Air quality in Europe — 2020 report

ISSN 1977-8449

European Environment Agency

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Layout: Rosendahls a/s/EEA

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The withdrawal of the United Kingdom from the European Union did not affect the production of this report. Data reported by the United Kingdom are included in all analyses and assessments contained herein, unless otherwise indicated.

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Luxembourg: Publications Office of the European Union, 2020
ISBN 978-92-9480-292-7
ISSN 1977-8449
doi:10.2800/786656

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Acknowledgements

This report was written by the EEA and its European Topic Centre on Air Pollution, Noise, Transport and Industrial Pollution (ETC/ATNI).

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The special chapter on the effects of the COVID-19-related lockdown measures on air pollution was written in collaboration with the Copernicus Atmosphere Monitoring Service (CAMS). We appreciate the contribution from Vincent-Henri Peuch, Jérôme Barré, Augustin Colette, Blandine Raux, Laurence Rouïl, Marc Guevara and all CAMS regional modelling teams. The computations for the GAM model were performed on resources provided by UNINETT Sigma2 — the National Infrastructure for High Performance Computing and Data Storage in Norway.

The report was edited by Brendan Killeen. Maps and figures were produced by Bilbomatica with the support of Carsten Iversen. The design and layout was carried out by Alejandra Bize.

Thanks are due to the air quality data suppliers in the reporting countries for collecting and providing the data on which this report is based.

The EEA acknowledges comments received on the draft report from the European Environment Information and Observation Network national reference centres, the European Commission and the World Health Organization's Regional Office for Europe. These comments were included in the final version of the report as far as possible.

Executive summary

The *Air quality in Europe* report series from the European Environment Agency presents annual assessments of Europe's air pollutant emissions and concentrations as well as associated impacts on health and the environment. The annual assessments are based on official data available from countries.

This, the 10th edition in the series, presents an overview and analysis of air quality in Europe including:

- Updated information for 2018 on air pollutant emissions and concentrations;
- A review of trends in ambient air concentrations of key pollutants 2009-2018;
- The latest findings and estimates of population and ecosystem exposure to air pollutants with the greatest impacts.

The *Air Quality in Europe* report continues to develop. This year, for the first time, unvalidated 'up-to-date' data for selected pollutants are used to provide:

- A preliminary assessment of ambient air concentrations of key pollutants in 2019;
- An analysis of the effect on air pollutant concentrations of lockdown measures in 2020 to stop the spread of the coronavirus disease 2019 (COVID-19).

Air pollution and COVID-19

The COVID-19 pandemic continues to have severe implications for human health, as well as major financial and societal impacts. Measures taken by governments across Europe in early 2020 to manage the outbreak had an impact on many of the upstream economic activities that drive emissions of air pollutants, thus affecting air quality. There is also early evidence to suggest that exposure to air pollution can influence human vulnerability and susceptibility to the disease.

The use of preliminary up-to-date data allows an analysis of the effect of the measures taken to avoid the spread of COVID-19 on concentrations of some pollutants during spring 2020. The report also describes early research investigating a possible role for air pollution in influencing the transmission of novel coronavirus, 'severe acute respiratory syndrome coronavirus 2' (SARS-CoV-2) and its associated disease, COVID-19, *and* the health outcomes of infection.

The effect on air pollution of the lockdown measures to prevent the spread of COVID-19

The lockdown measures introduced by most European countries to reduce transmission of COVID-19 in the spring of 2020 led to significant reductions in emissions of air pollutants, particularly from road transport, aviation and international shipping. This report assesses subsequent impacts on air quality based on up-to-date monitoring data reported by EEA member and cooperating countries and supporting modelling undertaken by the Copernicus Atmospheric Monitoring Service (CAMS). The assessment distinguishes changes in concentrations that resulted from the lockdown measures from any changes driven by meteorological conditions.

In particular, nitrogen dioxide (NO_2) concentrations were significantly reduced in April 2020, independently of meteorological conditions. The extent of the reductions varied considerably within cities and across cities and countries, however reductions exceeding 60 % were observed in some cases.

PM_{10} (particulate matter with a diameter of 10 µm or less) concentrations were also lower overall across Europe in April 2020 as a result of the lockdown measures and independently of meteorological conditions, although the impact was less pronounced than for NO_2. Nevertheless, it reached up to 30 % in certain countries.

A possible role for air pollution in increasing susceptibility to COVID-19

There are two other relationships between air pollution and COVID-19:

- the possible effect of air pollution on vulnerability and susceptibility to COVID-19 (via previous long-term exposure to air pollutants);
- the possible role of air pollution in spreading SARS-CoV-2, the virus that causes COVID-19.

Some early studies have explored the links between air pollution and high incidence, severity or mortality rates for COVID-19 and, although they have found spatial coincidence among these elements of the pandemic and high levels of air pollution, the causality is not clear and further epidemiological research is needed. On the other hand, even if short-range aerosol transmission of SARS-CoV-2 seems plausible, particularly in specific indoor locations, the role of outdoor air pollution in the spread of the virus is much more uncertain and further research on this matter will be needed as well.

Impacts of air pollution on health

Air pollution continues to have significant impacts on the health of the European population, particularly in urban areas. Europe's most serious pollutants, in terms of harm to human health, are particulate matter (PM), NO_2 and ground-level ozone (O_3) . Some population groups are more affected by air pollution than others, because they are more exposed or susceptible to environmental hazards. Lower socio-economic groups tend to be more exposed to air pollution, while older people, children and those with pre-existing health conditions are more susceptible. Air pollution also has considerable economic impacts, reducing life expectancy, increasing medical costs and reducing productivity through working days lost across various economic sectors.

Estimates of the health impact of exposure to air pollution indicate that in 2018 long-term exposure to particulate matter with a diameter of 2.5 µm or less ($PM_{2.5}$) in Europe (including 41 countries) was responsible for approximately 417 000 premature deaths, of which around 379 000 were in the EU-28. This represents a 13 % reduction in premature deaths in both Europe and the EU-28, compared with the 477 000 premature deaths in Europe (437 000 in the EU-28) estimated, using the same methodology for 2009 (2009 air quality data were presented in the first edition of the EEA's *Air quality in Europe* report series).

The estimated impact attributable to the population exposure to NO_2 in these 41 European countries in 2018 was around 55 000 premature deaths (around 54 000 in the EU-28). For NO_2, a comparison with 2009 impacts (120 000 premature deaths in Europe and 117 000 in the EU-28) shows that premature deaths have more than halved, with a reduction of 54 %.

Finally, exposure to ground-level O_3 is estimated to have caused 20 600 premature deaths in 2018 in Europe and 19 400 in the EU-28. In contrast to the results for $PM_{2.5}$ and NO_2, this represents an increase of 20 % for Europe and 24 % for the EU-28 based on 2009 figures (17 100 premature deaths in Europe and 15 700 in the EU-28). 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.

Exposure and impacts on European ecosystems

Air pollution also damages vegetation and ecosystems. It leads to several important environmental impacts, which affect vegetation and fauna directly, as well as the quality of water and soil and the ecosystem services they support. The air pollutants that currently cause most damage to ecosystems are O_3, ammonia and nitrogen oxides (NO_X).

Ground-level O_3 can damage crops, forests and other vegetation, impairing their growth and affecting biodiversity. The deposition of nitrogen compounds can cause eutrophication, an oversupply of nutrients. Eutrophication can affect terrestrial and aquatic ecosystems and lead to changes in species diversity and invasions by new species.

In 2018 a significant proportion of the European agricultural and ecosystem area was still exposed to harmful concentrations of O_3 and to eutrophication.

Overarching reflections

The fluctuations in air quality related to the COVID-19 pandemic, emphasise the links between our lifestyles and the well-being of the natural systems that sustain us. By providing data and analysis across time series including spring 2020, the *Air quality in Europe — 2020 report* provides a unique opportunity to reflect on these interlinkages and how we might balance human activity with environmental resilience.

Figure ES.1 Key numbers

		EU: EU-28 urban population exposure to concentrations **above** EU standards (¹)	WHO: Urban population exposure to concentrations **above** WHO AQG value (²)	EU: Reporting stations that registered concentrations **above** EU standards (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) for 33 countries	(*)	(*)	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	(*)	(*)	<1 % One EU MS	28 % 22 countries

Notes: (¹) The following EU standards are considered: PM_{10} daily limit value, $PM_{2.5}$ annual limit value, O_3 target value, NO_2 annual limit value, BaP target value and SO_2 daily limit value. Please see Table 1.1.

(²) For BaP, reference level. Please see Table 1.3.

(³) For NO_2, 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.

Sources: EEA (2020a, 2020c).

1 Introduction

1.1 Background

Air pollution is a global threat leading to large impacts on human health and ecosystems. Emissions and concentrations have increased in many areas worldwide. In Europe air quality remains poor in many areas, despite reductions in emissions and ambient concentrations.

Air pollution is currently the most important environmental risk to human health, and it is perceived as the second biggest environmental concern for Europeans, after climate change (European Commission, 2017). Furthermore, poor air quality-related problems, such as respiratory diseases, cardiovascular diseases, asthma and allergy, are considered a very serious problem by European citizens (European Commission, 2019a). As a result, there is growing political, media and public interest in air quality issues and increased public support for action. Growing public engagement around air pollution challenges, including ongoing citizen science initiatives engaged in supporting air quality monitoring (EEA, 2020b) and initiatives targeting public awareness and behavioural changes, have led to growing support and demand for measures to improve air quality. The European Commission supports the Member States in taking appropriate action and has implemented various initiatives to increase its cooperation with them (European Commission, 2018). The European Commission has also launched infringement procedures against several Member States that are in breach of air quality standards, while both national and local governments face an increasing number of lawsuits filed by non-governmental organisations (NGOs) and citizen groups.

Effective action to reduce air pollution and its impacts requires a good understanding of its sources, how pollutants are transported and transformed in the atmosphere, how the chemical composition of the atmosphere changes over time and how pollutants affect humans, ecosystems, the climate and subsequently society and the economy. To curb air pollution, collaboration and coordinated action at international, national and local levels must be maintained, in coordination with other environmental, climate and sectoral policies. Holistic solutions involving technological developments, structural changes and behavioural changes are also needed, together with an integrated multidisciplinary approach. Efforts to achieve most of the Sustainable Development Goals (SDGs) ([1]) are linked directly or indirectly to mitigating air emissions and changes in atmospheric composition (UNEP, 2019).

Although air pollution affects the whole population, certain groups are more susceptible to its effects on health, such as children, elderly people, pregnant women and those with pre-existing health problems. People living on low incomes are, in large parts of Europe, more likely to live next to busy roads or industrial areas and so face higher exposure to air pollution. Energy poverty, which is more prevalent in southern and central-eastern Europe, is a key driver of the combustion of low-quality solid fuels, such as coal and wood, in low-efficiency ovens for domestic heating (Maxim et al., 2017; InventAir, 2018). This leads to high exposure of the low-income population to particulate matter (PM) and polycyclic aromatic hydrocarbons (PAHs), both indoors and outdoors. Furthermore, the most deprived people in society often have poorer health and less access to high-quality medical care, increasing their vulnerability to air pollution (EEA, 2018a; WHO, 2019a).

([1]) These goals were set in the United Nations' (UN) 2030 Agenda for Sustainable Development (UN, 2015a), covering the social, environmental and economic development dimensions at a global level (UN, 2015b).

1.2 Objectives and coverage

This report presents an updated overview and analysis of ambient (outdoor) air quality in Europe ([2]) and is focused on the state of air quality in 2018. It also presents preliminary information on some air pollutant concentrations in 2019 and on the impact of the lockdown measures to prevent the spread of COVID-19 on air pollutant concentrations in early spring of 2020. The evaluation of the status of air quality is based mainly on officially reported ambient air measurements (Box 1.1), in conjunction with officially reported data on anthropogenic emissions and the trends they exhibit over time. Parts of the assessment also rely on air quality modelling.

In addition, the report includes an overview of the latest findings and estimates of ecosystems' exposure to air pollution and of the effects of air pollution on health.

The report reviews progress towards meeting the air quality standards (Tables 1.1 and 1.2) established in the two Ambient Air Quality Directives presently in force (EU, 2004, 2008). It also assesses progress towards the long-term objectives of achieving levels of air pollution that do not lead to unacceptable harm to human health and the environment, as presented in the latest two European environment action programmes (EU, 2002, 2013), moving closer to the World Health Organization (WHO) air quality guidelines (AQGs) (WHO, 2000, 2006a) (Table 1.3).

This year's edition celebrates the 10th edition of the *Air quality in Europe report*. On this occasion, trend analysis for the main pollutants were performed for the period 2009-2018 and the results are presented in the corresponding chapters, together with additional information from the most recent trend analysis studies by the European Topic Centre on Air Pollution, Noise, Transport and Industrial Pollution (ETC/ATNI), covering the period 2000-2017. The health impacts of air pollution in 2009 have also been estimated for comparison with the situation in 2018.

Finally, 2020 was an exceptional year, with exceptional lockdown measures implemented between the end of February and May in most European countries to stop the spread of the new coronavirus SARS-CoV-2 (severe acute respiratory syndrome coronavirus 2) and its associated disease, coronavirus disease 2019 or COVID-19. Those measures resulted in a decrease in several economic activities and a subsequent decrease in the related emissions. An analysis of their impacts on the concentrations of particulate matter (PM) and nitrogen dioxide (NO_2) in March and April 2020 is presented in a special chapter.

1.3 Effects of air pollution

1.3.1 Human health

Air pollution is a major cause of premature death and disease and is the single largest environmental health risk in Europe (WHO, 2014, 2018a; GBD 2016 Risk Factors Collaborators, 2017; HEI, 2019), responsible for around 400 000 premature deaths per year in the EEA-39 (excluding Turkey) as a result of exposure to $PM_{2.5}$ (particulate matter with a diameter of 2.5 μm or less). Heart disease and stroke are the most common reasons for premature deaths attributable to air pollution, followed by lung diseases and lung cancer (WHO, 2018b). The International Agency for Research on Cancer has classified air pollution in general, as well as PM as a major component of air pollution mixtures, as carcinogenic (IARC, 2013).

Furthermore, short- and long-term exposure to air pollution can lead to reduced lung function, respiratory infections and aggravated asthma. Maternal exposure to ambient air pollution is associated with adverse impacts on fertility, pregnancy, newborns and children (WHO, 2005, 2013a). There is also emerging evidence that exposure to air pollution is associated with new-onset type 2 diabetes in adults and it may be linked to obesity, systemic inflammation, Alzheimer's disease and dementia (RCP, 2016, and references therein; WHO, 2016).

([2]) The withdrawal of the United Kingdom from the European Union did not affect the production of this assessment. Data for the UK appears here in agreement with the terms of the Withdrawal Agreement, which entered into force on 1 February 2020. Data reported by the United Kingdom are included in all analyses and assessments contained herein, unless otherwise indicated. References to the EU-28 in this assessment, follow guidance from the EU Publications Office, and refer to the first 28 countries who were members of the EU (including the UK) up until February 1, 2020.
The report focuses as much as possible on the EEA-39 countries, that is:
- the 28 Member States of the EU, or EU-28 (up to 2020) — Austria, Belgium, Bulgaria, Croatia, Cyprus, Czechia, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, the Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden and the United Kingdom;
- plus the five other member countries of the EEA — Iceland, Liechtenstein, Norway, Switzerland and Turkey — that, together with the EU-28, form the EEA-33;
- plus the six cooperating countries of the EEA — Albania, Bosnia and Herzegovina, Kosovo under UN Security Council Resolution 1244/99, Montenegro, North Macedonia and Serbia — that, together with the EEA-33, form the EEA-39 countries.

Finally, most information also covers Andorra as a voluntary reporting country, and some information also covers other smaller European countries, such as Monaco and San Marino.

Box 1.1 Ambient air measurements

The analysis of concentrations in relation to the defined EU and World Health Organization (WHO) standards is based on measurements at fixed sampling points, officially reported by the Member States. Supplementary assessment by modelling is also presented when it resulted in exceedances of the EU standards in 2018.

When it comes to monitoring data, only valid measurement data received by 21 April 2020 were included in the analysis for 2018 and, therefore, the maps, figures and tables reflect these data. By that cut-off date, 37 countries had submitted 2018 data: the EEA-39 (except Albania, Kosovo and Liechtenstein) and Andorra. The term '2018 37 reporting countries' will be used to refer to those 37 countries. Data officially reported after the cut-off date are regularly updated and are available through the EEA's download service for air quality data (EEA, 2020c).

For the preliminary analysis of 2019, up-to-date (UTD) data reported in that year were included. UTD data were introduced by the EU (2011) to make information available to the public without delay and they are therefore considered provisional data. Data are reported in near-real time, normally by a subset of the total number of monitoring stations in a country; therefore, the final analysis that is performed for 2019 using officially validated data may be based on a greater number of stations and this can affect the percentage of stations with values above the legal standards. Thirty-three countries have reported UTD data for the whole of 2019: the EEA-39 (except Albania, Bosnia and Herzegovina, Kosovo, Liechtenstein, Montenegro, Romania and Turkey) and Andorra. In the analysis they are referred to as '2019 33 UTD reporting countries'. In addition, Georgia started to submit UTD data in April 2019 and Bosnia and Herzegovina in May 2019. These two countries are not included in the analysis, because they could not reach the minimum data coverage of 75 % of valid data.

Fixed sampling points in Europe are situated at different types of stations following rules for macro- and micro-scale-siting, as stated by the EU (2004, 2008, 2011). Briefly, depending on the predominant emission sources, stations are classified as follows:

- traffic stations — located in close proximity to a single major road;
- industrial stations — located in close proximity to an industrial area or an industrial source;
- background stations — where pollution levels are representative of the average exposure of the general population or vegetation.

Depending on the distribution/density of buildings, the area surrounding the station is classified as follows:

- urban — continuously built-up urban area;
- suburban — largely built-up urban area;
- rural — all other areas.

For most of the pollutants (sulphur dioxide, SO_2; nitrogen dioxide, NO_2; ozone, O_3; particulate matter, PM; and carbon monoxide, CO), monitoring stations have to fulfil the criterion of reporting more than 75 % of valid data out of all the possible data in a year to be included in this assessment. The Ambient Air Quality Directive (EU, 2008) sets, for compliance purposes, the objective of a minimum data capture of 90 % for monitoring stations, but, for assessment purposes, a coverage of 75 % allows more stations to be taken into account without a significant increase in monitoring uncertainties (ETC/ACM, 2012).

For benzene (C_6H_6), the required amount of valid data for the analysis is 50 %. For toxic metals (arsenic, cadmium, nickel and lead) and benzo[*a*]pyrene (BaP), it is 14 % (according to the air quality objectives for indicative measurements; EU, 2004, 2008).

Measurement data are rounded following the general recommendations as stated in EU (2011). The number of decimal places considered are indicated in the legend of the corresponding maps.

The assessments, in the cases of PM and SO_2, do not account for the fact that the Ambient Air Quality Directive (EU, 2008) provides Member States with the possibility of subtracting contributions to the measured concentrations from natural sources and winter road sanding/salting under specific circumstances.

The effects of air pollution on health depend not only on exposure but also on the susceptibility of people. Susceptibility to the impacts of air pollution can increase as a result of age, pre-existing health conditions or particular behaviours, such as diet, physical activity and smoking. A large body of evidence suggests that people of lower socio-economic status tend to live in environments with worse air quality (EEA, 2018a).

In 2018, household (indoor) and ambient air pollution were recognised as one of the main risk factors for non-communicable diseases, alongside unhealthy diets, tobacco smoking, harmful use of alcohol and physical inactivity (UN, 2018). Most outdoor air pollutants penetrate into our homes, work and schools and can react with indoor air pollutants. In fact, harmful air pollutants can exist in higher concentrations in indoor spaces than in outdoor spaces (EEA, 2013). As Europeans spend most of their time (over 90 %) indoors, exposure to indoor air pollution (including chemicals) is a very important health risk factor that needs to be controlled and reduced (WHO, 2015). Nevertheless, this report focuses only on ambient air quality.

1.3.2 Ecosystems

Air pollution has several important environmental impacts and may directly affect natural ecosystems and biodiversity. For example, nitrogen oxides (NO_X, the sum of nitrogen monoxide (NO) and NO_2) and ammonia (NH_3) emissions disrupt terrestrial and aquatic ecosystems by introducing excessive amounts of nitrogen nutrient. This leads to eutrophication, which is an oversupply of nutrients that can lead to changes in species diversity and to invasions of new species. NO_X, together with sulphur dioxide (SO_2), also contribute to the acidification of soil, lakes and rivers, causing loss of biodiversity. Finally, ground-level ozone (O_3) damages agricultural crops, forests and plants by reducing their growth rates and yields and has negative impacts on biodiversity and ecosystem services.

1.3.3 Climate change

Air pollution and climate change are intertwined. Several air pollutants are also climate forcers, which have a potential impact on climate and global warming in the short term. Tropospheric O_3 and black carbon (BC), a constituent of PM, are examples of air pollutants that are short-lived climate forcers and that contribute directly to global warming. Other PM components, such as organic carbon, ammonium (NH_4^+), sulphate (SO_4^{2-}) and nitrate (NO_3^-), have a cooling effect (IPCC, 2013). In addition, methane (CH_4), a powerful greenhouse gas, is also a contributor to the formation of ground-level O_3. Changes in weather patterns due to climate change may alter the transport, dispersion, deposition and formation of air pollutants in the atmosphere, and higher temperatures will lead to increased O_3 formation.

As greenhouse gases and air pollutants share the same main emission sources, potential benefits can arise from limiting emissions of one or the other. Policies aimed at reducing air pollutants might help to keep the global mean temperature increase below two degrees. Moreover, climate policies aimed at reducing combustion of fossil fuels or reducing BC and CH_4 emissions contribute to mitigating the damage of air pollution to human health and the environment. Implementing integrated policies would avoid the negative impact of climate policies on air quality. Examples are the negative impacts on air quality arising from subsidising diesel cars (which have lower carbon dioxide (CO_2) but higher PM and NO_X emissions) and the potential increase in PM emissions and emissions of other carcinogenic air pollutants, which an increase in wood burning for residential heating may cause (EEA, 2015a; ETC/CME, 2019).

1.3.4 The built environment and cultural heritage

Air pollution can damage materials, properties, buildings and artworks, including Europe's culturally most significant buildings. The impact of air pollution on cultural heritage materials is a serious concern, because it can lead to the loss of parts of European history and culture. Damage includes corrosion (caused by acidifying compounds), biodegradation and soiling (caused by particles), and weathering and fading of colours (caused by O_3).

1.3.5 Economic impacts

The effects of air pollution on health, crop and forest yields, ecosystems, the climate and the built environment also entail considerable market and non-market costs. The market costs of air pollution include reduced labour productivity, additional health expenditure, and crop and forest yield losses. Non-market costs are those associated with increased mortality and morbidity (e.g. illnesses causing pain and suffering), degradation of air and water quality and consequently the health of ecosystems, and climate change.

A recent study by the Organisation for Economic Co-operation and Development (OECD) of the impact of air pollution on market economic activity in Europe (OECD, 2019) estimated that a 1 $\mu g/m^3$

decrease in annual mean $PM_{2.5}$ concentration would increase Europe's gross domestic product (GDP) by 0.8 %, representing around EUR 200 per capita per year (for 2017). Of this increase in GDP 95 % is the result of increases in output per worker, through lower absenteeism at work or increased labour productivity, due to lower air pollution. This study concludes that more stringent air quality regulations could be warranted based solely on economic grounds, as the direct economic benefits from air pollution control policies are much larger than the abatement costs, even when ignoring the large benefits in terms of avoided mortality.

The OECD (2019) also estimated that if all Member States meet their national exposure reduction targets for $PM_{2.5}$ (see Table 1.1 and Section 4.4) in 2020, the European 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 the United Kingdom, and even for countries with low $PM_{2.5}$ concentrations, such as Ireland or Norway, the GDP increases are still substantial at around 0.8 %.

Table 1.1 Air quality standards for the protection of health, as given in the EU Ambient Air Quality Directives

Pollutant	Averaging period	Legal nature and concentration	Comments
PM_{10}	1 day	Limit value: 50 µg/m³	Not to be exceeded on more than 35 days per year
	Calendar year	Limit value: 40 µg/m³	
$PM_{2.5}$	Calendar year	Limit value: 25 µg/m³	
		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.

Sources: EU (2004, 2008).

Table 1.2 Air quality standards for the protection of vegetation, as given in the EU Ambient Air Quality Directive and the Convention on Long-range Transboundary Air Pollution (CLRTAP)

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.

Sources: EU (2008); UNECE (2011).

Table 1.3 World Health Organization (WHO) air quality guidelines (AQGs) and estimated reference levels (RLs) ([a])

Pollutant	Averaging period	AQG	RL	Comments
PM_{10}	1 day	50 µg/m³		99th percentile (3 days per year)
	Calendar year	20 µg/m³		
$PM_{2.5}$	1 day	25 µg/m³		99th percentile (3 days per year)
	Calendar year	10 µg/m³		
O_3	Maximum daily 8-hour mean	100 µg/m³		
NO_2	1 hour	200 µg/m³		
	Calendar year	40 µg/m³		
BaP	Calendar year		0.12 ng/m³	
SO_2	10 minutes	500 µg/m³		
	1 day	20 µg/m³		
CO	1 hour	30 mg/m³		
	Maximum daily 8-hour mean	10 mg/m³		
C_6H_6	Calendar year		1.7 µg/m³	
Pb	Calendar year	0.5 µg/m³		
As	Calendar year		6.6 ng/m³	
Cd	Calendar year	5 ng/m³ ([b])		
Ni	Calendar year		25 ng/m³	

Notes: ([a]) As WHO has not set an AQG for BaP, C_6H_6, As and Ni, the RL was estimated assuming an acceptable risk of additional lifetime cancer risk of approximately 1 in 100 000.

([b]) AQG set to prevent any further increase of Cd in agricultural soil, likely to increase the dietary intake of future generations.

Sources: WHO (2000, 2006a).

1.4 International policy

Increased recognition of the effects and costs of air pollution has led international organisations, national and local authorities, industry and NGOs to take action.

At an international level, the United Nations Economic Commission for Europe (UNECE), WHO and the United Nations Environment Programme (UNEP), among others, have continued to decide on global actions to address the long-term challenges of air pollution.

The UNECE Convention on Long-range Transboundary Air Pollution (CLRTAP, also known as the Air Convention) (UNECE, 1979), consisting of 51 Parties, addresses emissions of air pollutants through its various protocols, among which the 2012 amended Gothenburg Protocol is key in reducing emissions of selected pollutants across the pan-European region. In 2019, the Convention celebrated its 40th anniversary. On that occasion, an anniversary declaration (UNECE, 2019) was approved to renew the commitment for action on cleaner air in the region, in line with the long-term strategy for the Convention for 2020-2030 and beyond (UNECE, 2018). The declaration recognises the contribution of the CLRTAP in the control and reduction of the damage to human health and the environment caused by transboundary air pollution. However, it also recognises that air pollution still causes significant environmental threats and health problems and that new challenges continue to emerge. Therefore, it urges action to address, among other things, remaining and emerging air pollution issues, improving cooperation between different levels of government and promoting an integrated approach to environmental policymaking, recognising that air pollution is the central link in the interaction between ground-level ozone, nitrogen, human health, climate change and ecosystems. A forum for international cooperation on air pollution was also created, whose terms of reference still need to be developed, to prevent and reduce air pollution and to improve air quality globally, working closely with other relevant initiatives.

WHO has long been working on air pollution and health. The BreatheLife campaign (WHO, 2020a), which is among its most recent activities, has reached more than 75 members. This campaign, developed together with the Climate and Clean Air Coalition, UNEP and the World Bank, mobilises communities to reduce the impact of air pollution on our health and climate.

In the wake of the COVID-19 recovery, WHO has issued a manifesto (WHO, 2020b) to ask governments to resuscitate economic activity in a healthy and green way. It makes some prescriptions that touch on air pollution. Specifically, it calls on governments to:

- protect nature and preserve clean air;
- invest in clean energy to ensure a quick healthy energy transition, which will also bring co-benefits in the fight against climate change;
- build healthy, liveable cities, focusing on mobility issues, such as public transport, and promotion of walking and cycling;
- stop using taxpayer's money to subsidise the fossil fuels that cause air pollution.

WHO, through its Regional Office in Europe, continues its work towards the update of the global AQGs, which will provide up-to-date recommendations to protect populations worldwide from the adverse health effects of ambient air pollution.

Finally, WHO is a custodian agency for the air quality-related United Nations' SDG indicators (UNEP, 2019). SDG 3 (Good health and well-being) targets substantially reducing the number of deaths and illnesses caused by air pollution by 2030; SDG 11 (Sustainable cities and communities) targets reducing the adverse per capita environmental impact of cities by 2030 by paying particular attention to air quality; and SDG 13 (Take urgent action to combat climate change and its impacts) targets integrating climate change measures into national policies, strategies and planning.

1.5 European Union legislation and activities

The EU has been working for decades to improve air quality by controlling emissions of harmful substances into the atmosphere, improving fuel quality, and integrating environmental protection requirements into the transport, industrial and energy sectors. The EU's clean air policy is based on three main pillars (European Commission, 2018): (1) the Ambient Air Quality Directives (EU, 2004, 2008), which set out air quality standards (Tables 1.1 and 1.2) and require Member States to assess air quality and to implement air quality plans to improve or maintain the quality of air; (2) the NEC Directive (EU, 2016), which establishes national emission reduction commitments; and (3) source-specific legislation establishing specific emission and energy efficiency standards for key sources of air pollution ([3]).

([3]) For more information on specific legislation, please check: http://ec.europa.eu/environment/air/quality/existing_leg.htm

The Seventh Environment Action Programme, 'Living well, within the limits of our planet' (EU, 2013) recognises the long-term goal within the EU to achieve 'levels of air quality that do not give rise to significant negative impacts on, and risks to, human health and the environment'. In addition, the Clean Air Programme for Europe, published by the European Commission in late 2013 (European Commission, 2013), aims to ensure full compliance with existing legislation by 2020 at the latest and to further improve Europe's air quality so that, by 2030, the number of premature deaths caused by exposure to $PM_{2.5}$ and O_3 is reduced by half compared with 2005.

The European Commission held the Second EU Clean Air Forum in November 2019, in Bratislava, Slovakia. The forum focused on air quality and health, air quality and energy, air quality and agriculture, and clean air funding mechanisms. Participants noted the existing gap between EU air quality standards and WHO AQGs, and it was pointed out that implementation and enforcement are paramount when standards are not met. Increased policy coherence between air quality and the production and use of energy was considered key to reach win-win solutions that reduce air pollutant and greenhouse gas emissions. Since agriculture is the sector with the least reductions in air pollutant emissions (see Chapter 3) the importance of making the most of funding available under the Common Agricultural Policy was underlined as well as the need to focus action on the largest emitters in the first place. Finally, it was concluded that action for clean air can be used as leverage to fund the climate transition, tapping into all relevant funds available, including private investment (European Commission, 2019b).

In 2019, a fitness check of the EU Ambient Air Quality Directives was published (European Commission, 2019c). It assessed whether or not all the directives' provisions are fit for purpose, looking in particular at the monitoring and assessment methods, the air quality standards, the provisions on public information and the extent to which the directives have facilitated action to prevent or reduce adverse impacts. It applied five criteria: relevance, effectiveness, efficiency, coherence and EU added value. The fitness check concluded that the Ambient Air Quality Directives have been partly effective in improving air quality and achieving air quality standards. It also acknowledges that they have not been fully effective, that not all their objectives have been met to date and that the remaining gap to achieve agreed air quality standards is too wide in certain cases. So, even if the Ambient Air Quality Directives have been broadly fit for purpose, there is scope for improvements in the existing framework such that good air quality be achieved across the EU. In particular, additional guidance, or clearer requirements in the Ambient Air Quality Directives themselves, could help make monitoring, modelling and the provisions for air quality plans and measures more effective and efficient.

Finally, in 2019, the European Green Deal (European Commission, 2019d) was published. This is the European Commission's response to the climate and environmental challenges Europe (and the world) is facing. It aims to transform the EU into a fair and prosperous society, with a modern, resource-efficient and competitive economy with no net emissions of greenhouse gases in 2050 and whose economic growth is decoupled from resource use. This transition must be just and inclusive. In this way, the EU's natural capital would be protected, conserved and enhanced and the health and well-being of citizens would be protected from environment-related risks and impacts.

A key element of the European Green Deal is the zero pollution ambition, for a toxic-free environment. To reach this ambition, the Commission will adopt a zero pollution action plan for air, water and soil in 2021. In it, the Commission will draw on the lessons learnt from the evaluation of the current air quality legislation. In line with the conclusions from the fitness check, it will also propose to strengthen provisions on monitoring, modelling and air quality plans to help local authorities achieve cleaner air. Finally, the Commission will notably propose to revise air quality standards to align them more closely with the WHO recommendations, which are due to be updated in 2021.

