support-covid-19-crisis

[59] CREA, Air pollution returns to European capitals: Paris faces largest rebound, 2020. Available at: https://energyandcleanair.org/pollution-returns-to-european-capitals/

Table 3.2 Overview of changes in pollutant concentration during lockdown period

			NO_2				$PM_{2.5}$		
City	Lockdown dates	Maximum Stringency Index (country)	Sampled monitoring stations - roadside (maximum change during lockdown relative to average of lockdown periods 2013-2019)	Sampled monitoring stations – background (maximum change during lockdown relative to average of lockdown periods 2013-2019)	CAMS (change in concentration relative to Jan-Feb 2020)	CREA	Sampled monitoring stations - roadside (maximum change during lockdown relative to average of lockdown periods 2013-2019)	Sampled monitoring stations – background (maximum change during lockdown relative to average of lockdown periods 2013-2019)	CAMS (change in concentration relative to Jan-Feb 2020)
Athens	23 March-29 May	84	-14.0 (-28%)	-4.7 (-36%)	-7.9 (-33%)	-11 (-32%)	-5.3 (-28%)	-0.6 (-5%)	1.0 (9%)
Barcelona	14 March-26 May	85	-20.2 (-54%)	-18.1 (-55%)	-12.6 (-46%)	-11 (-43%)	N/A	N/A	-1.5 (-9%)
Berlin	21 March-5 May	77	-12.9 (-33%)	-10.9 (-44%)	-5.4 (-34%)	-4 (-18%)	N/A	N/A	-0.2 (-2%)
Bucharest	25 March-14 May	87	-35.9 (-58%)	-10.9 (-41%)	-10.9 (-56%)	-35 (-65%)	N/A	N/A	-11.5 (-52%)
Krakow[1]	31 March-8 April	83	-20.2 (-31%)	-8.1 (-29%)	N/A	N/A	-11.9 (-33%)	-6.9 (-25%)	N/A
Lisbon	19 March-3 May	83	-20.9 (-56%)	-11.6 (-46%)	-7.1 (-44%)	-17 (-44%)	-3.3 (-30%)	-3.1 (-30%)	-4.4 (-31%)
Madrid	14 March-26 May	85	-23.6 (-68%)	-15.7 (-53%)	-18.7 (-55%)	-14 (-49%)	-2.8 (-34%)	-1.0 (-13%)	-7.3 (-46%)
Paris	27 March-10 May	91	-25.8 (-37%)	-13.0 (-43%)	-6.5 (-26%)	-21 (-60%)	-5.4 (-28%)	0.1 (0%)	-0.2 (-2%)
Rome	23 March-3 May	94	-35.6 (-58%)	-25.4 (-54%)	-13.4 (-49%)	N/A	-4.2 (-25%)	-4.1 (-26%)	-4.2 (-28%)
Stockholm[2]	N/A	46	-19.2 (-56%)	-4.9 (-42%)	-2.2 (-26%)	N/A	-4.3 (47%)	N/A	0.0 (0%)

[1] Period of requirement to 'stay at home' was limited, so lockdown timings for Germany used for calculations.
[2] No 'stay at home' requirements, so lockdown timings for Germany used for calculations.

Other studies have reported changes in pollutant concentrations during lockdown in the cities studied. Examples include:

- A study of AQ in Barcelona during lockdown reported a 21.8µg/m3 (51 %) reduction in NO2 and a 9.1µg/m3 (31 %) reduction in PM10 at roadside locations and a 14.1µg/m3 (47 %) reduction in NO2 and a 6.2µg/m3 (27.8 %) reduction in PM10 at urban background locations;[60]
- Reductions in NO2 of up to 33 % (15 % average) during lockdown were reported for Berlin, with no effect on PM10;[61]
- Reports of 63 % and 54 % reductions in NO2 at traffic and background sites, respectively, in both Madrid and Barcelona relative to 2019 concentrations;[62]
- A reduction of 64 % in NO2 has been reported during lockdown at the most polluted monitoring station in Lisbon;[63]
- A reported 25 % reduction in NO2 concentrations in Paris during lockdown;[64]
- Reported reductions in NO2 and PM2.5 at roadside monitoring stations of up to 68 % and 30 %, respectively, in Rome in March;[65]
- Reported reduction in NO2 concentrations and traffic in Stockholm.[66]

Similar changes in NO_2 and PM concentrations were seen across Europe. The EEA reports that estimates produced using a variety of methods showed that NO_2 concentrations were considerably reduced across Europe in April 2020.[67] It also reports that PM concentrations were generally reduced across Europe as a result of lockdown measures, although less than those of NO_2. Data from the Copernicus Sentinel-5P satellite via the EU Copernicus programme showed that the lockdown measures implemented across Europe resulted in reductions in pollution in urban areas across the continent similar to those observed in the 10 agglomerations studied. [68] For example, Milan and Budapest saw reductions in NO_2 concentrations of 40% and 29%, respectively, compared to 2019 concentrations. This was also seen in industrialised areas of Europe, such as the Ruhr region in Germany, the Scheldt Estuary region in Belgium and the Netherlands, and the Po Valley in Italy, which saw NO_2 concentrations during lockdown at 21 %, 33 % and 36 % lower than 2019 concentrations, respectively.

[60] Tobias et al., 'Changes in air quality during the lockdown in Barcelona (Spain) one month into the SARS-CoV-2 epidemic', *Science of the Total Environment,* 2020, p. 726.

[61] Berlin Hauptstadtportal, Ist die Luft wegen der Corona-Beschränkungen besser geworden?, 2020. Available at: https://www.berlin.de/sen/uvk/presse/weitere-meldungen/2020/ist-die-luft-wegen-der-corona-beschraenkungen-besser-geworden-929793.php

[62] Baldasano, 'COVID-19 lockdown effects on air quality by NO2 in the cities of Barcelona and Madrid (Spain)', *Science of the Total Environment,* 2020, p. 741.

[63] Transport & Environment, In Portugal, there's hope to maintain some of the benefits of lockdown, 2020. Available at: https://www.transportenvironment.org/news/portugal-theres-hope-maintain-some-benefits-lockdown

[64] Airparif, Impact of lifting lockdown restriction on air quality in the Ile-De-France region, 2020.

[65] Arpalazio, *L'effetto sulla qualità dell'aria nel Lazio dell'emergenza COVID-19 Analisi preliminare dei dati (marzo-maggio 2020*), 2020.

[66] SLB, *Coronavirusets effekt på luftkvaliteten i Stockholm*, 2020. Available at:
http://slb.nu/slbanalys/coronas-effekt-pa-luftkvaliteten/

[67] EEA, Air quality in Europe - 2020 report, 2020. Available at: https://www.eea.europa.eu/publications/air-quality-in-europe-2020-report

[68] European Space Agency, Air pollution in a post-COVID-19 world, 2020. Available at: https://www.esa.int/Applications/Observing_the_Earth/Copernicus/Sentinel-5P/Air_pollution_in_a_post-COVID-19_world

3.3.3. Conclusions

The changes in pollutant concentrations at any particular location depend on a considerable variety of factors, including the distance to local sources of pollution (i.e. roadside or background), street orientation, the arrangement of buildings that can trap pollution, and the weather (including long-range transport of pollution). Changes in pollutant concentrations are also reported in a number of ways: for individual stations; averages of stations grouped by location type; or at city or regional level. The following conclusions can nevertheless be drawn from the data:

- Lockdown and the ensuing limits on activities that release pollutants resulted in significant reductions in pollutant concentrations. NO2 concentrations at the sampled roadside monitoring stations fell by 28-68 % in the 10 agglomerations during the lockdown period, with concentrations at background monitoring stations falling by between 29-55 %. PM2.5 concentrations at roadside monitoring stations fell by 25-47 % in the 10 agglomerations during the lockdown period, with concentrations at background monitoring stations falling by 0-30 %.
- Proximity to the source of pollution is important. Less road traffic activity, for example, resulted in greater reductions in pollutant concentrations at roadside locations, where people are exposed to the highest levels of pollution. This is evident in the reductions in pollutant concentrations being generally greater at roadside locations than at background locations.
- Local emissions contribute a greater proportion of NO2 than PM2.5 concentrations. Regional pollution transported from outside urban areas (including natural sources such as sea salt and Saharan dust) is more important for PM2.5. This is illustrated by the observation that reductions in NO2 concentrations were generally greater than reductions in PM2.5.
- There is not a direct relationship between government lockdown stringency and pollutant reductions. Rather, the public response to the pandemic appears to be the important factor. For example, a strict lockdown was not implemented in Stockholm in the period studied (the city's maximum Stringency Index score was 46), but NO2 concentrations at the monitoring stations were around 40-60 % lower than 2013-2019 averages for the same dates. This was a result of voluntarily reduced driving activity following recommendations by the Public Health Agency of Sweden (Folkhalsomyndigheten, or FoHM), including significantly increased home working. Corresponding reductions in noise were also observed.[69]

3.4. Research Question 3: Evaluation of changes in air pollution sources during lockdown

3.4.1. Methodology

The development of plans to manage AQ requires an understanding of the sources contributing to pollution at particular locations, especially those with high levels of pollution. Source apportionment studies are carried out to determine the sources of emissions that should be reduced to deliver the greatest improvements in AQ. These studies (typically based on dispersion modelling or characterisation of PM) for the normal situation (prior to the pandemic) were collated for the 10 agglomerations. Source apportionment studies for NO_X (the precursor to NO_2) and $PM_{2.5}$ have been reviewed. PM_{10} source apportionment studies have also been included to provide more data and are considered relevant for roadside locations where combustion emissions dominate.

[69] Rumpler et al., 'An observation of the impact of CoViD-19 recommendation measures monitored through urban noise levels in central Stockholm, Sweden', *Sustainable Cities and Society,* 2020, p. 63.

Information on changes in polluting activity during lockdown for each city (or country where necessary) has been collected so that this can be related to the source apportionment and the reductions in pollutant concentrations seen over the lockdown period relative to the normal situation. Mobility data showing changes in driving rates have been obtained from the Apple Mobility Trends Report.[70] Industrial production data have been taken from the Eurostat short-term business statistics.[71] The focus is on road traffic and industrial emissions, as domestic heating emissions are not anticipated to have changed much during lockdown, given the timing and resulting lower heating requirements than during winter months. Emissions from other sources potentially have important effects on concentrations at certain locations near to particular sources, but these are not considered to be representative or typical for each city. Further contextual information was obtained from the representatives of each agglomeration in the interview process for Task 1.

3.4.2. Baseline source apportionment

Table 3.3 and Table 3.4 show the baseline source apportionment results obtained. It is clear that the relative influence of different sources of pollution on AQ varies depending on location within a city (i.e. near a road or in a park; near an important source of pollution like an industrial area or port) but common patterns can be seen across locations and between cities. Air pollution from distant sources (regional background) has a relatively low influence on NO_X (around 12-24 %), with road traffic being the most important source in most locations and contributing 60-90 % (including local emissions and pollution emitted across the city). Regional pollution transported to the location of interest is a much more important source of PM, with a contribution of 50-80 %. Local road traffic emissions only contribute up to around 40-50 % of the total concentration even at roadside locations with the highest concentrations. A significant portion of this regional particulate pollution does not have a human source: for example, sea salt and mineral dust are important components of total $PM_{2.5}$, as is Saharan dust, which affected $PM_{2.5}$ concentrations in Barcelona in March 2020, for example.[72]

The source apportionment studies reviewed have been used to create illustrative typical source apportionments for roadside and background locations. These represent the typical sources of pollution at locations of these types in urban areas across Europe. Using these, it is possible to consider how pollutant concentrations would have been expected to change as a result of the changes in polluting activity during lockdown. These are shown in Figure 3-1 and Figure 3-2.

[70] https://www.apple.com/covid19/mobility

[71] https://ec.europa.eu/eurostat/web/short-term-business-statistics/data/main-tables

[72] Tobias et al., 2020.

Table 3.3 Summary of NOX Source Apportionment

			Urban background					
Agglomeration	Source	Regional background	Industry/ commercial/ energy	Domestic	Other transport and mobile machinery (e.g. aircraft/rail)	Waste/ agricultural/ natural	Road transport	Local road contribution
Athens	None identified							
Barcelona	None identified							
Berlin	Air Quality Plan for Berlin 2011-2017	12 %	2 %	5 %	1 %	2 %	31 %	45 %
	Luftreinhalteplan für Berlin 2. Fortschreibung	14 %	2 %	4 %	6 %		26 %	48 %
Bucharest	*Planul Integrat de Calitate a Aerului în Municipiul București 2018-2022*	24 %	5 %	11 %		0 %		60 %
Krakow	*Malopolska w zdrowej atmosferze streszczenie, 2020*	15 %		8 %				75 %
Lisbon	*Plano de Melhoria da Qualidade do Ar das aglomerações da Área Metropolitana de Lisboa Norte e Área Metropolitana de Lisboa Sul, para os poluentes partículas PM10 e dióxido de azoto, 2019*	12 %	2 %	23 %	4 %		21 %	38 %
Madrid	Borge et al., Emission inventories and modelling requirements for the development of air quality plans, 2014. Application to Madrid (Spain)	24 %	17 %					59 %
Paris	None identified							
Rome	None identified							
Stockholm	*Burman et al., Fordonsmätningar på Kungsgatan i Uppsala, 2020*		11 %					89 %

Table 3.4 Summary of PM source apportionment

			Urban background						
Agglomeration	Source	Regional background	Industry/ commercial/ energy	Domestic	Other transport and mobile machinery (e.g. aircraft/rail)	Waste/ agricultural/ natural (or unaccounted)	Dusts (calcium and iron rich)	Road transport	Local road contribution
Athens	Grivas et al., Elemental composition and source apportionment of fine and coarse particles at traffic and urban background locations in Athens, Greece, 2018 Traffic site	34 %	7 %	7 %		3 %	6 %		43 %
	Grivas et al., 2018 Urban background site	54 %	4 %	8 %		1%	7%		24%
	Theodosi et al., Multi-year chemical composition of the fine-aerosol fraction in Athens, Greece, with emphasis on the contribution of residential heating in wintertime, 2018 Daytime	43 %	8 %	19 %		1 %	10 %		19 %
	Theodosi et al., 2018 Night time	21 %	6 %	39 %		8 %	7 %		19 %
	TRANSPHORM, Transport related air pollution and health impacts – integrated methodologies for assessing particulate matter, 2014	21 %	40 %						38 %
	Diapouli, 2017 SUB	63 %	4 %	23 %			1 %		9 %
	Diapouli, 2017 UB	29 %	6 %	46 %			4 %		16 %
	Amato et al., AIRUSE-LIFE+: a harmonised PM speciation and source	55 %	10 %	2 %		21 %	2 %		11 %

			Urban background						
Agglomeration	Source	Regional background	Industry/ commercial/ energy	Domestic	Other transport and mobile machinery (e.g. aircraft/rail)	Waste/ agricultural/ natural (or unaccounted)	Dusts (calcium and iron rich)	Road transport	Local road contribution
	apportionment in five Southern European cities, 2015								
Barcelona	TRANSPHORM, 2014	19 %	32 %	37 %					12 %
	Amato et al., 2015	52 %	24 %				2 %		22 %
	APICE report - Air quality status in Barcelona, Marseille, Genoa, Venice and Thessaloniki (WP 3.2), 2013 Port	41 %	15 %				25 %		18 %
	APICE, 2013 Urban	67 %	7 %				2 %		15 %
	APICE, 2013 Urban summer	46 %	7 %	7 %	17 %	3 %			20 %
	APICE, 2013 Urban winter	73 %	9 %	4 %	5 %	1 %			8 %
Berlin	Air Quality Plan for Berlin 2011-2017	58%	2%	4%	4%	4%	3%	12%	13%
	Luftreinhalteplan für Berlin 2. Fortschreibung	62%	5%	1%	2%		4%	5%	21%
Bucharest	*Planul Integrat de Calitate a Aerului în Municipiul București 2018-2022*	78%	1%	9%		0%			12%
Krakow	Samek et al., Quantitative assessment of PM2.5 sources and their seasonal variation in Krakow, 2017	36 %	25 %	16 %		14 %			8 %
Lisbon	*Plano de Melhoria da Qualidade do Ar,* 2019	41 %	1 %	11 %	0 %			17 %	30 %
Madrid	None identified								