This ambition is interlinked with other elements of the European Green Deal, such as increasing the EU's climate ambition for 2030 and 2050; supplying clean, affordable and secure energy; mobilising industry for a clean and circular economy; building and renovating in an energy- and resource-efficient way; accelerating the shift to sustainable and smart mobility; designing a fair, healthy and environmentally friendly food system; and preserving and restoring ecosystems and biodiversity ([4]).

([4]) More information on the European Commission's activities related to air pollution can be found at: http://ec.europa.eu/environment/air

1.6 National and local measures to improve air quality in Europe

Air quality plans and measures to reduce air pollutant emissions and improve air quality have been implemented throughout Europe and form a core element in air quality management. The Ambient Air Quality Directives (EU, 2004, 2008) set the obligation of developing and implementing air quality plans and measures for zones and agglomerations where concentrations of pollutants exceed the EU standards (and of maintaining quality where it is good; Section 1.5). These plans and measures should be consistent and integrated with those under the NEC Directive (EU, 2016). The integrated national energy and climate plans under the Regulation on the Governance of the Energy Union and Climate Action (EU, 2018) should also be considered in terms of their capacity to reduce emissions of air pollutants.

More than 50 % of the respondents of the latest Eurobarometer on air quality (European Commission, 2019a) think that public authorities are not doing enough to promote good air quality and they think the same of households, car manufacturers and energy producers. Most of the respondents also think that the most effective way to tackle air quality problems is to apply stricter pollution controls on industrial and energy production activities, and they think these issues should be addressed at the international level. This is why a majority (71 %) of respondents think that the EU should propose additional measures, although half of them think that it should also be addressed at the national level.

The abatement measures implemented at the national level have addressed the whole set of emissions sectors, for example:

- road traffic: low-emission zones, switching to cleaner public transport such as low-emission buses or trams, promoting cycling and walking, car-sharing schemes, lowering speed limits and issuing congestion charges;
- residential heating: expanding district heating, using cleaner fuels for heating, reducing energy use via insulation of buildings, use of energy certification system/labelling;
- inland shipping;
- industry: implementation of the requirements of the Integrated Pollution Prevention and Control (IPPC) Directive;
- construction and demolition activities, including emissions from non-road mobile machinery.

The measures also address public awareness and behavioural changes. The latest Eurobarometer on air quality (European Commission, 2019a) showed an increase in the respondents taking at least one action to reduce their harmful emissions. The main action taken seems to be the replacement of older energy-intensive equipment with equipment with better energy performance.

Information on the air quality plans and measures reported by national authorities under the Ambient Air Quality Directives can be found in the air quality management section of the EEA's website ([5]).

([5]) https://www.eea.europa.eu/themes/air/explore-air-pollution-data#tab-air-quality-management

2 COVID-19 lockdown effects on air quality

Following the emergence of the novel coronavirus SARS-CoV-2 (severe acute respiratory virus coronavirus 2) in late 2019 and its spread across Europe in 2020, most European countries introduced lockdown measures in mid-March 2020. As people were asked to stay at home, many economic activities were temporarily closed or reduced and demand for personal transport plunged. This led to significant reductions in emissions of air pollutants, particularly from road transport, aviation and international shipping. Although the movement of people was severely reduced during the lockdown in many countries, the transport of goods and their associated emissions were little affected. In addition, as several businesses and industrial activities were temporarily shut down or reduced, emissions of air pollutants from some industrial sites also dropped in different regions in Europe, although with more localised effects than the road transport emission reductions. Emissions from other sectors may also have been affected, such as domestic combustion, but such changes have not yet been quantified across Europe.

These changes in emissions entailed a decrease in air pollutant concentrations, which was shown early in observations from both satellite data (Map 2.1) and *in situ* data presented in an EEA online tool (EEA, 2020d; Box 2.1); the decrease was immediately perceptible even to citizens. Although these early confirmations of the decrease in concentrations allowed a comparison with previous years (with 2019 in the case of satellite and with 2016-2019 in the case of the EEA viewer), the effect of meteorological variability was difficult to disentangle. Meteorology is one of the key factors determining the transport and dispersion, chemical transformation and deposition of air pollutants ([6]). Thus, meteorology greatly affects concentrations of air pollutants and its variability from one year to another.

In this chapter we present an assessment of the impact of the lockdown on air quality across Europe during spring 2020, focusing on nitrogen dioxide (NO_2) and PM_{10} (particulate matter with a diameter of 10 µm or less ([7]). This assessment was carried out using the abovementioned observation data and supporting modelling approaches in order to distinguish the changes in measured concentrations due to the lockdown measures from the changes due to meteorological variability. The assessment also includes estimates made by the Copernicus Atmospheric Monitoring Service (CAMS), using chemical transport models (CTMs) with custom-developed emission inventories (Guevara et al., forthcoming), to estimate the reductions in emissions and concentrations during the lockdown in Europe (CAMS, 2020). It is important to note that the current assessment has several limitations and uncertainties, as will be further explained. For example, up-to-date (UTD) data have higher uncertainty than validated data (Box 1.1), the estimation of emission changes during the lockdown (input to modelling) is uncertain and limited to a few sectors and the contribution of natural sources to the observed changes in PM concentrations is also highly uncertain in this preliminary assessment.

2.1 Monitoring NO_2 pollution levels from space during the lockdown measures in Europe

Whereas air quality monitoring stations tend to be relatively sparsely distributed across Europe and measure concentrations in both background and hotspot areas (e.g. highly impacted by traffic and industrial emission sources), satellite measurements allow spatially continuous measurements of NO_2 levels across Europe. However, observations made

([6]) For example, the month of February 2020 was exceptionally warm in Europe: it was 1.4 °C above the second warmest February on record in 2016 (CCS, 2020), which led to, for example, lower NO_2 concentrations than normal in February. Such weather anomalies have indeed a substantial influence on surface concentrations of pollutants.

([7]) NO_2 is highly affected by changes in road transport emissions and therefore a very interesting air pollutant to analyse. PM_{10} is a key air pollutant, affected by changes in road traffic and industrial emissions. Data availability determined the choice of PM_{10} instead of $PM_{2.5}$. The assessment of the effect of the lockdown on ozone (O_3) concentrations would require an analysis over a longer period of data collection, which was not compatible with the timeline for the production of this report.

by satellite instruments typically provide vertically integrated measurements of the whole atmosphere (or parts thereof) and are thus not directly comparable to surface concentration observations by reference monitoring stations.

Map 2.1 (right panel) shows the average satellite-observed vertical columns of NO_2 from 15 March to 15 April 2020, corresponding to the month immediately after the introduction of the lockdown measures in most countries in Europe, while the left panel shows the same observation over the same period in 2019. It is based on the data provided by the Tropospheric Monitoring Instrument (TROPOMI) onboard the Sentinel-5P satellite platform ([8]).
Map 2.1 shows that all the typical hotspot areas for NO_2 concentrations, such as northern Italy, western Germany, Belgium and the Netherlands, exhibited lower NO_2 pollution levels in the considered period in 2020 than in the same period of the reference year 2019. Such satellite-only comparisons provide a useful qualitative assessment of the spatial patterns and relative magnitude of how the NO_2 levels between two periods have changed; however, they cannot be used to directly quantify the exact effect of the COVID-19-related lockdown because it is entangled with air quality changes due to interannual meteorological variability.

In order to quantify the change in observed NO_2 pollution levels due to emissions changes because of the lockdown, it is necessary to estimate what would have been the situation under the same meteorological conditions if the lockdown had not happened, i.e. in a 'business as usual' (BAU) scenario. As previously mentioned, it is necessary to account for the meteorological impact on concentrations, which can be as large as or even larger than the impact of emission changes. This was done by using NO_2 TROPOMI satellite observations with the most stringent cloud filtering (clear sky pixels only) and applying a method based on machine learning ([9]) to account for the meteorological variability and compare 2020 observations with an estimate of what would have been the concentrations in 2020 if there had been no lockdown

Box 2.1 The EEA's data viewer on the development of air pollutant concentrations under the lockdown measures

As soon as the decrease in air pollutants concentrations started becoming evident, the EEA developed a viewer to help tracking those changes (https://www.eea.europa.eu/themes/air/air-quality-and-covid19). The viewer shows weekly and monthly averages of hourly or daily concentrations of nitrogen dioxide (NO_2) and particulate matter (PM) at the city level. Weekly and monthly concentrations are not related to any legal standard, but they allow the changes to be followed in time, in spite of the hour-to-hour variations and the diurnal cycle of, mainly, NO_2.

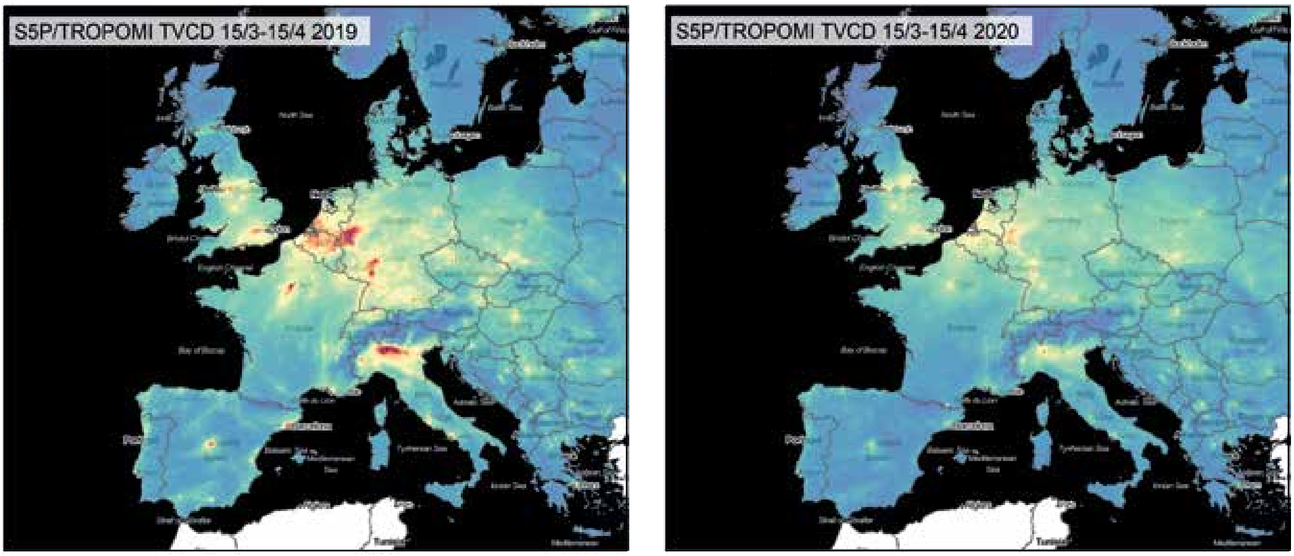
Cities were chosen according to their definition in Eurostat's city statistics database (formerly Urban Audit; Eurostat, 2020a). A daily value is obtained for each station in the city and then all daily values from stations in the city are averaged to get the weekly or monthly city concentration. Both validated and up-to-date data (see Box 1.1) are used.

As a qualitative example, the graphs below (Figure 2.1) show the weekly NO_2 concentrations for Madrid (Spain) and Milan (Italy) since the beginning of 2020 until the last week of June (starting on 29 June). These two cities were affected by very strict lockdown measures in the week starting 9 March. A significant drop in concentrations in relation to the previous weeks in 2020 can be observed from that week onwards. The lockdown measures started being relaxed around mid-May and some increases in concentrations can be seen for both cities since then, without reaching the pre-pandemic levels in either of these two cases.

([8]) All available data from the official Level-2 offline NO_2 product were gridded to 0.025 ° by 0.025 ° spatial resolution, filtered for clouds and other retrieval issues (using only retrievals with quality assurance flag values of greater than 0.75), composited to daily mosaics and subsequently averaged over the 1 month period. TROPOMI observations typically need to be averaged over multiple weeks to obtain robust estimates, as cloud cover can cause substantial data gaps, especially during winter.

([9]) The gradient boosting regressor machine learning technique was used to simulate BAU NO_2 tropospheric columns satellite observations. Weather variables from the European Centre for Medium-Range Weather Forecasts (ECMWF) and CAMS operational forecasts at 9 km and 10 km resolutions, respectively, were used to extract the following: 10 m windspeed, planetary boundary layer height, 2 m temperature, surface relative humidity, geopotential at 500 hPa and NO_2 surface concentrations from CAMS forecasts (without assimilation of surface stations), as well as latitude, longitude, population, day of the year and day of the week. This constitutes a list of predictors per city that can be used to simulate TROPOMI NO_2 tropospheric columns. The BAU NO_2 tropospheric columns were generated with the gradient boosting regressor trained with data from January to April 2019 and applied to 2020 to generate predictions. The training set is small, as 2019 and 2020 are the only years available with TROPOMI for the spring period. Thus, the predictions are likely to be noisy but they are still able to represent the main BAU NO_2 tropospheric column variability. By subtracting the BAU NO_2 simulated columns from the real observed NO_2 columns during the lockdown period considered (15 March to 30 April 2020) an estimate of the changes of NO_2 background levels on medium-to-large European cities was obtained. For more details about the machine learning function used, please see https://scikit-learn.org/stable/modules/generated/sklearn.ensemble.GradientBoostingRegressor.html

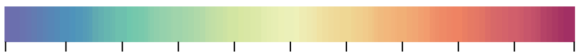
Map 2.1 **Average NO_2 pollution level (tropospheric vertical column) from Sentinel-5P/TROPOMI for the period 15 March to 15 April 2019 (left panel) and for the same period in 2020 (right panel)**



Reference data: © NILU - Norwegian Institute for Air Research. Contains modified Copernicus Sentinel data (2020), processed by NILU. Basemap © OpenStreetMap contributors and map tiles by Stamen Design, under CC BY 3.0.

Average NO_2 pollution level (tropospheric vertical column) for 15 March - 15 April 2019 (left panel) and for the same period in 2020 (right panel)

Peta-molecules/cm²



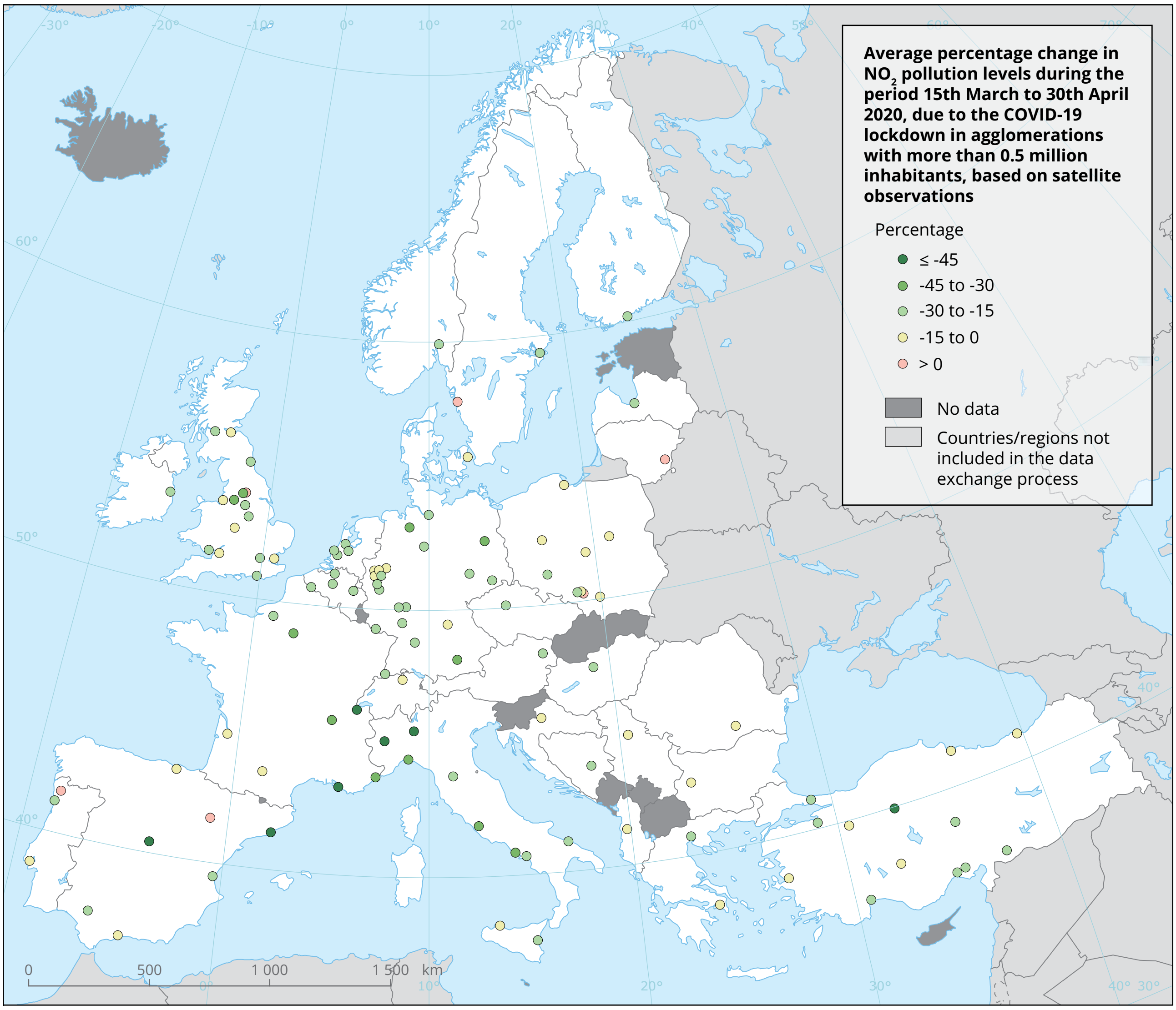
Note: Units are given in 10^{15} molecules per square centimetre.

(Barré et al., 2020). This satellite-based analysis provides an estimate of the relative changes in NO_2 background concentrations due to the lockdown, excluding the effect of meteorological variability (Map 2.2). This enabled a consistent assessment of all European urban areas, including those areas that had no, or an insufficient number of, air quality monitoring stations available to feed into a robust station-based analysis of the impacts of COVID-19 measures on NO_2 levels across Europe.

The lockdown measures varied across European countries, from milder measures based on advice (e.g. in Sweden) to strictly enforced measures assuring that people do not leave their homes except for a few exceptional reasons (e.g. in Spain and Italy). This variability is also reflected in the reductions in activity, emissions and concentrations, as can be seen on the map.

Map 2.2 shows the average percentage change in NO_2 pollution levels during the period 15 March to 30 April, comparing the observations under the COVID-19 lockdown with the BAU scenario, in European agglomerations with more than 0.5 million inhabitants. This estimation shows that the cities with the greatest NO_2 concentrations reduction in this period were in Spain (Barcelona: 59 %, Madrid: 47 %), Italy (Milan: 54 %, Turin: 47 %, Rome and Genoa: 39 %, Naples: 36 %), France (Marseille: 49 %, Nice and Lyon: 34 %, Paris: 30 %, Lille: 27 %), Switzerland (Geneva: 47 %), Turkey (Ankara: 46 %), Germany (Munich: 37 %, Bremen: 36 %, Berlin: 33 %, Hamburg: 28 %, Frankfurt: 27 %), the United Kingdom (Bradford: 36 %, Manchester: 31 %, Glasgow: 29 %, London: 26 %), and Belgium (Antwerp: 29 %). On the other hand, a few cities seem to have registered an increase (around 10-13 %), for example Gothenburg (Sweden), Braga (Portugal), Vilnius (Lithuania) and Katowice (Poland).

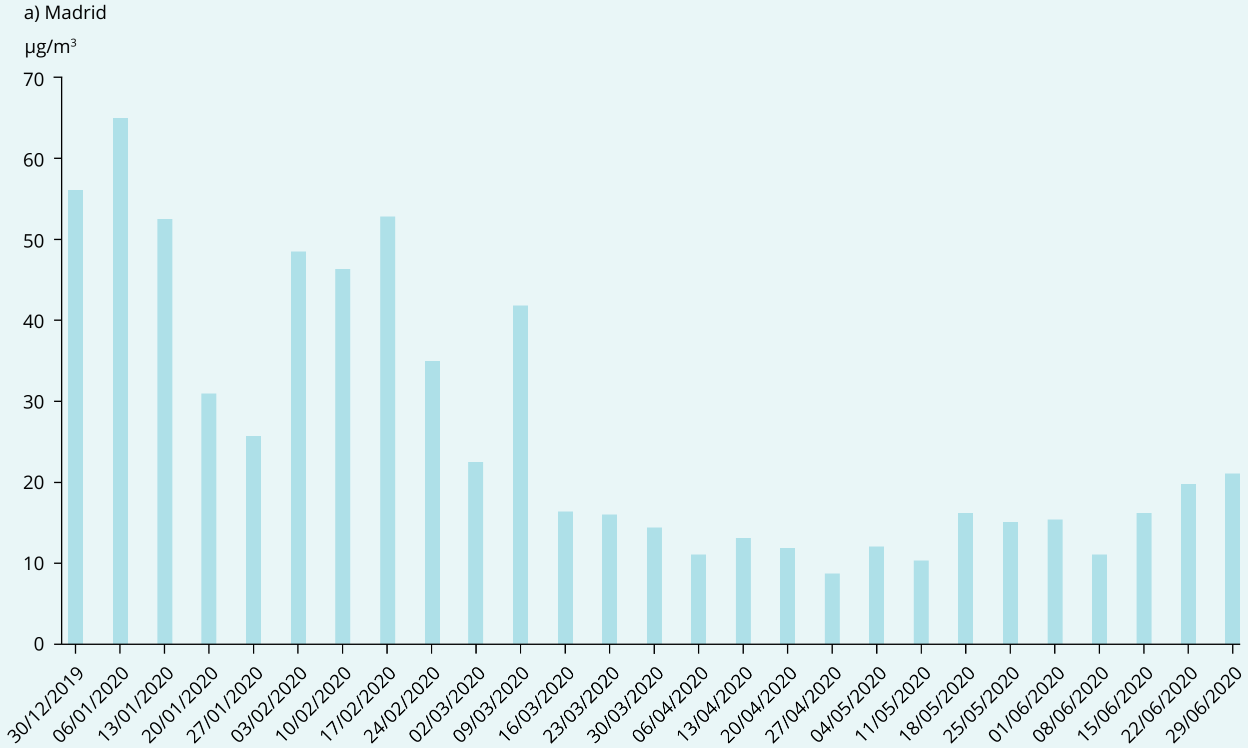
Map 2.2 **Average percentage change in NO_2 pollution levels during the period 15 March to 30 April, due to the COVID-19 lockdown in agglomerations with more than 0.5 million inhabitants, based on satellite observations**

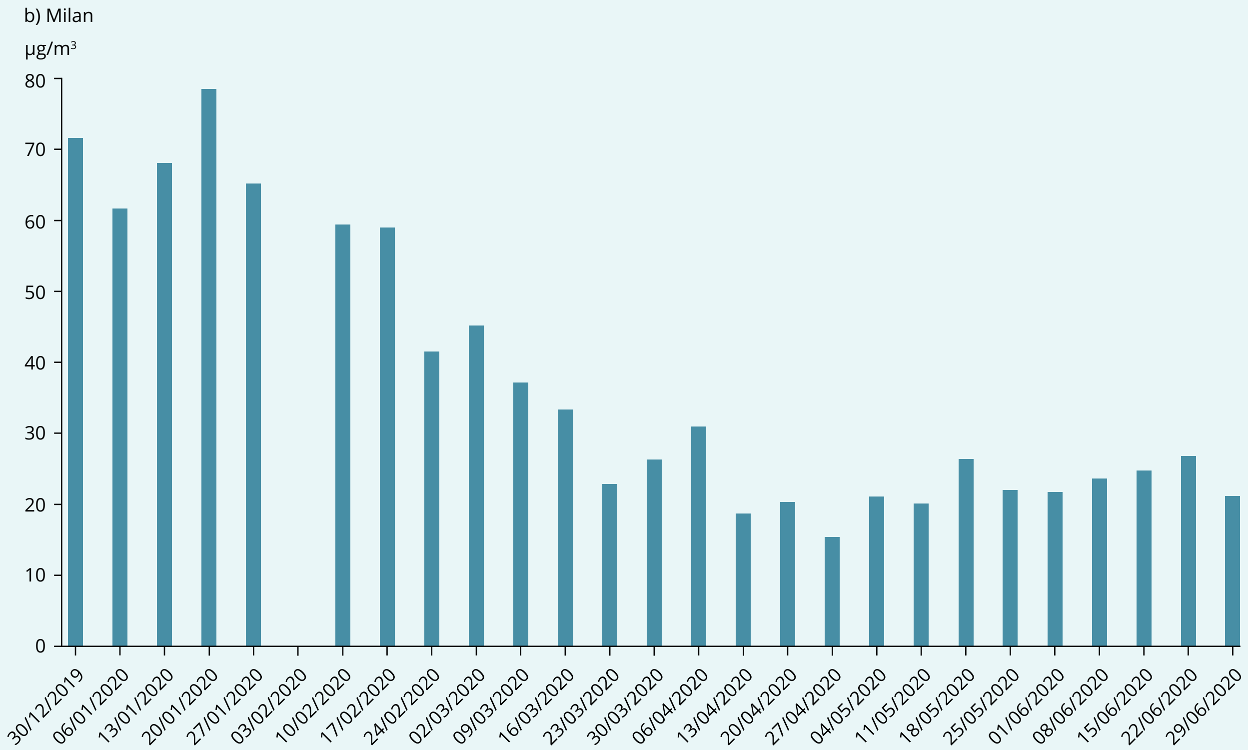


Reference data: ©ESRI

Box 2.1 The EEA's data viewer on the development of air pollutant concentrations under the lockdown measures (cont.)

Figure 2.1 Development of weekly NO_2 concentrations in Madrid and Milan, January to June 2020

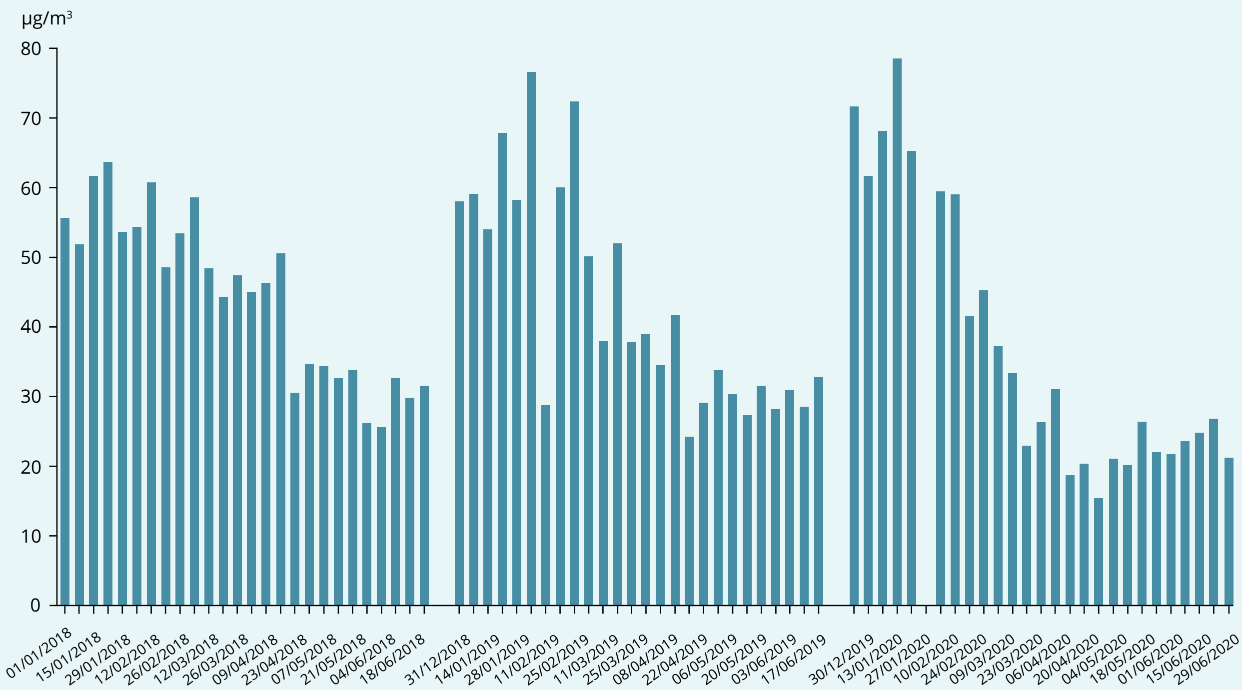




Box 2.1 The EEA's data viewer on the development of air pollutant concentrations under the lockdown measures (cont.)

Since the fall in concentrations might be due not only to the fall in emissions but also to the impact of meteorology (especially significant in the first weeks of the year, when thermal inversions and poor ventilation favour the accumulation of pollutants in the low atmosphere), the viewer also allows a comparison with previous years. The graph below (Figure 2.2) shows the weekly NO_2 concentrations for Milan until the end of June, in the period 2018-2020. In the 3 years high values during winter can be observed, followed by a decrease in springtime values, but it can also be seen that those decreases were higher in 2020 than in the previous years.

Figure 2.2 Development of weekly NO_2 concentrations in Milan (January to June) in the period 2018-2020



Following this brief qualitative analysis, data can be downloaded from the viewer to perform a quantitative analysis. For instance, averaging the weekly NO_2 mean values for the first 11 weeks (until mid-March) for the period 2016-2019 and comparing it with the average of the weekly NO_2 mean values for the following 7 weeks (from mid-March until the end of April) in the same 4 years, the following reductions could be expected: 32 % in Madrid and 31 % in Milan. However, the real reduction that occurred in 2020 in those two periods (first 11 weeks compared with the following 7 weeks) were of 70 % and 59 %, respectively, and this additional decrease in NO_2 concentrations can be mostly attributed to the decrease in emissions caused by the lockdown measures.

In the rest of the chapter, other tools (basically modelling) are used for a more in-depth and generalised quantitative analysis, taking into account the impact of meteorology on concentrations in spring 2020.

2.2 Assessment of the lockdown impact on NO_2 and PM_{10} concentrations using in situ monitoring data and both statistical and chemical transport modelling

To estimate the effect of the lockdown measures on NO_2 and PM_{10} *in situ* measured concentrations, all reported monitoring data (UTD) of NO_2 and PM_{10} concentrations measured across Europe ([10]) were considered and combined with a generalised additive model (GAM) (ETC/ATNI, 2020a). This statistical model is used to predict concentrations at the measurement stations, considering meteorological variability ([11]).

The GAM results are shown in Map 2.3 for NO_2 and in Map 2.4 for PM_{10} as coloured dots for all stations with available data (February to April 2015-2020) and where the GAM performance was good enough ([12]) for this assessment. These results show the relative change (in percentage) of concentrations in April 2020 due to the lockdown, compared with a BAU scenario and taking into account the meteorological variability.

2.2.1 NO_2 concentrations

Dots in Map 2.3 show that almost all the assessed locations registered a reduction in concentrations during April 2020, which is not explained by the meteorology. The map shows a south-west to central-east gradient in the reductions, with the highest reductions in Spain, France, Italy and Portugal, and with the lowest in central-eastern Europe. The maximum estimated reduction occurred at traffic stations in Spain and Italy and was around 70 % of the BAU average concentration estimated for April 2020. Looking at individual cities, a considerable variability from station to station within the same urban area, depending on the station and area types, is observed. For example, in Madrid relative changes in NO_2 concentrations varied from -56 % to -72 % (12 stations), in Rome from -48 % to -71 % (four stations in the centre) and -21 % (in a suburban station), in Lisbon from -46 % to -61 % (three stations), whereas in London estimated concentration changes varied all the way from -16 % to -45 % (three stations) and in Oslo from -26 % to -37 % (six stations) ([13]).

Figure 2.3 shows, in the red bars, the same relative reductions estimated for all the stations in each country for April 2020. The figure shows clearly that the greatest reductions in 2020 are estimated in Spain and France, whereas Czechia, Hungary and Poland had the lowest reductions of the countries with available data. With a few exceptions (ca 1 % of stations), all stations registered reductions in concentrations in April 2020, which are not explained by meteorological variability. The few increases were observed mainly at sites where previous levels of NO_2 were low. The blue bars in Figure 2.3 show the mean differences between the observations and the GAM predictions for the reference period (April 2015-2019). The closer to zero and the smaller these blue bars are, the smaller the mean bias given by the GAM is. For NO_2 these differences are very small, as the GAM is designed to minimise the overall bias between the predictions and observations.