			Urban background						
Agglomeration	Source	Regional background	Industry/ commercial/ energy	Domestic	Other transport and mobile machinery (e.g. aircraft/rail)	Waste/ agricultural/ natural (or unaccounted)	Dusts (calcium and iron rich)	Road transport	Local road contribution
Paris	Airparif, Source apportionment of airborne particles in the Ile-De-France region, 2012	39 %	2 %	5 %	0 %	0 %	5 %	5 %	44 %
	TRANSPHORM, 2014	28 %	53 %						18 %
Rome	TRANSPHORM, 2014	15 %	27 %	47 %					10 %
Stockholm	Segersson et al., Health impact of PM10, PM2.5 and black carbon exposure due to different source sectors in Stockholm, Gothenburg and Umea, Sweden, 2017	71 %		15 %	0 %	0 %			14 %

Figure 3-1 Illustrative NO_X source apportionment at background and roadside locations

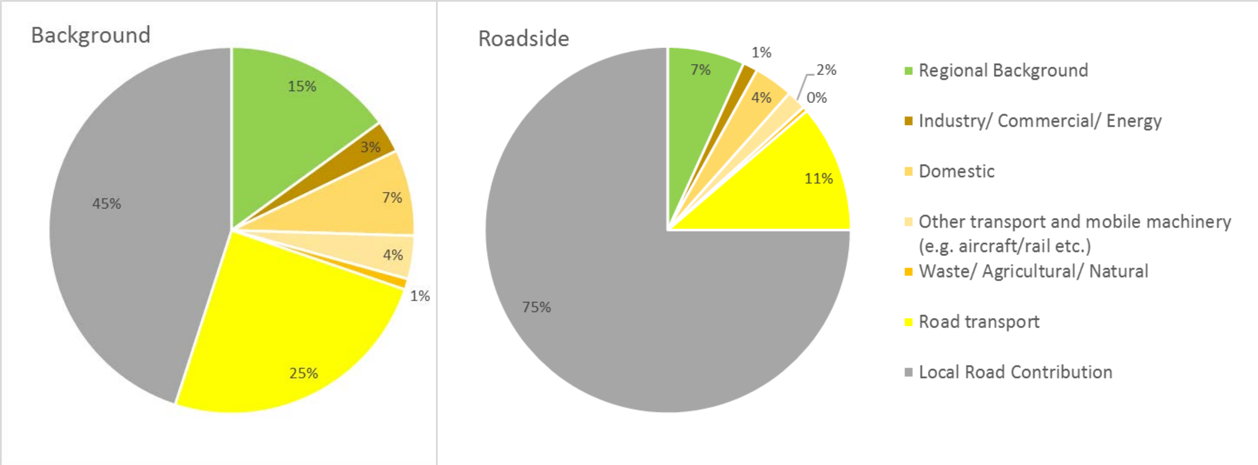
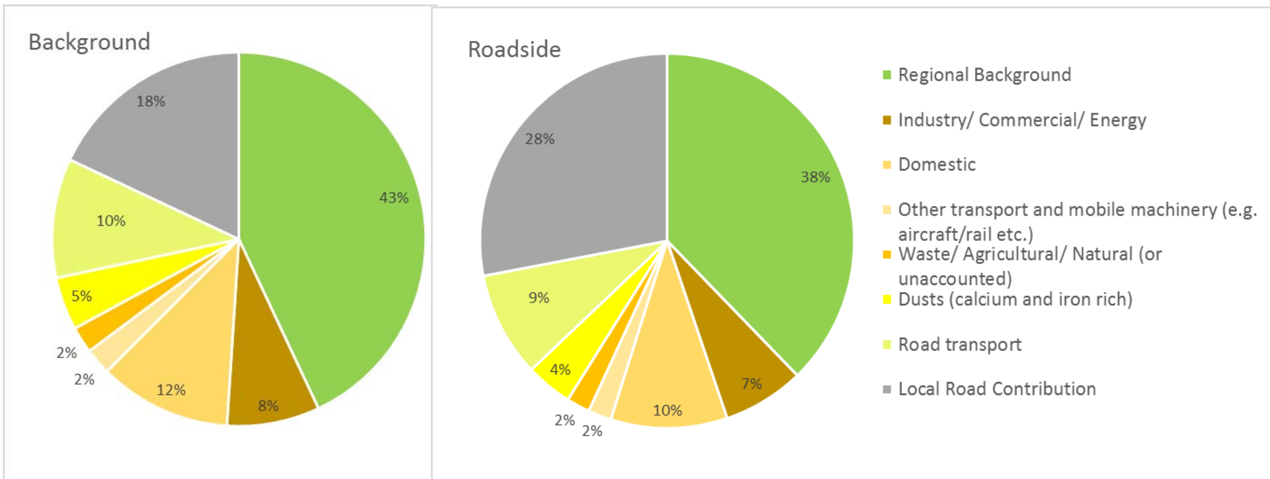


Figure 3-2 Illustrative $PM_{2.5}$ source apportionment at background and roadside locations



3.4.3. Changes in activity during lockdown

Data for the 10 agglomerations (see section 3.4.4) show significant reductions in polluting activity (driving and industrial production) during lockdown. For example, driving fell by up to 82 % (Paris), and production in industry by up to 44 % (Rome).

There are important policy lessons from lockdown. The situation demonstrates what can be achieved with sufficient policy drivers and changes to mobility patterns that lead to reductions in combustion vehicle road traffic, which appear to be the most effective way to reduce NO_2 concentrations. The reductions in driving observed during lockdown were, in many cases, supported by temporary and permanent changes to walking and cycling infrastructure to enable people to take short journeys by active modes. Many people favoured ways of travelling that guaranteed adequate physical distancing, such as walking and cycling, while there was a drop in the use of public transport.[73] The interviews carried out for Task 1 identified examples of the relaxation of normal administrative and planning requirements to enable rapid changes to infrastructure.

[73] European Parliament, COVID-19 and urban mobility: impacts and perspectives. Rapid-response briefing, 2020.

- The use of digital information to provide Mobility as a Service (MaaS) to enable the full integration of a multimodal transportation system.[84]

There is evidence of public support for measures to encourage walking and cycling. In a survey carried out in May 2020 in 21 metropolitan areas across six countries, 74 % of respondents agreed that 'cities must take effective measures to protect citizens from air pollution, even if this requires reallocating public space to walking, cycling and public transport'.[85] The survey also showed that 21 % of respondents plan to cycle more following lockdown and 35 % plan to walk more. It is recommended that engagement with the public on these options continues as lockdowns extend into the autumn and winter months.

3.4.4. Data analysis

Table 3.5 shows the changes in driving and industrial production in each of the 10 agglomerations studied. Driving in private vehicles fell by as much as 82 % (Paris), while production in industry fell by as much as 44 % (Rome). Similar trends were seen across Europe. A study using the Apple Mobility Trends data for 26 countries showed rapid reductions in car traffic of 40 % (uncertainty ±21 %) in early March. [86] Eurostat data showed that production in industry was 27 % lower in the 27 EU Member States in April 2020 than in January 2020.

The reductions in activity have been applied to the emission sources in the illustrative source apportionment for background and roadside locations. This enables the derivation of the reductions in overall NO_X and $PM_{2.5}$ concentrations that would be expected as a result of the reductions in activity. The results are shown in Table 3-5. The results show generally good agreement between the expected and actual reduction in pollutant concentration during lockdown. These results are illustrative and deviations are to be expected as the actual source apportionment will vary between monitoring stations, but the majority of the expected results are within 20 % of actuals. This confirms that the illustrative source apportionment provides a good representation of the current situation in the 10 agglomerations, and is also considered relevant to urban areas across Europe given the similarity of sources of pollution (in particular the importance of road traffic and regional sources of pollution).

[84] European Commission, 2020.

[85] Transport & Environment, No going back: European public opinion on air pollution in the Covid-19 era, 2020. Available at: https://www.transportenvironment.org/sites/te/files/publications/Briefing%20-%20polling%20Covid-19%20%26%20mobility.pdf

[86] Linka, K., Goriely, A. and Kuhl, E., 'Global and local mobility as a barometer for COVID-19 dynamics', *Medrxiv*, 2020.

Table 3.5 Changes in activity and illustrative expected changes in pollutant concentrations

			NO_2				$PM_{2.5}$			
City	Driving	Production in industry (Member States)	Expected roadside change	Actual roadside change	Expected background change	Actual background change	Expected roadside change	Actual roadside change	Expected background change	Actual background change
Athens	-56 %	-11 %	-48 %	-28 %	-39 %	-36 %	-26 %	-28 %	-19 %	-5 %
Barcelona	-80 %	-33 %	-69 %	-54 %	-57 %	-55 %	-36 %	-31 %	-29 %	-28 %
Berlin	-45 %	-29 %	-39 %	-33 %	-32 %	-44 %	-23 %	0 %	-17 %	0 %
Bucharest	-74 %	-36 %	-64 %	-58 %	-53 %	-41 %	-34 %	N/A	-27 %	-52 %
Krakow	-73 %	-26 %	-64 %	-31 %	-52 %	-21 %	-33 %	-33 %	-26 %	0 %
Lisbon	-79 %	-30 %	-69 %	-56 %	-56 %	-46 %	-36 %	-30 %	-28 %	-30 %
Madrid	-79 %	-33 %	-68 %	-68 %	-56 %	-53 %	-36 %	-34 %	-29 %	-13 %
Paris	-82 %	-34 %	-72 %	-37 %	-59 %	-43 %	-37 %	-28 %	-30 %	0 %
Rome	-67 %	-44 %	-59 %	-58 %	-48 %	-54 %	-32 %	-25 %	-26 %	-26 %
Stockholm	-15 %	-16 %	-13 %	-56 %	-11 %	-42 %	-11 %	-47 %	-6 %	0 %

See Table 3.2. for changes in pollutant concentrations during the lockdown periods in each city
Dark blue shading: <10 % difference
Light blue shading: <20 % difference

3.4.5. Conclusions

The agreement between the expected and actual reduction in NO_X concentrations during lockdown corroborates the long-held consensus that motor vehicles with combustion engines represent the most important source of NO_X in cities, and reductions in traffic emissions have a considerable effect on NO_2 levels [87]. Consequently, measures that are able to significantly reduce road traffic are likely to be highly effective at reducing NO_2 concentrations in urban areas and should therefore be prioritised.

The results for $PM_{2.5}$ show that road traffic is an important source in cities but the influence of regional pollution moderates the effect of local reductions in activity. Efforts to reduce $PM_{2.5}$ therefore need to combine local and regional actions.

Decreases in road traffic were achieved in the 10 agglomerations by reducing the need to travel (e.g. increased home working and reduced commuting) and enabling the public to undertake short journeys by active travel (walking and cycling). There is evidence of public support for urban mobility policies that encourage active travel by creating the necessary space and infrastructure. The speed with which the measures were implemented shows that making changes to streets to promote active travel does not always require large amounts of money, complex design, or time-consuming administrative processes[88].

3.5. Research Question 4: Effects of decreased air pollution levels on health and the environment

3.5.1. Methodology

The effects on the health of the population of similar reductions in pollutant concentrations to those experienced during lockdown – if they were to continue into the future – have been estimated using EEA data together with the AQ monitoring data results gathered for the 10 agglomerations studied (section 3.3).

The EEA's report, 'Air quality in Europe – 2019' considers the health effects of air pollution using population-weighted pollutant concentrations across Member States and relative risk factors for NO_2 and $PM_{2.5}$.[89] This information can be used to provide approximate values for the change in premature deaths in the relevant Member States that would result if concentrations were reduced to the degree seen during lockdown over a longer period.

The EEA report considers health effects using population-weighted pollutant concentrations over entire Member States. This means that the levels of pollution exposure at background locations and the number of people in these areas are considered, as well as peak roadside concentrations. As the majority of people do not live in roadside locations with the highest pollutant concentration, the pollutant changes at background monitoring sites during lockdown shown in Table 3.2 have been used in this analysis.

These reductions have been applied to the annual mean concentrations for each country taken from the 'Air quality in Europe – 2019' report (which uses data for 2017). This has also been considered

[87] Baldasano, 2020.

[88] European Commission, 2020.

[89] EEA, Air quality in Europe – 2019, 2019. Available at: https://www.eea.europa.eu/publications/air-quality-in-europe-2019
Analysis carried out using data from this report prior to the publication of "Air quality in Europe – 2020"

for the EU total, assuming that the average background reductions across the 10 agglomerations studied occur across the EU. These reductions are 43 % for NO_2 and 15 % for $PM_{2.5}$. The calculations assume an increase in the risk of mortality of 6.2 % for a 10 µg/m^3 increase in $PM_{2.5}$ and an increase in the risk of mortality of 5.5 % for a 10 µg/m^3 increase in NO_2. Mortality is the only health effect considered in the EEA report and therefore the only one available for this analysis. These relative risk factors do not account for any interactions between COVID-19 and mortality.

Calculations to consider the effects of atmospheric pollution on natural ecosystems are more complex, as factors such as the distance to urban areas and the type of ecosystem are important considerations. The effect of continued changes to pollutant concentrations on the environment have therefore been considered qualitatively using the identified literature.

3.5.2. Health impact data analysis (countries and EU-wide)

The results of the analysis are shown in Table 3.6. The quantifications of health impacts are presented individually for the separate air pollutants. They cannot be added together, as they exhibit some degree of correlation by acting on the same pathways, so effects may be double counted.

The table highlights the relative health effects of NO_2 and $PM_{2.5}$, with significantly more deaths being attributable to $PM_{2.5}$ than NO_2. The analysis shows that nationwide reductions (over one year) in PM_{25} and NO_2 concentrations of the scale seen during lockdown would result in around 4 500 and 2 500 fewer premature deaths per year attributable to each pollutant, respectively, across the EU.

Table 3.6 Potential changes in mortality risk from air pollution using changes in pollutant concentration during lockdown

		$PM_{2.5}$					NO_2				
Country	Pop (1,000)	Annual mean	premature deaths	Change in annual mean	Change in mortality risk	Reduced premature deaths	Annual mean	Premature deaths	Change in annual mean	Change in mortality risk	Reduced premature deaths
Germany	82 176	11.6	59 600	0.0	0.0 %	0	20.2	11 900	-8.8	-4.9 %	-577
Greece	10 784	19.6	12 900	-1.0	-0.6 %	-82	19.6	2 900	-7.0	-3.8 %	-111
Spain	44 145	11.1	24 100	-3.1	-1.9 %	-464	20.0	7 700	-11.1	-6.1 %	-469
Spain	44 145	11.1	24 100	-1.4	-0.9 %	-209	20.0	7 700	-10.5	-5.8 %	-445
France	64 977	10.9	33 200	0.0	0.0 %	10	17.3	7 500	-7.5	-4.1 %	-308
Italy	60 666	16.6	58 600	-4.3	-2.6 %	-1 553	22.1	14 600	-12.0	-6.6 %	-964
Poland	37 967	20.6	43 100	0.0	0.0 %	0	15.2	1 500	-3.2	-1.7 %	-26
Portugal	9 809	8.3	4 900	-2.4	-1.5 %	-74	15.3	610	-7.0	-3.8 %	-23
Romania	19 761	16.8	23 400	-8.7	-5.4 %	-1 267	17.6	2 600	-7.2	-4.0 %	-103
Sweden	9 851	5.7	2 900	0.0	0.0 %	0	10.7	30	-4.5	-2.5 %	-1
EU-27	50 628	12.9	374 000	-2.0	-1.2 %	-4 566	16.3	68 000	-7.1	-3.9 %	-2 648

4. References

Air, R., Pouponneau, M., Forestier, B. and Cape, F., *Les zones à faibles émissions (Low Emission Zones) à travers l'Europe: déploiement, retours d'expériences, évaluation d'impacts et efficacité du système – Rapport,* ADEME, 2019. Retrieved from https://www.ademe.fr/sites/default/files/assets/documents/rapport-zones-faibles-emissions-lez-europe-ademe-2018.pdf

Air, R., Pouponneau, M., Forestier, B. and Cape, F., *Les zones à faibles émissions (Low Emission Zones) à travers l'Europe: déploiement, retours d'expériences, évaluation d'impacts et efficacité du système, 2020.* Retrieved from https://www.ademe.fr/sites/default/files/assets/documents/rapport-zones-faibles-emissions-lez-europe-ademe-2020.pdf

Air Quality Expert Group, *Estimation of changes in air pollution emissions, concentrations and exposure during the COVID-19 outbreak in the UK*, 2020. Retrieved from https://uk-air.defra.gov.uk/assets/documents/reports/cat09/2007010844_Estimation_of_Changes_in_Air_Pollution_During_COVID-19_outbreak_in_the_UK.pdf

Amundsen, A. H. and Sundvor, I., *Low Emission Zones in Europe: Requirements, enforcement and air quality,* Institute of Transport Economics, 2018. Retrieved from https://www.toi.no/getfile.php?mmfileid=49204

Bontempi, E., 'First data analysis about possible COVID-19 virus airborne diffusion due to air particulate matter (PM): The case of Lombardy (Italy)', *Environmental Research,* 2020, p. 186. Retrieved from https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7204748/

Borro, M., Di Girolamo, P., Gentile, G., De Luca, O., Preissner, R., Marcolongo, A. and Simmaco, M., 'Evidence-based considerations exploring relations between the SARS-CoV-2 pandemic and air pollution: Involvement of PM2.5-mediated up-regulation of the viral receptor ACE-2. 17', *International Journal of Environmental Research and Public Health,* Vol. 17, No. 15, 2020. Retrieved from https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7432777/

CE Delft, *Health impacts and costs of diesel emissions in the EU,* 2018. Retrieved from https://epha.org/wp-content/uploads/2018/11/embargoed-until-27-november-00-01-am-cet-time-ce-delft-4r30-health-impacts-costs-diesel-emissions-eu-def.pdf

Chakraborty, P., Jayachandran, S., Padalkar, P., Sitlhou, L., Chakraborty, S., Kar, R. and Srivastava, M., 'Exposure to nitrogen dioxide (NO2) from vehicular emission could increase the COVID-19 pandemic fatality in India: A perspective', *Bulletin of Environmental Contamination and Toxicology*, Vol. 1, No. 7, 2020. Retrieved from https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7363019/

Chia, P., Coleman, K., Tan, Y., Xiang Ong, S., Gum, M., Lau, S. and Marimuthu, K., 'Detection of air and surface contamination by SARS-CoV-2 in hospital rooms of infected patients', *Nature,* Vol. 11, 2020. Retrieved from https://www.nature.com/articles/s41467-020-16670-2#article-info

Coccia, M., 'Factors determining the diffusion of COVID-19 and suggested strategy to prevent future accelerated viral infectivity similar to COVID', *Science of the Total Environment,* 2020, p. 729. Retrieved from https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7169901/

Cole, M. A., Ozgen, C. and Strobl, E., 'Air pollution exposure and COVID-19', *IZA Institute of Labour Economics Discussion*, 2020. Retrieved from http://ftp.iza.org/dp13367.pdf

Comunian, S., Dongo, D., Milani, C. and Palestini, P., 'Air pollution and COVID-19: The role of particulate matter in the spread and increase of COVID-19's morbidity and mortality', *International Journal* *of Environmental Research and Public Health,* Vol. 17, No. 12, 2020. Retrieved from https://www.mdpi.com/1660-4601/17/12/4487/htm

Conticini, E., Frediani, B. and Caro, D., 'Can atmospheric pollution be considered a co-factor in extremely high level of SARS-CoV-2 lethality in Northern Italy?', *Environmental Pollution,* 2020, p. 261. Retrieved from https://www.sciencedirect.com/science/article/abs/pii/S0269749120320601

Contini, D. and Costabile, F., 'Does air pollution Influence COVID-19 outbreaks?' *Atmosphere,* Vol. 11, No. 4, 2020, p. 377. Retrieved from https://www.mdpi.com/2073-4433/11/4/377/htm

de Man, P., Paltansing, S., Ong, D. S., Vaessen, N., van Nielen, G. and Koeleman, J. G., 'Outbreak of coronavirus disease 2019 (COVID-19) in a nursing home associated with aerosol transmission as a result of inadequate ventilation', *Clinical Infectious Diseases*, 2020. Retrieved from https://academic.oup.com/cid/advance-article/doi/10.1093/cid/ciaa1270/5898577

European Environemntal Agency, *Healthy environment, healthy lives: how the environment influences health and well-being in Europe,* Luxembourg: Publications Office of the European Union, 2019. Retrieved from https://www.eea.europa.eu/publications/healthy-environment-healthy-lives

European Parliament - Directorate General for Internal Poilicies of the Union, *Air quality and urban traffic in the EU: best practices and possible solution,* European Parliament, 2018. Retrieved from https://www.europarl.europa.eu/RegData/etudes/STUD/2018/604988/IPOL_STU(2018)604988_EN.pdf

Fattorini, D. and Regoli, F., 'Role of the chronic air pollution levels in the Covid-19 outbreak risk in Italy', *Environmental Pollution,* 2020. Retrieved from https://pubmed.ncbi.nlm.nih.gov/32387671/

Filippini, T., Rothman, K. J., Goffi, A., Ferrari, F., Maffeis, G., Orsini, N. and Vincetia, M., 'Satellite-detected tropospheric nitrogen dioxide and spread of SARS-CoV-2 infection in Northern Italy', *Science of the Total Environment,* 2020, p. 739. Retrieved from https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7297152/

Frontera, A., Cianfanelli, L., Vlachos, K., Landoni, G. and Cremona, G., 'Severe air pollution links to higher mortality in COVID-19 patients: The "double-hit" hypothesis', *Journal of Infection,* Vol. *81, No*. 2, 2020, pp. 255-259. Retrieved from https://www.journalofinfection.com/article/S0163-4453(20)30285-1/fulltext

Gehrsitz, M., 'The effect of low emission zones on air pollution and infant health', *Journal of Environmental Economics and Management*, 2016. Retrieved from https://strathprints.strath.ac.uk/59756/1/Gehrsitz_JEEM_2017_effect_of_low_emission_zones_on_air_pollution_and_infant_health.pdf

Hendryx, M. and Luob, J., 'COVID-19 prevalence and fatality rates in association with air pollution emission concentrations and emission sources', *Environmental Pollution,* 2020, p. 265. Retrieved from https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7320861/

Layman, *Clean air for European cities*, 2016. Retrieved from http://www.cleanair-europe.org/fileadmin/user_upload/redaktion/downloads/Clean_Air_Publikationen/83_D4_Laymans_Report_EN.pdf

Li, H., Xu, X.-L., Dai, D.-W., Huang, Z.-Y., Ma, Z. and Guan, Y.-J., 'Air pollution and temperature are associated with increased COVID-19 incidence: A time series study', *International Journal of Infectious Diseases,* Vol. 97, 2020, pp. 272-282. Retrieved from https://www.ijidonline.com/article/S1201-9712(20)30383-0/fulltext

Liang, D., Shi, L., Zhao, J., Liu, P., Schwartz, J., Gao, S. and Howard, C., 'Urban air pollution may enhance COVID-19 case fatality and mortality rates in the United States', *medRxiv*, 2020. Retrieved from https://www.medrxiv.org/content/10.1101/2020.05.04.20090746v1

Lin, C.-I., Tsai, C.-H., Sun, Y.-L., Hsieh, W.-Y., Yi-Chang, L., Chen, C.-Y. and Lin, C.-S., 'Instillation of particulate matter 2.5 induced acute lung injury and attenuated the injury recovery in ACE2 knockout mice', *International Journal of Biological Sciences,* Vol. 14, No. 3, 2020, pp. 253–265. Retrieved from https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5859472/

Liu, Y., Ning, Z., Chen, Y., Guo, M., Liu, Y., Gali, N. and Lan, K., 'Aerodynamic analysis of SARS-CoV-2 in two Wuhan hospitals', *Nature,* Vol. 582, 2020, pp. 557-560. Retrieved from https://www.nature.com/articles/s41586-020-2271-3

Ma, J., Qi, X., Chen, H., Li, X., Zhang, Z., Wang, H. and Maosheng, Y., 'Coronavirus disease 2019 patients in earlier stages exhaled millions of severe acute respiratory syndrome coronavirus 2 per hour', *Clinical Infectious Diseases*, 2020. Retrieved from https://academic.oup.com/cid/advance-article/doi/10.1093/cid/ciaa1283/5898624

Office for National Statistics, *Does exposure to air pollution increase the risk of dying from the coronavirus (COVID19)?* 2020, Retrieved from https://www.ons.gov.uk/economy/environmentalaccounts/articles/doesexposuretoairpollutionincreasetheriskofdyingfromthecoronaviruscovid19/2020-08-13

Office for National Statistics, *ONS (2020) Coronavirus (COVID-19) related mortality rates and the effects of air pollution in England*, 2020. Retrieved from https://www.ons.gov.uk/economy/environmentalaccounts/methodologies/coronaviruscovid19relatedmortalityratesandtheeffectsofairpollutioninengland

Ogen, Y., 'Assessing nitrogen dioxide (NO2) levels as a contributing factor to coronavirus (COVID-19) fatality', *Science of the Total Environment*, 2020. Retrieved from https://www.sciencedirect.com/science/article/pii/S0048969720321215

Pansini, R. and Fornacca, D., 'Early evidence of a higher incidence of COVID-19 in the air polluted regions of eight severely affected countries', *MedRxiv*, 2020. Retrieved from https://www.medrxiv.org/content/10.1101/2020.04.30.20086496v2.full.pdf

Popkin, B. M., Du, S., Green, W. D., Beck, M. A., Algaith, T., Herbst, C. H. and Shekar, M., 'Individuals with obesity and COVID-19: A global perspective on the epidemiology and biological relationships', *Obesity Review*, 2020. Retrieved from https://onlinelibrary.wiley.com/doi/10.1111/obr.13128

Public Health England, *Review of interventions to improve outdoor air quality and public health,* 2019. Retrieved from https://www.gov.uk/government/publications/improving-outdoor-air-quality-and-health-review-of-interventions

Santarpia, J., Rivera, D., Herrera, V., Morwitzer, M. J., Creager, H., Santarpia, G. W. and Lowe, J. J., 'Transmission Potential of SARS-CoV-2 in Viral Shedding Observed at the University of Nebraska Medical Centre', *Scientific Reports,* Vol. 10, 2020. Retrieved from https://www.medrxiv.org/content/10.1101/2020.03.23.20039446v2.full.pdf

Setti, L., Passarini, F., De Gennaro, B. P., Perrone, M. G., Borelli, M., Palmisani, J. and Miani, A., 'SARS-Cov-2 RNA found on particulate matter of Bergamo in Northern Italy: First preliminary evidence', *Environmental Research*, 2020. Retrieved from https://www.medrxiv.org/content/10.1101/2020.04.15.20065995v2

Tang, S., Mao, Y., Jones, R. M., Tan, Q., Ji, J. S., Li, N. and Shi, X., 'Aerosol transmission of SARS-CoV-2? Evidence, prevention and control', *Environmental International,* Vol. 144, 2020. Retrieved from https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7413047/

Transport & Environment *Low-Emission Zones are a success - but they must now move to zero-emission mobility*, 2019. Retrieved from https://www.transportenvironment.org/sites/te/files/publications/2019_09_Briefing_LEZ-ZEZ_final.pdf

Travaglio, M., Yu, Y., Popovic, R., Selley, L., Santos Leal, N. and Martins, M., 'Links between air pollution and COVID-19 in England', *medRxiv*, 2020. Retrieved from https://www.medrxiv.org/content/10.1101/2020.04.16.20067405v5

Wu, X., Nethery, R. C., Sabath, B. M., Braun, D. and Dominici, F., 'Exposure to air pollution and COVID-19 mortality in the United States: A nationwide cross-sectional study', *medRxiv*, 2020. Retrieved from https://www.medrxiv.org/content/10.1101/2020.04.05.20054502v2

Zhang, R., Li, Y., Zhang, A. L., Wang, Y. and Molina, M. J., 'Identifying airborne transmission as the dominant route for the spread of COVID-19', *Proceedings of the National Academy of Science of the United States of America,* Vol. 117, No. 26, 2020, pp. 14857-14863. Retrieved from https://www.pnas.org/content/pnas/117/26/14857.full.pdf

Zoran, M. A., Savastru, R. A., Savastru, D. M. and Tautan, M. N., 'Assessing the relationship between ground levels of ozone (O3) and nitrogen dioxide (NO2) with coronavirus (COVID-19) in Milan, Italy', *Science of the Total Environment,* 2020, p. 740. Retrieved from https://www.sciencedirect.com/science/article/pii/S0048969720335257

References per city - sections 2.3.1 to 2.3.10

Athens

Joint Research Centre, *Catalogue of Air Quality Measures*. Retrieved on 17 September 2020 from https://fairmode.jrc.ec.europa.eu/measure-catalogue/

Nomothesia. *Legislative Content Act of 16-9-2009-2 Government Gazette 181 / A / 16-9-2009*. Retrieved on 17 September 2020 from https://www.e-nomothesia.gr/kat-aytokinita/tele-kuklophorias/prakse-nomothetikou-periekhomenou-16-9-2009-2.html

Urban access regulations. *Athens*. Retrieved on 17 September 2020 from https://urbanaccessregulations.eu/countries-mainmenu-147/greece/athens

Barcelona

Ajuntament de Barcelona. *Mesura de Govern: Programa de Mesures contra la Contaminació at Atmosfèrica*. Retrieved from https://bcnroc.ajuntament.barcelona.cat/jspui/bitstream/11703/99264/1/mesuradegove.pdf.pdf

Àrea Metropolitana de Barcelona. Retrieved on 17 September 2020 from https://www.amb.cat/es/web/amb/seu-electronica/tramits/detall/-/tramit/targeta-t-verda/6546634/11696

Àrea Metropolitana de Barcelona. Retrieved on 17 September 2020 from https://www.zbe.barcelona/es/index.html

Urban access regulations. *Barcelona*. Retrieved on 17 September 2020 from https://urbanaccessregulations.eu/countries-mainmenu-147/spain/barcelona

Berlin

European Environmental Agency, *Europe's urban air quality — re-assessing implementation challenges in cities EEA Report No 24/2018*, 2019. Retrieved from https://www.eea.europa.eu/publications/europes-urban-air-quality

Joint Research Centre, *Catalogue of Air Quality Measures*. Retrieved on 17 September 2020 from https://fairmode.jrc.ec.europa.eu/measure-catalogue/

Senate Department for Urban Development and the Environment, *Air Quality Plan for Berlin 2011-2017*, 2017. Retrieved from https://www.berlin.de/senuvk/umwelt/luftqualitaet/de/luftreinhalteplan/download/lrp_150310_en.pdf

Senatsverwaltung für umwelt verkehr und klimaschutz. *Die wichtigsten Ergebnisse Evaluierung umgesetzter Maßnahmen aus dem Luftreinhalteplan 2005-2010.* Retrieved on 17 September 2020 from https://www.berlin.de/senuvk/umwelt/luftqualitaet/de/luftreinhalteplan/situation_evaluierung.shtml

Senatsverwaltung für umwelt verkehr und klimaschutz, *Luftreinhalteplan für Berlin 2. Fortschreibung*, 2019. Retrieved from https://www.berlin.de/senuvk/umwelt/luft/luftreinhaltung/luftreinhalteplan_2025/download/Luftreinhalteplan.pdf

Soot free cities, *Berlin*. Retrieved on 17 September 2020 from http://www.sootfreecities.eu/sootfreecities.eu/public/city/berlin

Urban access regulations, *Germany*. Retrieved on 17 September 2020 from https://urbanaccessregulations.eu/countries-mainmenu-147/germany-mainmenu-61

Bucharest

Aer. Retrieved on 17 September 2020 from https://aerlive.ro/category/proiect/

Consiliul General al Municipiului București, *Planul Integrat de Calitate a Aerului în Municipiul București 2018-2022*, 2018. Retrieved from https://api.pmb.ro/storage/Mediu/PlanuriCalitateAer/PlanIntegrat/2018-2022/plan_integrat_calitate_aer_buc_2018_2022.pdf

Decizia Consiliului General al Municipiului București nr. 377 / 2018. Retrieved on 4 November 2020 from http://acteinterne.pmb.ro/legis/acteinterne/AtachInt/H377_18.pdf

Decizia Consiliului General al Municipiului București nr. 377 / 2018. Retrieved on 4 November 2020 from http://acteinterne.pmb.ro/legis/acteinterne/AtachInt/H539_19.pdf

Raport referitor la stadiul realizării măsurilor din Planul Integrat de Calitate a Aerului în municipiul București 2018 – 2022, aferent anului 2019. Retrieved on 4 November 2020 from https://doc.pmb.ro/institutii/primaria/directii/directia_mediu/planuri_de_calitate_aer/docs/plan_integrat_calitate_aer_buc/raport_anual_privind_stadiul_realizarii_masurilor_PICA_2019.pdf

Raport anual de monitorizare privind efectele aplicării măsurilor cuprinse în Planul integrat de calitate a aerului în municipiul București pentru anul 2019. Retrieved on 4 November 2020 from http://www.anpm.ro/documents/16241/38124058/RAPORT+PICA+2019+APMB+v.4.docx/49e92fb2-5b3d-4d01-b5dc-3d67be67b3b3

Interview with representatives of the National Environmental Protection Agency, October 2020.