Map 2.3 also shows (in background colours outside the circles) the estimated relative reductions in NO_2 background concentrations, using the ensemble of 11 CTMs simulations by CAMS (2020), with input from a newly developed emission inventory fitted for the lockdown period (Guevara et al., forthcoming). The new emission inventory estimated the reductions in activity for industry, road transport and aviation ([14]) for most European countries during lockdown. The relative reduction was estimated by comparing, for April 2020, ensemble results of simulations with the estimated emissions under the lockdown scenario and simulations with emissions in the BAU scenario.

([10]) For stations with a minimum data coverage of 75 % in the period February-April for all the years from 2015 to 2020. The data for 2015 to 2018 are validated data, whereas the data for 2019 and 2020 are UTD reported data. UTD data may be more uncertain than validated data, as the data are reported before final quality control (see also Box 1.1).

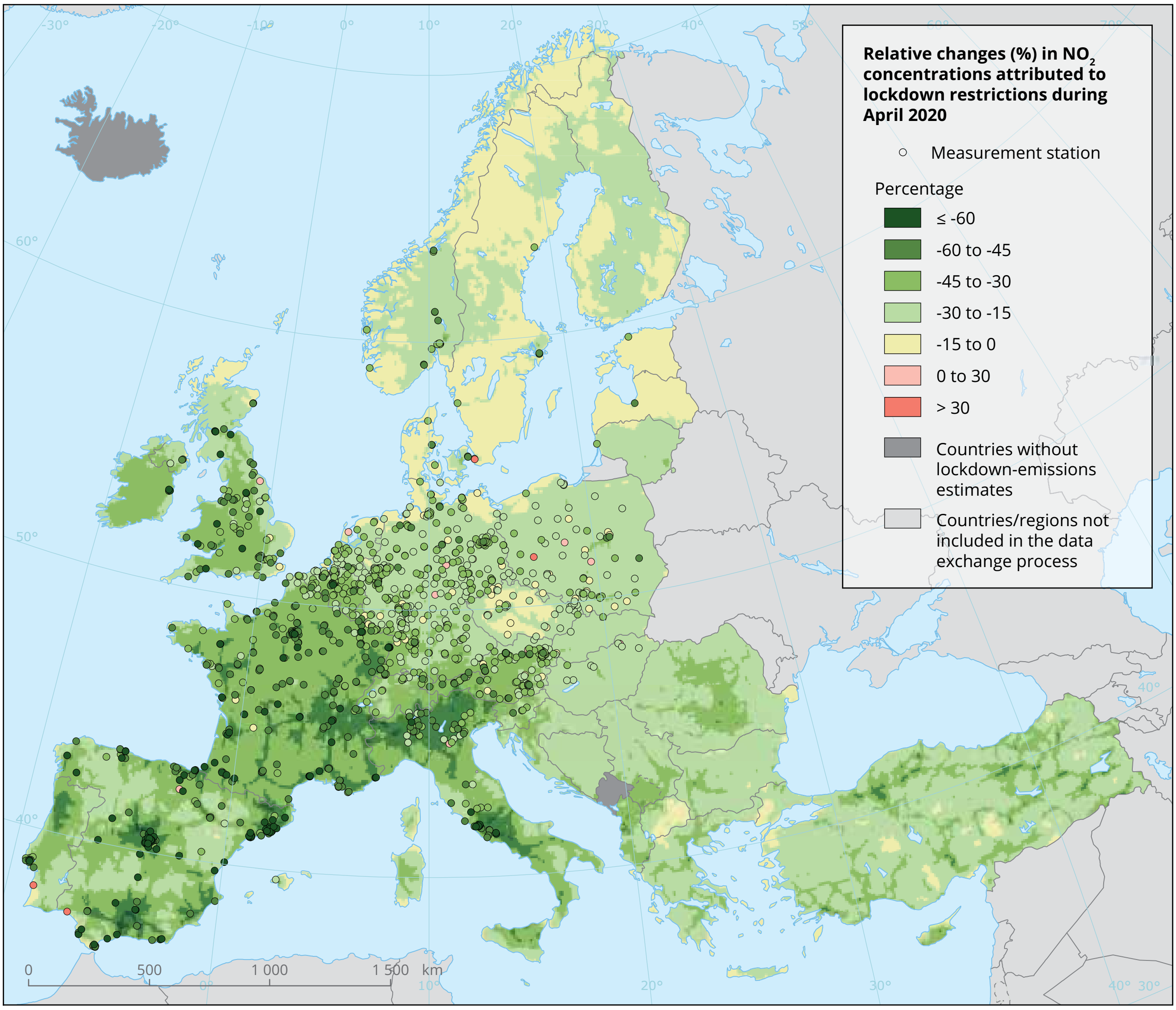
([11]) The GAM model is a non-linear regression model, which uses daily modelled meteorological data from ECMWF to predict daily air pollutant concentrations. Previously, the model needed to be 'trained' and in order to do so both modelled meteorological data and daily measured air pollutant concentrations were used. For this assessment, the model was 'trained' with measurement data for the months of February to April and for the years 2015-2019, in order to predict BAU concentrations, that is the concentrations expected under the current meteorological conditions, of NO_2 and PM_{10} in the period February-April 2020. The predicted BAU concentrations during April 2020 were then compared with the actual measured concentrations in that month at each station, and the difference between the two was assumed to be the result of the reductions in emissions on account of the COVID-19 lockdown measures.

([12]) Only locations where the linear correlation coefficient (r) between the predicted and the measured daily mean concentrations in 2015-2019 was equal to or higher than 0.65 for NO_2 and equal to or higher than 0.55 for PM_{10} were selected for this assessment. The GAM model performance is poorer for PM_{10} than for NO_2, as PM_{10} concentrations are influenced by not only meteorological variability, but also natural emissions and secondary PM formation, which is more difficult to be predicted by a simple statistical model. For this reason, and in order to include more stations in the assessment, the requirement on r was relaxed from 0.65 to 0.55 for PM_{10}.

([13]) In this case, stations located in Gothenburg, Vilnius and Katowice also show decreases, contrary to the results based on satellite data.

([14]) Changes in emissions of other sectors, such as residential heating or international shipping, were not estimated, though.

Map 2.3 Relative changes (%) in NO_2 concentrations attributed to lockdown restrictions during April 2020



Reference data: ©ESRI

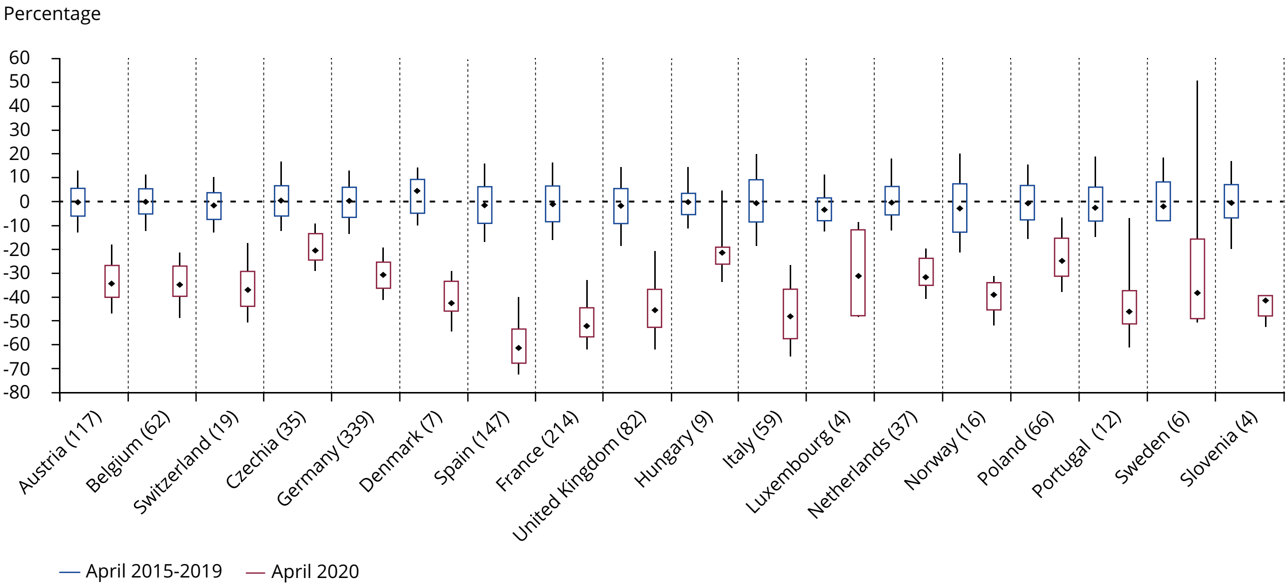
Note: The dots represent measurements stations, where the changes have been estimated using UTD monitoring data and the GAM. The background shading represents the changes estimated using CAMS chemical transport modelling with an emission inventory estimated for the lockdown conditions.

The ensemble results show that background NO_2 surface concentration was reduced up to about 60 % during the lockdown and confirm the main findings in terms of spatial distribution of the reductions, i.e. reductions were greatest in the most affected countries in April 2020, Spain, Italy and France, where lockdown measures were more severe, and over urban areas with high population densities.

2.2.2 PM_{10} concentrations

The assessment of the impact of the lockdown on PM_{10} levels is more complex and the GAM estimates are more uncertain. PM concentrations vary, not only with meteorology and emissions of primary PM from anthropogenic sources but also with emissions from natural sources, which are difficult to predict and are

Figure 2.3 **Relative changes (%) per country in NO_2 concentrations during April 2020 estimated by the GAM**



Note: The graph shows countries with a minimum of four stations with available data (February to April 2015-2020) and a minimum data coverage of 75 % per year. The red bars show the daily differences between the measured concentrations and the predicted BAU in April 2020 and reflect the changes in concentrations due to the COVID-19 lockdown measures. The blue bars show the daily differences between the measured and the predicted concentrations in April for the years 2015-2019 at every station and every day. The number at the country name indicates the number of stations included in the analysis. The rectangles in the bars mark the 25th and 75th percentiles (p25 and p75) and show the median value within the rectangle. At 25 % of the stations, levels are below p25; at 25 % of the stations, concentrations are above p75. The whiskers extend to the 9th and 91st percentiles.

Source: ETC/ATNI (2020a).

highly variable from one year to another, and emissions of precursor gases from different sources. Thus, the behaviour of emissions and PM formation during the lockdown is more complex than for NO_2; for example, in some regions, as people had to stay home, there might have been an increase in primary PM emissions from domestic combustion of coal or wood, while emissions of NO_2 and primary PM from traffic were reduced. Agricultural emissions of primary PM and ammonia (NH_3) were probably not affected by the lockdown, while some industrial emissions (e.g. primary PM and nitrogen and sulphur oxides, NO_X and SO_X) were reduced in several sites and countries.

The coloured dots in Map 2.4 show that for the large majority of PM_{10} stations the GAM model estimated a decrease in concentrations during the lockdown, not explained by the meteorology in April 2020. The largest reductions were estimated at traffic stations in Spain and Italy, with an average reduction of almost 40 % and 35 %, respectively, followed by France and Norway with an approximately 25 % reduction in PM_{10} concentrations at traffic stations. The highest reduction at suburban and urban background stations were estimated in Spain, with an average of 30 % reduction, followed by some others in the United Kingdom, Italy and Austria, with an average reduction of around 20 %.

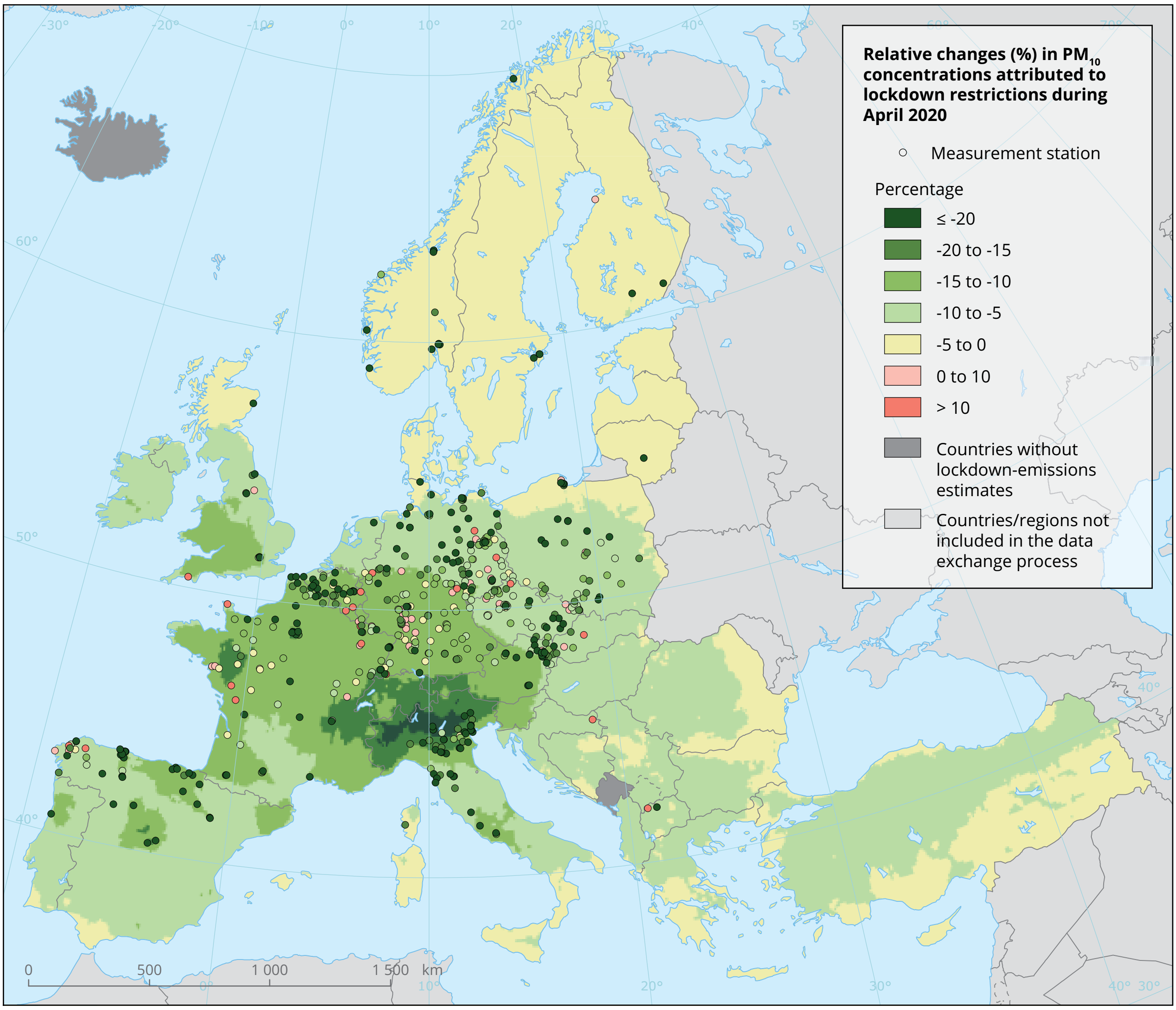
The lowest relative reductions were estimated at rural background stations, which are further away from the traffic (and other sources) emission reductions.

Rural stations also registered the highest uncertainties in the relative change estimations, partly because concentrations are lower in rural background areas and partly because of the complexity of the estimation, as secondary PM makes up a larger fraction of the measured PM mass and is more difficult to estimate with a statistical model such as GAM. The stations with an estimated increase shown in Map 2.4 are mostly rural background stations, and many of them are associated with a higher uncertainty (lower linear correlation coefficient — *r*). This is the case for the stations showing an increase in Spain, France and Belgium. Minor increases were estimated in a few suburban and urban background stations in Germany, France and the United Kingdom. For PM_{10}, too, increases are mainly seen at sites with previous low concentrations, although the pattern is less clear than for NO_2.

Figure 2.4 shows, in the red bars, the same relative reductions in PM_{10} estimated for all stations in each country, for April 2020. The blue bars show, for PM_{10} (similar to Figure 2.3 for NO_2), the mean difference between the measurements and the GAM predictions based on data from April in the years 2015-2019 combined. The closer to zero and the smaller these blue bars are, the smaller the mean bias is given by the GAM. The model performs less well for PM_{10} than for NO_2. The figure shows that the GAM calculates the greatest PM_{10} reductions for Spain and Italy. A marked decrease in PM_{10} concentrations is also calculated for Norway, but it is important to note that 10 out of these 12 stations are traffic stations, and are thus highly impacted by the reductions in traffic. Of the few countries with enough available data, the smallest reductions in PM_{10} concentrations are calculated for Czechia.

Map 2.4 also shows (in the background colours outside the circles) the estimated relative reductions in PM_{10} background concentrations, using the ensemble of 11 CTMs (CAMS, 2020). The ensemble results show that background PM_{10} surface concentration was reduced up to 20 % during the lockdown month of April 2020 in some areas, which is a considerably smaller reduction than for NO_2 concentrations. As the emission inventory estimated only the reductions in emissions from road transport, aviation and industry, changes in emissions from other sources, for instance domestic combustion, have not been considered at this stage. Thus, the modelling results show only reductions in

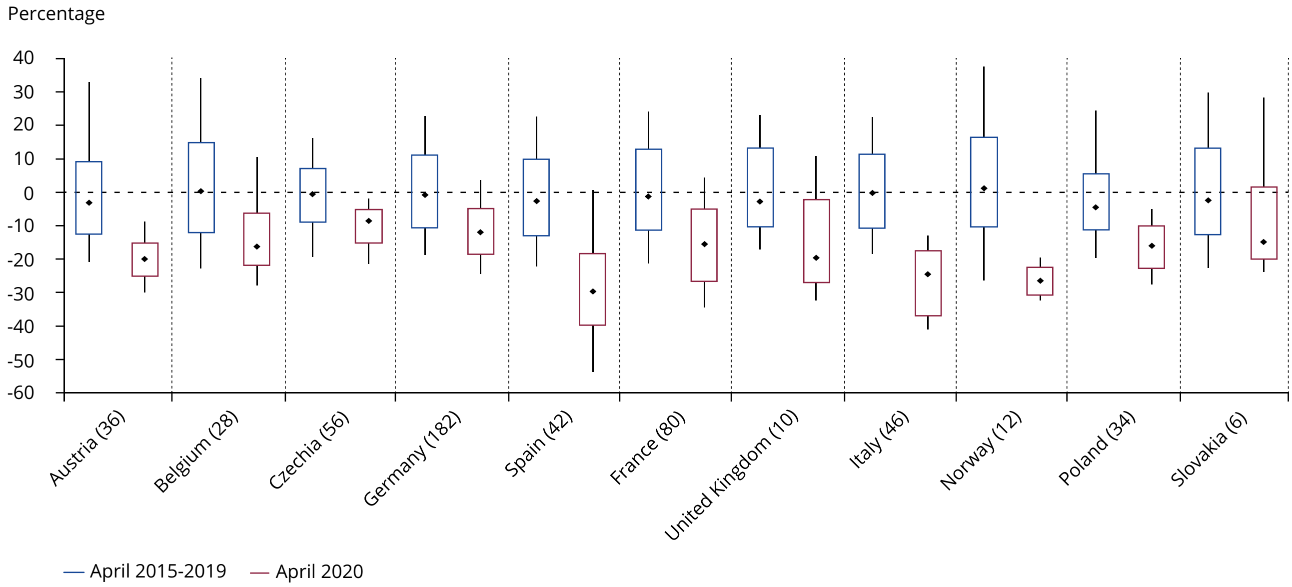
Map 2.4 Relative changes (%) in PM_{10} concentrations attributed to lockdown restrictions during April 2020



Reference data: ©ESRI

Note: The dots represent measurements stations, where the changes have been estimated using UTD monitoring data and the GAM. The background shading represents the changes estimated using CAMS chemical transport modelling with an emission inventory estimated for the lockdown conditions.

Figure 2.4 Relative changes (%) per country in PM_{10} concentrations during April 2020 estimated by the GAM



Note: The graph shows countries with a minimum of four stations with available data (February to April 2015-2020) and a minimum data coverage of 75 % per year. The red bars show the daily differences between the measured concentrations and the predicted BAU in April 2020 and reflect the changes in concentrations due to the COVID-19 lockdown measures. The blue bars show the daily differences between the measured and the predicted concentrations in April for the years 2015-2019 at every station and every day. The number at the country name indicates the number of stations included in the analysis. The rectangles in the bars mark the 25th and 75th percentiles (p25 and p75) and show the median value within the rectangle. At 25 % of the stations, levels are below p25; at 25 % of the stations, concentrations are above p75. The whiskers extend to the 9th and 91st percentiles.

Source: ETC/ATNI (2020a).

PM_{10} concentrations and no increases. The greatest modelled background PM_{10} concentration reductions are located in northern Italy. Considerable reductions over Madrid, Paris and Rome are also modelled. Overall, the modelled reductions were greater in Italy, France, Spain, Belgium, Germany and England (United Kingdom). Further east, Turkey is the country with the highest relative reductions in modelled PM_{10} background concentration. Important to note is that the reductions in PM_{10} are more homogeneous over Europe than for NO_2, which shall not be attributed to the resolution of the CTMs (which are capable of producing much pronounced urban gradients for NO_2) but rather to the more secondary nature of PM_{10}. There are differences with the GAM estimates that indicate lower reductions in western France and southern Germany but also some localised increases. Nevertheless, the overall magnitude of the change is quite similar, i.e. of the order of 20 %.

2.3 Conclusion

The lockdown measures introduced by most European countries, in order to reduce the spread of the novel coronavirus SARS-CoV-2 in the spring of 2020, led to significant reductions in emissions of air pollutants, particularly from road transport, aviation and international shipping. It has been illustrated how the variety of data and tools available from the EEA and CAMS, ranging from satellite to regulatory *in situ* monitoring, and from statistical machine learning to ensemble CTM, can help understand the impact of the lockdown on air quality. The interpretation of the results in this preliminary assessment of the impact of lockdown measures on air quality in Europe must take into consideration the various uncertainties in the input data and assessment methods. Nevertheless, the overall conclusions presented here are robust.

All estimates show that NO_2 concentrations were considerably reduced across Europe in April 2020, independently of the meteorological conditions. The estimated relative reductions in NO_2 concentrations varied considerably within cities and across countries. The relative reductions were greatest where lockdown measures were more severe, i.e. in Spain, Italy and France, and closest to traffic, while reductions were lower in central-eastern Europe, except for Turkey. The maximum estimated reduction, of around 70 %, occurred at traffic stations in Spain and Italy. The maximum estimated reductions of background NO_2 concentrations were also around 60 % for the different estimation methods, based on both satellite and *in situ* monitoring data, combined with statistical models to adjust for meteorological variability, and based on CTMs relying on emissions scenarios fitted to the lockdown.

PM_{10} concentrations were also generally reduced across Europe as a result of lockdown measures and independently of the meteorological conditions, although less than for NO_2. The greatest relative reductions were estimated over Spain and Italy with the GAM and over Italy with the CTMs ensemble. The GAM estimated an average reduction of almost 40 % and 35 %, respectively, at traffic stations in Spain and Italy.

On the other hand, the GAM estimated an increase in PM_{10} concentrations in a few localised areas. The modelled ensemble CTM results show that background PM_{10} concentration were reduced by up to 20 % during the lockdown. The assessment in changes in PM_{10} concentrations as a result of the lockdown is more uncertain than for NO_2 concentrations.

Whereas the larger impact on NO_2 response is mainly attributed to lockdown measures targeting primarily road transport, which is a key source of NO_X emissions, the lower impact on PM_{10} shows that other sources of air pollutant emissions contribute to PM pollution.

Box 2.2 Further links between air pollution and COVID-19: could air pollution be making the pandemic worse?

Apart from the reduction in concentrations that occurred because of the lockdown measures implemented to stop the spread of the COVID-19 pandemic, there are two other links between air pollution and COVID-19. These are the possible effect of air pollution on vulnerability and susceptibility to COVID-19 (via previous long-term exposure to air pollutants) and the possible role of air pollution in spreading the coronavirus.

Regarding the role that air pollution may play in influencing the severity of COVID-19, one can establish a plausibility to support such a role. Exposure to air pollution is associated with cardiovascular and respiratory disease. At the same time, both of these pre-existing health conditions have been reasonably identified as risk factors for death in COVID-19 patients (Yang et al., 2020). Furthermore, poor air can also cause lung inflammation, which could worsen the symptoms of COVID-19. Therefore, long-term exposure to air pollution might be expected to increase susceptibility to COVID-19 in individuals. This would be analogous to the findings of previous studies that indicate a potential role for exposure to PM in worsening the impact of respiratory viruses.

Some very recent studies, some of which were produced in the early days of the COVID-19 pandemic, have explored the links between air pollution and high incidence, severity or mortality rates for COVID-19. Most of them are under scrutiny and debate, due to a number of significant limitations inherent to these early studies, as recognized by some of the studies' authors themselves; therefore, findings are highly uncertain and need to be interpreted with care.

For example, studies in Italy suggested that air pollution should be considered a co-factor in the high level of fatality in northern Italy; and that chronic exposure provides a favourable context for the spread of the virus. Associations between NO_2, $PM_{2.5}$ and/or ozone concentrations in ambient air and increases in the number of COVID-19 cases, the number of severe COVID-19 infections and the risk of death from COVID-19 have also been found in China, the United States and Europe (Zheng et al., 2020, Wu, et al., 2020, Cole, et al., 2020, Travaglio et al., 2020)

The limitations of these studies include the use of aggregated pollution data at a regional scale, the short period of assessment, frequent lack of reliable and consistent data on mortality rates in different regions, and challenges in effectively controlling for the numerous likely confounding factors. Among the last of these, the most significant are the nature and timing of government measures to control transmission; population density, structure, age and gender distribution and socioeconomic conditions; presence of pre-existing and background diseases or other individual risk factors; international connectivity of the community; land use; social and individual behaviours such as smoking; and quality and capacity of health systems. Spatial coincidence alone cannot be taken as causality, and it is apparent that further epidemiological research will be required to elucidate causal associations between past exposure to air pollution and COVID-19 health impacts (Heederik et al., 2020; Villeneuve and Goldberg, 2020).

The second area of interest regarding COVID-19 and air pollution is whether PM can act as a physical carrier for the virus. Several scientists have published an appeal to recognize the potential for airborne spread of COVID-19 (Morawska and Milton, 2020), especially in indoor or enclosed environments, and particularly those that are crowded and have inadequate ventilation. They also recommended specific measures to mitigate airborne transmission risk in certain indoor environments. WHO has recognized that short-range aerosol transmission, particularly in specific indoor locations, cannot be ruled out, although droplet and fomite transmission also need to be considered (WHO, 2020c).

On the other hand, the role of outdoor air pollution in the spread of the coronavirus is much more uncertain and further research on the matter will be needed as well.

3 Sources and emissions of air pollutants

Air pollutants may be categorised as primary or secondary. Primary pollutants are directly emitted to the atmosphere, whereas secondary pollutants are formed in the atmosphere from precursor pollutants through chemical reactions and microphysical processes. Air pollutants may have a natural, anthropogenic or mixed origin, depending on their sources or the sources of their precursors.

Key primary air pollutants include particulate matter (PM), black carbon (BC), sulphur oxides (SO_X), nitrogen oxides (NO_X) (which includes both nitrogen monoxide, NO, and nitrogen dioxide, NO_2), ammonia (NH_3), carbon monoxide (CO), methane (CH_4), non-methane volatile organic compounds (NMVOCs), including benzene (C_6H_6) ([15]), and certain metals and polycyclic aromatic hydrocarbons (PAHs), including benzo[*a*]pyrene (BaP).

Key secondary air pollutants are PM (formed in the atmosphere), ozone (O_3), NO_2 and several oxidised volatile organic compounds (VOCs). Key precursor gases for secondary PM are sulphur dioxide (SO_2), NO_X, NH_3, and VOCs. The gases 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 to form secondary inorganic PM. Certain NMVOCs are oxidised to form less volatile compounds, which form 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. These precursors can be of both natural (biogenic) and anthropogenic origin. NO_X in high-emission areas also depletes tropospheric O_3 as a result of the titration reaction with the emitted NO to form NO_2 and oxygen (O_2).

3.1 Total emissions of air pollutants

Figure 3.1 shows the total emissions of pollutants in the EU-28, indexed as a percentage of their value in the reference year 2000. Emissions for all primary and precursor pollutants contributing to ambient air concentrations of PM, O_3 and NO_2, as well as arsenic (As), cadmium (Cd), nickel (Ni), lead (Pb), mercury (Hg) and BaP ([16]), decreased between 2000 and 2018 in the EU-28 (Figure 3.1) and the EEA-33 ([17]). SO_X emissions show the largest reductions (79 % in the EU-28 and 62 % in the EEA-33) since 2000 and NH_3 emissions show the smallest reductions (10 % in the EU-28 and 2 % in the EEA-33). However, NH_3 emissions have been increasing since 2015 and 2012 for EU-28 and EEA-33, respectively, mainly driven by the agriculture sector. Anthropogenic emissions of As, Cd, Ni and Pb were reduced by 35 %, 42 %, 59 % and 68 %, respectively, from 2000 to 2018, in the EU-28 (Figure 3.1b) and by 36 %, 41 %, 59 % and 68 % in the same period in the EEA-33.

In general, reductions in emissions in the EU-28 and in the EEA-33 were similar. There were larger reductions in the EU-28 than in the EEA-33 for NH_3, primary $PM_{2.5}$ and SO_X, and smaller reductions for CO.

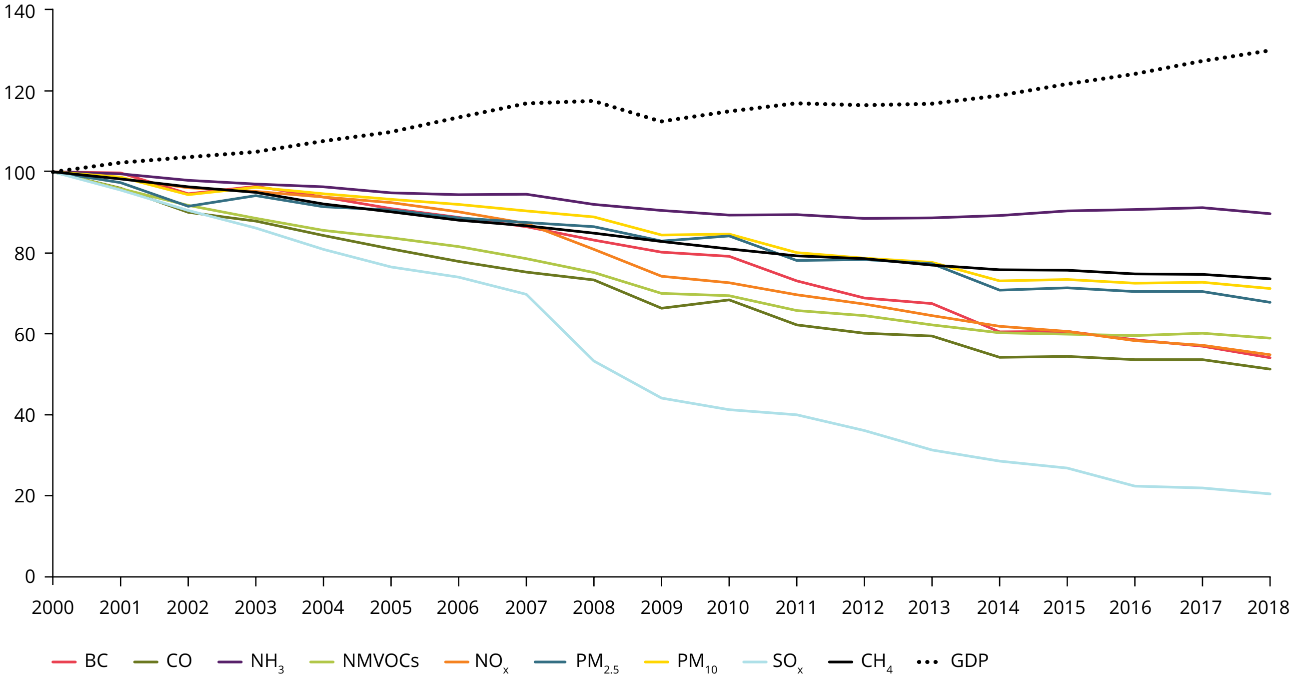
During the period 2000-2018, emissions showed a significant absolute decoupling ([18]) from economic activity, which is desirable for both environmental and productivity gains. This is indicated by the contrast between a reduction in EU-28 air pollutant emissions and an increase in EU-28 gross domestic product (GDP) ([19]) (Eurostat, 2020b), which effectively means that there are now fewer emissions for each unit of GDP produced per year. The greatest decoupling has been for SO_X, followed by NMVOCs, CO, NO_X, BC and certain metals (Ni, Pb, Cd, Hg) and organic species (BaP), for which emissions per unit of GDP

([15]) There is no separate emission inventory for C_6H_6, but it is included as a component of NMVOCs.
([16]) The emissions reported from Bulgaria for the activity 'chemical products' under the manufacturing and extractive industry sector were not taken into account, as they were calculated applying an old value of the emission factor for PAHs in that sector.
([17]) The analysis of the changes in emissions in Europe is based on emissions reported by the countries (EEA, 2020e,2020f). The nominal increase or decrease in reported emissions is analysed, not statistical trends.
([18]) 'Absolute decoupling' is when a variable is stable or decreasing when the growth rate of the economic driving force is growing, while 'relative decoupling' is when the growth rate of the variable is positive but less than the growth rate of the economic variable (OECD, 2002).
([19]) Based on chain-linked volumes (2010), in euro, to obtain a time series adjusted for price changes (inflation/deflation).