Comunicat de presă PMB: Vinieta ecologica a fost abrogata prin votul Consiliului General al Municipiului București. Retrieved on 4 November 2020 from https://www2.pmb.ro/pmb/comunicate/presa_com.php?msj=7748

Tot ce trebuie să știi despre taxa Oxigen și absurditățile ei. Retrieved on 4 November 2020 from https://romania.europalibera.org/a/tot-ce-trebuie-sa-stii-taxa-oxigen-/30366927.html

Krakow

Krakow.pl, *ABC strefy czystego transportu na Kazimierzu*. Retrieved on 17 September 2020 from https://www.krakow.pl/aktualnosci/226585,29,komunikat,abc_strefy_czystego_transportu_na_kazimierzu.html

Małopolska in a healthy environment, *Effects of activities*. Retrieved on 17 September 2020 from https://powietrze.malopolska.pl/program-ochrony-powietrza/efekty-realizacji/

Małopolska in a healthy environment, *Air quality plan*. Retrieved on 17 September 2020 from https://powietrze.malopolska.pl/en/air-quality-plan/

Małopolska in a healthy environment, *Anti-smog resolution for Małopolska*. Retrieved on 17 September 2020 from https://powietrze.malopolska.pl/en/anti-smog-resolution/

Urban access regulations, *Krakow*. Retrieved on 17 September 2020 from https://urbanaccessregulations.eu/countries-mainmenu-147/poland/krakow-cracow

Wysokienapiecie.pl, *Koniec strefy czystego transportu w Krakowie*. Retrieved on 17 September 2020 from https://wysokienapiecie.pl/17607-koniec-strefy-czystego-transportu-w-krakowie/

Lisbon

Câmara Municipal de Lisboa, *Resoluções dos Órgãos do Município*, 2014. Retrieved from http://www.cm-lisboa.pt/fileadmin/VIVER/Mobilidade/ZER/Proposta_642_CM_2014_3fase_ZER.pdf

Câmara Municipal de Lisboa, *Lisboa mais verde e mais saudável: os desafios da poluição atmosférica*. Retrieved on 27 November 2020 from https://www.lisboa.pt/agenda/o-que-fazer/detalhe/1430/lisboa-mais-verde-e-mais-saudavel-os-desafios-da-poluicao-atmosferica

Carris, *Renovação da frota de veículos de transporte público da CARRIS: Autocarros Limpos 2020*. Retrieved on 17 September 2020 from https://www.carris.pt/media/3hsfn1x4/poseur_autocarros-limpos.pdf

Faculdade de Ciências e Tecnologia da Universidade Nova de Lisboa, *Plano de Melhoria da Qualidade do ar da região de Lisboa e vale do tejo para os poluentes partículas* PM_{10} *e* NO_2 *nas aglomerações da área metropolitana de Lisboa Norte e área metropolitana de Lisboa Sul*, 2017. Retrieved from http://www.ccdr-lvt.pt/files/ce7600294264a00712abc87c6e04c4458d9d7dac.pdf

Diário de Notícias, *Já circulam por Lisboa os novos autocarros elétricos da Carris*. Retrieved on 17 September 2020 from https://www.dn.pt/lisboa/ja-circulam-por-lisboa-os-novos-autocarros-eletricos-da-carris--11914699.html

Lisboa Camera Municipal, *Avenida Baixa Chiado*. Retrieved on 17 September 2020 from https://zer.lisboa.pt/

Partido Pessoas-Animais-Natureza, *Recomendação – Pela redução da poluição dos navios cruzeiros*. Retrieved on 17 September 2020 from https://www.pan.com.pt/recomendacao-pela-reducao-da-poluicao-dos-navios-cruzeiros/#_ftn2

Público, *Se a câmara gerisse os transportes a poluição em Lisboa seria menor, diz vereador*. Retrieved on 17 September 2020 from https://www.publico.pt/2015/04/01/local/noticia/se-a-camara-gerisse-os-transportes-a-poluicao-em-lisboa-seria-menor-diz-vereador-1691045

Renascença, *Lisboa deixará de receber navios cruzeiro a gasóleo em 2022*. Retrieved on 17 September 2020 from https://rr.sapo.pt/2020/06/05/pais/lisboa-deixara-de-receber-navios-cruzeiro-a-gasoleo-em-2022/noticia/195662/

Soot-free cities, *Lisbon*. Retrieved on 17 September 2020 from http://www.sootfreecities.eu/sootfreecities.eu/public/city/lisbon

Urban access regulations, *Lisbon*. Retrieved on 17 September 2020 from https://urbanaccessregulations.eu/countries-mainmenu-147/portugal/lisbon

Zero, *Quatro anos após o início da 3ª fase, zero quer zer de Lisboa com maior exigência e medidas complementares*. Retrieved on 17 September 2020 from https://zero.ong/quatro-anos-apos-o-inicio-da-3a-fase-zero-quer-zer-de-lisboa-com-maior-exigencia-e-medidas-complementares/

Madrid

Area de Gobierno de Medio Ambiente, Seguridad y Movilidad, *Madrid's air quality plan 2011-2015*, 2012. Retrieved from https://www.madrid.es/UnidadesDescentralizadas/AreasUrbanas_EducacionAmbiental/Catalogo/AirQualityPlan2011-15.pdf

European Commission, *LIFE GySTRA - Global system for Sustainable TRAffic emissions management*. Retrieved on 17 September 2020 from https://ec.europa.eu/environment/life/project/Projects/index.cfm?fuseaction=search.dspPage&n_proj_id=6278

Madrid.es, *Plan A: Air quality and climate change plan for the city of Madrid*. Retrieved from https://www.madrid.es/UnidadesDescentralizadas/Sostenibilidad/CalidadAire/Ficheros/PlanAire&CC_Eng.pdf

Portal web del Ayuntamiento de Madrid, *Criterios de Acceso y Autorizaciones*. Retrieved on 17 September 2020 from https://www.madrid.es/portales/munimadrid/es/Inicio/Movilidad-y-transportes/Madrid-Central-Zona-de-Bajas-Emisiones/Criterios-de-acceso/Criterios-de-Acceso-y-Autorizaciones/?vgnextfmt=default&vgnextoid=b22fda4581f64610VgnVCM2000001f4a900aRCRD&vgnextchannel=cdfd96d2742f6610VgnVCM1000001d4a900aRCRD

Urban access regulations, *Spain*. Retrieved on 17 September 2020 from https://urbanaccessregulations.eu/countries-mainmenu-147/spain

Paris

AirParif, *Évaluation prospective de la qualité de l'air à l'horizon 2020 en Île-de-France*, 2017. Retrieved from https://www.airparif.asso.fr/_pdf/publications/rapport-ppa_180917.pdf

AirParif, *Zone à faibles émissions dans l'agglomération parisienne*, 2018. Retrieved from https://www.airparif.asso.fr/_pdf/publications/Rapport_ZFE_agglo_synthese_20190401.pdf

Direction Régionale et Interdépartementale de l'Environnement et de l'Energie, Île-de-France, *L'impact du chauffage au bois sur la qualité de l'air*. Retrieved on 17 September 2020 from http://www.driee.ile-de-france.developpement-durable.gouv.fr/5-l-impact-du-chauffage-au-bois-sur-la-qualite-de-a3791.html

Direction Régionale et Interdépartementale de l'Environnement et de l'Énergie, *Diminuer les émissions des APU et des véhicules et engins de pistes au sol*, 2017. Retrieved from https://www.maqualitedelair-idf.fr/w2020/wp-content/uploads/2017/06/PPA-fiches-juilletweb.pdf

Direction Régionale et Interdépartementale de l'Environnement et de l'Énergie, *Plan de Protection de l'Atmosphère d'Île-de-France. 2018-2025*, 2018. Retrieved from https://www.maqualitedelair-idf.fr/w2020/wp-content/uploads/2018/02/PPAjanvier18-sans-fiche.pdf

European Environmental Agency, *Europe's urban air quality — re-assessing implementation challenges in cities EEA Report No 24/2018*, 2019. Retrieved from https://www.eea.europa.eu/publications/europes-urban-air-quality

Journal officiel de la République française - N° 150 du 29 juin 2016. (2016), *Arrêté inter-préfectoral n° IDF-2018-01-31-007 relatif à l'approbation et à la mise en œuvre du Plan de Protection de l'Atmosphère pour l'Île-de-France*. Retrieved from http://www.driee.ile-de-france.developpement-durable.gouv.fr/IMG/pdf/2018-_arrete_ppa3_vsigne.pdf

Ministère de la Transition Ecologique, *Prime à la conversion des véhicules et Bonus écologique 2020*. Retrieved on 17 September 2020 from https://www.primealaconversion.gouv.fr/dboneco/accueil/

Ministère de la Transition Ecologique, *Questions fréquentes sur le dispositif de prime à la conversion 2020*. Retrieved on 17 September 2020 from https://www.primealaconversion.gouv.fr/dboneco/accueil/faq.html#:~:text=Oui.,une%20voiture%20particuli%C3%A8re%20%C3%A9lectrique%20neuve.

Ministère de la Transition Écologique et Solidaire, *Service de délivrance des certificats qualité de l'air*. Retrieved on 17 September 2020 from https://www.certificat-air.gouv.fr/fr/foire-aux-questions.

Paris.fr, *La Zone à faibles émissions (ZFE) pour lutter contre la pollution de l'air*. Retrieved on 17 September 2020 from https://www.paris.fr/pages/nouvelle-etape-crit-air-des-le-1er-juillet-2017-4834

Soot-free cities, *Paris*. Retrieved on 17 September 2020 from http://www.sootfreecities.eu/sootfreecities.eu/public/city/paris

Urban access regulations, *Paris*. Retrieved on 17 September 2020 from https://urbanaccessregulations.eu/countries-mainmenu-147/france/paris

Rome

Comune Roma, *Trasporto pubblico, entro novembre 2020 arrivano 328 nuovi bus*. Retrieved on 17 September 2020 from https://www.comune.roma.it/web/it/notizia/trasporto-pubblico-entro-novembre-2020-arrivano-328-nuovi-bus.page#:~:text=Trasporto%20pubblico%2C%20entro%20novembre%202020%20arrivano%20328%20nuovi%20bus,-Tematica%3A%20Mobilit%C3%A0%20e&text=Una%20flotta%20bus%20rinnovata%2C%20migliaia,trasporto%20pubblico%20migliore%20per%20Roma

La Stampa. Smog a Roma, Raggi blocca tutti i diesel, *Ma per molti è un 'provvedimento inutile'*. Retrieved on 17 September 2020 from https://www.lastampa.it/roma/2020/01/13/news/smog-a-roma-raggi-blocca-tutti-i-diesel-ma-per-molti-e-un-provvedimento-inutile-1.38324938

Lega Coop Lazio, *Revisione delle discipline di accesso dei veicoli immatricolati come autocarri alla ZTL Centro Storico, ZTL Trastevere e ZTL Merci*, 2011. Retrieved from http://www.legacooplazio.it/wp-content/uploads/2011/11/Delibera-Merci.pdf

Regione Lazio, Direzione regionale Ambiente e Cooperazione tra i Popoli, *Piano per il risanamento della qualità dell'aria*, 2010. Retrieved from https://www.regione.lazio.it/binary/prl_ambiente/tbl_contenuti/AMB_DGR_164_05_03_2010_Allegato.pdf

Regione Lazio, *Piano per il risanamento della qualità dell'aria*, 2020. Retrieved from http://www.regione.lazio.it/binary/rl_main/tbl_documenti/Burl_102_del_18agosto2020.pdf

Roma Mobilita, *I confini, gli orari, le informazioni su come ottenere un permesso per accedere, passare o sostare nelle Zone a Traffico Limitato di Roma*, Retrieved on 17 September 2020 from https://romamobilita.it/it/servizi/ztl

Roma Mobilita, *Procedura infrazione 2015/20143 della Commissione Europea, Ricognizione degli interventi dell'Amministrazione Capitolina per il miglioramento della qualità dell'aria. Interventi relativi alla mobilità e relativo contenimento emissioni di ossidi di azoto. Relazione sullo stato di avanzamento al 31/12/19 per le attività attuate da Roma Capitale con il supporto di Roma Servizi per la Mobilità S.r.l.*, 2019.

Soot-free cities, Rome. Retrieved on 17 September 2020 from http://www.sootfreecities.eu/sootfreecities.eu/public/city/rome

Urban access regulations, Rome. Retrieved on 17 September 2020 from https://urbanaccessregulations.eu/countries-mainmenu-147/italy-mainmenu-81/rome

6 sicuro risparmio assicurato, *Bollino blu auto 2018: cos'è, come funziona, il costo e quando rinnovarlo*. Retrieved on 17 September 2020 from https://www.6sicuro.it/tagliandi-e-revisioni/bollino-blu-auto#:~:text=Multa%20senza%20bollino%20blu%20(o%20scaduto),-La%20multa%20per&text=Quindi%20si%20applica%20l'articolo,159%20fino%20a%20639%20euro.&text=Con%20la%20violazione%20e%20l,libretto%20di%20circolazione%20della%20vettura

Stockholm

Institute of Transport Economics. Norwegian Centre for Transport Research. (2018). Low Emission Zones in Europe. Requirements, enforcement and air quality. Retrieved from https://www.toi.no/getfile.php?mmfileid=49204

Joint Research Centre. Catalogue of Air Quality Measures. Retrieved on 17 September 2020 from https://fairmode.jrc.ec.europa.eu/measure-catalogue/

SLB Analys. (2001). Stockholms miljözon. Effekter på luftkvalitet 2000. Retrieved from http://slb.nu/slb/rapporter/pdf8/slb2001_004.pdf

SLB Analys. (2007). Tunga fordon i Stockholms miljözon. Retrieved from http://miljobarometern.stockholm.se/content/docs/tema/trafik/Miljozon_kontroller_2007.pdf

SLB Analys. (2008). Trängselskattens inverkan på utsläpp och luftkvalitet. Retrieved from http://slb.nu/slb/rapporter/pdf8/slb2009_008.pdf

SLB Analys. (2009). Trängselskattens inverkan på utsläpp och luftkvalitet. Utvardering till och med år 2008. Retrieved from http://slb.nu/slb/rapporter/pdf8/slb2009_008.pdf

Soot free cities. Stockholm. Retrieved on 17 September 2020 from http://www.sootfreecities.eu/sootfreecities.eu/public/city/stockholm

Stockholm Hamnar. Miljöåtgärder Retrieved on 17 September 2020 from https://www.stockholmshamnar.se/om-oss/miljoarbete/miljoatgarder/

Stockholms stad. (2018). Effekter av miljözoner i Stockholms stad December 2018. Retrieved from https://start.stockholm/globalassets/start/om-stockholms-stad/utredningar-statistik-och-fakta/utredningar-och-rapporter/klimat-och-miljo/effekter-av-miljozoner-i-stockholms-stad.pdf

Transport Styrelsen. (2018). Hur ska regelefterlevnaden av miljözonsbestämmelser säkerställas? En utökad kommunal parkeringsövervakning. Retrieved from https://transportstyrelsen.se/globalassets/global/publikationer/vag/rapport---hur-ska-man-sakerstalla-regelefterlevnaden-av-miljozoner.pdf

Urban access regulations. Stockholm. Retrieved on 17 September 2020 from https://urbanaccessregulations.eu/countries-mainmenu-147/sweden-mainmenu-248/stockholm