Figure 3.1 **Development in EU-28 emissions, 2000-2018 (% of 2000 levels): (a) SO_x, NO_x, NH_3, PM_{10}, $PM_{2.5}$, NMVOCs, CO, CH_4 and BC; (b) As, Cd, Ni, Pb, Hg and BaP. Also shown for comparison is the EU-28 GDP (expressed in chain-linked volumes (2010), % of 2000 level)**

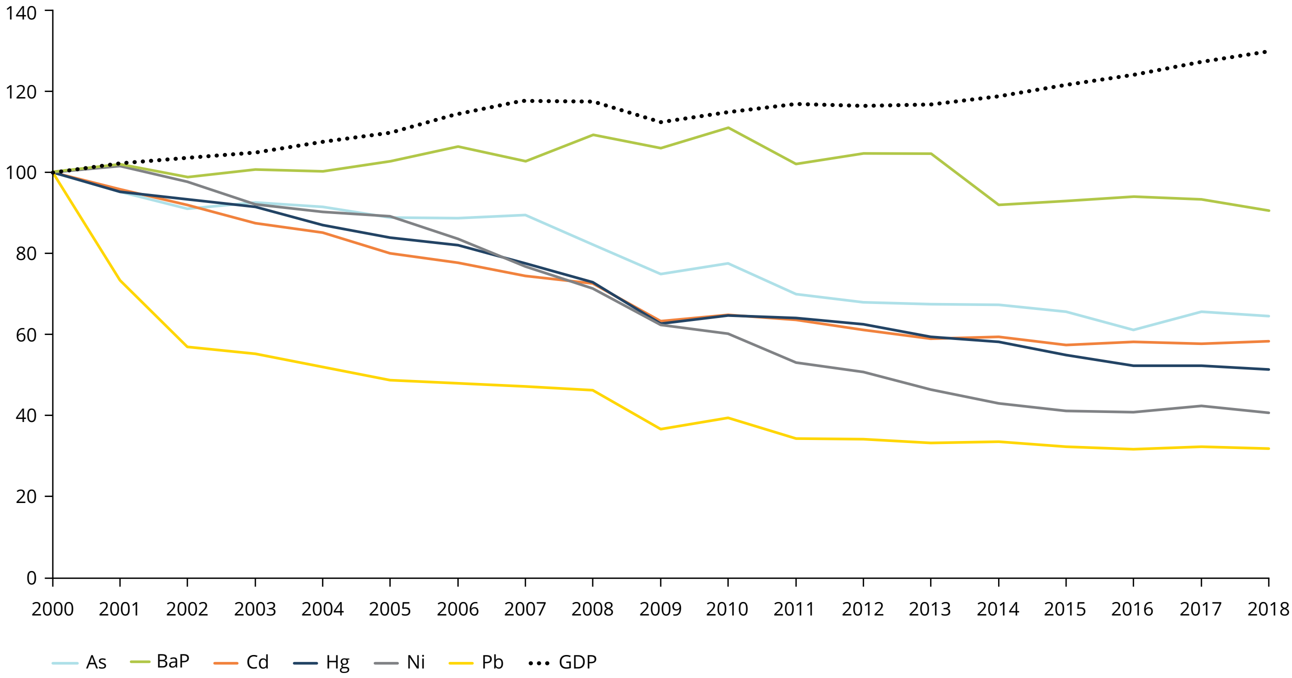
a)

Index (% of 2000)



b)

Index (% of 2000)



Note: CH_4 emissions are total emissions (as set by the Intergovernmental Panel on Climate Change (IPCC) sectors 1-7) excluding those from land use, land use change and forestry (sector 5).

Sources: EEA (2020e, 2020f); Eurostat (2020b).

were reduced by over 30 % between the years 2000 and 2018. A decoupling of emissions from economic activity may be due to a combination of factors, such as increased regulation and policy implementation, fuel switching, technological improvements and improvements in energy or process efficiencies (see Sections 1.5 and 1.6), and the increase in the consumption of goods produced in industries outside the EU (ETC/ATNI, 2020b).

3.2 Sources of regulated pollutants by emissions sector

The main sectors contributing to emissions of air pollutants in Europe are (1) transport — split into road and non-road, which includes air, rail, sea and inland water transport; note that emissions from aviation cruise and international maritime navigation are not considered in the total emissions because of the reporting regulation ([20]); (2) residential, commercial and institutional; (3) energy supply, which includes fuel production and processing and energy production; (4) manufacturing and extractive industry, which includes heavy and light industry; (5) agriculture; and (6) waste, which includes waste water management ([21]).

Figure 3.2 shows the time series in SO_X, NO_X, NH_3, primary PM_{10}, primary $PM_{2.5}$, NMVOCs, CO, BC and CH_4 emissions from the main sectors in the EU-28 between the years 2000 and 2018. Similarly, Figure 3.3 shows the time series in As, Cd, Ni, Pb, Hg and BaP emissions. For clarity, these figures show only pollutants for which the sector contributed more than 5 % of the total EU-28 emissions in 2018. In general, most sectors show significant reduction in emissions, with the residential, commercial and institutional (except SO_X), and the agriculture (except BC) sectors showing the smallest reduction in emissions. Changes in emissions by sector and air pollutant were generally similar in the EU-28 and the EEA-33, except for NH_3 emitted from agriculture. To indicate the degrees of emission decoupling from sectoral activities within the EU-28 between 2000 and 2018, Figure 3.2 also shows the change in sectoral activity (Box 3.1) for comparison with the change in emissions over time; the emissions data are expressed as an index (percentage relative to the year 2000) on the figure.

Box 3.1 Choice of sectoral activity data

The change in emissions over time was compared with the changes in sectoral activity data that would best represent the sector to be analysed. The indicators are briefly described below.

For road and non-road transport sectors, the sectoral activity is expressed in terms of passenger (billion passenger-kilometres (pkm)) and freight transport (billion tonne-kilometres (tkm)) demand, representing the transport of one passenger or tonne of goods, respectively, over 1 km in a year (Directorate-General for Mobility and Transport, 2020a, 2020b). Road transport includes cars, motorbikes, buses and coaches, and non-road transport includes travel by railway, tram, metro and air.

For the energy supply sector, the sectoral activity is expressed in terms of total primary energy production (Eurostat, 2020c), described in tonnes of oil equivalent (toe). The production of primary energy is the extraction of energy products, from natural sources, in any useable form, and the total gross electricity generation covers gross electricity generation in all types of power plants.

Sectoral activity key indicator for the residential, commercial and institutional is the energy use expressed in terms of the final energy consumption (described in units of toe) by the end users in the commercial and public services (Eurostat, 2020d) and by households (Eurostat, 2020e).

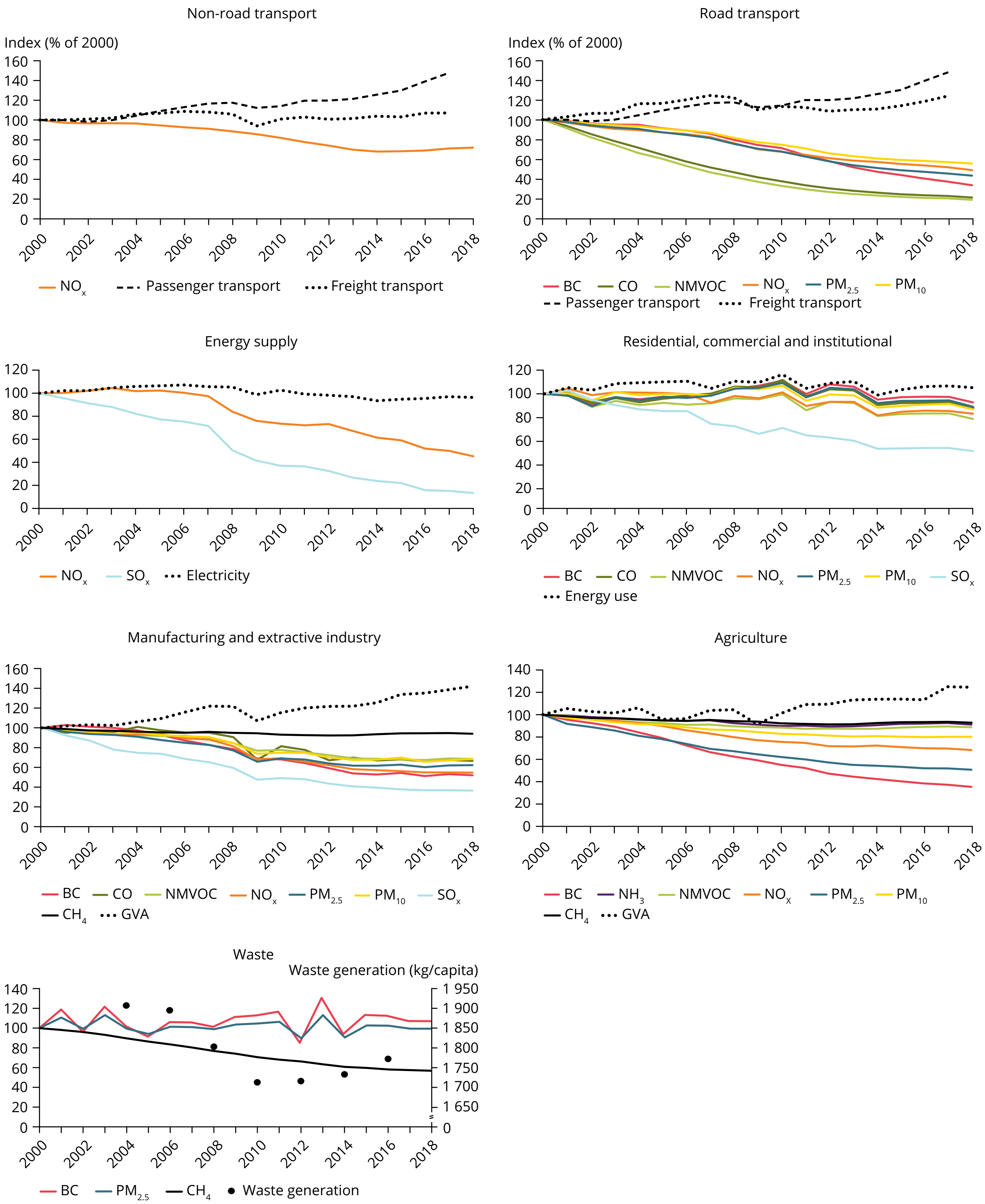
The sectoral activity for the manufacturing and extractive industry and for the agriculture sectors is expressed in terms of gross value added (GVA) in euro (Eurostat, 2020f — for industry; Eurostat, 2020g — for agriculture). GVA is a measure of the value of goods and services produced by the sector.

For the waste sector, the sectoral activity is expressed by the mass (in kg) per capita of waste generated (Eurostat, 2020h) and described in the original units of tonnes. The indicator excludes major mineral waste generation.

([20]) According to the reporting regulation, emissions from these activities are not taken into account for assessing the national total emissions, even if they are estimated and reported under what are called 'memo items' (https://www.ceip.at/reporting-instructions).

([21]) The mapping of nomenclatures relevant to emission reporting can be found at: https://cdr.eionet.europa.eu/help/nomenclature_emission

Figure 3.2 Development in EU-28 emissions from the main source sectors of NO_X, PM_{10}, $PM_{2.5}$, 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))

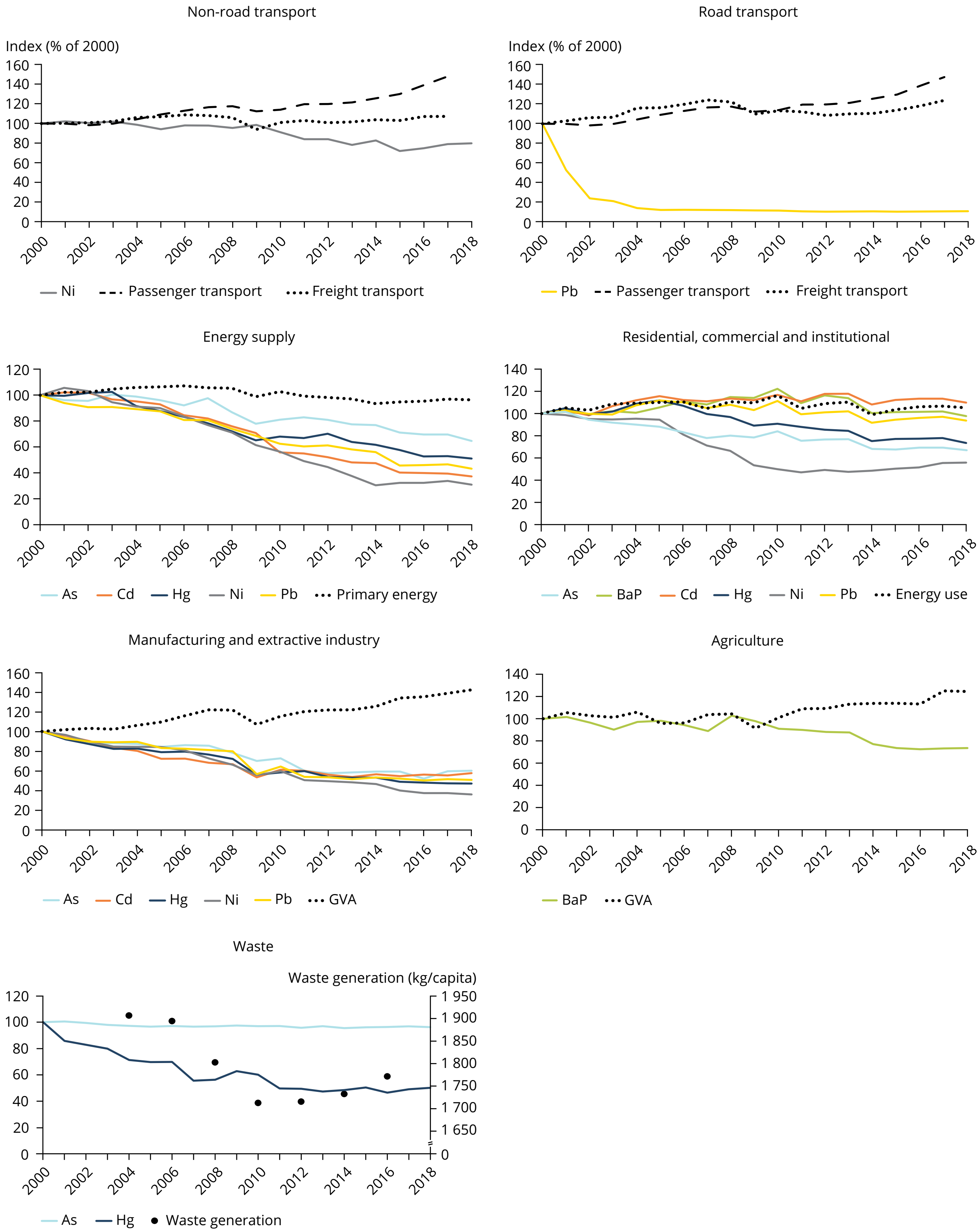


Notes: Only pollutants for which the sector contributes more than 5 % to the total pollutant emissions are shown in the figures.

Sectoral statistics are plotted as an index (% of 2000 levels), except for the waste sector, where total waste generated was available only from 2004. These data are therefore plotted on a secondary (right-hand) axis.

Sources: EEA (2020e; 2020f), Directorate-General for Mobility and Transport (2020a, 2020b), Eurostat (2020c, 2020d, 2020e, 2020f, 2020g, 2020h).

Figure 3.3 **Development in EU-28 emissions from the main source sectors of As, Cd, Ni, Pb, Hg, and BaP between 2000 and 2018 (% 2000 levels). For comparison, EU-28 key sectoral activity statistics are shown (% 2000 levels, except waste (kg per capita))**



Note: Sectoral statistics are plotted as an index (% of 2000 levels), except for the waste sector, where total waste generated was available only from 2004. These data are therefore plotted on a secondary (right-hand) axis.

Sources: EEA (2020e), Directorate-General for Mobility and Transport (2020a, 2020b), Eurostat, (2020c, 2020d, 2020e, 2020f, 2020g, 2020h).

For both road and non-road transport sectors, emissions of key pollutants (e.g. NO_X) have decreased significantly, although transported passenger and freight volumes have been gradually increasing. Policy actions at the EU level have been taken to address transport-related air pollution while allowing sectoral growth. Regulating emissions by setting increasingly stringent emission standards (e.g. Euro 1 to Euro 6) or by establishing requirements for fuel quality are good examples of such actions at EU level.

Emissions of pollutants from energy supply have also significantly decreased since 2000, being the sector with the largest decoupling between emissions and key indicators together with the manufacturing and extractive industry sector.

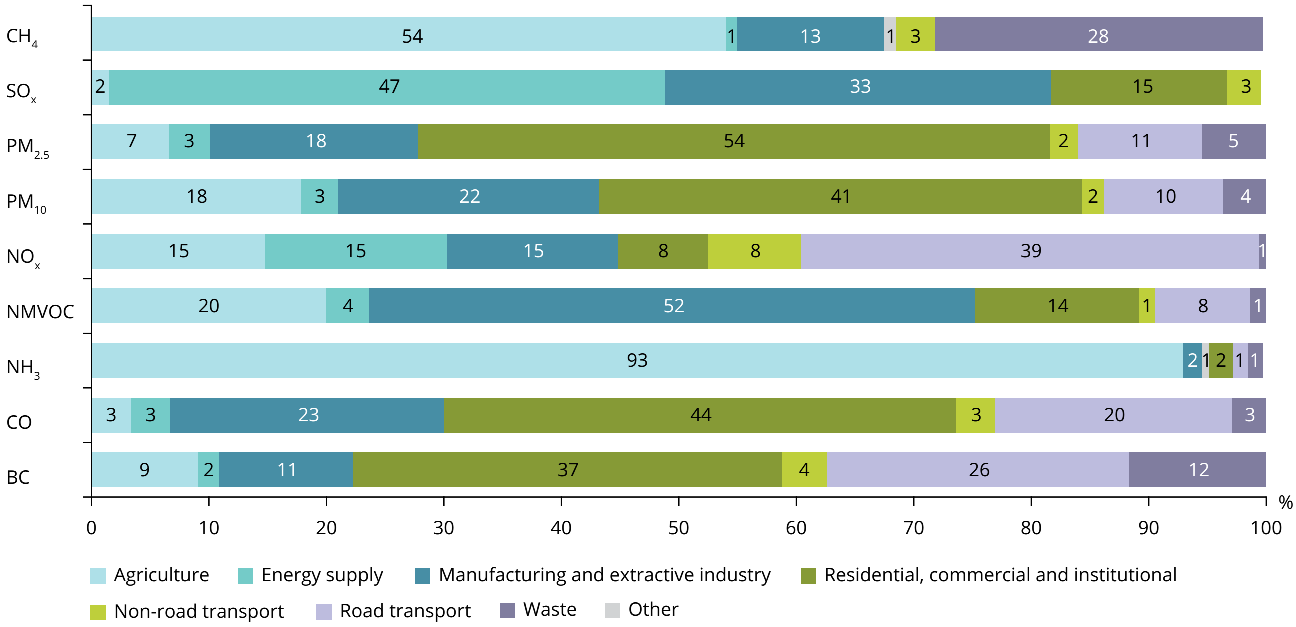
The sector with the least decoupling is the residential, commercial and institutional sector, where the energy use and respective emissions have been decoupling since 2014, but not substantially, except for SO_2. This is also the sector where emissions show the lowest decrease since 2000. Agriculture and waste are the other sectors in which the reduction in emissions has been the lowest since 2000. The agriculture sector shows some degree of decoupling with the key indicators, especially for BC, NO_X, $PM_{2.5}$ and BaP; the waste sector only shows decoupling with the emissions of CH_4 (with a reduction of 43 % in emissions since 2000).

Figures 3.4 and 3.5 give an overview of each sector's contribution to total emissions for all chosen pollutants in the EU-28 for 2018. The road transport sector was the most significant contributor to total NO_X emissions and the second largest contributor to BC and Pb emissions. The non-road contribution is significant mainly for Ni emissions. The energy supply sector was the largest contributor to SO_X, and Ni, as well as a significant contributor to NO_X, As and Hg emissions. The manufacturing and extractive industry was the largest contributor to NMVOC, As, Cd, Hg and Pb emissions and the second largest emitter of primary PM, SO_X, NO_X, CO and Ni. The residential, commercial and institutional sector was the largest contributor to CO, BC, primary PM and BaP and the second largest contributor to Cd emissions. The agriculture sector contributed to the majority of NH_3 and CH_4 emissions, as well as a significant amount of BaP, NMVOC and NO_X emissions. The waste sector is the second largest contributor to CH_4 emissions and the third largest contributor to BC, As and BaP emissions.

Sector contributions to total emissions for the EEA-33 countries are similar to those of the EU-28 described previously. Some of the largest distribution differences are seen for primary PM_{10} and SO_X emissions. The largest difference between the EU-28 and EEA-33 was the SO_X emissions from the energy supply sector, which accounted for 47 % of the total SO_X in 2018 in the EU-28 and for 60 % in the EEA-33.

As a final point, note that the contributions from the different emission source sectors to ambient air pollutant concentrations and air pollution impacts depend not only on the amount of pollutant emitted but also on the proximity to the source, emission/dispersion conditions and other factors, such as topography. Emission sectors with low emission heights, such as traffic and household emissions, generally make larger contributions to surface concentrations and health impacts in urban areas than emissions from high stacks.

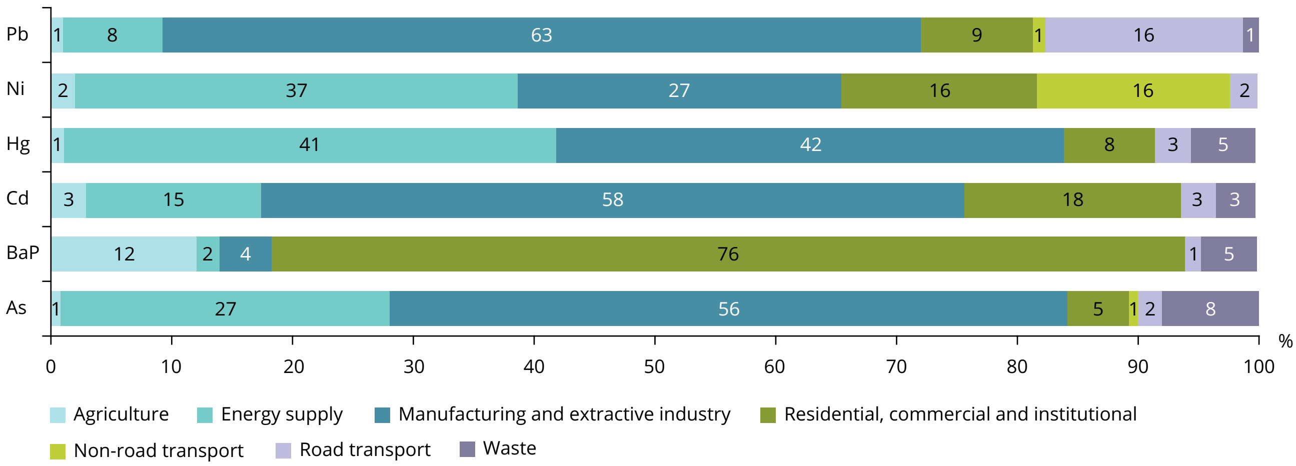
Figure 3.4 **Contribution to EU-28 emissions from the main source sectors in 2018 of CH_4, SO_X, NO_X, primary PM_{10}, primary $PM_{2.5}$, NH_3, NMVOCs, CO and BC**



Note: Only sectors contributing more than 0.5 % of the total emissions of each pollutant were considered.

Source: EEA (2020e; 2020f).

Figure 3.5 **Contribution to EU-28 emissions from the main source sectors in 2018 of As, Cd, Ni, Pb, Hg and BaP**



Note: Only sectors contributing more than 0.5 % of the total emissions of each pollutant were considered.

Source: EEA (2020e).

4 Particulate matter

4.1 European air quality standards and World Health Organization guideline values for particulate matter

The legal standards set by the Ambient Air Quality Directive (EU, 2008) for both particulate matter with a diameter of 10 µm or less (PM_{10}) and particulate matter with a diameter of 2.5 µm or less ($PM_{2.5}$) can be found in Table 1.1 and the air quality guidelines (AQGs) set by the World Health Organization (WHO) can be found in Table 1.3. For convenience, they are summarised in Table 4.1.

4.2 Status of concentrations in 2018

The EEA received PM_{10} data for 2018, with sufficient valid measurements (a minimum coverage of 75 %) from around 3 000 stations (2 979 stations were analysed in relation to the daily limit value, of which 84 % were either urban or suburban; and 3 015 stations were analysed in relation to the annual limit value). The stations were located in all the 2018 37 reporting countries.

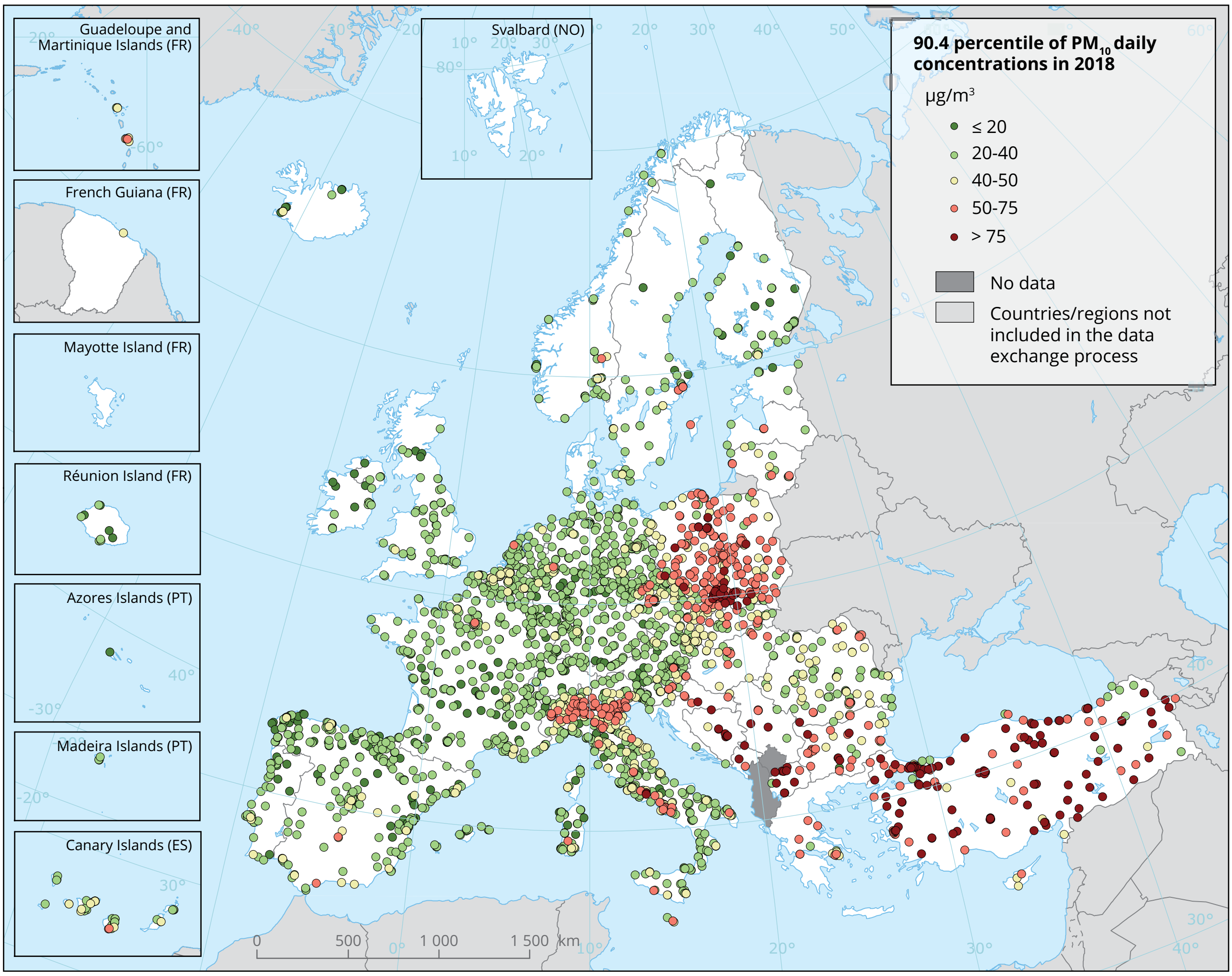
Table 4.1 Air quality standards for protecting human health from PM

Pollutant	Averaging period	Standard type and concentration	Comments
PM_{10}	1 day	EU limit value: 50 µg/m^3	Not to be exceeded on more than 35 days per year
		WHO AQG: 50 µg/m^3	99th percentile (3 days per year)
	Calendar year	Limit value: 40 µg/m^3	
		WHO AQG: 20 µg/m^3	
$PM_{2.5}$	1 day	WHO AQG: 25 µg/m^3	99th percentile (3 days per year)
	Calendar year	EU limit value: 25 µg/m^3	
		EU exposure concentration obligation: 20 µg/m^3	Average exposure indicator (AEI) ([a]) in 2015 (2013-2015 average)
		EU national exposure reduction target: 0-20 % reduction in exposure	AEI ([a]) in 2020, the percentage reduction depends on the initial AEI
		WHO AQG: 10 µg/m^3	

Note: ([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.

Twenty Member States and six other reporting countries (Map 4.1 and Figure 4.1) reported PM_{10} concentrations above the EU daily limit value in 2018. This was the case for 19 % (552) of reporting stations. In total, 97 % of those stations were either urban (89 %) or suburban (8%).

Map 4.1 Concentrations of PM_{10}, 2018 — daily limit value

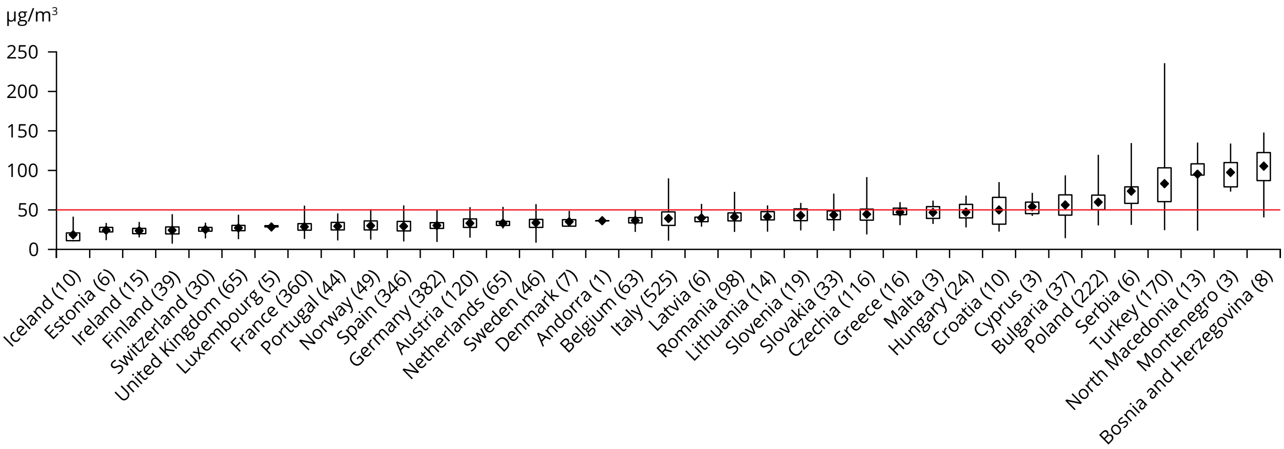


Reference data: ©ESRI | ©EuroGeographics

Note: Observed concentrations of PM_{10} in 2018. The possibility of subtracting contributions to the measured concentrations from natural sources and winter road sanding/salting has not been considered. The map shows the 90.4 percentile of the PM_{10} daily mean concentrations, representing the 36th highest value in a complete series. It is related to the PM_{10} daily limit value, allowing 35 exceedances of the 50 µg/m³ threshold over 1 year. Dots in the last two colour categories indicate stations with concentrations above this daily limit value. Only stations with more than 75 % of valid data are included in the map.