Appendix 1. Monitoring stations selected

City	Station Name	Sampling Point ID	Station ID	Type	Longitude	Latitude
Athens	Agia Paraskevi	SPO-GR0039A	ATH_AGI	Background	23.819	37.995
Athens	Lykovrisi	SPO-GR0035A	ATH_LYK	Background	23.777	38.070
Athens	Pireaus-1	SPO-GR0030A	ATH_PIR	Traffic	23.648	37.943
Bucharest	B-1	SPO-RO0065A	B-1	Background	26.037	44.447
Bucharest	B-3	SPO-RO0067A	B-3	Traffic	26.127	44.445
Bucharest	B-6	SPO-RO0070A	B-6	Traffic	26.098	44.435
Barcelona	L'hospitalet De Llobregat (Av. Del Torrent Gornal)	SP_08101001	BAR_HOS	Background	2.115	41.371
Barcelona	Rubí (Ca N'oriol)	SP_08184006	BAR_RUB	Background	2.042	41.492
Barcelona	Sant Adrià De Besòs (Olímpic)	SP_08194008	BAR_SAN	Traffic	2.222	41.426
Berlin	Berlin Frankfurter Allee	SPO.DE_DEBE065	BER_FRA	Traffic	13.470	52.514
Berlin	Berlin Mitte	SPO.DE_DEBE068	BER_MIT	Background	13.419	52.514
Berlin	Berlin Neukölln	SPO.DE_DEBE034	BER_NEU	Background	13.431	52.489
Krakow	"Kraków, Aleja Krasińskiego"	SPO_PL0012A	KRA_ALE	Traffic	19.926	50.058
Krakow	"Kraków, Ul. Bujaka"	SPO_PL0501A	KRA_BUJ	Background	19.949	50.011
Krakow	"Kraków, Ul. Bulwarowa"	SPO_PL0039A	KRA_BUL	Industrial	20.053	50.069
Lisbon	Entrecampos	SPO-PT03072	LIS_ENT	Traffic	-9.149	38.749
Lisbon	Laranjeiro	SPO-PT03083	LIS_LAR	Background	-9.158	38.664
Lisbon	Olivais	SPO-PT03071	LIS_OLI	Background	-9.108	38.769
Madrid	Escuelas Aguirre	SP_28079008	MAD_ESC	Traffic	-3.682	40.422
Madrid	Mendez Alvaro	SP_28079047	MAD_MEN	Background	-3.687	40.398
Madrid	Plaza Castilla-Canal	SP_28079050	MAD_PLA	Traffic	-3.688	40.466
Paris	Auto A1 -Saint-Denis	SPO-FR04058	PAR_AUT	Traffic	2.357	48.925
Paris	Bobigny	SPO-FR04156	PAR_BOB	Background	2.453	48.903
Paris	Bld Peripherique Est	SPO-FR04329	PAR_PER	Traffic	2.413	48.839
Rome	Lgo. Belolli - Roma (Rm)	SPO.IT0956A	ROM_BEL	Background	12.569	41.858

City	Station Name	Sampling Point ID	Station ID	Type	Longitude	Latitude
Rome	Corso Francia - Roma (Rm)	SPO.IT0825A	ROM_COR	Traffic	12.470	41.947
Rome	"Via Della Meloria, Fronte Civico 27 - Roma (Rm)"	SPO.IT1836A	ROM_VIA	Background	12.448	41.906
Stockholm	Stockholm Hornsgatan 108 Gata	SPO-SE0003A	STO_HOR	Traffic	18.049	59.317
Stockholm	Stockholm Sveavägen 59 Gata	SPO-SE0027A	STO_SVE	Traffic	18.058	59.341
Stockholm	Stockholm Torkel Knutssongatan	SPO-SE0022A	STO_TOR	Background	18.058	59.316

Appendix 2. Long-term trend analysis at monitoring stations

NO_2 annual mean concentrations and trends (µgm^{-3} and %)

City	Station Name	Type	Annual average concentrations (µgm^{-3})							Trend (µgm^{-3})	Trend (%)
			2013	2014	2015	2016	2017	2018	2019		
Athens	ATH_AGI	Background	8.4	8.0	11.2	13.9*	13.5	14.1*	12.8	0.9	11 %
	ATH_LYK	Background	21.2	24.0	18.6	20.3	22.3	20.0	20.0	-0.3	-1 %
	ATH_PIR	Traffic	34.0*	32.9	51.8	64.2	62.0	62.5	63.0*	5.0	15 %
Barcelona	BAR_HOS	Background	33.3	33.9	38.7	35.4	36.2	36.2	33.3	0.3	1 %
	BAR_RUB	Background	25.1	27.2	30.9	28.0	28.1	22.9	23.4	-0.5	-2 %
	BAR_SAN	Traffic	40.9	42.2	41.8	40.0	39.8	40.1	36.9	-0.6	-1 %
Berlin	BER_FRA	Traffic	40.5	41.6	41.2	40.9	41.4	37.5	35.1	-0.9	-2 %
	BER_MIT	Background	26.8	27.5	27.5	27.6	27.1	24.3	22.9	-0.8	-3 %
	BER_NEU	Background	26.9	26.8	26.8	27.1	26.3	24.2	22.4	-0.7	-3 %
Bucharest	BUC_B1	Background	N/A	N/A	N/A	27.9*	31.3	27.9	N/A	2.8	10 %
	BUC_B3	Traffic	60.0	N/A	N/A	N/A	52.8	59.3	N/A	-3.3	-5 %
	BUC_B6	Traffic	N/A	N/A	N/A	44.0*	56.7	62.8	40.0	2.9	6 %
Krakow	KRA_ALE	Traffic	68.0	61.5	63.1	59.3	60.5	60.8	57.1	-1.2	-2 %
	KRA_BUJ	Background	27.5	28.5	31.9	32.8	32.5	31.9	32.3	0.7	3 %

	KRA_BUL	Industrial	24.8	24.1	27.9	27.5	29.5	27.0	25.1	0.3	1 %
Lisbon	LIS_ENT	Traffic	38.8	37.0	38.8	37.0	40.8	40.5	35.8	<0.1	<1 %
	LIS_LAR	Background	24.1	22.5	26.6	23.1	24.9	25.4	22.4	-0.2	-1 %
	LIS_OLI	Background	29.4	26.0	29.2	27.8	30.5	30.4	27.2	0.1	<1 %
Madrid	MAD_ESC	Traffic	42.6	51.3	58.1	57.1	61.9	54.8	51.2	1.7	4 %
	MAD_MEN	Background	32.1	32.6	39.2	38.4	43.4	34.8	33.3	0.7	2 %
	MAD_PLA	Traffic	42.5	44.0	46.7	43.5	41.1	39.7	36.6	-0.9	-2 %
Paris	PAR_AUT	Traffic	49.9	51.6	52.5	47.0	54.3	48.0	42.7	-0.8	-2 %
	PAR_BOB	Background	N/A	32.9	30.1	30.4	31.2	26.9	28.1	-0.6	-2 %
	PAR_PER	Traffic	N/A	72.1	66.9	66.1	64.7	67.4	60.7	-1.7	-2 %
Rome	ROM_BEL	Background	41.9	34.5	40.3	40.7	41.0	39.1	35.2	-0.2	<1 %
	ROM_COR	Traffic	65.8	64.7	61.0	59.3	60.5	50.7	47.9	-2.9	-4 %
	ROM_VIA	Background	49.4	42.5	45.8	46.7	46.9	42.6	37.7	-1.1	-2 %
Stockholm	STO_HOR	Traffic	46.2	41.3	41.7	42.9	35.2	34.2	32.8	-2.2	-5 %
	STO_SVE	Traffic	40.0	36.0	40.2	35.4	32.5	29.2	27.9	-2.0	-5 %
	STO_TOR	Background	13.7	12.3	13.2	11.1	10.7	11.5	10.4	-0.5	-3 %

PM$_{2.5}$ annual mean concentrations and trends (µgm^{-3} and %)

City	Station Name	Type	Annual average concentrations (µgm^{-3})							Trend (µgm^{-3})	Trend ()
			2013	2014	2015	2016	2017	2018	2019		
Athens	ATH_AGI	Background	9.9"	11.2"*	10.4"	12.3	10.7	11.6	11.9	0.1	1 %
	ATH_LYK	Background	11.8"*	15.7"*	16.5"	17.1	16.3	15.3	16.5	0.1	1 %
	ATH_PIR	Traffic	24.9"*	19.8"	21.2"	20.1	18.1	18.0	16.1	-1.2	-5 %
Barcelona	BAR_HOS	Background	12.7"*	13.0"*	15.9"*	12.6"*	13.8"*	13.3"*	N/A	0.2	1 %
	BAR_RUB	Background	14.6"*	14.0"*	17.5"*	12.8"*	14.0"*	12.9"*	N/A	-0.3	-2 %
	BAR_SAN	Traffic	16.7"*	14.7"*	18.6"*	15.7"*	16.3"*	14.8"*	N/A	-0.2	-1 %
Berlin	BER_FRA	Traffic	18.5"	21.8"	18.0"	18.3"	17.4"	17.7"	N/A	-0.2	-1 %
	BER_MIT	Background	16.7"	19.8"	16.1"	15.9"	15.1"	15.5"	N/A	-0.4	-2 %
	BER_NEU	Background	16.9"	21.2"	17.1"	16.4"	15.5"	16.3"	N/A	-0.3	-1 %
Bucharest	BUC_B1	Background	N/a	N/a	N/a	29.1	20.9	21.3	N/A	-2.4	-8 %
Krakow	KRA_ALE	Traffic	43.5	45.0	43.8	37.9	40.1	39.4	29.2	-2.3	-5 %
	KRA_BUJ	Background	N/A	N/A	N/A	28.8	31.0	29.4	23.7	-0.4	-1 %
	KRA_BUL	Industrial	35.2	31.8	33.3	29.1	28.4	26.7	21.6	-1.9	-5 %
Lisbon	LIS_ENT	Traffic	11.8	10.9	15.0	14.4	N/A	13.5	11.6	0.3	3 %
	LIS_LAR	Background	10.9	8.6	13.6	12.7	14.8	13.5	9.7	0.3	3 %
	LIS_OLI	Background	11.8	11.2	11.4	9.8	11.6	10.1	9.1	-0.4	-3 %

Madrid	MAD_ESC	Traffic	11.6	11.8	13.5	11.3	10.6	11.2	10.5	-0.3	-3 %
	MAD_MEN	Background	9.9	10.8	11.9	11.2	11.5	10.4	9.8	0.0	0 %
	MAD_PLA	Traffic	10.5	11.1	10.8	10.0	9.0	9.6	8.9	-0.4	-3 %
Paris	PAR_AUT	Traffic	N/A	N/A	N/A	20.0	19.5	19.1	19.3	-0.2	-1 %
	PAR_BOB	Background	N/A	13.5	13.4	12.6	11.2	11.1	N/A	-0.4	-3 %
	PAR_PER	Traffic	N/A	19.7	20.1	18.2	16.1	16.2	N/A	-1.0	-5 %
Rome	ROM_BEL	Background	19.5″	16.7″	21.8″	17.5″	17.3″	16.3″	12.4″	-0.4	-2 %
	ROM_COR	Traffic	19.9″	18.9″	20.6″	17.2″	15.9″	15.6″	13.6″	-0.8	-4 %
	ROM_VIA	Background	15.8″	15.4″	17.5″	14.4″	13.6″	13.4″	12.2″	-0.3	-2 %
Stockholm	STO_HOR	Traffic	N/A	N/A	5.6	5.9	6.0	7.5	6.5	0.3	6 %
	STO_SVE	Traffic	5.4	6.6*	N/A	6.2	5.0	5.2	6.3	-0.1	-2 %
	STO_TOR	Background	4.7	6.4	4.8	4.9	4.1	4.8	N/A	-0.1	-3 %

*Data capture below 75 %; ″Data available as daily average rather than hourly average.

Appendix 3. Full literature review for Research Question 1 of Task 2

Does particulate matter play a role in the transmission of the SARS-Cov-2 Virus?

There are different possible transmission routes of respiratory viruses between people. The main routes of transmission are considered to be:[99]

a) direct contact between an infected and a susceptible individual;
b) indirect contact between an infected and a susceptible individual mediated by a 'fomite' (an object or surface that has been contaminated with the virus);
c) airborne transmission via large (>5 µm in diameter) virus-laden droplets released by infected individuals via a cough or sneeze. These droplets are quickly stopped by the resistance of air and removed by dry deposition, mainly through gravitational settling, generally at a distance smaller than 1–1.5 metres from the infected individual;
d) airborne transmission via inhalation of small virus-laden aerosols released during respiration or vocalism (use of the voice in speaking or singing) or the residual solid component after the evaporation of droplets. The smaller virus-laden particles (<5 µm in diameter) related to the respiratory emissions of infected individuals could remain in the air for hours and could be transported and dispersed by winds and turbulent eddies.

This last route is the transmission route that could potentially be enhanced by PM. Tang *et al.* evaluated evidence for the plausibility of aerosol transmission of the SARS-CoV-2 virus against the following criteria: [100]

a) virus-containing aerosols are generated by and are transmitted from an infected person;
b) the virus remains viable and infective in the aerosols for some period of time; and
c) sufficient virus load reaches alveolae cells in the lungs where the virus initiates infection.

To evaluate the role of PM acting as a carrier of SARS-CoV-2, it is also necessary to consider evidence of the virus being found on PM.

In their review of aerosol transmission of SARS-CoV-2, Tang *et al.* state that it has been established that infectious SARS-CoV-2 may be discharged into the surrounding environment through respiratory emissions, body fluids or excreta and that SARS-CoV-2 genetic material and/or viable viruses have been frequently detected in throat swabs, anal swabs, conjunctival swabs, blood, sputum, feces, and urine of infected cases.[Error! Bookmark not defined.]. They cite studies showing that SARS-CoV-2 could remain viable in aerosols for at least 90 mins, or even persist and maintain infectivity for up to 16 hours.[Error! Bookmark not defined.]

Several studies have shown evidence of SARS-CoV-2 being found on PM. This is particularly clear in indoor environments. Examples include:

[99] Contini, D. and Costabile, F., 'Does air pollution influence COVID-19 outbreaks?' *Atmosphere*, Vol. 11, No. 4, 2020, p. 377. Retrieved from https://www.mdpi.com/2073-4433/11/4/377/htm

[100] Tang, S., Mao, Y., Jones, R. M., Tan, Q., Ji, J. S., Li, N. and Shi, X., 'Aerosol transmission of SARS-CoV-2? Evidence, prevention and control', *Environmental International*, Vol. 144, 2020. Retrieved from https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7413047/

- Chia *et al.* tested the air in three airborne infection isolation rooms (AIIR) at the National Centre for Infectious Diseases, Singapore, and found that air samples from two (66.7 %) of these tested positive for SARS-CoV-2 (in particle sizes >4 µm and 1–4 µm in diameter).[101]
- Liu *et al.* analysed the occurrence of airborne SARS-CoV-2 and its aerosol deposition at 30 sites in two designated hospitals and public areas in Wuhan, China.[102] Low concentrations of SARS-CoV-2 Ribonucleic acid (RNA) in aerosols were detected in isolation wards and ventilated patient rooms, but it was higher in the toilet areas used by the patients.
- de Man *et al.* detected SARS-CoV-2 RNA in dust present on the mesh of the living room air conditioners and in four block filters from three of the eight ventilation cabinets and concluded that the data suggest that this outbreak is caused by aerosol transmission of COVID-19 in a situation of inadequate ventilation.[103]
- Santarpia *et al.* found that 63 % of room air samples from the University of Nebraska Medical Centre where Covid-19 patients were being treated were found to contain SARS-CoV-2 RNA.[104]

Other studies have found less clear evidence of aerosol transmission. Ma *et al.* found that from 26 air samples collected at two hospitals in Beijing, only one sample from an unventilated quarantine hotel toilet room was found to contain SARS-CoV-2 RNA.[105] The overall SARS-CoV-2 positive rate for Exhaled Breath Condensate (EBC) samples was 26.9 % (n=52), while surface swabs and air samples had low positive rates of 5.4 % (n=242) and 3.8 % (n=26), respectively. The authors concluded that the SARS-CoV-2 negative air samples may be due to low SARS-CoV-2 emissions, virus inactivation by disinfectants, and rapid dilution or removal of SARS-CoV-2 by fresh air flow. The authors did conclude, however, that exhaled breath emission plays an important role in SARS-CoV-2 emission into the air.