Source: EEA (2020c).

Figure 4.1 PM$_{10}$ concentrations in relation to the daily limit value in 2018 and number of stations considered for each country

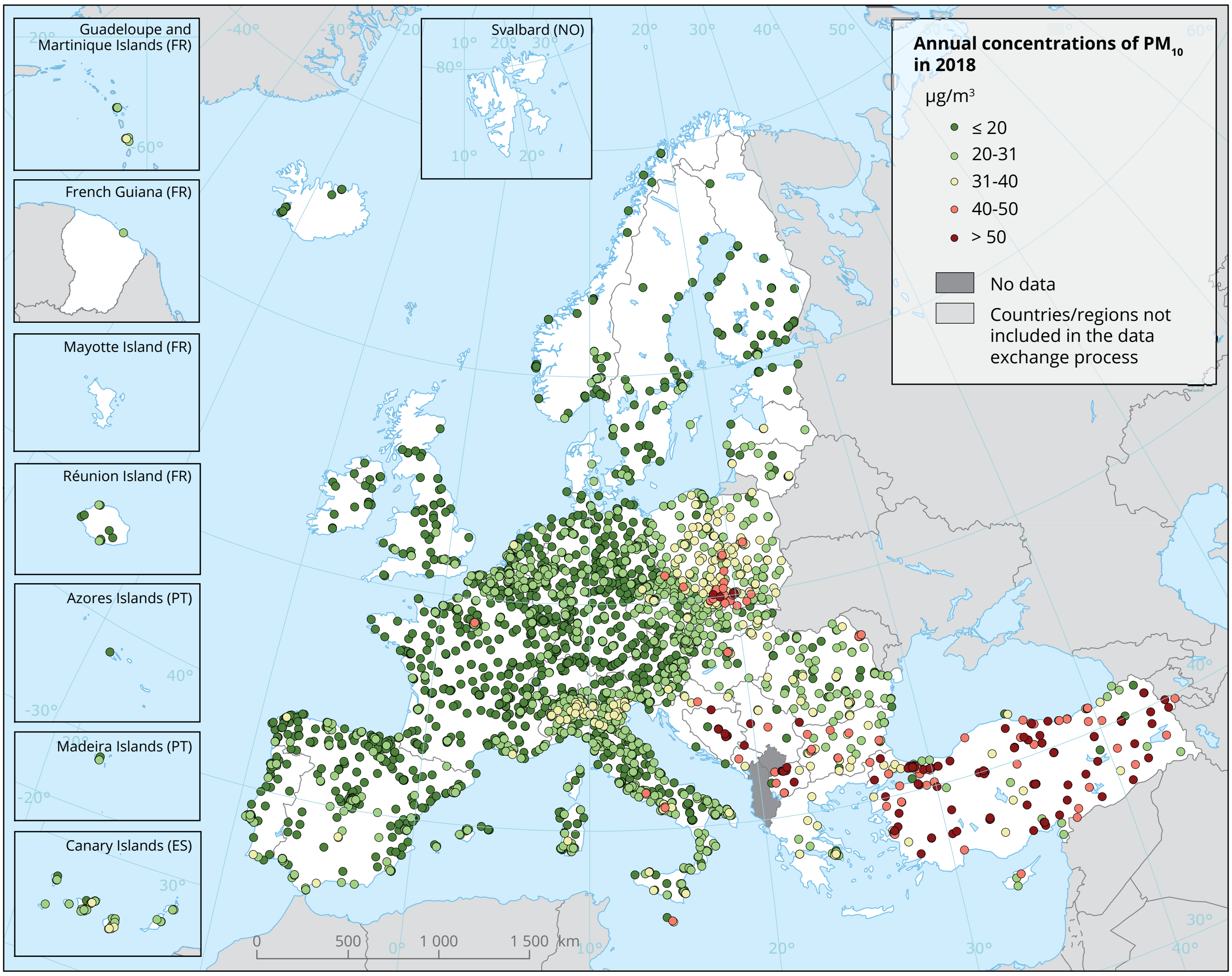


Note: The graph is based, for each country, on the 90.4 percentile of daily mean concentration values corresponding to the 36th highest daily mean. For each country, the number of stations considered (in brackets) and the lowest, highest and average 90.4 percentile values (in µg/m³) recorded at its stations are given. The rectangles mark the 25th and 75th percentiles. At 25 % of the stations, levels are below the lower percentile; at 25 % of the stations, concentrations are above the upper percentile. The daily limit value set by EU legislation is marked by the horizontal line. The graph should be read in relation to Map 4.1, as a country's situation depends on the number of stations considered.

Source: EEA (2020c).

Concentrations above the PM_{10} annual limit value (40 µg/m³) in 2018 were monitored at 6 % (186 stations) of all the reporting stations, located in 10 Member States and five other reporting countries. The stricter value of the WHO AQG for PM_{10} annual mean (20 µg/m³) was exceeded at 53 % (1 594) of the stations and in all the reporting countries, except Estonia, Iceland and Ireland (Map 4.2 and Figure 4.2).

Map 4.2 Concentrations of PM_{10}, 2018 — annual limit value

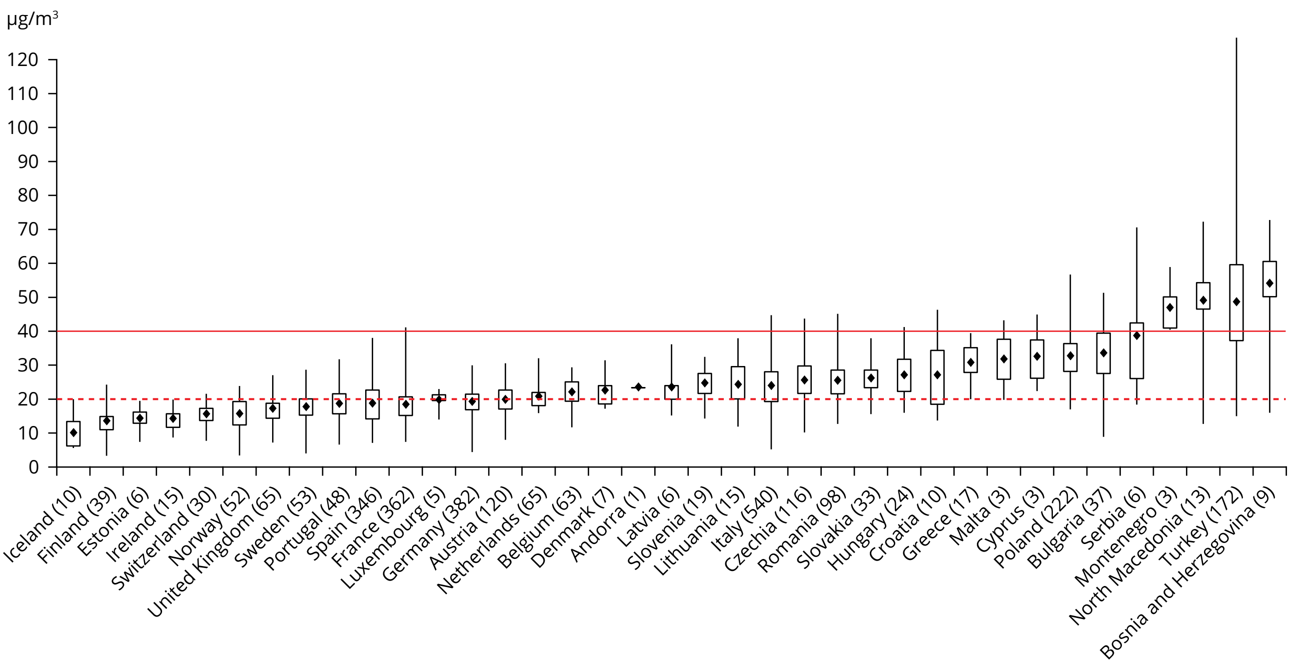


Reference data: ©ESRI | ©EuroGeographics

Note: Observed concentrations of PM_{10} in 2018. The possibility of subtracting contributions to the measured concentrations from natural sources and winter road sanding/salting has not been considered. Dots in the last two colour categories indicate stations reporting concentrations above the EU annual limit value (40 µg/m³). Dots in the first colour category indicate stations reporting values below the WHO AQG for PM_{10} (20 µg/m³). Only stations with more than 75 % of valid data are included in the map.

Source: EEA (2020c).

Figure 4.2 PM$_{10}$ concentrations in relation to the annual limit value in 2018 and number of stations considered for each country



Note: The graph is based on annual mean concentration values. For each country, the number of stations considered (in brackets) and the lowest, highest and average values (in μg/m³) recorded at its stations are given. The rectangles mark the 25th and 75th percentiles. At 25 % of the stations, levels are below the lower percentile; at 25 % of the stations, concentrations are above the upper percentile. The annual limit value set by EU legislation is marked by the upper continuous horizontal line. The WHO AQG is marked by the lower dashed horizontal line. The graph should be read in relation to Map 4.2, as a country's situation depends on the number of stations considered.

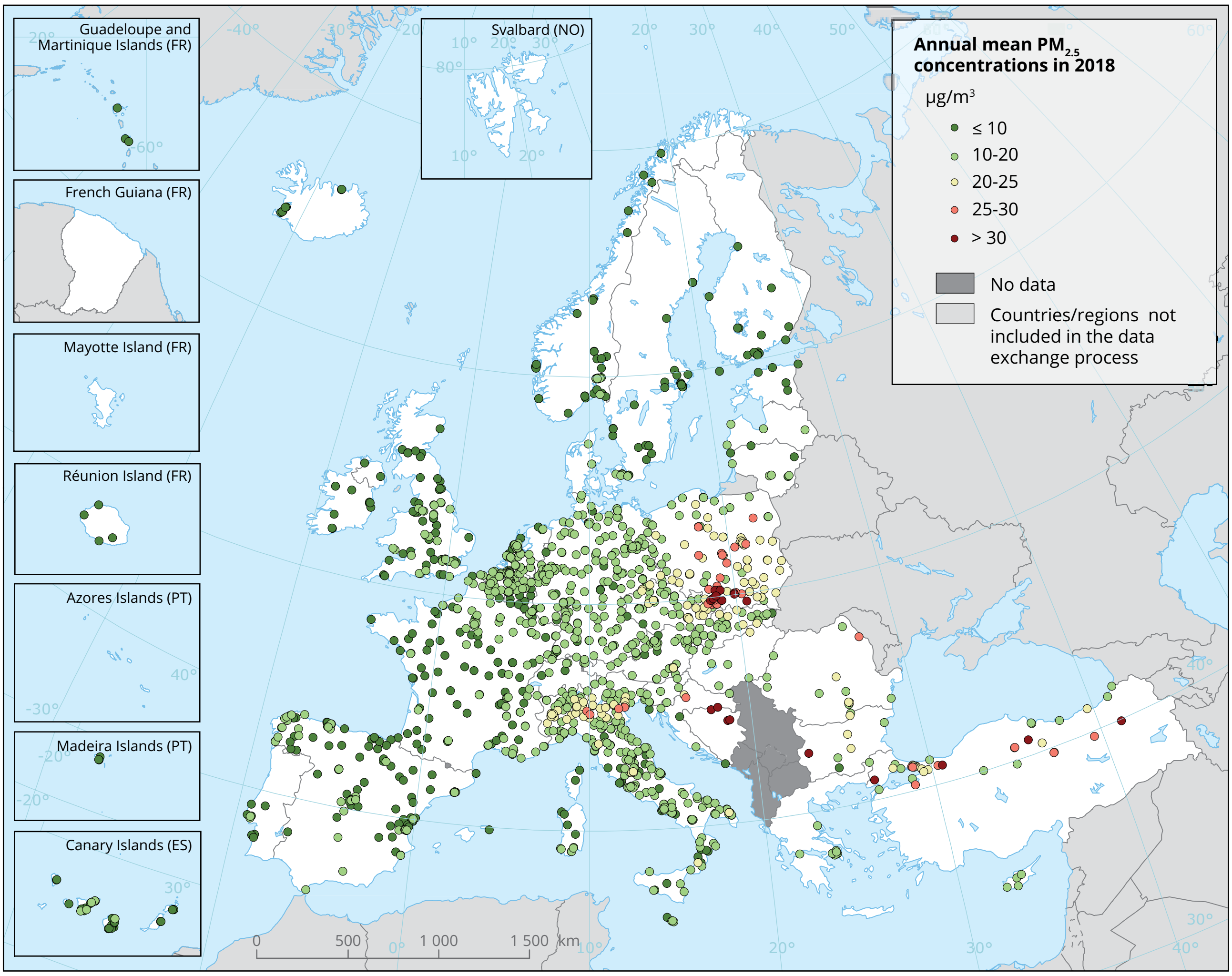
Source: EEA (2020c).

Regarding $PM_{2.5}$, data with a minimum coverage of 75 % of valid data were received from 1 438 stations (of which 83 % were either urban or suburban) located in 33 countries: EEA-33 (except Liechtenstein) and Bosnia and Herzegovina.

In 2018, the $PM_{2.5}$ concentrations were higher than the annual limit value in six Member States and two other reporting countries (Figure 4.3 and Map 4.3). These values above the limit value were registered at 4 % (58) of all the reporting stations and also occurred primarily (in 95 % of cases) in urban (83 %) or suburban (12 %) areas.

The stricter value of the WHO AQG for $PM_{2.5}$ annual mean (10 μg/m³) was exceeded at 70 % (1 013) of the stations, located in 29 of the 33 countries reporting $PM_{2.5}$ data (Figure 4.3 and Map 4.3). Estonia, Finland, Iceland and Ireland did not report any concentrations above the WHO AQG for $PM_{2.5}$.

Map 4.3 Concentrations of $PM_{2.5}$, 2018 — annual limit value

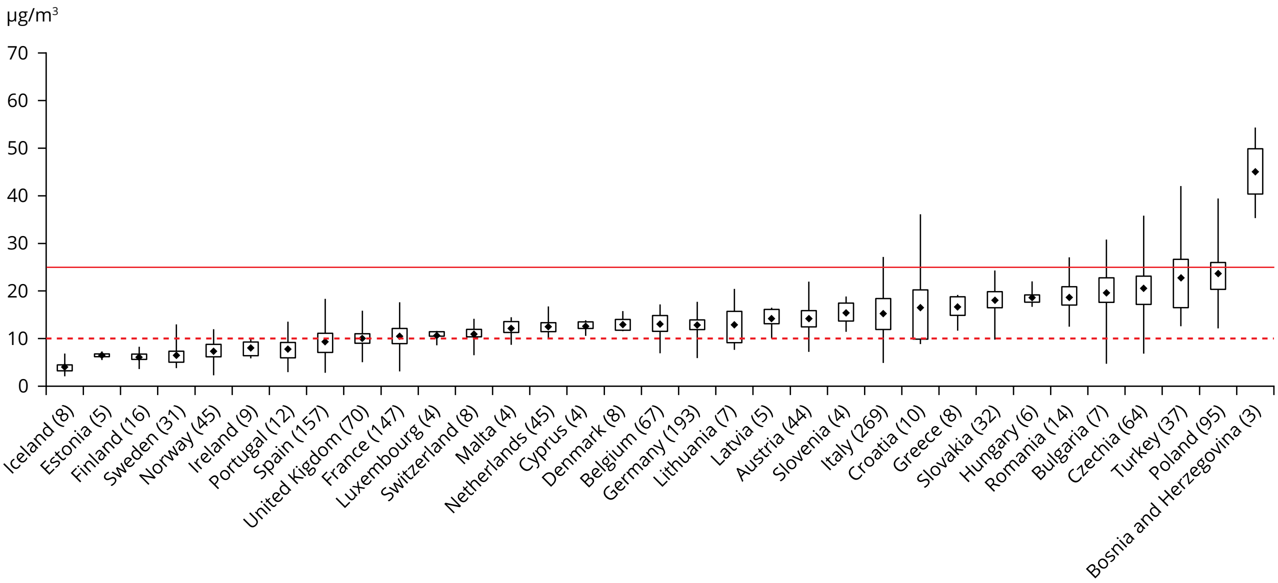


Reference data: ©ESRI | ©EuroGeographics

Note: Observed concentrations of $PM_{2.5}$ in 2018. The possibility of subtracting contributions to the measured concentrations from natural sources and winter road sanding/salting has not been considered. Dots in the last two colour categories indicate stations reporting concentrations above the EU annual limit value (25 μg/m³). Dots in the first colour category indicate stations reporting values below the WHO AQG for $PM_{2.5}$ (10 μg/m³). Only stations with more than 75 % of valid data are included in the map.

Source: EEA (2020c).

Figure 4.3 **$PM_{2.5}$ concentrations in relation to the annual limit value in 2018 and number of stations considered for each country**



Note: The graph is based on annual mean concentration values. For each country, the number of stations considered (in brackets) and the lowest, highest and average values (in µg/m³) recorded at its stations are given. The rectangles mark the 25th and 75th percentiles. At 25 % of the stations, levels are below the lower percentile; at 25 % of the stations, concentrations are above the upper percentile. The limit value set by EU legislation is marked by the upper continuous horizontal line. The WHO AQG is marked by the lower dashed horizontal line. The graph should be read in relation to Map 4.3, as a country's situation depends on the number of stations considered.

Source: EEA (2020c).

Annex 1 offers additional information on PM concentrations, showing the frequency distributions (PM_{10} 90.4 percentile: Figure A1.1; PM_{10} annual mean: Figure A1.3; $PM_{2.5}$ annual mean: Figure A1.5), and the values by station and area types (PM_{10} 90.4 percentile: Figure A1.2; PM_{10} annual mean: Figure A1.4; $PM_{2.5}$ annual mean: Figure A1.6).

The rural background concentration levels of PM vary across Europe. In 2018, concentrations above the PM_{10} daily limit value occurred in 16 rural background stations across Czechia (five), Italy (five), Turkey (three), Poland (two) and Slovenia (one). There were also two rural background stations in Turkey and one in Czechia, the 2018 annual mean concentrations of which were above the PM_{10} annual limit value. With regard to $PM_{2.5}$, Czechia (two stations) and Turkey (one) registered concentrations above the annual limit value in rural background stations.

Natural sources, which are not targeted by mitigation measures, contribute to both background PM concentrations and episodes with high PM levels, such as those that occur as a result of the transport of desert dust and wildfires. Measures to abate local emissions and to alert the most susceptible populations could be effective during dust outbreaks. Wildfires are a significant cause of air pollutants; sometimes they can affect air quality far from their source (EEA, 2019). The occurrence and severity of wildfires seem to have increased in recent decades, and this increase is predicted to continue as a result of climate change (Knorr et al., 2017). Developing and implementing effective methods for wildfire management and prevention will therefore become increasingly important.

The Copernicus Atmosphere Monitoring Service (CAMS) (2019) identified three main PM events during the winter and autumn of 2018. Two large episodes occurred in February 2018. The first event was from 7 to 10 February, when high PM concentrations were measured in central and south-eastern Europe, mostly associated with domestic combustion and a Saharan dust intrusion over the eastern Mediterranean area, which crossed France and reached the English Channel on 9 February. The second event with high PM levels occurred from 21 to 28 February over central-western Europe and was associated with domestic combustion emissions. The third event occurred from 21 to 26 October 2018 over western Europe and was associated with natural sources, a combination of a sea salt episode over the Atlantic coast and a Saharan dust intrusion over the Mediterranean area and south-eastern Europe.

In addition, CAMS (2019) identified five additional events of high PM levels, three of which were caused by dust storms and two by wildfires. In 2018, high temperatures and dry conditions (in northern Europe) increased the risk of wildfires in Europe. A series of wildfires in Greece, during the 2018 European heat wave, began in the coastal areas of Attica in July 2018, resulting in the world's second-deadliest wildfire event in the 21st century, with 102 people confirmed dead. Wildfires in July 2018 also reached an unprecedented extent in Sweden, as a result of the persistent heat wave and drought in northern Europe. Over 24 000 hectares burned and this was considered to be the most serious wildfire event in Sweden's modern history (JRC, 2019). The three dust storm events that led to high regional PM concentrations occurred from 22 to 27 April, affecting the Iberian Peninsula and the western Mediterranean basin, from 1 to 4 August, also over the Iberian Peninsula, and from 16 to 20 October, affecting the central and eastern Mediterranean basin (CAMS, 2019).

The Ambient Air Quality Directive (EU, 2008) also requires Member States to take additional measurements on the chemical speciation concentrations of fine particulate matter ($PM_{2.5}$) at least at one rural background station. The chemical species that have to be measured are sulphate (SO_4^{2-}), nitrate (NO_3^-), sodium (Na^+), potassium (K^+), ammonium (NH_4^+), chloride (Cl^-), calcium (Ca^{2+}), magnesium (Mg^{2+}), elemental carbon (EC) and organic carbon (OC).

In 2018, the countries that reported these species as measured in $PM_{2.5}$ (22) were Austria, Belgium, Croatia, Cyprus, Denmark, Finland, Germany, Ireland (only Na^+, K^+, NH_4^+, Ca^{2+} and Mg^{2+}), Latvia (except EC and OC), Lithuania, Malta, the Netherlands, Poland, Slovenia, Spain and the United Kingdom. Values can be found in the EEA's 'Air quality statistics — Expert viewer' (EEA, 2020g).

4.3 Trends in concentrations

4.3.1 PM_{10}

The average PM_{10} annual mean concentrations from 2009 to 2018 are presented in Figure 4.4 for urban, suburban and rural background, traffic and industrial stations. PM_{10} annual mean concentrations mainly decreased between 2010 and 2016, but there was an increase in average concentrations for all station types, except industrial stations, from 2016 to 2018. On average, over the decade considered (2009-2018) there was an 18-19 % reduction in annual mean concentrations of PM_{10} for all station types, except rural (13%). This decrease seems to be in accordance with the decrease in emissions of primary PM_{10} and its precursors. Primary PM_{10} emissions in the EEA-33 decreased by 22 % from 2009 to 2018, while precursor emissions decreased by 54 % for sulphur oxides (SO_X), 34 % for nitrogen oxides (NO_X) and 16 % for non-methane volatile organic compounds (NMVOCs) and increased by 8 % for ammonia (NH_3). Energy supply and transport were the sectors with the highest relative reduction in primary PM_{10} and NO_X emissions in the decade considered (Figure 3.2); both pollutants were reduced by over 29 % for both sectors in the EEA-33. This might explain the faster decrease in traffic and (sub)urban background stations; the reduction in primary PM from the energy supply sector could explain the reduction of PM_{10} concentration in industrial sites.

The trend analysis for the same period (see Annex 2 for further information) shows an overall decreasing trend. Map 4.4 shows the spatial distribution of the trends calculated for each station. More than half of the stations (55 %) show a significant trend. Almost all of the stations with a significant trend show a decreasing trend. Of the stations with non-significant trends, 13 % show an average increase in the PM_{10} annual mean. The distribution of the trend slopes, per station type, for significant and non-significant trends, is shown in Figure 4.5. Table A2.1 (Annex 2) shows the results of the trend analysis per country and station type. Bulgaria, one of the countries with the highest PM_{10} concentrations back in 2009, has registered a considerable decrease, with an average slope of -1.4 µg/m³ per year (-1.6 µg/m³ per year for (sub) urban background stations), over the last decade. Only North Macedonia (-2.5 µg/m³ per year, three stations) and Cyprus (-1.6 µg/m³ per year, three stations) saw higher decreases. There are only two countries with an average increase in PM_{10} concentrations, namely Croatia (1.1 µg/m³ per year, two stations) and Denmark (0.1 µg/m³ per year, one station).

The trend analysis for the period 2009-2018 shows that the highest average decreases in PM_{10} concentrations were observed in traffic stations, closely followed by urban and suburban background stations, while the lowest decrease was in rural background stations. This is as expected, as the concentrations are highest in urban and traffic sites and lowest in rural areas, and the reduction in emissions was higher in the transport sector, occurring mostly in urban areas.

(22) Sweden reported all the species (except EC and OC) as aerosols, without specifying the PM fraction.

A trend assessment study in Europe for the period 2000-2017 shows that the average PM_{10} annual mean concentration decreased by more than 40 %, averaged across the stations with data available ([23]) (ETC/ATNI, 2020c). The assessment also indicates that PM_{10} annual concentrations decreased faster between 2000 and 2008 than between 2008 and 2017 (ETC/ATNI, 2020c).

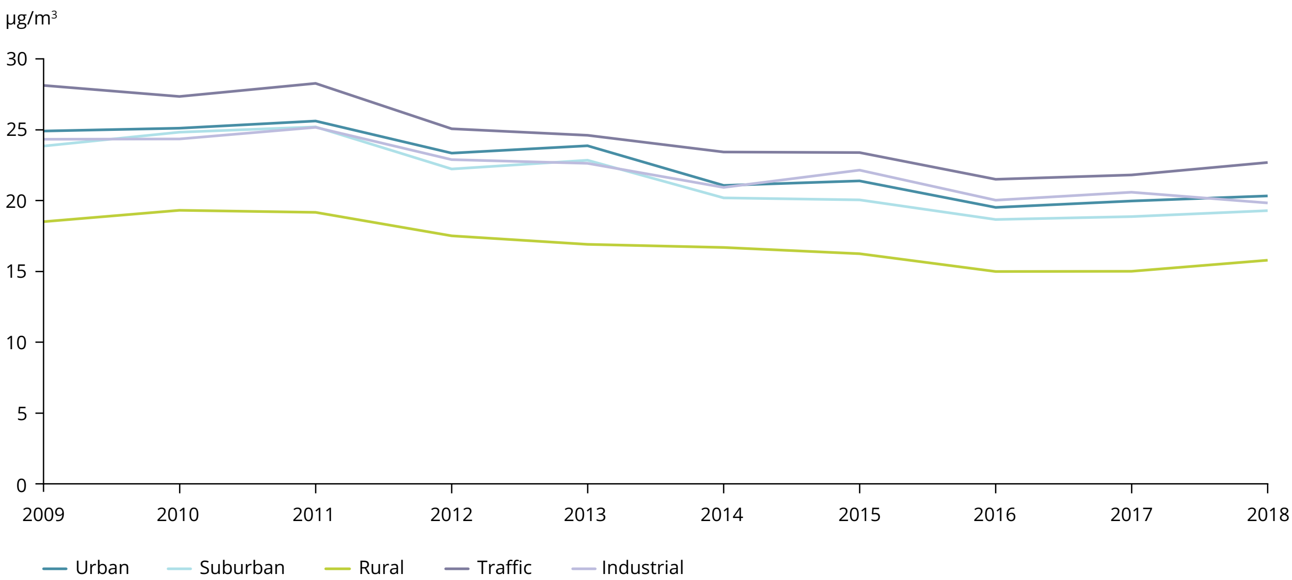
Figure 4.6 presents the average value for the 90.4 percentile (p90.4) of the daily PM_{10} concentrations (36th highest daily) in a year for urban, suburban and rural background, traffic and industrial stations. The time series indicate a similar behaviour as shown for the annual average in Figure 4.4, except that the values observed at rural stations have been decreasing at a faster rate.

Map 4.5 shows the spatial distribution of stations, colour-coded according to their trend slope. Only 18 % of the stations show a significant trend, with most of these stations (90 %) showing a decreasing trend. Most of the stations with significant positive trends in p90.4 are situated in Poland and Bulgaria (see Map 4.5), while the PM_{10} annual mean shows significant decreasing trends. The trend slopes, per station type, for significant and non-significant trends, are shown in Figure 4.7. Table A2.2 (Annex 2) shows the results of the trend analysis per country and station type. The trend analysis indicates that the highest reductions of the p90.4 PM_{10} concentrations values are for Estonia (-3.8 μg/m³ per year, for seven stations), Luxembourg (-3.8 μg/m³ per year, for one station) and Finland (-3.0 μg/m³ per year, for 31 stations); the highest increase is for Croatia (4.3 μg/m³ per year, for two stations), followed by Bulgaria (2.4 μg/m³ per year, for 31 stations) and Cyprus (2.6 μg/m³ per year, for three stations). The discrepancy between the annual mean and the percentile trends shows that, although annual mean concentrations may be decreasing, this does not necessarily mean that the highest values will follow the same trend. In addition, contrary to the annual mean, for the p90.4 the trend analysis shows that the highest average decrease was observed in rural background stations, while the lowest was observed in traffic stations.

4.3.2 $PM_{2.5}$

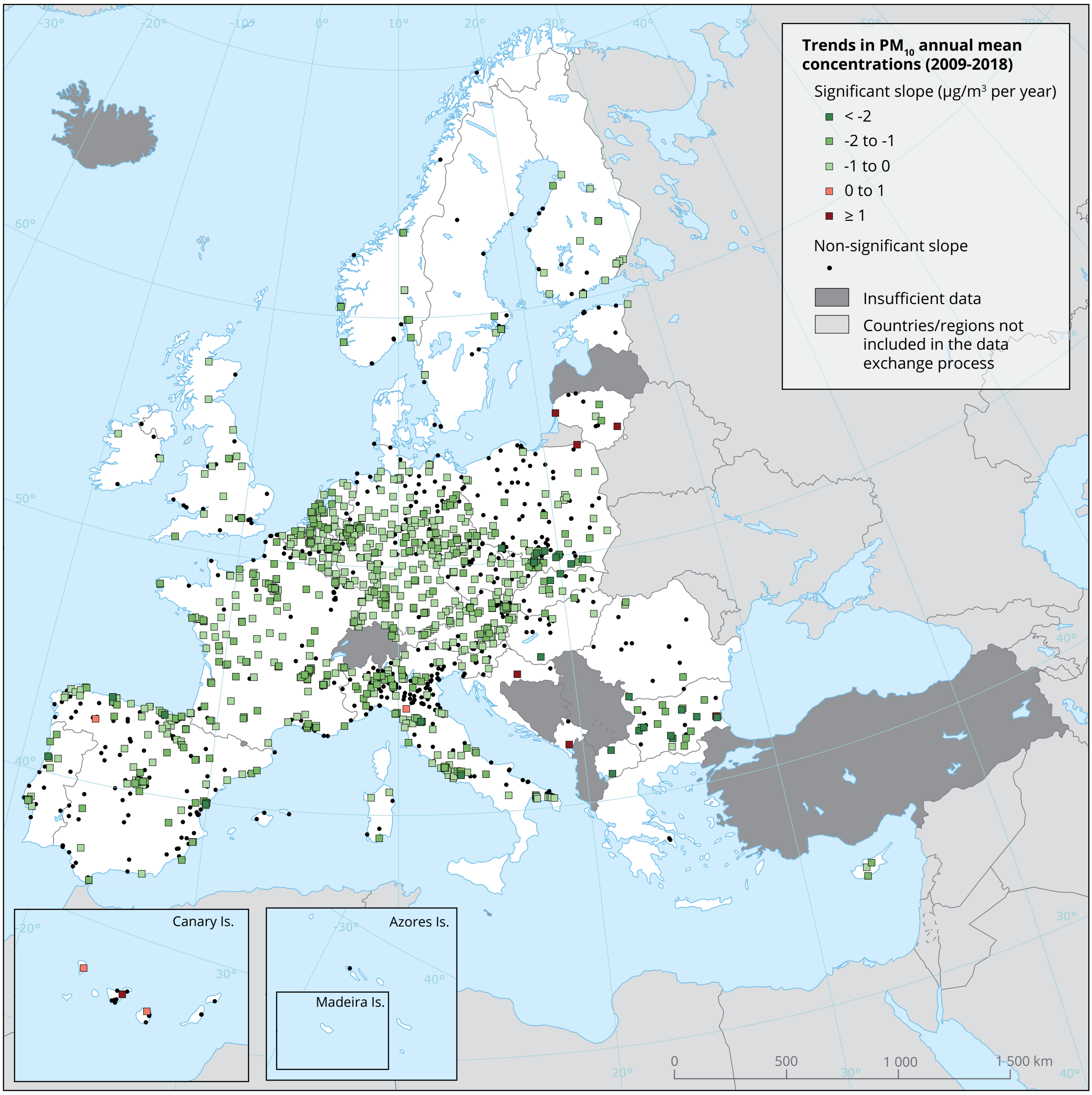
The development in average $PM_{2.5}$ annual mean concentrations from 2009 to 2018 is presented in Figure 4.8 for urban, suburban and rural background, traffic and industrial stations. $PM_{2.5}$ concentrations mainly decreased between 2011 and 2016, but, as for PM_{10}, there was an increase in average concentrations for rural background stations from 2016 to 2018 and a slight increase for (sub)urban background stations. On average, over the decade considered (2009-2018) there was a reduction of 22 % in annual mean concentrations of $PM_{2.5}$ for all station types, with the highest reduction for industrial (34 %), followed by (sub)urban background (22 %) and traffic (20 %) and the lowest was for rural (14 %) stations. Primary $PM_{2.5}$ emissions in the EEA-33 decreased by 19 % from 2009 to 2018, 54 % for SO_X, 34 % for NO_X and 16 % for

Figure 4.4 Average PM_{10} annual mean concentrations by station type



([23]) The countries included in the analysis were Austria, Belgium, Bulgaria, Czechia, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Lithuania, the Netherlands, Poland, Portugal, Slovakia, Slovenia, Spain, Sweden and the United Kingdom.

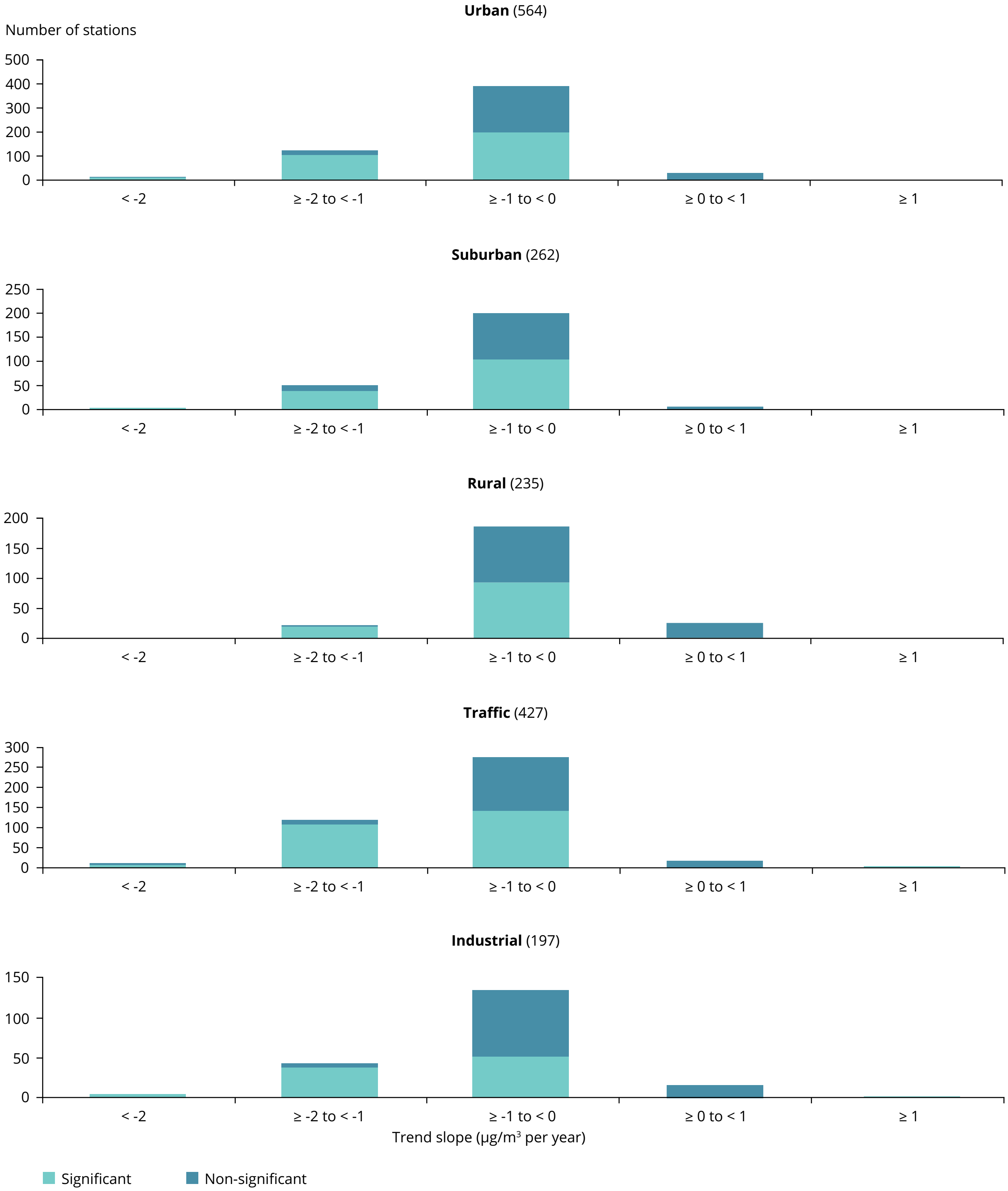
Map 4.4 **Trends in PM_{10} annual mean concentrations (2009-2018)**



Reference data: ©ESRI

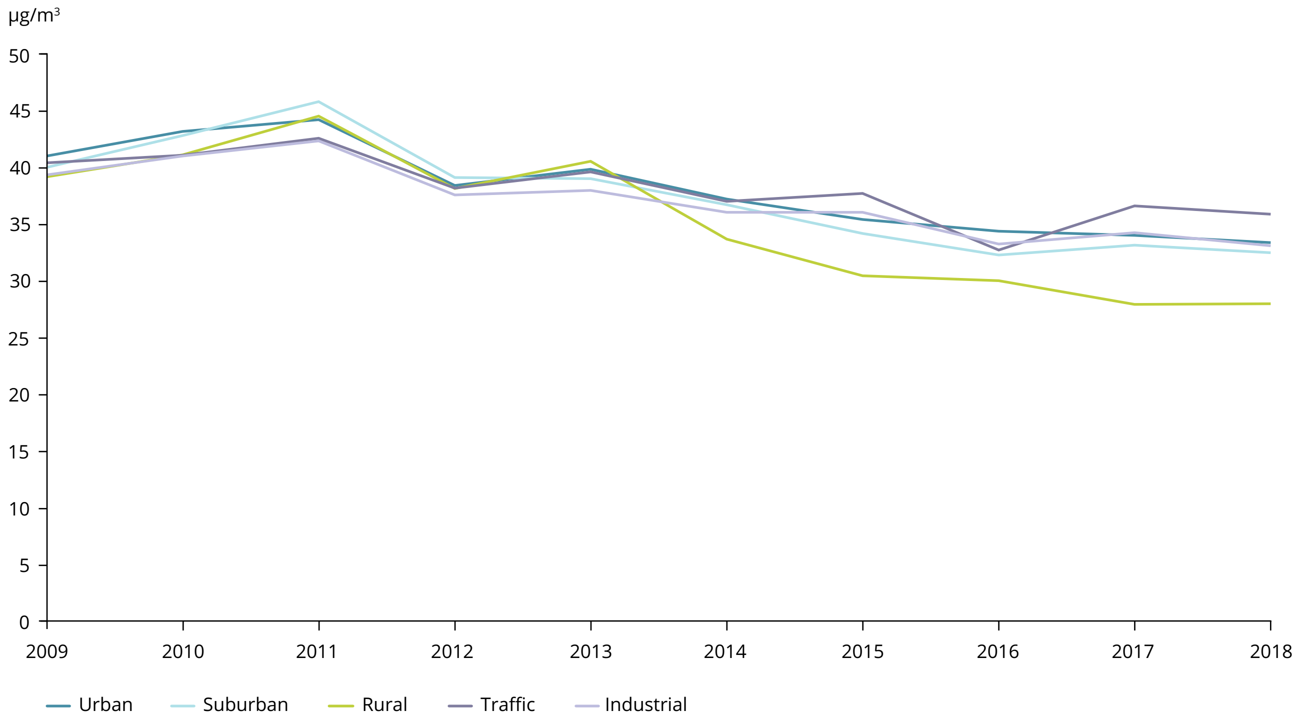
Note: For further information, please see Annex 2.

Figure 4.5 Trend slope distribution (2009-2018) for PM_{10} annual mean, per station type, for both significant and non-significant trends



Note: The calculated trend slope represents the average change in concentration per year at each station in the period 2009-2018. The graphs should be read in relation to Map 4.4 and Table A2.1

Figure 4.6 Average value for the 90.4 percentile of the PM_{10} daily concentration values



Note: The 90.4 percentile of the PM_{10} daily mean concentrations represents the 36th highest value in a complete series and is related to the PM_{10} daily limit value.

NMVOCs and it increased by 8 % for NH_3. Transport was the sector with the highest relative reduction in primary $PM_{2.5}$ in the decade considered (Figure 3.2), with a reduction of 38 % in the EEA-33, and emissions of the precursor sulphur dioxide (SO_2), also saw the highest reduction in transport (46 %), followed by residential, commercial and institutional (43 %) and energy supply (39 %) sectors. These emission reductions might explain the reduction in secondary formation of $PM_{2.5}$, thus reducing the levels of $PM_{2.5}$ concentrations observed in industrial and (sub)urban background sites.

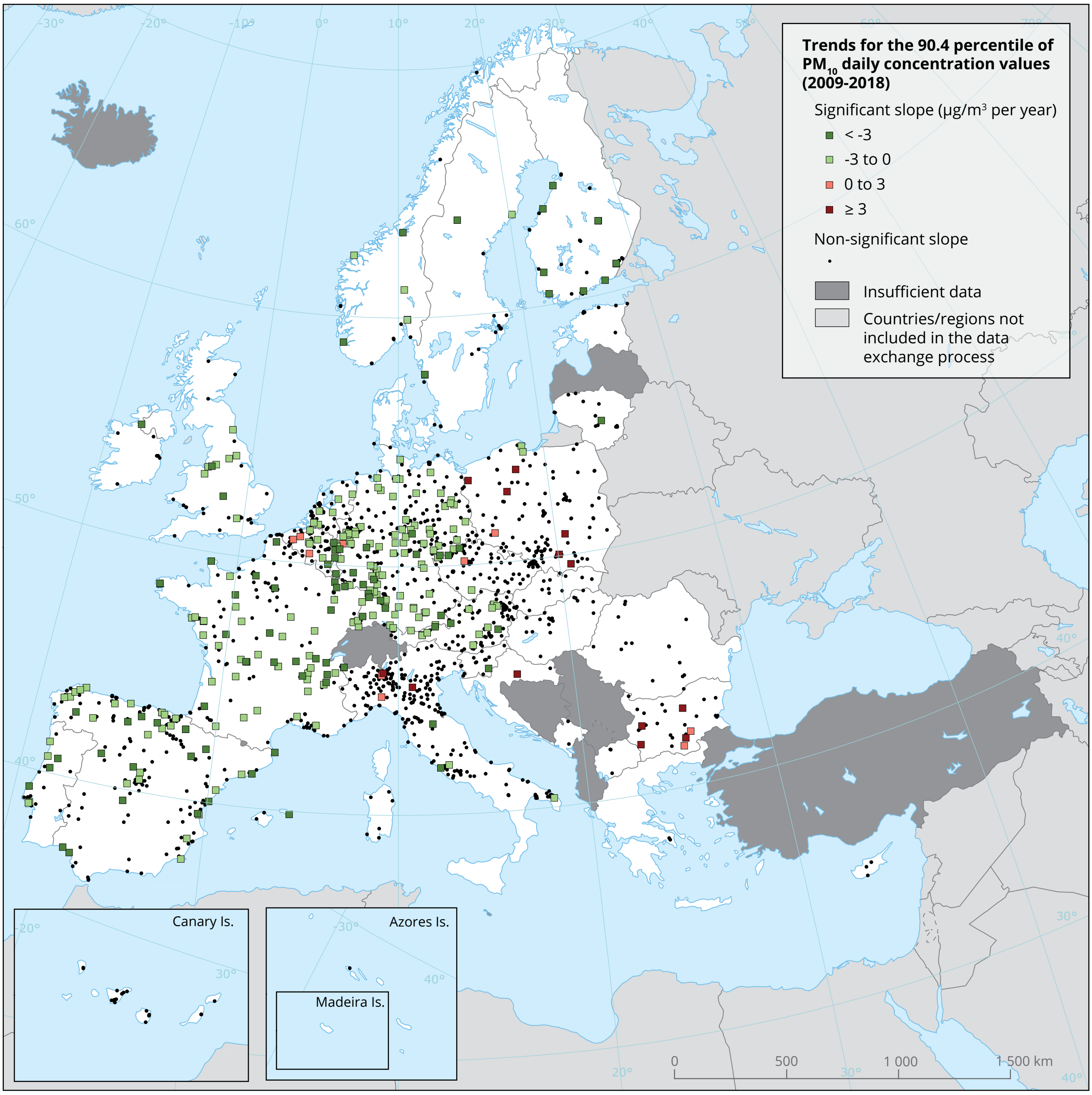
Map 4.6 shows the spatial distribution of the trend significance and slope from the trend analysis for the same period. The analysis shows that 58 % of the stations have a significant trend and most of the stations with a significant trend have a decreasing trend (92 %). The trend slopes, per station type, for significant and non-significant trends, are shown in Figure 4.9. Table A2.3 (Annex 2) shows the results of the trend analysis per country and station type. The Netherlands registered the highest average decreasing trend (-1.03 μg/m³ per year, 12 stations), followed by Cyprus (-0.97 μg/m³ per year, five stations), Hungary (-0.88 μg/m³ per year, one station), Luxembourg (-0.86 μg/m³ per year, two stations), France (-0.80 μg/m³ per year, 46 stations), Poland (-0.74 μg/m³ per year, 55 stations) and Belgium (-0.71 μg/m³ per year, 30 stations).

The trend analysis for the period 2009-2018 shows that the lowest average decrease in $PM_{2.5}$ concentrations was observed in rural background stations, where concentrations are lowest; the highest average decrease was observed in (sub)urban background and traffic stations.

A trend assessment study in Europe for the period 2008-2017 shows that average $PM_{2.5}$ annual mean concentration has decreased by about 30 %, averaged across the stations with data available ([24]) (ETC/ATNI, 2020c).

([24]) The countries included in the analysis were Austria, Belgium, Bulgaria, Cyprus, Czechia, Denmark, Estonia, Finland, France, Germany, Hungary, Ireland, Italy, Lithuania, Luxembourg, the Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden and the United Kingdom.

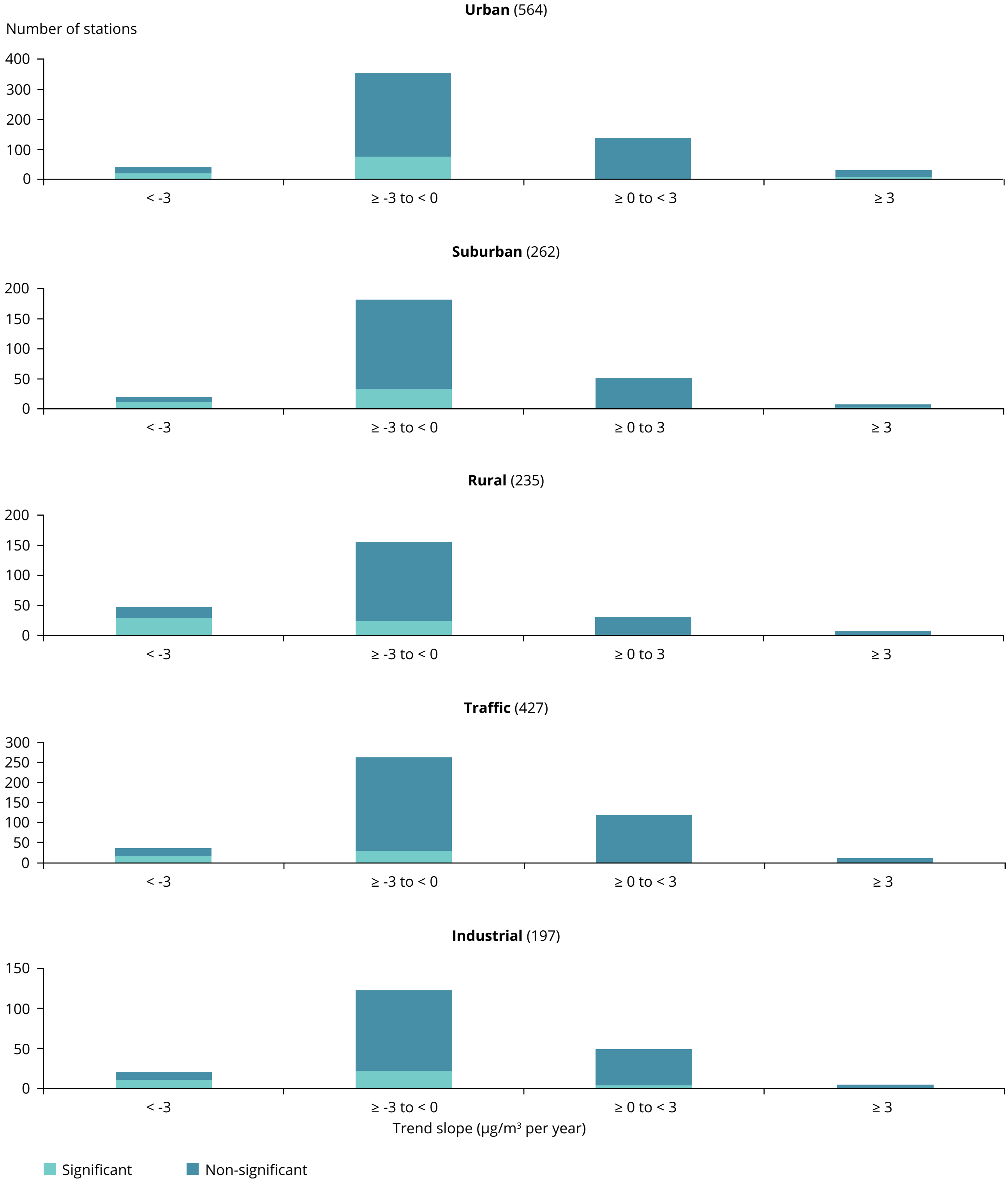
Map 4.5 **Trends for the 90.4 percentile of PM_{10} daily concentration values (2009-2018)**



Reference data: ©ESRI

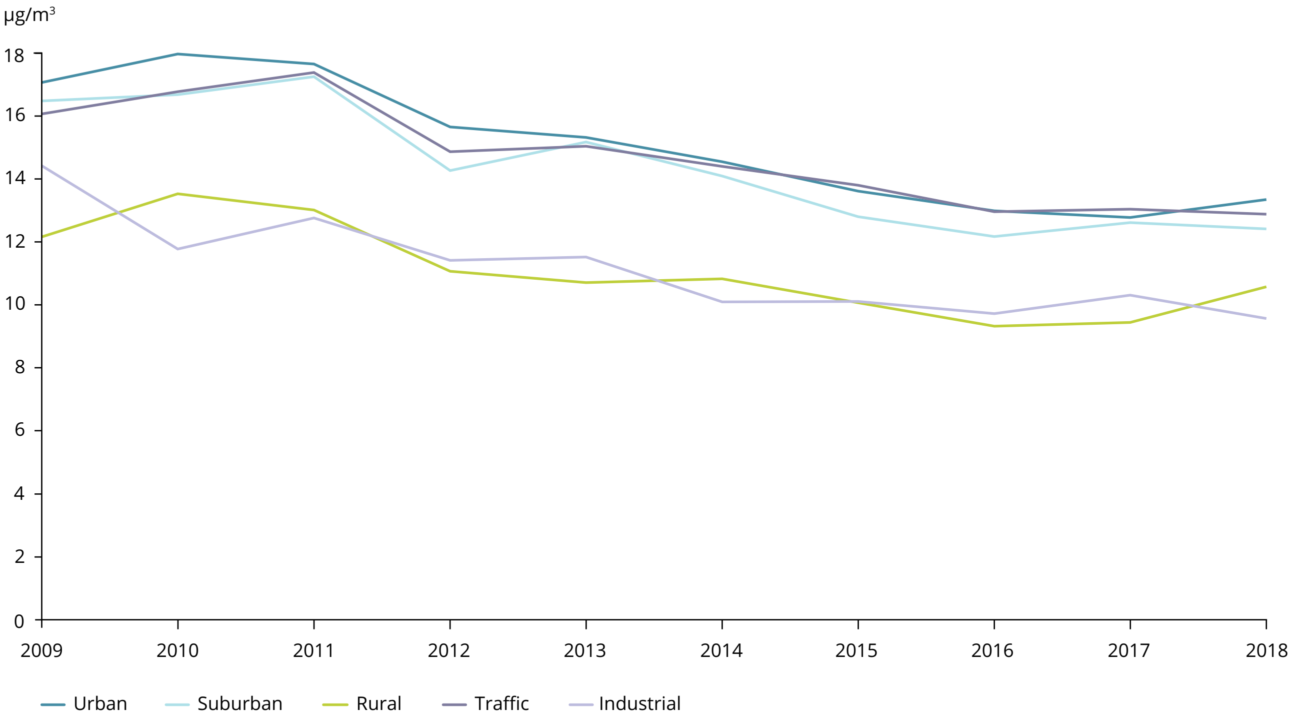
Note: The 90.4 percentile of the PM_{10} daily mean concentrations represents the 36th highest value in a complete series and is related to the PM_{10} daily limit value. For further information on the trend analysis, please see Annex 2.

Figure 4.7 **Trend slope distribution (2009-2018) for the 90.4 percentile of the PM_{10} daily concentration, per station type, for both significant and non-significant trends**



Note: The 90.4 percentile of the PM_{10} daily mean concentrations represents the 36th highest value in a complete series and is related to the PM_{10} daily limit value. The calculated trend slope represents the average change in concentration per year at each station in the period 2009-2018. The graphs should be read in relation to Map 4.5 and Table A2.2.

Figure 4.8 Average $PM_{2.5}$ annual mean concentrations by station type



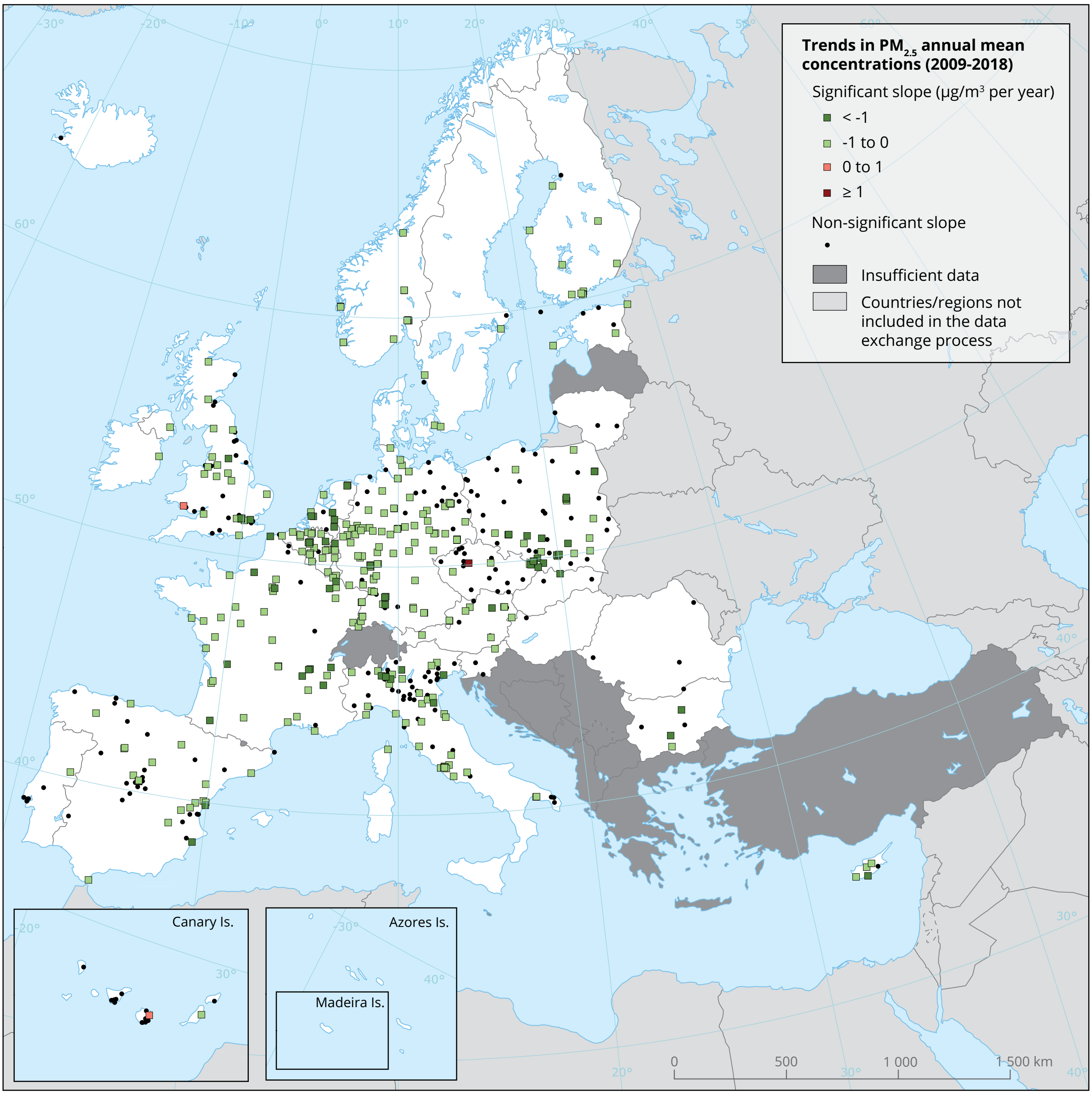
4.4 $PM_{2.5}$ average exposure indicator

The Ambient Air Quality Directive (EU, 2008) also sets two additional targets for $PM_{2.5}$: the exposure concentration obligation (ECO) and the national exposure reduction target (NERT) (Table 1.1). Both targets are based on the average exposure indicator (AEI), calculated at the national level. The AEI is an average of concentration levels (over a 3-year period) measured at urban background stations (representative of general urban population exposure) selected for this purpose by every national authority. The reference year for the AEI is 2010 (average 2008-2010), but the Ambient Air Quality Directive offered two additional alternatives if data were not available for 2008: (1) an alternative AEI 2010, with a 2-year average (2009 and 2010) instead of the 3-year average; or (2) the AEI 2011 (average 2009-2011). For comparability purposes, the data presented here are analysed with reference to the AEI 2011, independently of the reference year chosen by each Member State. The exception is Croatia for which 2015 is the AEI reference year (average 2013-2015).

Figure 4.10 shows the AEI for every EU-28 Member State calculated for 2018 (average 2016-2018) and the situation in relation to the ECO. The bars show the AEI 2018 using the stations designated for this purpose by the Member States ([25]), while the dots show the 3-year (2016-2018) average concentrations from measurements at all urban and suburban background stations with 75 % data coverage. This calculation, covering the urban and suburban background stations, has been used in previous *Air quality in Europe* reports as an approximation of the AEI and is presented here for comparison with the information presented in those reports. The calculation using reported urban and suburban background stations is also made for the rest of the non-EU countries.

([25]) For Bulgaria, which does not have AEI stations fulfilling the requirement of a minimum data coverage of 75 % in 2018, the AEI2018 has been calculated as the average for 2016 and 2017. For Malta, which does not have AEI stations fulfilling the requirement of a minimum data coverage of 75 % in 2017, the AEI has been calculated as the average for 2016 and 2018. Hungary does not have AEI stations fulfilling the requirement of a minimum data coverage of 75 % in any year of the period 2016-2018. The non-EU countries Iceland and Norway also have designated AEI stations. The rest of the countries covered by this report in which the EU directives do not apply are not obliged to designate AEI stations.

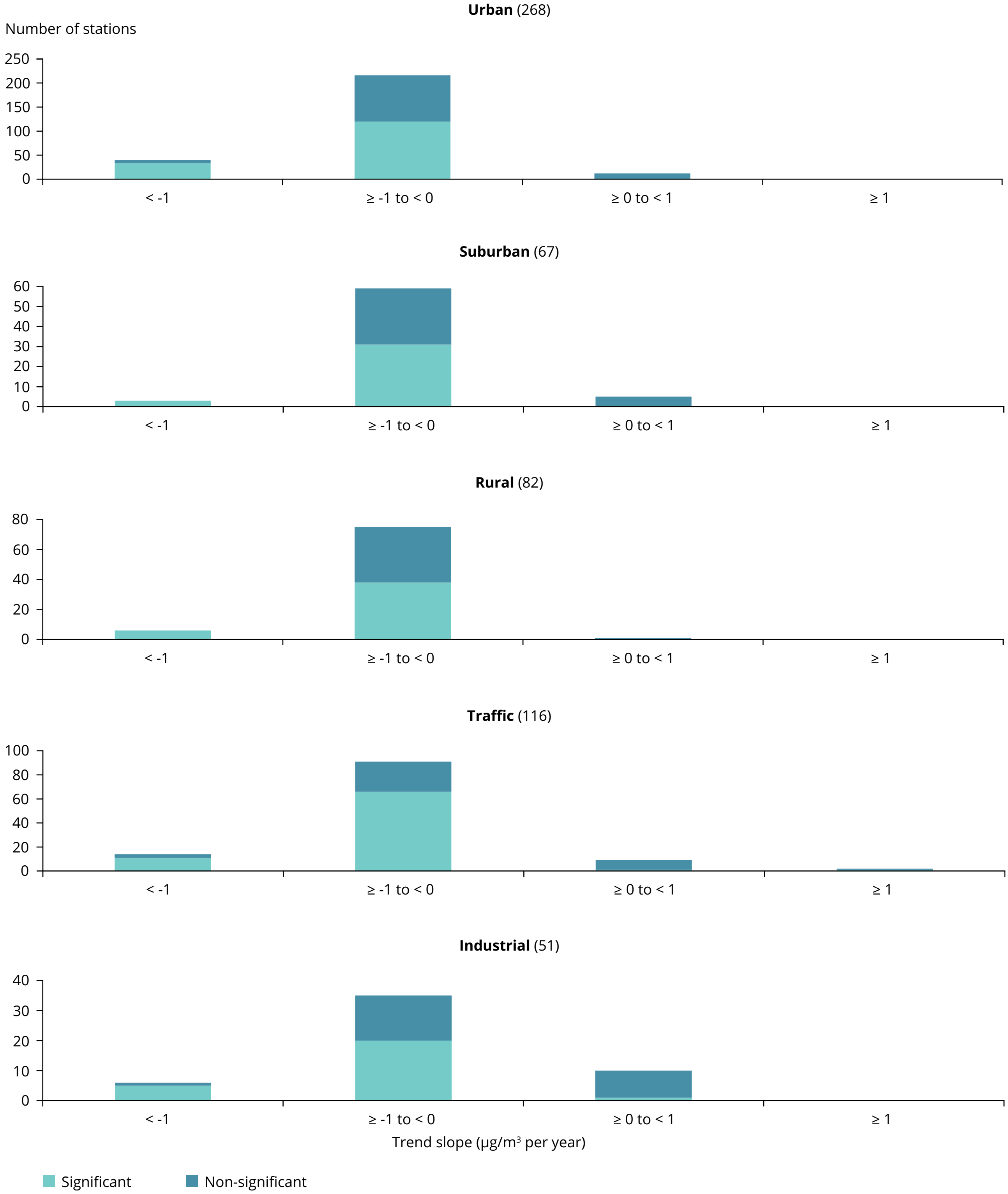
Map 4.6 Trends in $PM_{2.5}$ annual mean concentrations (2009-2018)



Reference data: ©ESRI

Note: For further information, please see Annex 2.

Figure 4.9 Trend slope distribution (2009-2018) for $PM_{2.5}$ annual mean concentration, per station type, for both significant and non-significant trends



Note: The calculated trend slope represents the average change in concentration per year at each station in the period 2009-2018. The graphs should be read in relation to Map 4.6 and Table A2.3.

For the 29 countries where the AEI 2018 could be calculated using the designated stations, the AEI continued to be above the ECO in Slovakia (21 µg/m^3) ([26]), Poland (22 µg/m^3) and Bulgaria (24 µg/m^3).

Furthermore, based on the average of $PM_{2.5}$ concentrations measured at urban and suburban background stations, Switzerland and Hungary met the exposure concentration obligation with an estimated AEI 2018 of 11 and 20 µg/m^3, respectively ([27]). Finally, Turkey had an estimated AEI 2018 above the ECO (21 µg/m^3).