The evidence for SARS-Cov-2 being present in aerosol or on PM in outdoor air appears to be less strong than for indoor air. Setti *et al.* reported preliminary evidence that SARS-CoV-2 RNA can be present on outdoor PM, and suggested that in conditions of atmospheric stability and high concentrations of PM, SARS-CoV-2 could create virus clusters associated with outdoor PM.[106] On the other hand, Liu *et al.* found that in public areas outside the hospitals studied, most of the sites had undetectable or very low concentrations of SARS-CoV-2 aerosols (below 3 SAR-CoV-2 RNA copies m^{-3}), except for one crowd-gathering site about one metre from the entrance of a busy department store and a site next to a hospital, through which the public, including outpatients,

[101] Chia, P., Coleman, K., Tan, Y., Xiang Ong, S., Gum, M., Lau, S. and Marimuthu, K., 'Detection of air and surface contamination by SARS-CoV-2 in hospital rooms of infected patients', Nature, Vol. 11, 2020. Retrieved from https://www.nature.com/articles/s41467-020-16670-2#article-info0

[102] Liu, Y., Ning, Z., Chen, Y., Guo, M., Liu, Y., Gali, N. and Lan, K., 'Aerodynamic analysis of SARS-CoV-2 in two Wuhan hospitals', Nature, Vol. 582, 2020, pp. 557-560. Retrieved from https://www.nature.com/articles/s41586-020-2271-3

[103] de Man, P., Paltansing, S., Ong, D. S., Vaessen, N., van Nielen, G. and Koeleman, J. G., 'Outbreak of coronavirus disease 2019 (COVID-19) in a nursing home associated with aerosol transmission as a result of inadequate ventilation,' *Clinical Infectious Diseases*, 2020. Retrieved from https://academic.oup.com/cid/advance-article/doi/10.1093/cid/ciaa1270/5898577

[104] Santarpia, J., Rivera, D., Herrera, V., Morwitzer, M. J., Creager, H., Santarpia, G. W. and Lowe, J. J., 'Transmission potential of SARS-CoV-2 in viral shedding observed at the University of Nebraska Medical Centre', *Scientific Reports*, Vol. 10, 2020. Retrieved from https://www.medrxiv.org/content/10.1101/2020.03.23.20039446v2.full.pdf

[105] Ma, J., Qi, X., Chen, H., Li, X., Zhang, Z., Wang, H. And Maosheng, Y., Coronavirus disease 2019 patients in earlier stages exhaled millions of severe acute respiratory syndrome coronavirus 2 per hour', *Clinical Infectious Diseases*, 2020. Retrieved from https://academic.oup.com/cid/advance-article/doi/10.1093/cid/ciaa1283/5898624

[106] Setti, L., Passarini, F., De Gennaro, B. P., Perrone, M. G., Borelli, M., Palmisani, J. and Miani, A., 'SARS-Cov-2 RNA found on particulate matter of Bergamo in Northern Italy: First preliminary evidence', *Environmental Research*, 2020. Retrieved from https://www.medrxiv.org/content/10.1101/2020.04.15.20065995v2

walked.[107] It was concluded that the risks of infection are low in well-ventilated or open public venues.

Other studies have focused on analysis of correlations between PM concentrations and COVID-19 infection rates to consider the role played by PM in transmission. For example:

- Li *et al.* showed a positive association between $PM_{2.5}$ concentration and daily COVID-19 incidence.[108] The authors hypothesised that PM could form condensation nuclei for viral attachment and stated a belief that $PM_{2.5}$ is a stronger factor promoting SARS-CoV-2 transmission.
- Setti *et al.* concluded that it is reasonable to assume that PM_{10} concentration levels higher than the daily limit value during the period 7-29 February 2020 resulted in a 'boost' process promoting the diffusion the COVID-19 among the exposed population, with airborne particles serving as a carrier of pathogens.[109]
- Coccia showed a significant association between high diffusion of viral infectivity of Sars-CoV-2 and long-term air pollution, and concluded that air pollution in Italian cities under study seemed to be a more important predictor in the initial phase of transmission dynamics than human-to-human transmission.[110] Results also indicated that the number of infected individuals was lower when wind speeds where higher. The authors linked this to the cleaning from the air of pollutants that are associated with transmission dynamics of COVID-19.

While some studies have used correlations between PM concentrations and infection rates to hypothesise that PM plays a role in virus transmission, these correlations may also relate to the increased susceptibility of people living in polluted areas and the socioeconomic status of these people. The correlations with pollutant concentrations could also result from physiological mechanisms, such as the increased expression of enzymes that act as viral receptors in the cells of people living in polluted areas, discussed below, or from factors associated with diet and lifestyle.

Other studies have not drawn the same conclusions with regards to the role of PM in virus transmission. For example:

- Bontempi[111] carried out further investigation into hypotheses[112] that PM may be a carrier of Cov-SARS-2 on the basis of episodes of high PM_{10} concentration between 22 and 26 February 2020 in Lombardy and the number of infected people in March of the same year. To account for different geographical dimensions, the author also considered the percentage of people infected. No correlation was found, which the author concluded strongly suggested the absence of a direct contribution due to PM_{10} transport for SARS-Cov-2 diffusion. Furthermore, it was shown that cities that suffered the most severe events of PM_{10} pollution (Torino and

[107] Liu, Y., Ning, Z., Chen, Y., Guo, M., Liu, Y., Gali, N. and Lan, K., 'Aerodynamic analysis of SARS-CoV-2 in two Wuhan hospitals', Nature, Vol. 582, 2020, pp. 557-560. Retrieved from https://www.nature.com/articles/s41586-020-2271-3

[108] Li, H., Xu, X.-L., Dai, D.-W., Huang, Z.-Y., Ma, Z. and Guan, Y.-J., 'Air pollution and temperature are associated with increased COVID-19 incidence: A time series study', *International Journal of Infectious Diseases*, Vol. 97, 2020, pp. 272-282. Retrieved from https://www.ijidonline.com/article/S1201-9712(20)30383-0/fulltext

[109] Setti et al., 2020.

[110] Coccia, M., 'Factors determining the diffusion of COVID-19 and suggested strategy to prevent future accelerated viral infectivity similar to COVID', *Science of the Total Environment*, Vol. 729, 2020. Retrieved from https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7169901/

[111] Bontempi, E., 'First data analysis about possible COVID-19 virus airborne diffusion due to air particulate matter (PM): The case of Lombardy (Italy)', *Environmental Research*, Vol. 186, 2020. Retrieved from https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7204748/

[112] Setti et al., 2020.

Alessandria) in the 20 days before the Italian COVID-19 crisis had low infections cases (0.01 % and 0.03 % respectively, evaluated on total population on 12 March).

- Chakraborty *et al.* did not find any relationships between $PM_{2.5}$ and the number of COVID-19 deaths or Case Fatality Rate (CFR) in India.[113] The authors suggest that this is probably due to the fact that the COVID-19 pandemic in India was in stage 2 (clusters of cases) and that atmospheric $PM_{2.5}$ probably plays an important role in spreading the virus when the epidemic is in stage 3 level (community transfer level), therefore $PM_{2.5}$ might play a crucial role in spreading the virus in the future.
- Borro *et al.* found a statistically significant correlation between the average $PM_{2.5}$ level in the period 15-26 February 2020 and the incidence of COVID-19 (infected/population ratio) in the period 20 February-31 March 2020 in Italy but hypothesised that this is because $PM_{2.5}$ is an enhancer of SARS-CoV-2 infectivity, rather than relating this to transmission.[114]

The nature of SARS-Cov-2 transmission has been considered from another perspective by Zhang *et al.*, who investigated the effectiveness of face coverings in managing the spread of the virus.[115] They concluded that social distancing, quarantine, and isolation were policy measures that alone were insufficient to curb the spread of COVID-19, but that the introduction of policies requiring face coverings in Italy and New York City reduced the number of infections by over 78 000 in Italy from 6 April to 9 May 2020 and by over 66 000 in New York City from 17 April to 9 May in the same year. They concluded that airborne transmission, particularly via nascent aerosols from human atomisation, is highly virulent and represents the dominant route for the transmission of this disease and that wearing of face masks in public is the most effective means to prevent interhuman transmission.

It is clear that a great deal of the research published has been based on preliminary findings. Further research is required (in particular into the presence of SARS-Cov-2 on PM, and the infectivity of the airborne virus). Furthermore, full analysis of routes of SARS-Cov-2 transmission cannot be undertaken until strong infection rate data is available, to account for asymptomatic carriers.

Are there feasible mechanisms by which air pollution could worsen COVID-19 health outcomes?

There are several mechanisms discussed by which air pollutants could influence COVID-19 infection. These include:[116]

- non-specific impacts on host immunity;

[113] Chakraborty, P., Jayachandran, S., Padalkar, P., Sitlhou, L., Chakraborty, S., Kar, R. and Srivastava, M., 'Exposure to nitrogen dioxide (NO2) from vehicular emissions could increase the COVID-19 pandemic fatality in India: A perspective', *Bulletin of Environmental Contamination and Toxicology*, 2020, pp. 1-7. Retrieved from https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7363019

[114] Borro, M., Di Girolamo, P., Gentile, G., De Luca, O., Preissner, R., Marcolongo, A. and Simmaco, M., 'Evidence-based considerations exploring relations between the SARS-CoV-2 pandemic and air pollution: Involvement of PM2.5-mediated up-regulation of the viral receptor ACE-2.17', *International Journal of Environmental Research and Public Health*, Vol. 17, No. 15, 2020. Retrieved from https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7432777/

[115] Zhang, R., Li, Y., Zhang, A. L., Wang, Y. and Molina, M. J., ‚Identifying airborne transmission as the dominant route for the spread of COVID-19', *Proceedings of the National Academy of Science of the United States of America*, Vol. 117, No. 26, 2020, 14857-14863. Retrieved from https://www.pnas.org/content/pnas/117/26/14857.full.pdf

[116] Popkin, B. M., Du, S., Green, W. D., Beck, M. A., Algaith, T., Herbst, C. H. and Shekar, M., 'Individuals with obesity and COVID-19: A global perspective on the epidemiology and biological relationships', *Obesity Review*, 2020. Retrieved from https://onlinelibrary.wiley.com/doi/10.1111/obr.13128

- specific impacts of pollutants on receptors such as angiotensin-converting enzyme 2 (ACE-2) by which SARS-CoV-2 enters cells; and
- the contribution of air pollution to cytokine production during infection thereby making a potential contribution to the cytokine storm that is a feature of Acute Respiratory Distress Syndrome (ARDS) seen in severe COVID-19 disease cases.

Several studies have made the link between prolonged exposure to air pollution and reduced immunity, making infected people more susceptible to the disease.[117]. Respiratory tract cells are the first point of contact with PM, as well as the first point of contact of respiratory viruses. The stressed status of cells in subjects who have been exposed to PM for a long time facilitates the attack of viruses and increases the severity of viral infections in exposed subjects. Two main mechanisms inducing cellular stress have been demonstrated in lungs after PM exposure:[118]

1. Oxidative stress; exposure to these pollutants induces the production of free radicals that damage cells.
2. Inflammation; PM induces the activation of the immune response and thus the cell enters an inflammatory state.

Several studies have highlighted the role of pre-existing immune disorders induced by long-term or short-term exposure to high levels of PM_{10} and $PM_{2.5}$ in contributing to the high levels of SARS-CoV-2 lethality in Lombardy.[119, 120]

SARS-Cov-2 enters has been found to enter human cells through binding of the capsid Spike protein to the cellular surface protein ACE-2, an enzyme involved in regulation of cardiovascular physiology and with a clear role in regulation of inflammation processes. ACE-2 is found in the upper part of the oesophagus and the lungs, which are where the main COVID-19 symptoms are expressed.[121] PM_{25} is known as a trigger of inflammation in upper and lower airways, and in vivo experiments with mice have demonstrated that $PM_{2.5}$ in the lungs induces ACE-2 over-expression. Mice without ACE-2 are more prone to develop lung injury after exposure to PM 2.5, which suggests a crucial role for ACE-2 in lung protection from air pollutants.[122]. It is therefore hypothesized that prolonged exposition to $PM_{2.5}$ promotes inflammation in the airways, inducing increased expression of ACE-2 as a cellular response. An increase in ACE-2 therefore increases the probability of attack by COVID-19, and also, through binding to ACE-2, blocks its activity, reducing the immune defence and protection against

[117] Bontempi, 2020.

[118] Lin, C.-I., Tsai, C.-H., Sun, Y.-L., Hsieh, W.-Y., Yi-Chang, L., Chen, C.-Y. and Lin, C.-S., 'Instillation of particulate matter 2.5 induced acute lung injury and attenuated the injury recovery in ACE2 knockout mice', *International Journal of Biological Sciences*, Vol. 14, No. 3, 2020, pp. 253–265. Retrieved from https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5859472/

[119] Fattorini, D. and Regoli, F., 'Role of the chronic air pollution levels in the Covid-19 outbreak risk in Italy', *Environmental Pollution*, 2020. Retrieved from https://pubmed.ncbi.nlm.nih.gov/32387671/

[120] Conticini, E., Frediani, B. and Caro, D., 'Can atmospheric pollution be considered a co-factor in extremely high level of SARS-CoV-2 lethality in Northern Italy?', *Environmental Pollution*, Vol. 261, 2020. Retrieved from https://www.sciencedirect.com/science/article/abs/pii/S0269749120320601

[121] Borro et al., 2020.

[122] Lin et al., 2020.

inflammation that have been observed as the major cause of deaths from COVID-19.[123, 124, 125] The presence of cholesterol has also been associated with viral Spike protein binding to cellular ACE-2 receptors which could help to explain the relationship between obesity and COVID-19 health outcomes.[126] It is also postulated in the 'double-hit' hypothesis that ACE-2 depletion following COVID-19 infection increases tissue vulnerability to NO_2 toxicity that eventually contributes to the acute lung injury observed in patients with pneumonia- ARDS.[127]

The hyper-activation of the immune system is thought to have a paramount role in ARDS. Inflammatory cytokines are overexpressed in the blood.[128] Atmospheric pollution, including high NO_2 concentrations, has been shown to correlate with cytokine levels and inflammatory status.[129]. A cytokine storm is observed where an excess of these pro-inflammatory signals can be harmful to the cells of the pulmonary epithelium, and cytokine storms have been associated with COVID-19 fatalities.[130]

Does exposure to pollution worsen COVID-19 health outcomes?

Numerous studies have shown strong correlations between a variety of medium and long-term PM concentrations and health outcomes of COVID-19 (e.g. hospital admissions, mortality, case fatality risk). For example:

- Borro *et al.*[131] showed that the case fatality risk (in the period 20 February – 31 March 2020) doubled with daily mean $PM_{2.5}$ concentrations increasing from 10 to 22 µg/m^3 in the period immediately (four to five days) prior to the studied cases. The authors conclude that this supports the role of $PM_{2.5}$ as an enhancer of SARS-CoV-2 virulence, e.g., the severity of the disease as measured by its lethality.
- In a study of 355 municipalities in the Netherlands, Cole *et al.*[132] found compelling evidence of a positive relationship between air pollution, and particularly long-term (averaged over the period 2015 to 2019) $PM_{2.5}$ concentrations, and Covid-19 cases, hospital admissions and deaths.
- Fattorini & Regoli showed significant correlations between long-term (from 2016 to 2019) air-quality data with cases of COVID-19 (and deaths) in Italian provinces.[133]
- Frontera *et al.* showed that patients in polluted areas experience more severe forms of the disease requiring Intensive Care Unit (ICU), with mortality being twice as high as in other

[123] Comunian, S., Dongo, D., Milani, C. and Palestini, P., 'Air pollution and COVID-19: The role of particulate matter in the spread and increase of COVID-19 morbidity and mortality', *International Journal of Environmental Research and Public Health*, Vol. 17, No. 12, 2020. Retrieved from https://www.mdpi.com/1660-4601/17/12/4487/htm

[124] Frontera, A., Cianfanelli, L., Vlachos, K., Landoni, G. and Cremona, G., 'Severe air pollution links to higher mortality in COVID-19 patients: The "double-hit" hypothesis', *Journal of Infection*, Vol. 81, No. 2, 2020, pp. 255-259. Retrieved from https://www.journalofinfection.com/article/S0163-4453(20)30285-1/fulltext

[125] Borro et al., 2020.

[126] Popkin et al., 2020.

[127] Frontera et al., 2020.

[128] Conticini et al., 2020.

[129] Fattorini et al., 2020.

[130] Comunian et al., 2020.

[131] Borro et al., 2020.

[132] Cole, M. A., Ozgen, C. and Strobl, E., 'Air pollution exposure and COVID-19', *IZA Institute of Labour Economics Discussion*, 2020. Retrieved from http://ftp.iza.org/dp13367.pdf

[133] Fattorini et al., 2020.

regions despite similar rates of ICU admission.[134] The authors note, however, that many other factors such as age, transmission patterns, population density and co-morbidities have an important impact on both the number and severity of COVID-19 cases.

- Hendryx and Luo produced results of mixed model linear multiple regression analyses indicating that, controlling for co-variates, COVID-19 prevalence and fatality rates were significantly associated with greater Diesel Particulate Matter (DPM) (based on 2016 concentrations).[135]
- Pansini and Fornacca found positive significant correlations between COVID-19 mortality and annual satellite AQ variables (including $PM_{2.5}$) and concluded that higher mortality was correlated with poor AQ, namely, with high $PM_{2.5}$, CO, and NO_2 values.[136]
- Wu *et al.* found that an increase of 1 µg/m^3 in long-term $PM_{2.5}$ is associated with an 8 % increase in the COVID-19 death rate, with the results adjusted by 20 potential confounding factors (including population size, age distribution, population density, time since the beginning of the outbreak, time since the state issued a stay-at-home order, hospital beds, number of individuals tested, weather, and socioeconomic and behavioural variables such as obesity and smoking).[137]

Studies also showed similar relationships between long-term NO2 concentrations and COVID-19 health outcomes, such as:

- Chakraborty et al. showed strong positive correlation between the concentration of atmospheric NO2 and both the absolute number of COVID-19 deaths and case fatality rate in India.[138]
- Liang et al.[139] observed significant positive associations between NO2 levels and both county-level COVID19 case-fatality rate and mortality rate.
- Ogen showed that 78 % of COVID-19 fatality cases in 66 administrative regions in Italy, Spain, France and Germany were in five regions located in north Italy and central Spain and that the same five regions show the highest NO2 concentrations combined with downwards airflow which prevent an efficient dispersion of air pollution.[140] It was concluded that these results indicate that the long-term exposure to NO2 may be one of the most important contributors to fatality caused by the COVID-19 virus in these regions and maybe across the whole world.