For the rest of the countries, no estimated AEI 2018 could be calculated, as they do not report 2018 $PM_{2.5}$ data (except Bosnia and Herzegovina, which did not report $PM_{2.5}$ data from urban background stations in 2018). In any case, with the most recent data, all of them had AEI values above 20 µg/m^3: Bosnia and Herzegovina (33 µg/m^3) and North Macedonia (51 µg/m^3) for AEI 2017 (with only 2016 and 2017 data), and Serbia (23 µg/m^3), Kosovo (25 µg/m^3) and Albania (29 µg/m^3) for AEI 2016 (with only 2016 data).

Figure 4.11 shows the situation in the EU Member States, Iceland and Norway in relation to the NERT. This reduction target is expressed as a percentage of the initial AEI 2010 (here, as stated above, AEI 2011 has been used for comparison). The dots indicate the percentage reduction to be attained in AEI 2020 (average 2018-2020) and the bars indicate the reduction in the AEI 2018 as a percentage of the AEI 2011 (AEI 2015 for Croatia). Figure 4.11 indicates that 18 out of the 30 countries considered ([28]) reduced their AEI in 2018 below their corresponding NERT values. On the contrary, in Portugal and Romania the AEI 2018 was higher than the AEI 2011 (not shown in Figure 4.11).

4.5 Preliminary status of concentrations in 2019

The EEA received up-to-date (UTD) PM_{10} data for 2019, with sufficient valid measurements (a minimum coverage of 75%) from 1 843 stations in relation to the annual limit value and from 1 821 stations in relation to the daily limit value. The stations were located in all the 2019 33 UTD reporting countries, except Cyprus, Denmark and Latvia.

Out of these countries sending UTD data, 13 Member States and two other reporting countries reported preliminary PM_{10} concentrations above the EU daily limit value in 2019 (Map 4.7). This was the case for 9 % of the reporting stations. Of those stations, 93 % were either urban (83 %) or suburban (10 %).

UTD concentrations above the PM_{10} annual limit value in 2019 were monitored in 0.5 % (10 stations) of all the reporting stations, located in four countries: North Macedonia (five), Poland (three), Bulgaria (one) and Italy (one). The stricter value of the WHO AQG for PM_{10} annual mean was exceeded at 37 % of the stations in all the reporting countries, except in Estonia, Finland, Iceland, Ireland and Luxembourg.

Regarding UTD $PM_{2.5}$, data with a minimum coverage of 75 % of valid measurements were received from 841 stations located in all the 2019 33 UTD reporting countries, except Andorra, Cyprus, Denmark, Latvia, Malta and Slovenia. In 2019, the $PM_{2.5}$ concentrations were provisionally higher than the annual limit value in four Member States and two other reporting countries (Map 4.8). These concentrations above the limit value were registered in 2 % of all the reporting stations and occurred primarily (87 % of cases) in urban (67%) and suburban (20 %) areas. The WHO guideline for $PM_{2.5}$ annual mean was exceeded at 58 % of the stations, located in 20 of the 27 countries reporting $PM_{2.5}$ UTD data. Estonia, Finland, Iceland, Ireland, Luxembourg, Norway and Sweden did not report any UTD concentrations above the WHO AQG for $PM_{2.5}$.

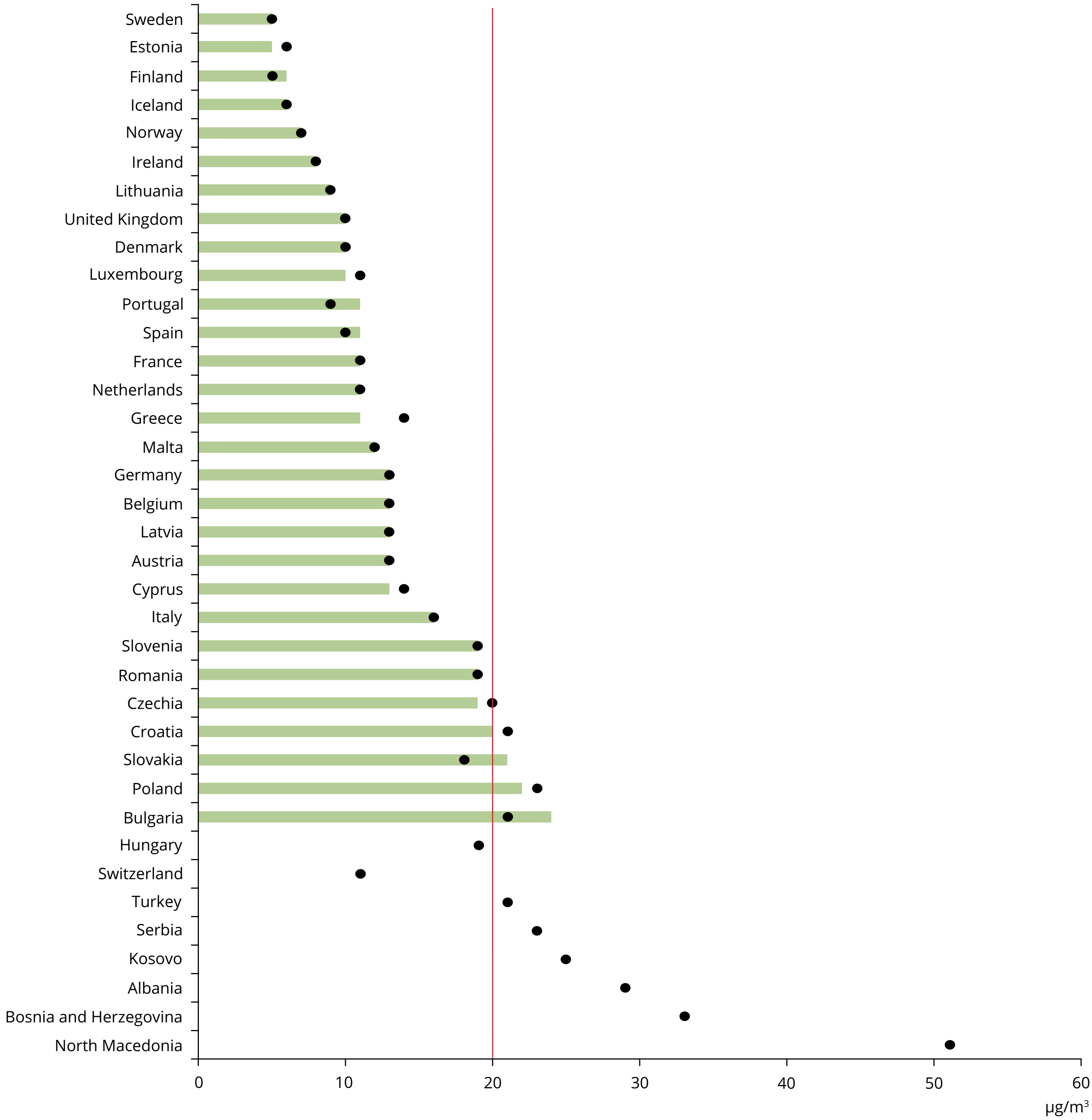
Regarding the rural background levels, in 2019, concentrations above the PM_{10} daily limit value occurred in nine rural background stations across Italy (eight) and Czechia (one), while no rural background stations reported PM_{10} annual mean concentration above the annual limit value. With regard to $PM_{2.5}$, Czechia registered concentrations above the annual limit value in one rural background station.

([26]) During the finalisation of this report, Slovakia was in the process of resubmitting information about the stations designated to calculate the AEI, which might imply a change in the AEI 2018 value.

([27]) AEI 2018 estimated using only 2017 and 2018 data, as Hungary did not report $PM_{2.5}$ data from urban or suburban background stations with enough data coverage in 2016.

([28]) Austria, Belgium, Cyprus, Denmark, Estonia, Finland, France, Germany, Greece, Iceland, Ireland, Lithuania, Luxembourg, the Netherlands, Norway, Spain, Sweden and the United Kingdom.

Figure 4.10 Average exposure indicator in 2018 and exposure concentration obligation



Notes: The bars show the AEI calculated in 2018 (average of 2016-2018) using the stations designated for this purpose by the Member States (except for Bulgaria and Malta, where 1 year was missing, and Hungary, for which the AEI 2018 could not be calculated — see the main text) and Iceland and Norway.

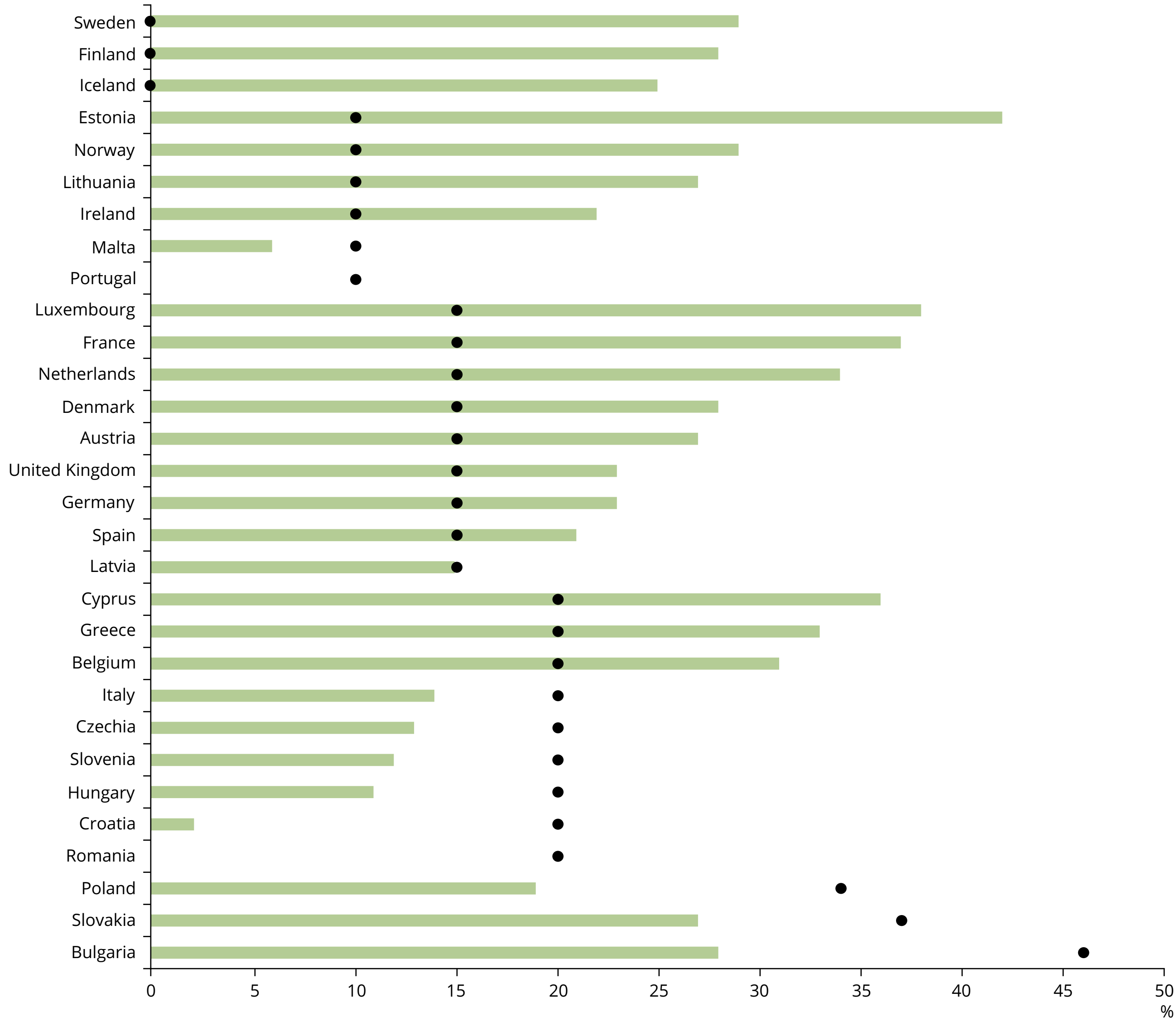
The dots show all urban and suburban background $PM_{2.5}$ concentrations (for stations with at least 75 % of data coverage) in all reporting countries presented as 3-year (2016-2018) averages, as an approximation of the AEI in 2018 and to facilitate comparison with information provided in previous *Air quality in Europe* reports.

The vertical line represents the exposure concentration obligation for the EU-28, set at 20 μg/m³, to be achieved as of 2015.

For Hungary, for which the reported $PM_{2.5}$ data from urban or suburban background stations in 2016 did not fulfil the minimum data coverage criterion, the estimation using urban background stations is presented for the average of 2017-2018. For Bosnia and Herzegovina (which did not report $PM_{2.5}$ data from urban background stations in 2018) and North Macedonia, the estimation using urban background stations considered only the years 2016 and 2017. For Albania, Kosovo and Serbia, which reported neither 2017 nor 2018 $PM_{2.5}$ data, only the year 2016 was considered.

Source: EEA (2020c).

Figure 4.11 **Percentage reduction in AEI 2018 in relation to AEI 2011 and distance to the national exposure reduction target**

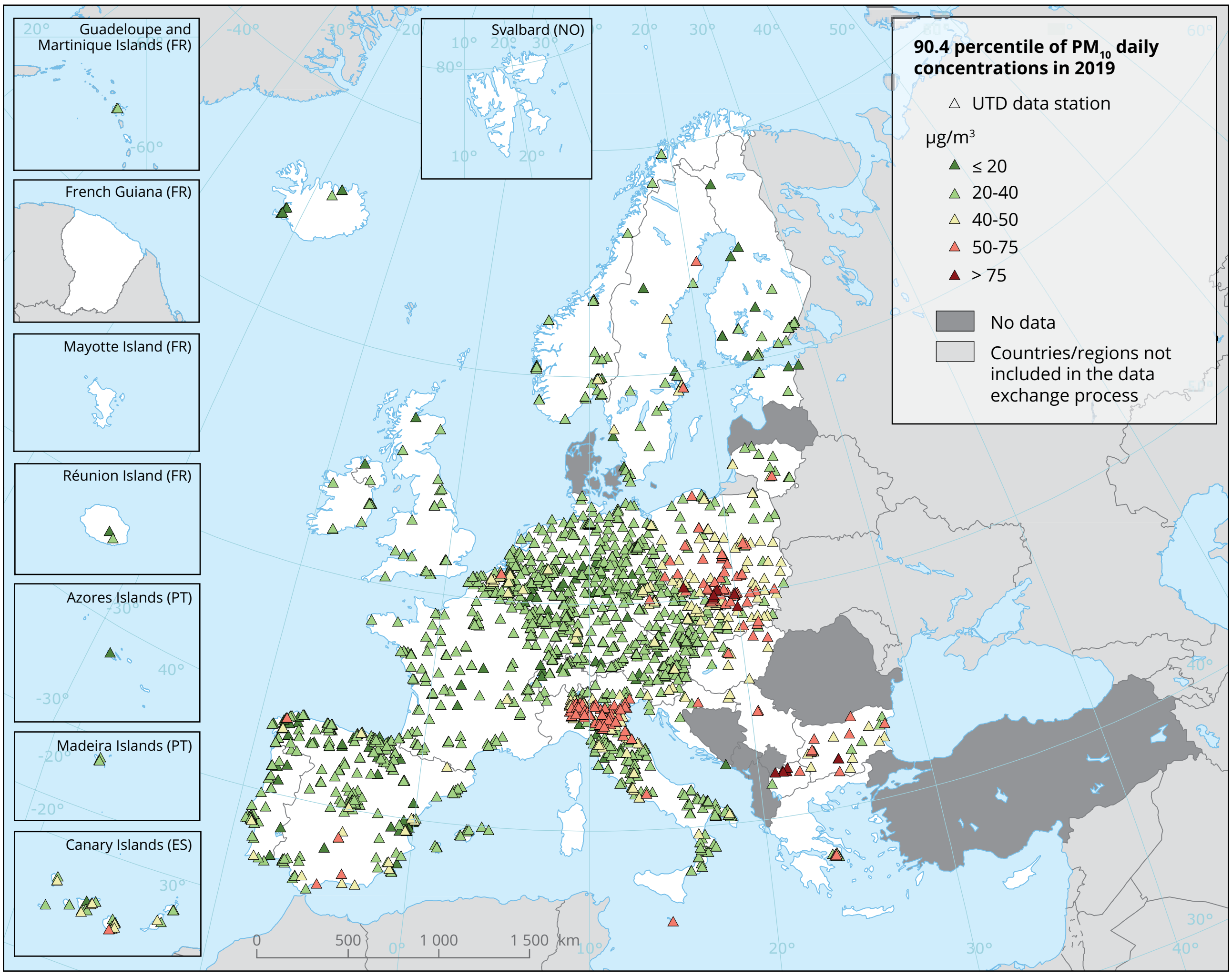


Notes: Bars indicate the reduction in the AEI 2018 as a percentage of the AEI 2011 (AEI 2015 in the case of Croatia — see the main text). Dots indicate the reduction to be obtained in the AEI 2020 as a percentage of the AEI 2011 (AEI 2015 in the case of Croatia). If the end of the bar is to the right of the dot or in the same spot, the NERT had already been achieved in 2018.

For Hungary (where the stations designated for the AEI calculation do not reach the minimum data coverage), all urban and suburban background stations have been used instead, but only for the years 2017 and 2018, as no urban background stations with enough data coverage were reported in 2016.

Source: EEA (2020c).

Map 4.7 Concentrations of PM_{10}, 2019 — daily limit value

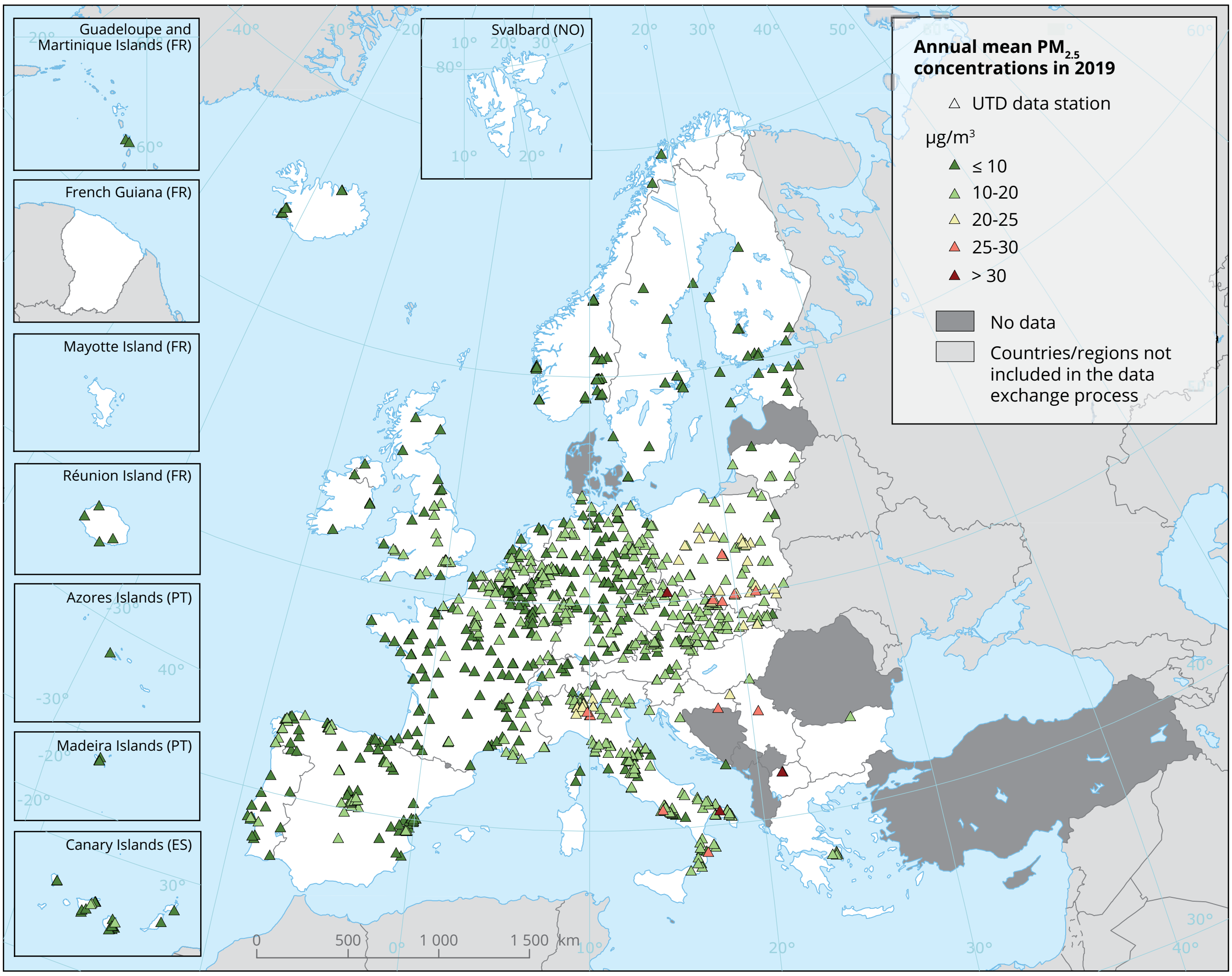


Reference data: ©ESRI | ©EuroGeographics

Note: Observed concentrations of PM_{10} in 2019. The data presented were reported as UTD data and therefore should be considered as not validated. They are used for the purpose of providing a preliminary assessment of the situation in 2019 in relation to the PM_{10} daily limit value. Furthermore, the possibility of subtracting contributions to the measured concentrations from natural sources and winter road sanding/salting has not been considered. The map shows the 90.4 percentile of the PM_{10} daily mean concentrations, representing the 36th highest value in a complete series. It is related to the PM_{10} daily limit value, allowing 35 exceedances of the 50 μg/m³ threshold over 1 year. Dots in the last two colour categories indicate stations with concentrations above this daily limit value. Only stations with more than 75 % of valid UTD data are included in the map. A few French stations could not be processed on account of errors in their metadata; therefore, they are not shown in the map.

Source: EEA (2020c).

Map 4.8 Concentrations of $PM_{2.5}$, 2019 — annual limit value



Reference data: ©ESRI | ©EuroGeographics

Note: Observed concentrations of $PM_{2.5}$ in 2019. The data presented were reported as UTD data and therefore should be considered as not validated. They are used for the purpose of providing a preliminary assessment of the situation in 2019 in relation to the $PM_{2.5}$ annual limit value. Furthermore, the possibility of subtracting contributions to the measured concentrations from natural sources and winter road sanding/salting has not been considered. Dots in the last two colour categories indicate stations reporting concentrations above the EU annual limit value (25 µg/m³). Dots in the first colour category indicate stations reporting values below the WHO AQG for $PM_{2.5}$ (10 µg/m³). Only stations with more than 75 % of valid UTD data are included in the map.

Source: EEA (2020c).

5 Ozone

5.1 European air quality standards and World Health Organization guideline values for ozone

The European air quality standards for the protection of health and the air quality guidelines (AQGs) set by the World Health Organization (WHO) for ozone (O_3) are shown in Tables 1.1 and 1.3, respectively. For convenience, they are summarised in Table 5.1.

The Ambient Air Quality Directive (EU, 2008) also sets targets for the protection of vegetation, shown in Table 1.2. In addition, the Convention on Long-range Transboundary Air Pollution (CLRTAP) (UNECE, 1979) defines a critical level (CL) for the protection of forests (Table 1.2). The O_3 concentrations in relation to these standards, the vegetation exposure to O_3 levels above these standards and the exposure of forests to O_3 levels above the CL are assessed in Section 11.1.

5.2 Status of concentrations in 2018

Data for O_3 in 2018 were reported from 2 195 stations (82 % of which were background stations) in all of the 2018 37 reporting countries, except Iceland ([29]).

Twenty Member States and five other reporting countries (Figure 5.1 and Map 5.1) registered concentrations above the O_3 target value more than 25 times in 2018. In total, 41 % (895) of all stations reporting O_3, with the minimum data coverage of 75 %, showed concentrations above the target value for the protection of human health in 2018. In addition, only 13 % (296) of all stations fulfilled the long-term objective. Overall, 85 % of the stations with values above the long-term objective were background stations.

In total, 4 % (81) of all stations and only 7 of the 560 rural background stations reported in 2018 had values below the WHO AQG value for O_3 (8-hour mean of 100 μg/m^3), set for the protection of human health.

Annex 1 offers additional information on O_3 concentrations, showing the frequency distributions (Figure A1.7) and the values by station and area types (Figure A1.8).

Higher atmospheric temperature leads to enhanced photochemical reactions and O_3 formation. The year 2018 was the third warmest on record in Europe and temperatures in central and northern Europe

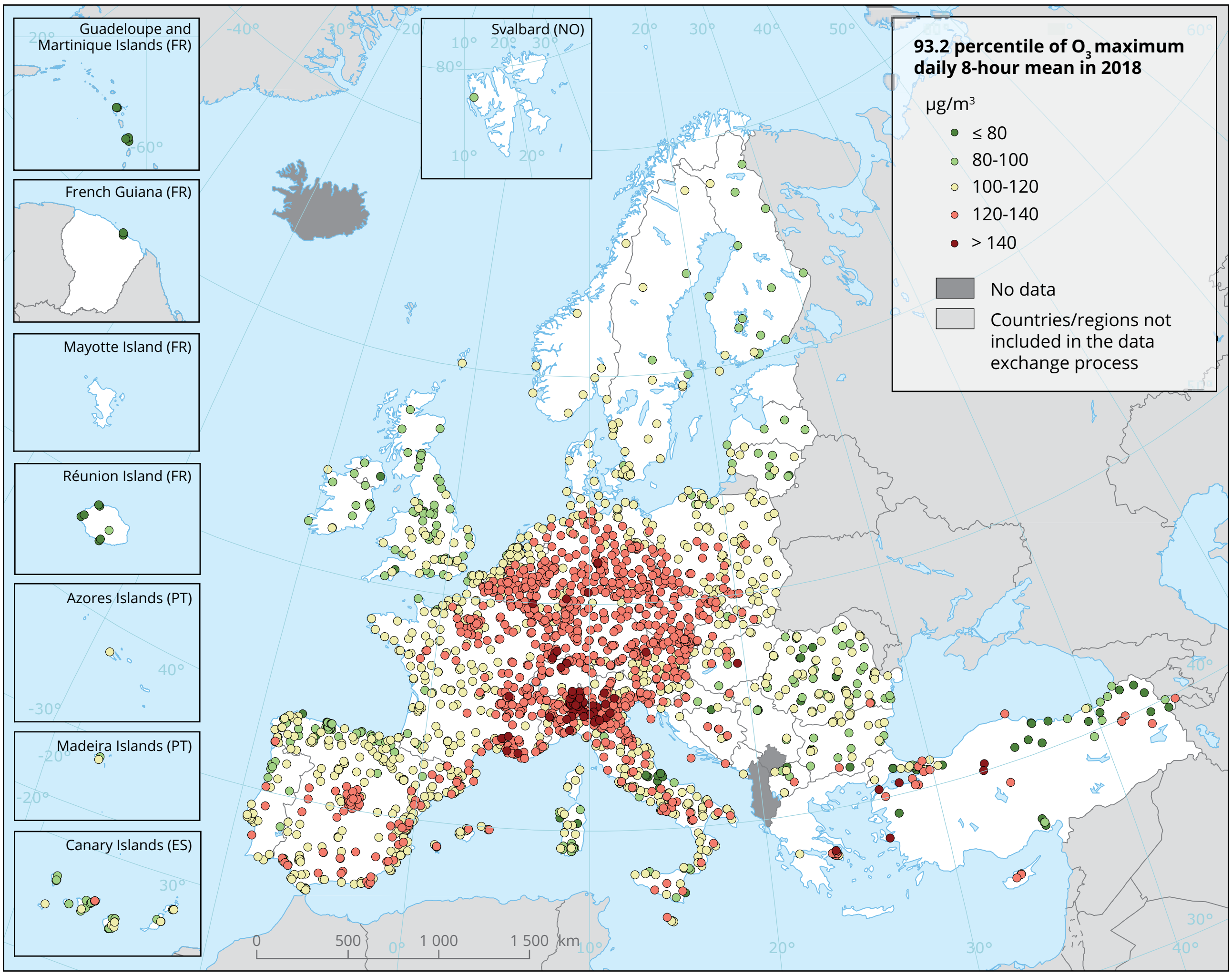
Table 5.1 Air quality standards for protecting human health from O_3

Pollutant	Averaging period	Standard type and concentration	Comments
O_3	Maximum daily 8-hour mean	EU target value: 120 μg/m^3	Not to be exceeded on more than 25 days/year, averaged over 3 years ([a])
		EU long-term objective: 120 μg/m^3	
		WHO AQG: 100 μg/m^3	
	1 hour	EU information threshold: 180 μg/m^3	
		EU alert threshold: 240 μg/m^3	

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

([29]) The seven stations reported by Estonia appear in the total count but not in the map and graph, as they could not be properly processed. In 2018, all of them had values below the target value threshold for the protection of health.

Map 5.1 Concentrations of O_3 in 2018



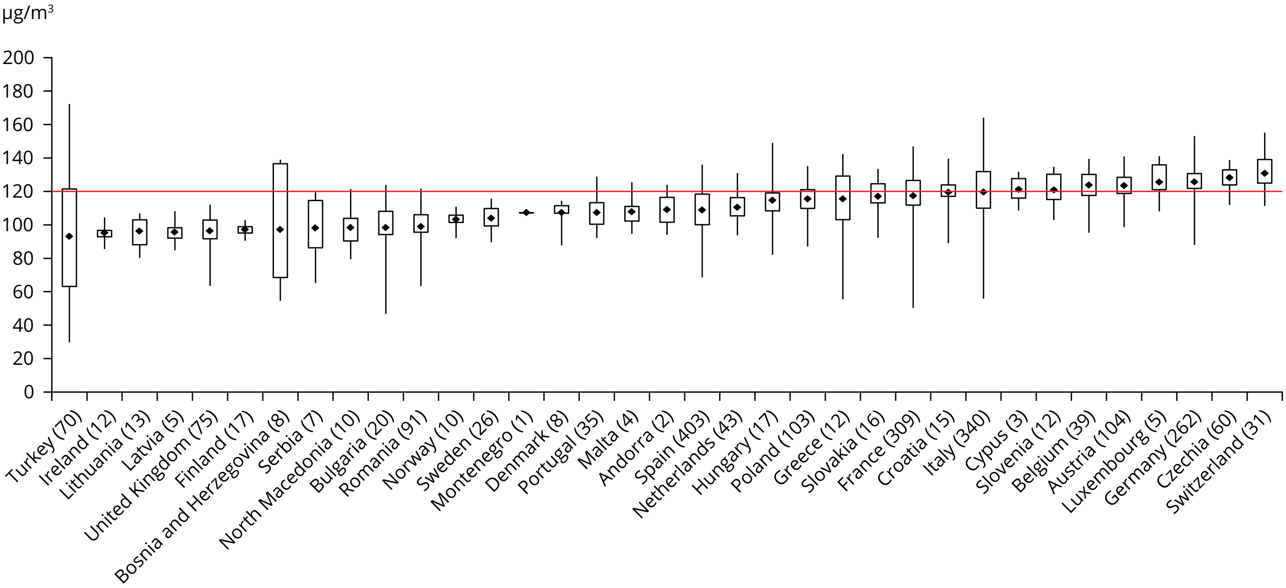
Reference data: ©ESRI | ©EuroGeographics

Notes: Observed concentrations of O_3 in 2018. The map shows the 93.2 percentile of the O_3 maximum daily 8-hour mean, representing the 26th highest value in a complete series. It is related to the O_3 target value. At sites marked with dots in the last two colour categories, the 26th highest daily O_3 concentrations were above the 120 μg/m³ threshold, implying an exceedance of the target value threshold. Please note that the legal definition of the target value considers not only 1 year but the average over 3 years. Only stations with more than 75 % of valid data are included in the map.

Estonia submitted data from seven stations that do not appear in the map because they could not been properly processed. All of them had values in 2018 below the target value threshold for the protection of health (see also note to Figure 5.1).

Source: EEA (2020c).

Figure 5.1 O_3 concentrations in relation to the target value in 2018 and number of stations considered for each country



Notes: The graph is based, for each country, on the 93.2 percentile of the maximum daily 8-hour mean concentration values, corresponding to the 26th highest daily maximum of the running 8-hour mean. For each country, the number of stations considered (in brackets), and the lowest, highest and average values (in µg/m³) recorded at its stations are given. The rectangles mark the 25th and 75th percentiles. At 25 % of the stations, levels are below the lower percentile; at 25 % of the stations, concentrations are above the upper percentile. The target value threshold set by the EU legislation is marked by the horizontal line. Please note that the legal definition of the target value considers not only 1 year but the average over 3 years. The graph should be read in relation to Map 5.1, as a country's situation depends on the number of stations considered.

The seven stations reported by Estonia do not appear in the graph because they could not be properly processed. Their data were in the process of being resubmitted while finalising this report. All of them had values in 2018 below the target value threshold for the protection of health.