[134] Frontera et al., 2020.

[135] Hendryx, M. and Luob, J., 'COVID-19 prevalence and fatality rates in association with air pollution emission concentrations and emission sources', *Environmental Pollution*, Vol. 265, 2020. Retrieved from https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7320861/

[136] Pansini, R. and Fornacca, D., 'Early evidence of a higher incidence of COVID-19 in the air polluted regions of eight severely affected countries', *MedRxiv*, 2020. Retrieved from https://www.medrxiv.org/content/10.1101/2020.04.30.20086496v2.full.pdf

[137] Wu, X., Nethery, R. C., Sabath, B. M., Braun, D. and Dominici, F., 'Exposure to air pollution and COVID-19 mortality in the United States: A nationwide cross-sectional study', *MedRxiv*, 2020. Retrieved from https://www.medrxiv.org/content/10.1101/2020.04.05.20054502v2

[138] Chakraborty et al., 2020.

[139] Liang, D., Shi, L., Zhao, J., Liu, P., Schwartz, J., Gao, S. and Howard, C., 'Urban air pollution may enhance COVID-19 case fatality and mortality rates in the United States', *MedRxiv*, 2020. Retrieved from https://www.medrxiv.org/content/10.1101/2020.05.04.20090746v1

[140] Ogen, Y., 'Assessing nitrogen dioxide (NO2) levels as a contributing factor to coronavirus (COVID-19) fatality', *Science of the Total Environment*, 2020. Retrieved from https://www.sciencedirect.com/science/article/pii/S0048969720321215

- Travaglio et al. showed that NO2 levels are significantly associated with COVID-19 deaths, together with the population density and that a 1 µg/m3 increase in NO2 levels is associated with an approximately 2 % increase in COVID-19 mortality.[141]

There are also studies that show relationships between short-term NO2 concentrations and COVID-19 health outcomes, such as:

- Filipini et al. found a positive association between NO2 levels and subsequence prevalence of SARS-CoV-2 positivity in Northern Italy, though this occurred only at high levels (above 130 µmol/m2) of NO2.[142]
- Data produced by Li et al. showed that COVID-19 incidence was highly correlated with ambient NO2 concentrations.[143]
- Zoran et al. showed correlations of NO2 with confirmed Total COVID-19 infections, daily new positive cases and total deaths.[144]
- Pansini and Fornacca reference preliminary evidence of a correlation between high levels of NO2 and 12-day delayed virus outbreaks.[145]
- Frontera et al. propose a 'double-hit hypothesis' where chronic exposure to PM2.5 causes increased viral load in patients exposed to pollutants which in turn impairs host defences. High atmospheric NO2 then provides a second hit causing a severe form of SARS-CoV-2 resulting in a worse outcome.[146]

Given the timescales of the COVID-19 pandemic, and the early publication of these correlation-based studies, it is important to note that they are based on data from the initial phases of infection and transmission. In the early phases of a pandemic, transmission and infection rates are likely to be higher in more densely populated, urban areas. These areas are also typically associated with higher pollution levels, which may partly explain the results presented. The EEA states that there are significant limitations with these early studies, such as a lack of reliable and consistent data on mortality rates in different regions and challenges in effectively controlling for confounding factors, such as measures to control transmission, population structure, international connectivity of the community, and social and individual behaviours. Findings therefore need to be interpreted with care.[147]

The UK Office for National Statistics (ONS) showed that the correlation between exposure to polluted air and death rate reduced as the COVID-19 pandemic progressed.[148] Up to the week when lockdown began (23 March 2020), 45 % of COVID-19 deaths in England had occurred in London. By

---

[141] Travaglio, M., Yu, Y., Popovic, R., Selley, L., Santos Leal, N. and Martins, M., 'Links between air pollution and COVID-19 in England', *MedRxiv*, 2020. Retrieved from https://www.medrxiv.org/content/10.1101/2020.04.16.20067405v5

[142] Filippini, T., Rothman, K. J., Goffi, A., Ferrari, F., Maffeis, G., Orsini, N. and Vincetia, M., 'Satellite-detected tropospheric nitrogen dioxide and spread of SARS-CoV-2 infection in Northern Italy', *Science of the Total Environment*, Vol. 739, 2020. Retrieved from https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7297152/

[143] Li et al., 2020.

[144] Zoran, M. A., Savastru, R. A., Savastru, D. M. and Tautan, M. N., 'Assessing the relationship between ground levels of ozone (O3) and nitrogen dioxide (NO2) with coronavirus (COVID-19) in Milan, Italy', *Science of the Total Environment*, Vol. 740, 2020. Retrieved from https://www.sciencedirect.com/science/article/pii/S0048969720335257

[145] Pansini et al., 2020.

[146] Frontera et al., 2020.

[147] EEA, 2019.

[148] Office for National Statistics, *Does exposure to air pollution increase the risk of dying from the coronavirus (COVID-19)?*, 2020. Retrieved from https://www.ons.gov.uk/economy/environmentalaccounts/articles/doesexposuretoairpollutionincreasetheriskofdyingfromthecoronaviruscovid19/2020-08-13

the week ending 12 June 2020 (cut-off date for the analysis), this had fallen to 18 % as the virus spread outwards to less polluted areas. It was shown that in the period when the death rate remained high, a week on week analysis of air pollution and number of deaths due to COVID-19 (controlling only for age and no other confounding variables) indicated a weakening in the degree of correlation. The ONS analysis does not discount the possibility of a correlation between PM exposure and COVID-19 related mortality, but the analysis does demonstrate that further research using data sets for longer periods than the initial phases of the pandemic is required. It seems reasonable that if there is a causative correlation between pollution and COVID-19 outcomes, it is likely to have a lower level of effect than the higher-end estimates that have been presented to date.

Furthermore, socioeconomic and demographic factors need to be included in the analysis. The ONS found that there is significant co-linearity between ethnicity and air pollution, such that it is impossible to entirely separate the effects of these co-variates with the confounding variables for which data are available.190 If there is a causal link between air pollution and COVID-19-related mortality, it would partially explain the disparities in COVID-19 outcomes for minority ethnic groups. As a further example of confounding variables, another study showed that individuals with obesity were more at risk for COVID-19 positive (>46 % higher), hospitalisation (113 % higher), ICU admission (74 % higher); and for mortality (48 % increase in deaths). [149]

[149] Air Quality Expert Group, *Estimation of changes in air pollution emissions, concentrations and exposure during the COVID-19 outbreak in the UK*, 2020. Retrieved from https://uk-air.defra.gov.uk/assets/documents/reports/cat09/2007010844_Estimation_of_Changes_in_Air_Pollution_During_COVID-19_outbreak_in_the_UK.pdf

Appendix 4. Analysis of pollutant concentrations during lockdown in the 10 cities analysed

Athens

	NO_2			$PM_{2.5}$		
Station ID	ATH_AGI	ATH_LYK	ATH_PIR	ATH_AGI	ATH_LYK	ATH_PIR
Station type	Background	Background	Traffic	Background	Background	Background
2020 lockdown concentration	8.5	36.8	14.8	48.2	10.9	14.4
Pre-lockdown concentration	15.3	45.3	26.3	56.0	10.3	20.3
2013 lockdown period concentration	8.2	54.5	20.5	35.6	11.4	N/A
2014 lockdown period concentration	7.5	44.1	18.6	30.5	9.6	N/A
2015 lockdown period concentration	11.6	55.1	21.0	50.6	8.6	N/A
2016 lockdown period concentration	16.7	45.8	22.8	68.4	14.5	19.1
2017 lockdown period concentration	16.7	55.4	23.4	67.4	10.7	16.1
2018 lockdown period concentration	16.3	54.6	24.1	70.2	13.8	19.3
2019 lockdown period concentration	15.8	45.8	25.1	70.2	12.0	18.2
Average of lockdown periods (2013-2019)	13.3	50.7	22.2	56.1	11.5	18.2
Annual trend 2013-2019	0.9	-0.8	-0.3	5.0	0.1	-0.2
Spring (MAM) trend 2013-2019	1.6	-0.2	1.3	7.8	0.3	0.1
Expected lockdown concentration (annual trend 2013-2019)	16.8	45.0	24.8	75.2	12.1	18.0

Expected lockdown concentration (spring (MAM) tTrend 2013-2019)	17.4	45.6	26.4	78.0	12.2	18.3
Lockdown concentration - average of lockdown periods (2013-2019)	-36 %	-28 %	-33 %	-14 %	-5 %	-21 %
Lockdown concentration - expected lockdown concentration (annual trend) (%)	-49 %	-18 %	-40 %	-36 %	-10 %	-20 %
Lockdown concentration - expected lockdown concentration (spring trend) (%)	-51 %	-19 %	-44 %	-38 %	-11 %	-22 %

Note: $PM_{2.5}$ data for 2013 to 2015 available as daily rather than hourly average.

Barcelona

	NO_2			$PM_{2.5}$		
Station ID	BAR_HOS	BAR_RUB	BAR_SAN	BAR_HOS	BAR_RUB	BAR_SAN
Station type	Background	Background	Traffic	Background	Background	Traffic
2020 lockdown concentration	14.6	11.2	17.0	N/A	N/A	N/A
Pre-lockdown concentration	37.0	25.6	38.9	N/A	N/A	N/A
2013 lockdown period concentration	28.7	22.3	37.3	10.6	11.7	14.2
2014 lockdown period concentration	29.7	22.7	39.6	10.4	10.6	12.2
2015 lockdown period concentration	33.7	26.4	34.3	12.0	14.7	15.2
2016 lockdown period concentration	31.2	23.7	36.5	11.6	9.0	12.3
2017 lockdown period concentration	39.8	27.9	40.6	12.7	12.5	15.9
2018 lockdown period concentration	36.2	22.5	37.8	12.9	10.3	14.3
2019 lockdown period concentration	29.9	22.6	33.8	N/A	N/A	N/A
Average of lockdown periods (2013-2019)	32.7	24.0	37.1	11.7	11.5	14.0

Annual trend 2013-2019	0.3	-0.5	-0.6	0.2	-0.3	-0.2
Spring (MAM) trend 2013-2019	-0.1	-0.5	-1.1	0.6	-0.3	0.0
Expected lockdown concentration (annual trend 2013-2019)	30.2	22.1	33.2	N/A	N/A	N/A
Expected lockdown concentration (spring (MAM) trend 2013-2019)	29.8	22.1	32.7	N/A	N/A	N/A
Lockdown concentration - average of lockdown periods (2013-2019)	-55 %	-53 %	-54 %	N/A	N/A	N/A
Lockdown concentration - expected lockdown concentration (annual trend) (%)	-52 %	-49 %	-49 %	N/A	N/A	N/A
Lockdown concentration - expected lockdown concentration (spring trend) (%)	-51 %	-49 %	-48 %	N/A	N/A	N/A

Note: $PM_{2.5}$ data available as daily rather than hourly average.

Berlin

	NO_2			$PM_{2.5}$		
Station ID	BER_FRA	BER_MIT	BER_NEU	BER_FRA	BER_MIT	BER_NEU
Station type	Traffic	Background	Background	Traffic	Background	Background
2020 lockdown concentration	25.9	14.1	17.1	N/A	N/A	N/A
Pre-lockdown concentration	32.6	20.4	22.8	N/a	N/a	N/a
2013 lockdown period concentration	38.8	25.5	26.3	22.2	20.9	20.5
2014 lockdown period concentration	38.2	25.7	26.1	20.2	18.3	19.5
2015 lockdown period concentration	40.5	26.4	26.5	17.7	15.0	16.4
2016 lockdown period concentration	43.0	28.1	27.9	15.5	13.8	14.2
2017 lockdown period concentration	41.3	27.1	26.4	15.3	13.8	14.2

2018 lockdown period concentration	40.2	25.6	24.9	18.3	16.8	16.8
2019 lockdown period concentration	29.8	18.1	18.4	N/A	N/A	N/A
Average of lockdown periods (2013-2019)	38.8	25.1	25.2	18.2	14.8	16.9
Annual trend 2013-2019	-0.9	-0.8	-0.7	-0.2	-0.4	-0.3
Spring (MAM) Ttend 2013-2019	-1.4	-1.2	-1.6	-0.5	-0.9	-0.6
Expected lockdown concentration (annual trend 2013-2019)	28.9	17.4	17.7	N/A	N/A	N/A
Expected lockdown concentration (spring (MAM) trend 2013-2019)	28.4	16.9	16.8	N/A	N/A	N/A
Lockdown concentration - average of lockdown periods (2013-2019)	-33 %	-44 %	-32 %	N/A	N/A	N/A
Lockdown concentration - expected lockdown concentration (annual trend) (%)	-10 %	-19 %	-3 %	N/A	N/A	N/A
Lockdown concentration - expected lockdown concentration (spring trend) (%)	-9 %	-16 %	2 %	N/A	N/A	N/A

Note: $PM_{2.5}$ data available as daily rather than hourly average.

Bucharest

	NO_2			$PM_{2.5}$		
Station ID	BUC_B1	BUC_B3	BUC_B6	BUC_B1	BUC_B3	BUC_B6
Station type	Background	Traffic	Traffic	Background	Traffic	Traffic
2020 lockdown concentration	15.6	25.8	26.7	N/A	N/A	N/A
Pre-lockdown concentration	31.0	41.7	53.1	N/A	N/A	N/A
2013 lockdown period concentration	N/a	63.7	N/a	N/A	N/A	N/A
2014 lockdown period concentration	N/a	N/a	N/a	N/A	N/A	N/A

2015 lockdown period concentration	N/a	N/a	N/a	N/A	N/A	N/A
2016 lockdown period concentration	N/a	N/a	N/a	N/A	N/A	N/A
2017 lockdown period concentration	26.4	55.8	58.6	21.2	N/A	N/A
2018 lockdown period concentration	26.7	67.7	58.9	24.1	N/A	N/A
2019 lockdown period concentration	N/A	N/A	N/A	N/A	N/A	N/A
Average of lockdown periods (2013-2018)	26.5	61.8	58.8	22.7	N/A	N/A
Annual trend 2013-2018	2.8	-3.3	2.9	-2.4	N/A	N/A
Spring (MAM) trend 2013-2018	-5.7	1.8	-1.7	-1.1	N/A	N/A
Expected lockdown concentration (annual trend 2013-2018)	29.5	64.4	61.7	N/A	N/A	N/A
Expected lockdown concentration (spring (MAM) trend 2013-2018)	21.0	69.5	57.1	N/A	N/A	N/A
Lockdown concentration - average of lockdown periods (2013-2018)	-41 %	-58 %	-55 %	N/A	N/A	N/A
Lockdown concentration - expected lockdown concentration (annual trend) (%)	-47.0 %	-59.9 %	-56.7 %	N/A	N/A	N/A
Lockdown concentration - expected lockdown concentration (spring trend) (%)	-25.5 %	-62.8 %	-53.3 %	N/A	N/A	N/A

Krakow

	NO_2			$PM_{2.5}$		
Station ID	KRA_ALE	KRA_BUJ	KRA_BUL	KRA_ALE	KRA_BUJ	KRA_BUL
Station type	Traffic	Background	Industrial	Traffic	Background	Industrial
2020 lockdown concentration (based on lockdown period in Germany)	51.0	34.9	28.0	35.5	N/A	31.1
Pre-lockdown concentration	41.1	16.9	15.0	32.4	N/A	30.5
2013 lockdown period concentration	73.3	35.6	25.5	54.4	N/A	46.0
2014 lockdown period concentration	73.3	32.4	35.0	46.4	N/A	35.4
2015 lockdown period concentration	43.5	19.4	19.9	28.6	N/A	17.4
2016 lockdown period concentration	66.3	37.7	33.2	43.9	34.2	41.5
2017 lockdown period concentration	70.9	37.2	32.1	31.1	28.4	25.4
2018 lockdown period concentration	57.9	33.2	31.0	32.2	22.6	22.1
2019 lockdown period concentration	68.0	26.2	21.2	33.7	29.9	25.7
Average of lockdown periods (2013-2019)	64.7	30.7	28.3	38.6	28.8	30.5
Annual trend 2013-2019	-1.2	0.7	0.3	-2.3	-0.4	-1.9
Spring (MAM) trend 2013-2019	-1.0	0.3	0.2	-2.5	-1.9	-2.6
Expected lockdown concentration (annual trend 2013-2019)	66.8	26.9	21.5	31.4	29.5	23.8
Expected lockdown concentration (spring (MAM) trend 2013-2019)	67.0	26.5	21.4	31.2	28.0	23.2
Lockdown concentration - average of lockdown periods (2013-2019)	-21 %	14 %	-1 %	-8 %	N/A	2 %

Lockdown concentration - expected lockdown concentration (annual trend) (%)	-24 %	30 %	30 %	13 %	N/A	31 %
Lockdown concentration - expected lockdown concentration (spring trend) (%)	-24 %	32 %	31 %	14 %	N/A	35 %

Lisbon

	NO_2			$PM_{2.5}$		
Station ID	LIS_ENT	LIS_LAR	LIS_OLI	LIS_ENT	LIS_LAR	LIS_OLI
Station type	Traffic	Background	Background	Traffic	Background	Background
2020 lockdown concentration	16.7	11.5	13.7	7.8	7.5	8.3
Pre-lockdown Concentration	43.0	27.4	32.7	13.5	10.0	13.9
2013 lockdown period concentration	37.1	17.1	23.4	9.7	8.6	8.8
2014 lockdown period concentration	37.0	20.3	26.9	10.9	8.9	11.1
2015 lockdown period concentration	35.5	25.0	26.2	13.4	10.8	10.3
2016 lockdown period concentration	31.5	15.4	20.9	10.8	8.8	6.3
2017 lockdown period concentration	42.3	23.4	27.6	N/A	13.7	11.1
2018 lockdown period concentration	38.8	19.1	25.8	12.0	11.6	9.1
2019 lockdown period concentration	41.0	20.1	26.5	9.7	8.3	7.6
Average of lockdown periods (2013-2019)	37.6	20.6	25.3	11.1	10.6	9.2
Annual trend 2013-2019	0.0	-0.2	0.1	0.3	0.3	-0.4
Spring (MAM) trend 2013-2019	0.1	-0.2	-0.4	-0.1	0.2	-0.3

Expected lockdown concentration (annual trend 2013-2019)	41.0	19.9	26.6	10.0	8.6	7.2
Expected lockdown concentration (spring (MAM) trend 2013-2019)	41.1	19.9	26.2	9.6	8.4	7.3
Lockdown concentration - average of lockdown periods (2013-2019)	-56 %	-44 %	-46 %	-30 %	-30 %	-9 %
Lockdown concentration - expected lockdown concentration (annual trend) (%)	-59 %	-43 %	-48 %	-22 %	-13 %	15 %
Lockdown concentration - expected lockdown concentration (spring trend) (%)	-59 %	-42 %	-47 %	-19 %	-11 %	15 %

Madrid

	NO_2			$PM_{2.5}$		
Station ID	MAD_ESC	MAD_MEN	MAD_PLA	MAD_ESC	MAD_MEN	MAD_PLA
Station type	Traffic	Background	Traffic	Traffic	Background	Traffic
2020 lockdown concentration	18.2	14.2	11.1	8.9	6.6	5.4
Pre-lockdown concentration	52.9	43.4	45.4	12.5	12.2	11.2
2013 lockdown period concentration	33.1	24.0	36.9	9.5	7.5	8.9
2014 lockdown period concentration	42.4	29.0	39.4	11.0	11.4	11.5
2015 lockdown period concentration	46.2	30.3	29.8	10.1	9.0	7.6
2016 lockdown period concentration	50.8	30.8	39.5	8.6	7.2	8.1
2017 lockdown period concentration	54.6	34.8	33.5	8.7	8.8	7.7
2018 lockdown period concentration	48.6	27.0	33.7	6.6	7.0	6.8
2019 lockdown period concentration	48.8	26.6	30.0	9.5	5.8	7.0

Average of lockdown periods (2013-2019)	46.3	29.9	34.7	9.1	7.6	8.2
Annual trend 2013-2019	1.7	0.7	-0.9	-0.3	0.0	-0.4
Spring (MAM) trend 2013-2019	2.3	0.1	-1.4	-0.5	-0.5	-0.5
Expected lockdown concentration (annual trend 2013-2019)	50.5	27.3	29.1	9.2	5.8	6.6
Expected lockdown concentration (spring (MAM) trend 2013-2019)	51.1	26.7	28.6	9.0	5.3	6.5
Lockdown concentration - average of lockdown periods (2013-2019)	-61 %	-53 %	-68 %	-3 %	-13 %	-34 %
Lockdown concentration - expected lockdown concentration (annual trend) (%)	-64 %	-48 %	-62 %	-3 %	14 %	-18 %
Lockdown concentration - expected lockdown concentration (spring trend) (%)	-64 %	-47 %	-61 %	-1 %	25 %	-16 %

Paris

	NO_2				$PM_{2.5}$			
Station ID	PAR_AUT	PAR_BOB	PAR_PER	PAR_VIT	PAR_AUT	PAR_BOB	PAR_PER	PAR_AUT
Station type	Traffic	Background	Traffic	Background	Traffic	Background	Traffic	Traffic
2020 lockdown concentration	33.4	22.6	43.3	17.1	13.9	14.0	15.5	33.4
Pre-lockdown concentration	46.8	24.7	48.0	26.4	21.3	10.9	14.0	46.8
2013 lockdown period concentration	54.9	N/A	N/A	N/A	N/A	N/A	N/A	54.9
2014 lockdown period concentration	46.0	33.9	66.6	25.4	N/A	15.3	19.5	46.0
2015 lockdown period concentration	54.8	34.3	70.5	31.7	N/A	17.8	22.6	54.8
2016 lockdown period concentration	47.2	28.3	67.8	30.1	20.4	11.6	17.2	47.2

2017 lockdown period concentration	57.3	31.3	67.1	30.9	17.5	12.3	17.2	57.3
2018 lockdown period concentration	56.8	31.4	73.3	30.2	20.3	12.5	15.8	56.8
2019 lockdown period concentration	44.5	33.3	69.5	32.2	18.8	N/A	N/A	44.5
Average of lockdown periods (2013-2019)	51.6	32.1	69.1	30.1	19.2	13.9	18.5	51.6
Annual trend 2013-2019	-0.8	-0.6	-1.7	-0.5	-0.2	-0.4	-1.0	-0.8
Spring (MAM) trend 2013-2019	-0.2	-1.7	-0.5	-1.3	0.1	-1.0	-1.6	-0.2
Expected Lockdown Concentration (Annual Trend 2013-2019)	43.6	32.7	67.8	31.7	18.6	12.0	14.8	43.6
Expected lockdown concentration (spring (MAM) trend 2013-2019)	44.3	31.6	69.0	31.0	18.9	11.5	14.2	44.3
Lockdown concentration - average of lockdown periods (2013-2019)	-35 %	-30 %	-37 %	-43 %	-28 %	0 %	-16 %	-35 %
Lockdown concentration - expected lockdown concentration (annual trend) (%)	-23 %	-31 %	-36 %	-46 %	-25 %	16 %	5 %	-23 %
Lockdown concentration - expected lockdown concentration (spring trend) (%)	-25 %	-29 %	-37 %	-45 %	-26 %	21 %	10 %	-25 %

Rome

	NO_2				$PM_{2.5}$			
Station ID	ROM_BEL	ROM_COR	ROM_VIA	ROM_MAG	ROM_BEL	ROM_COR	ROM_MAG	ROM_VIA
Station type	Background	Traffic	Background	Traffic	Background	Traffic	Traffic	Background
2020 lockdown concentration	22.4	25.9	21.4	27.9	11.8	12.3	N/A	11.9
Pre-lockdown concentration	49.7	61.1	51.5	60.4	22.6	17.0	N/A	17.8

2013 lockdown period concentration	46.2	67.1	49.6	67.7	17.5	18.0	N/A	14.4
2014 lockdown period concentration	35.8	73.4	44.6	69.3	17.7	19.4	N/A	15.8
2015 lockdown period concentration	37.9	59.7	44.2	62.3	18.3	18.4	N/A	14.7
2016 lockdown period concentration	39.5	61.4	45.7	61.3	15.3	14.2	N/A	11.9
2017 lockdown period concentration	41.8	62.0	50.8	68.2	16.6	16.4	N/A	12.7
2018 lockdown period concentration	37.0	55.4	46.5	64.6	14.6	14.7	N/A	12.4
2019 lockdown period concentration	37.8	52.2	46.3	41.7	11.5	14.0	N/A	12.1
Average of lockdown periods (2013-2019)	39.4	61.6	46.8	62.2	15.9	16.4	N/A	13.4
Annual trend 2013-2019	-0.2	-2.9	-1.1	-2.5	-0.4	-0.8	N/A	-0.3
Spring (MAM) trend 2013-2019	-0.9	-2.8	-0.8	-3.2	-0.7	-0.8	N/A	-0.4
Expected lockdown concentration (annual trend 2013-2019)	37.6	49.3	45.2	39.3	11.1	13.2	N/A	11.8
Expected lockdown concentration (spring (MAM) trend 2013-2019)	36.9	49.4	45.5	38.5	10.7	13.2	N/A	11.6
Lockdown concentration - average of lockdown periods (2013-2019)	-43 %	-58 %	-54 %	-55 %	-26 %	-25 %	N/A	-12 %
Lockdown concentration - expected lockdown concentration (annual trend) (%)	-41 %	-47 %	-53 %	-29 %	6 %	-7 %	N/A	1 %
Lockdown concentration - expected lockdown concentration (spring trend) (%)	-39 %	-47 %	-53 %	-28 %	10 %	-7 %	N/A	2 %

Note: $PM_{2.5}$ data available as daily rather than hourly average.

Stockholm

	NO_2				$PM_{2.5}$			
Station ID	STO_ERI	STO_HOR	STO_SVE	STO_TOR	STO_ERI	STO_HOR	STO_SVE	STO_TOR
Station type	Traffic	Traffic	Traffic	Background	Traffic	Traffic	Traffic	Background
2020 lockdown concentration (based on lockdown period in Germany)	15.9	21.0	15.3	6.7	4.9	5.3	N/A	N/A
Pre-lockdown concentration	21.9	30.3	27.3	10.0	5.5	5.4	N/A	N/A
2013 lockdown period concentration	N/A	51.4	41.0	10.5	N/A	N/A	4.8	4.8
2014 lockdown period concentration	N/A	48.7	36.8	13.6	N/A	N/A	4.6	4.8
2015 lockdown period concentration	N/A	42.8	33.4	12.3	N/A	6.4	N/A	5.2
2016 lockdown period concentration	N/A	46.7	41.3	11.3	N/A	7.9	5.8	6.0
2017 lockdown period concentration	N/A	42.4	30.3	9.5	N/A	6.6	3.7	3.6
2018 lockdown period concentration	30.0	42.6	31.5	13.3	8.9	9.0	5.0	4.9
2019 lockdown period concentration	22.3	37.2	27.2	11.0	9.6	10.4	9.9	N/a
Average of lockdown periods (2013-2019)	26.2	44.5	34.5	11.6	9.3	8.1	5.7	4.9
Annual trend 2013-2019	-5.8	-2.2	-2.0	-0.5	-1.4	0.3	-0.1	-0.1
Spring (MAM) trend 2013-2019	-11.2	-2.0	-2.0	-0.3	-3.0	0.1	0.1	-0.2
Expected lockdown concentration (annual trend 2013-2019)	16.5	35.0	25.2	10.5	8.2	10.8	9.8	N/A
Expected lockdown concentration (spring (MAM) trend 2013-2019)	11.1	35.2	25.2	10.7	6.6	10.6	10.0	N/A

Lockdown concentration - average of lockdown periods (2013-2019)	-39 %	-53 %	-56 %	-42 %	-47 %	-35 %	N/A	N/A
Lockdown concentration - expected lockdown concentration (annual trend) (%)	-4 %	-40 %	-39 %	-36 %	-40 %	-51 %	N/A	N/A
Lockdown concentration - expected lockdown concentration (spring trend) (%)	43 %	-40 %	-39 %	-37 %	-25 %	-50 %	N/A	N/A

Appendix 5 Interview topics and questions

Topics and questions covered during the interviews with experts in the agglomerations included in the sample

Topic	Interview questions
1. Introduction	• Please provide some general information about your background and experience of local AQ policies in your city. • What are your perspectives on the local AQ policies (governance, effectiveness, efficiency etc.)?
2. Overview of AQ policies implemented in the city	The literature review has identified a range of AQ policies that are applied in the city, including *[for each city/interview - to be populated with the overview of policies]* • According to your knowledge, which of these policies have been most successful in addressing local air pollution in the city, and why? • Does the list capture the main policies addressing air pollution in the city? Are there important policies missing from the list? • Are you aware of any other local AQ policies under development?
3. AQ policies for interview (LEZ, on-road polluting vehicle legacy and 'other')	**Overview – description of policy** Interviewer to provide a brief overview of the information compiled related to the specific AQ policy (description, scope, type). • Is the information presented correct? • Can you please provide further details on the policy description that is missing from the literature, such as the scope, timing of implementation, enforcement approach [to be specified for each policy]? • How is the governance of the policy implementation set up? Are responsibilities and accountabilities clearly defined? **Policy design** • What was the main driver for the choice of the policy measure? • What is explicitly excluded from the scope of the policy, i.e. what exemptions are granted, and why (e.g. type of vehicles, areas, residents)? • Have impacts on social inequalities been considered in the design of the policy and if so, how? • Was there involvement of stakeholders during the design phase of the policy (for example other government departments, surrounding regions or agglomerations, Small and Medium-sized Enterprises and public)? • Was the intervention well communicated to the public before its implementation? • Did the design take into account other planned or ongoing policy measures addressing emissions from the same source? If so, are these policy measures considered to be coherent? • Does the policy allow for changes in the design over time, for example based on lessons learnt from its implementation? • Have extensions of the scope of the policy been considered (or are being considered), such as type of vehicles or spatial extent? **Policy implementation** • Is there sufficient administrative capacity (rules, trained staff, knowledge, financial resources, technical equipment, etc.) to coordinate and enforce the implementation of the policy? • Is there evidence available on the impacts of the policy on emissions and/or concentrations of air pollutants? And is the policy meeting its initial objectives? • What are the costs of implementing the policy (administrative and compliance costs)? • Have there been any barriers for implementing the policy and if so, which ones?

Topic	Interview questions
	- Has the implementation of the policy led to any (un)expected co-benefits, such as wider environmental or health issues? - Are you aware of any specific local conditions supporting or hindering the policy implementation? **Pros and cons** - According to your knowledge, what is the key feature of the policy (such as its built-in flexibility, enforcement approach, scope or social aspect) or what would you identify as a best practice? - Are there any aspects related to the design or implementation of the policy that could be improved?
4. COVID-19	- Was there a reduction in road traffic during lockdown, and are you aware of documented evidence for this? - Was there a reduction in pollutant concentrations (NO_2 and $PM_{2.5}$) during lockdown and are you aware of documented evidence for this? - Did the national or regional government introduce policies to encourage walking and cycling, and how successful were these? - Did residents and workers in the city respond proactively to the COVID-19 pandemic?
5. Conclusions	- Is there anything else to add that has not already been discussed?

OA-02-21-002-EN-N

Air pollution is a cross-border problem with direct negative effects on health and the environment. It also has indirect but tangible adverse effects on economies and societies.

With the aim of securing good air quality status for its citizens and the environment, the EU has established a policy framework that employs legal regulation as the main policy instrument. This European implementation assessment (EIA) presents findings on the implementation of three major pieces of EU legislation on air quality, namely the two Ambient Air Quality Directives and the Industrial Emissions Directive, and makes recommendations for policy action.

In addition, the research paper annexed to this EIA maps and assesses the local policies designed and implemented by 10 EU agglomerations with the aim of tackling air pollution from relevant sources, and, in particular, from road transport. It also makes recommendations for policy action, some of which are relevant to any EU zone/agglomeration affected by air pollution exceedances, irrespective of specific local conditions. Furthermore, the research paper studies the effects of the first wave of pandemic lockdown measures implemented in the same 10 EU agglomerations and their effects on concentrations of certain air pollutants (particularly harmful for health), and, on this basis, outlines lessons that could be applied in future policy-making on air quality at all levels of governance.

This is a publication of the Ex-Post Evaluation Unit
EPRS | European Parliamentary Research Service

ISBN: 978-92-846-7683-5
DOI: 10.2861/808342
CAT: QA-02-21-002-EN-N