Source: EEA (2020c).

Figure 5.2 Average SOMO35 per station type from 2000 to 2018

during late spring and summer were 4-8 °C above the 10-year mean (2008-2017) (Copernicus, 2019). The meteorological conditions in 2018 were, thus, very favourable to O_3 formation and have led to high O_3 concentrations in Europe (Figure 5.2), particularly in northern and central Europe. In particular over central Europe, O_3 levels were well above levels registered in previous years and comparable to the high levels registered in 2015.

The Copernicus Atmosphere Monitoring Service (CAMS) (2019) estimated that the worst O_3 episode in 2018 occurred from 30 July to 7 August, when the largest exceedances of both the information threshold and the long-term objective were measured over large areas in central, southern and western Europe. Traffic and industrial emissions were considered the main contributors to this O_3 episode (CAMS, 2019).

5.3 Ozone precursors

With the objective of analysing any trend in O_3 precursors, checking the efficiency of emission reduction strategies, checking the consistency of emission inventories and helping attribute emission sources to observed pollution concentrations, the Ambient Air Quality Directive (EU, 2008) establishes the obligation of installing at least one sampling point per Member State to supply data on concentrations of some volatile organic compounds (VOCs), as they are O_3 precursors.

The 31 recommended VOCs for measurement are presented in Annex X to the Ambient Air Quality Directive (EU, 2008). Benzene (C_6H_6) is also recommended, but, as a regulated pollutant, it is analysed in Chapter 8. The reported concentrations for all the recommended VOCs can be found in the EEA's 'Air quality statistics — Expert viewer' (EEA, 2020g).

5.4 Trends in concentrations

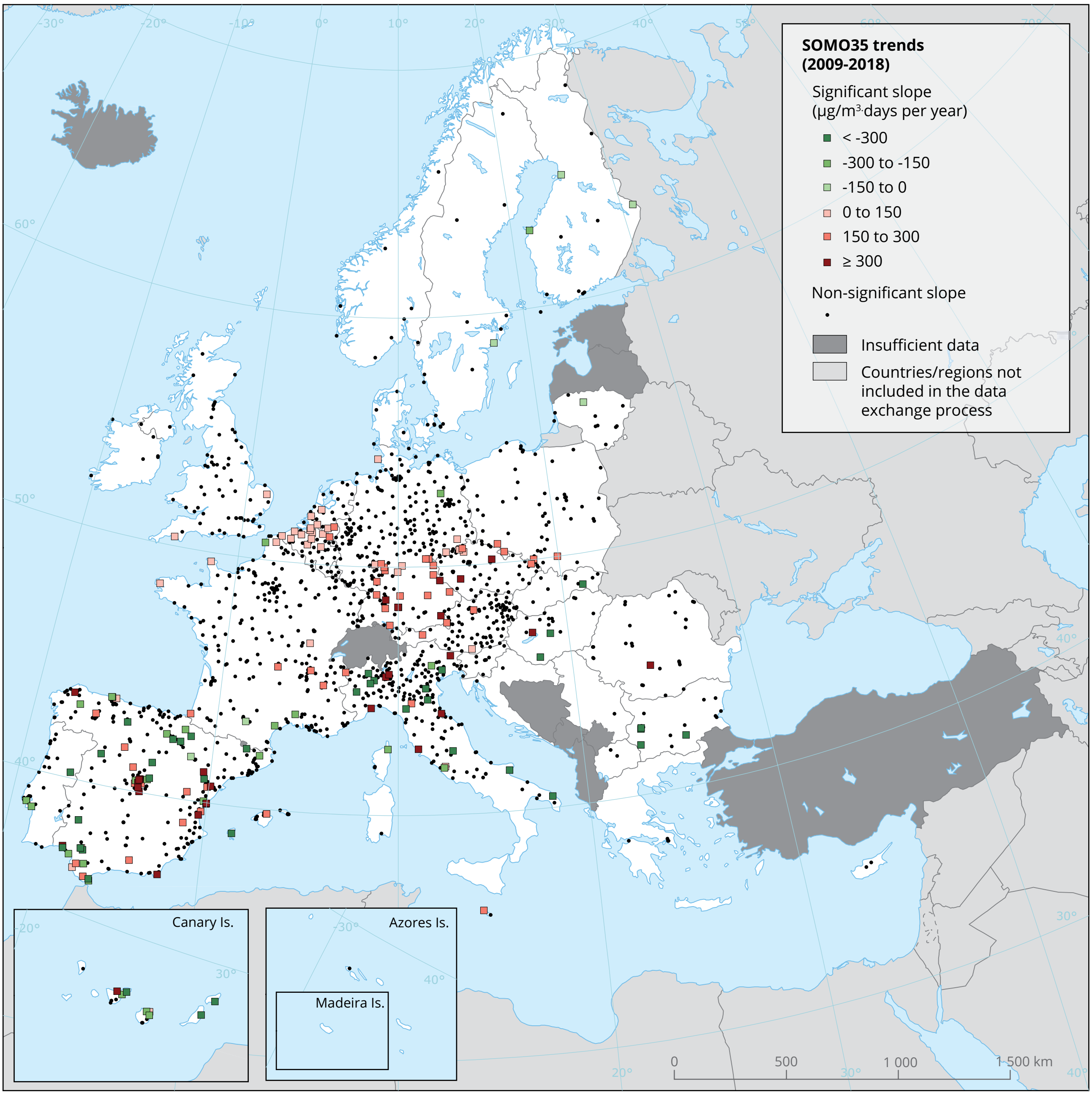
The average SOMO35 ([30]) O_3 concentrations from 2000 to 2018 are presented in Figure 5.2 for urban, suburban and rural background, traffic and industrial stations. Following the extreme values measured in 2003 and 2006, SOMO35 was relatively constant from 2009 to 2013 and varied more in the last 5 years considered, with a relative maximum in 2015 and an increase from 2016 to 2018. This variability is, to a large extent, explained by meteorological variability (see analysis on the impact of meteorology on O_3 levels from year to year later in this section). NO_X and NMVOCs emissions in the EEA-33 decreased between 2000 and 2018 by 45 % and 41 %, respectively, which contributes to decreased O_3 formation. On the other hand, and even if CH_4 emissions in the EU-33 have decreased by 29 % from 2000 to 2018, CH_4 concentrations in the northern hemisphere have increased considerably (Nisbet et al., 2019), counteracting to some extent the decrease in European emissions of O_3 precursors. The studies by Turnock et al. (2018) and Jonson et al. (2018) have documented the role of intercontinental transport of O_3 and long-lived O_3 precursors as well as the role of globally increasing CH_4 concentrations on O_3 levels. They show that non-European sources have a very significant influence on surface O_3 levels in Europe. However, the influence of these sources as well as the impact from CH_4 is most important for the annual mean O_3 levels, whereas metrics such as SOMO35 depend mainly on elevated O_3 levels in summer, which are more influenced by the European precursor emissions (Jonson et al., 2018).

The trend analysis for the period 2009-2018 shows an average increase for all station types, except for industrial stations (Figure 5.3 and Map 5.2). Map 5.2 shows the spatial distribution of the trends calculated for each station for the period 2009-2018. Most of the stations show a non-significant trend (90 %), and 7 % of the stations show a significant increasing trend in SOMO35, all of them situated in central and southern Europe. Only 3 % of stations show a significant decreasing trend, mostly located in Spain and Italy, and the majority of these stations are classified as rural background and industrial. The calculated trend slopes, per station type, for significant and non-significant trends, are shown in Figure 5.3; the average per country and station type are found in Table A2.4, in Annex 2. Serbia (-675 μg/m^3·days for one station), North Macedonia (-339 μg/m^3·days for two stations), Slovakia (-220 μg/m^3·days for 11 stations) and Bulgaria (-188 μg/m^3·days for 17 stations) show the highest decrease in SOMO35, with Malta (120 μg/m^3·days for two stations) and Austria (101 μg/m^3·days for 90 stations) showing the highest increase, followed by Czechia (94 μg/m^3·days for 51 stations) and Luxembourg (94 μg/m^3·days for five stations).

The GAM (ETC/ATNI, 2020a; see short description in Section 2.2) was used to assess the impact of meteorology on O_3 levels from year to year and its impact on the trend for different regions across Europe. The GAM model analysis indicated that SOMO35, excluding the effect of meteorology, was reduced from 2009 to 2014 and stabilised from 2015 to 2018 in rural background stations over the Nordic countries, while no clear trend is estimated for urban background stations. The same analysis estimated an average decrease in SOMO35 concentrations in stations located in Germany, the Benelux and France, especially in the rural background stations. For the region over central-eastern Europe (eastern Czechia, Hungary, Poland, Romania, Slovakia), a decreasing trend in rural background stations was estimated, while urban background stations did not show a clear trend. The same analysis also shows a clear decreasing trend in both rural and (sub)urban background stations in northern Italy. Over the Iberian Peninsula, the analysis shows no clear trend in rural background stations and an increasing trend from 2010 to 2016 in (sub)urban background stations. For the region covering southern Italy, the Balkan countries and Greece, the GAM analysis shows a decrease in SOMO35 concentrations from 2012/2013 to 2018 in background stations. No clear trends were estimated over the United Kingdom and Ireland.

([30]) SOMO35 is the accumulated O_3 concentration (daily maximum 8-hour mean) in excess of 35 ppb (i.e. 70 μg/m^3 for O_3). This aggregation has been selected because it is the one recommended by WHO for estimating health impacts of exposure to O_3.

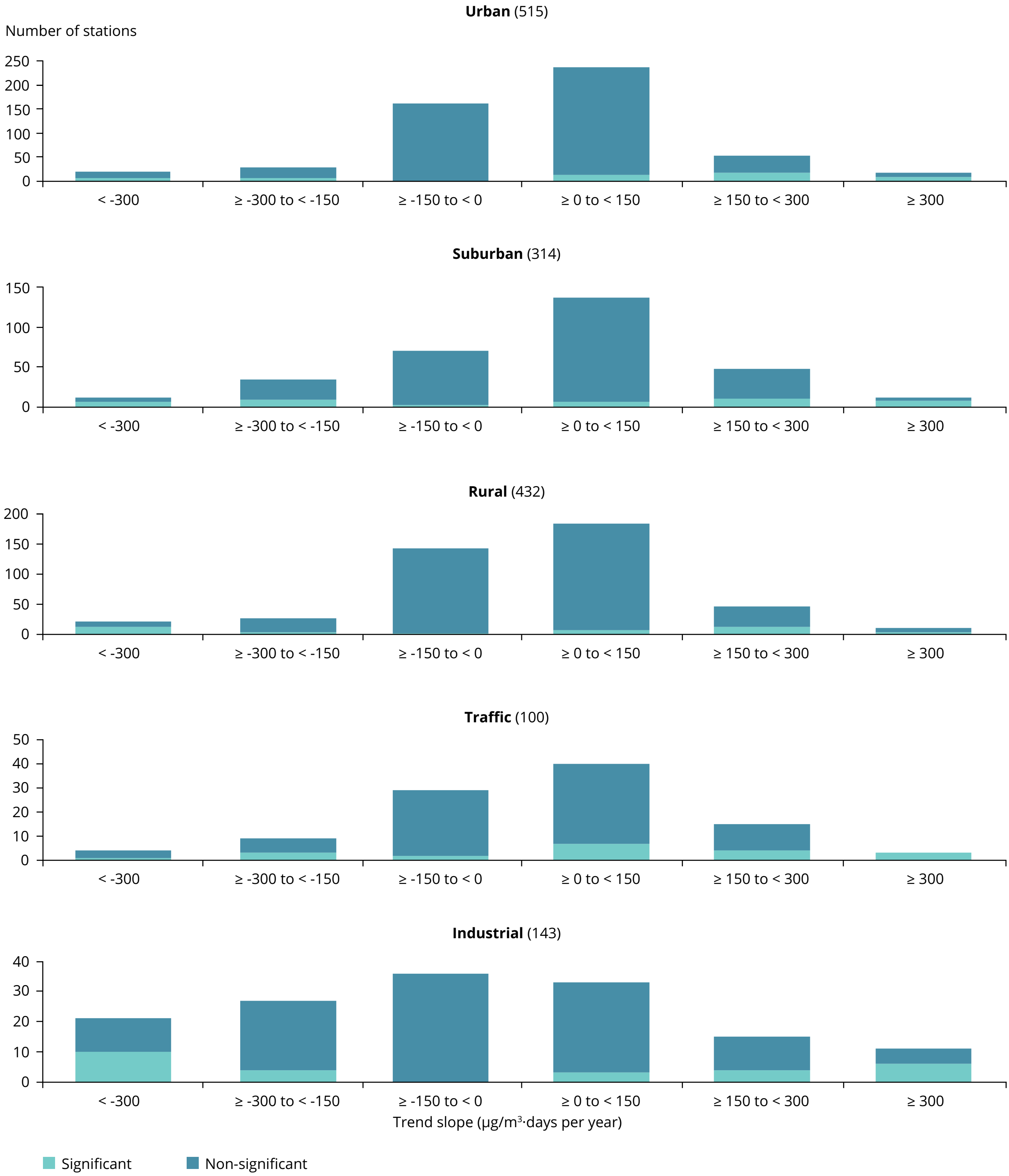
Map 5.2 **SOMO35 trends (2009-2018)**



Reference data: ©ESRI

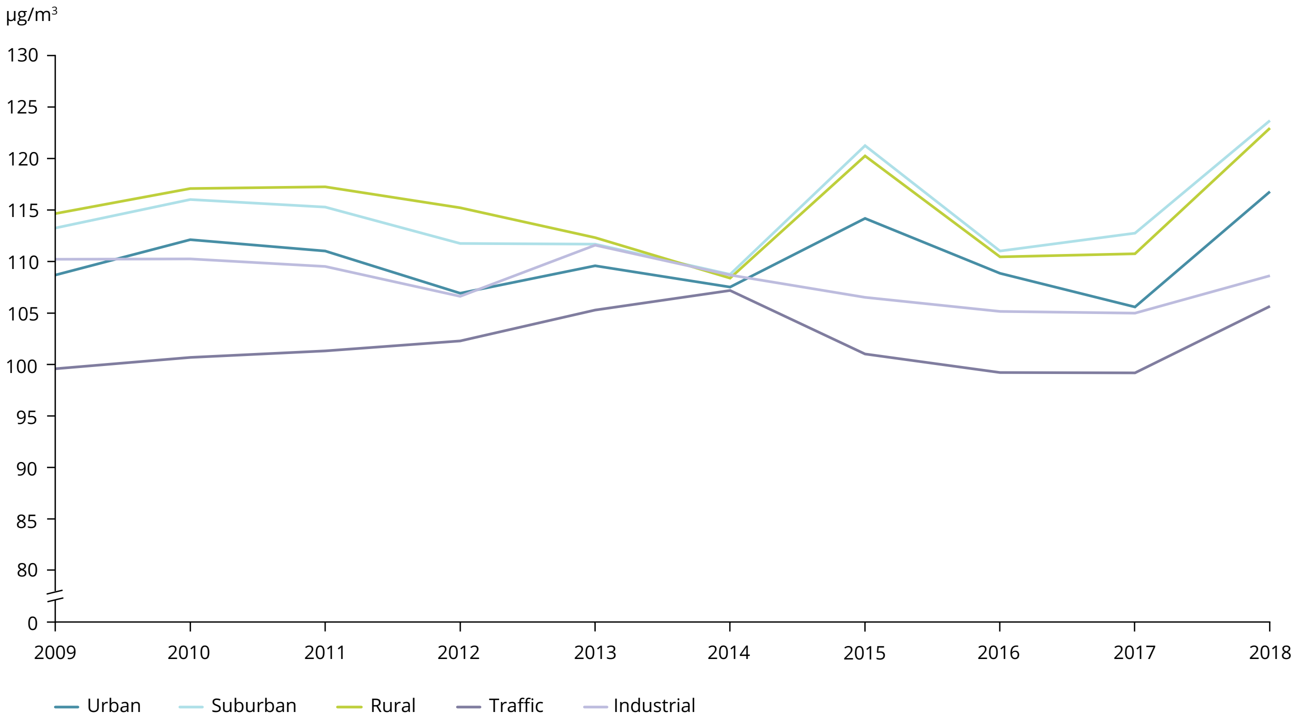
Note: For further information, please see Annex 2.

Figure 5.3 Trend slope distribution (2009-2018) for SOMO35 O_3 concentration, per station type, for both significant and non-significant trends



Note: The calculated trend slope represents the average change in SOMO35 per year at each station in the period 2009-2018. The graphs should be read in relation to Map 5.2 and Table A2.4.

Figure 5.4 Average 93.2 percentile of the O_3 maximum daily 8-hour mean concentrations per station type



Note: The 93.2 percentile of the O_3 maximum daily 8-hour mean represents the 26th highest value in a complete series and is related to the O_3 target value.

The GAM analysis shows that meteorological conditions in 2018 led to an exceptionally strong increase in O_3 SOMO35 concentrations in central and northern Europe, including the British Isles.

A trend assessment study in Europe for the period 2000-2017 confirms that SOMO35 does not show a clear trend, except for traffic stations, where concentrations have increased on average (71.4 %) (ETC/ATNI, 2020c). The trend in SOMO35 at urban and suburban sites is not significant and the relative changes were +1.3 % and -6.2%, respectively, while the decrease is significant at rural sites, with a relative change of -23 % (ETC/ATNI, 2020c).

Figure 5.4 presents the average value for the 93.2 percentile (p93.2) of the maximum daily 8-hour mean O_3 concentrations per year (the 26th highest value in a complete series, related to the target value for the protection of health), from 2009 to 2018, for urban, suburban and rural background, traffic and industrial stations. The time series shows no clear trend and a high variability from year to year. The trend analysis confirms that 95 % of the stations have non-significant trends, while the 5 % of the stations with significant trends were equally distributed between increasing and decreasing trends (Figure 5.5). Map 5.3 shows that, as for SOMO35, central European stations had some significant increasing trends, while southern Europe registered both increasing and decreasing trends. The calculated trend slopes, averaged per country and per station type, are found in Table A2.5 in Annex 2. North Macedonia is the country that shows the highest decrease in the p93.2 O_3 (-4.82 μg/m^3 per year, two stations), followed by Serbia (-1.46 μg/m^3 per year, one station), Bulgaria (-1.17 μg/m^3 per year, 17 stations) and Portugal (-1.03 μg/m^3 per year, 30 stations). Croatia (1.21 μg/m^3 for two stations) and Belgium (0.83 μg/m^3 per year, 38 stations) showed the highest increase, followed by Romania (0.75 μg/m^3 per year, 26 stations) and Czechia (0.71 μg/m^3 per year, 51 stations).

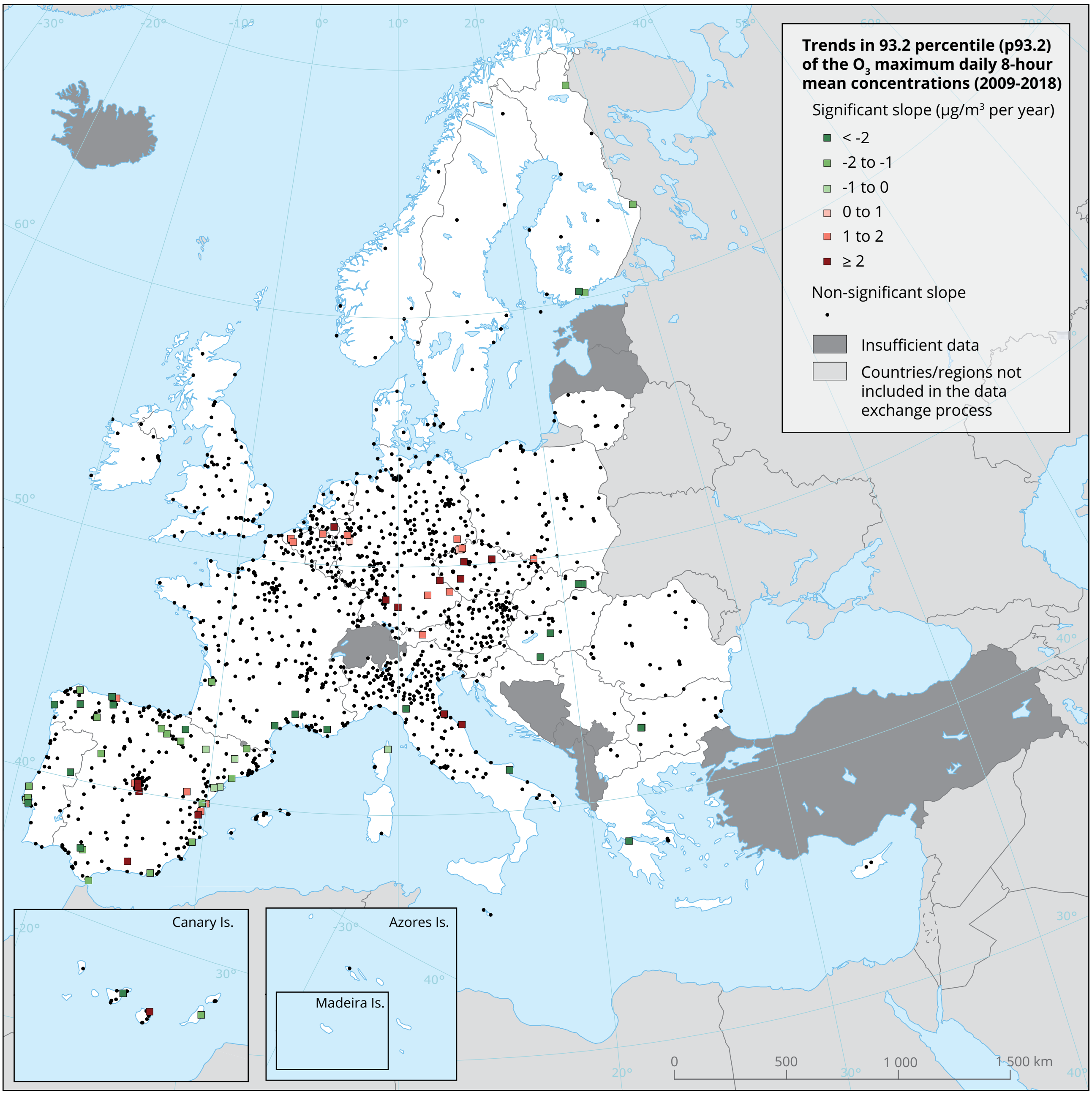
The analysis of trends in O_3 peaks from 2000 to 2017 looked at the fourth highest maximum daily 8-hour mean (p98.9) O_3 concentrations. This analysis indicates a clearer decreasing trend from 2000 to 2008 for all station types, except traffic, which shows no clear trend, and a flattening for all station types since 2009 (maybe due to the two outstanding years of 2003 and 2006) (ETC/ATNI, 2020c).

5.5 Preliminary status of concentrations in 2019

Up-to-date (UTD) data for O_3 in 2019 were reported from 1 665 stations in 32 countries (all the 2019 33 UTD reporting countries, except Iceland).

Eighteen Member States and two other reporting countries registered concentrations above the O_3 target value more than 25 times in 2019 (Map 5.4). In total, 27 % (450) of all stations reporting UTD O_3, with the minimum data coverage of 75 %, showed concentrations above the target value for the protection of human health in 2019. In addition, only 9 % (145) of all stations fulfilled the long-term objective. Of the stations with values above the long-term objective, 85 % were background stations. In total, 2 % (37) of all stations and only 1 of the 446 rural background stations reported in 2019 as UTD had values below the WHO AQG value for O_3 set for the protection of human health.

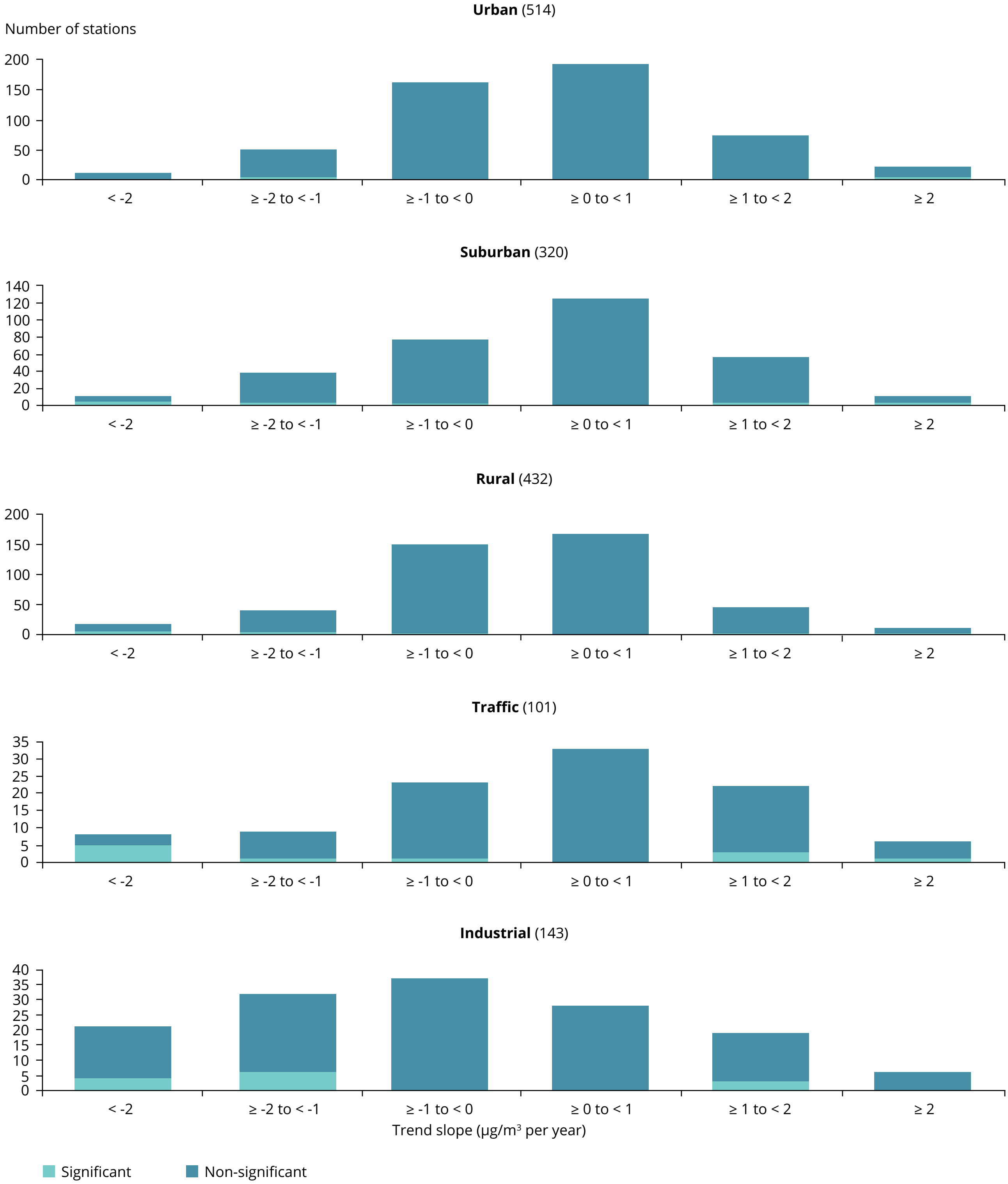
Map 5.3 **Trends for the 93.2 percentile of the O_3 maximum daily 8-hour mean concentrations (2009-2018)**



Reference data: ©ESRI

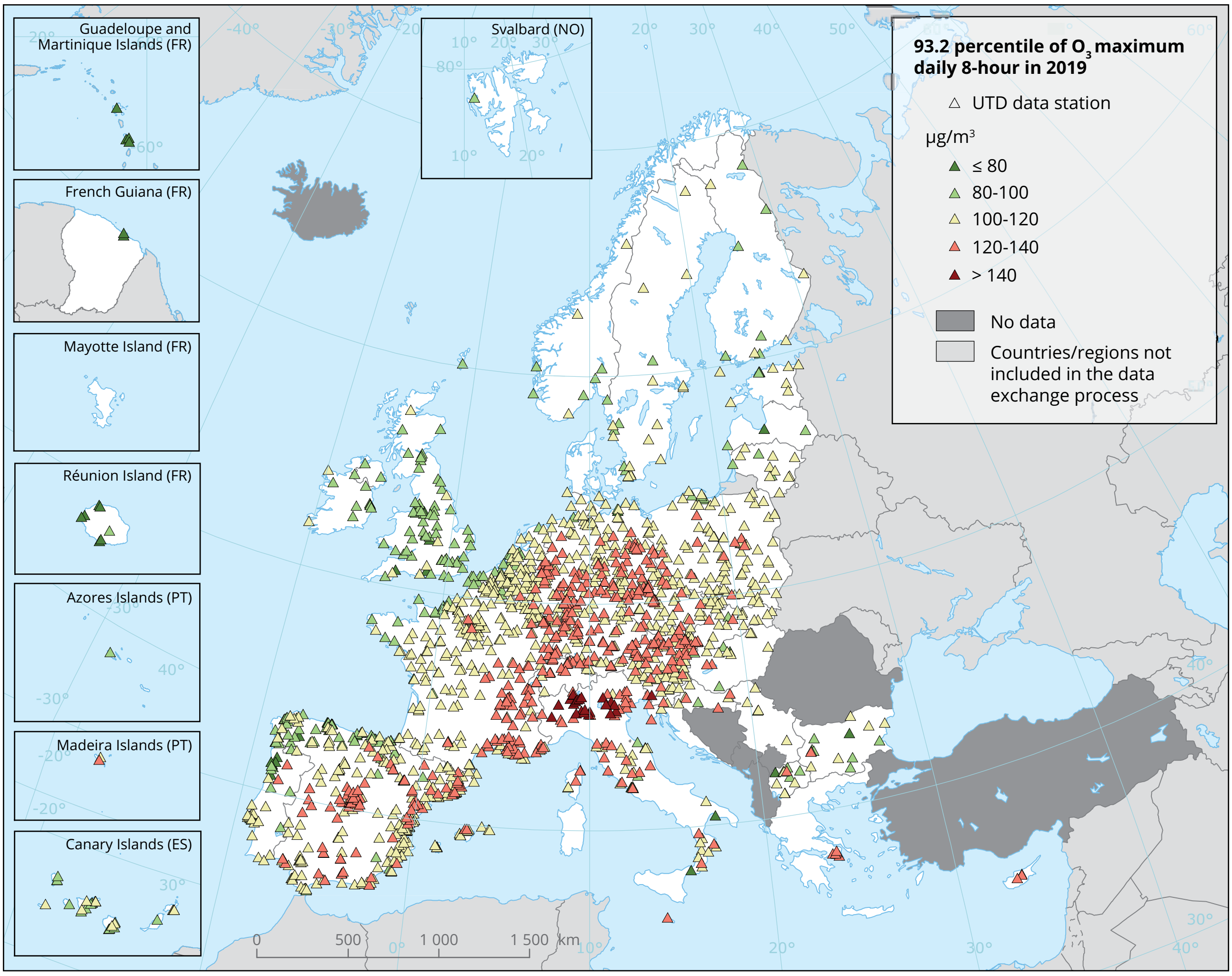
Note: The 93.2 percentile of the O_3 maximum daily 8-hour mean represents the 26th highest value in a complete series and is related to the O_3 target value. For further information, please see Annex 2.

Figure 5.5 **Trend slope distribution (2009-2018) for the 93.2 percentile of the O_3 maximum daily 8-hour mean concentration, per station type, for both significant and non-significant trends**



Note: The 93.2 percentile of the O_3 maximum daily 8-hour mean represents the 26th highest value in a complete series and is related to the O_3 target value. The calculated trend slope represents the average change in concentration per year at each station in the period 2009-2018. The graphs should be read in relation to Map 5.3 and Table A2.5.

Map 5.4 Concentrations of O_3 in 2019



Reference data: ©ESRI | ©EuroGeographics

Note: Observed concentrations of O_3 in 2019. The data presented were reported as UTD data and therefore should be considered as not validated. They are used for the purpose of providing a preliminary assessment of the situation in 2019 in relation to the O_3 target value. The map shows the 93.2 percentile of the O_3 maximum daily 8-hour mean, representing the 26th highest value in a complete series. It is related to the O_3 target value. At sites marked with dots in the last two colour categories, the 26th highest daily O_3 concentrations were above the 120 µg/m³ threshold, implying an exceedance of the target value threshold. Please note that the legal definition of the target value considers not only 1 year but the average over 3 years. Only stations with more than 75 % of valid UTD data are included in the map.

Source: EEA (2020c).

6 Nitrogen dioxide

6.1 European air quality standards and World Health Organization guideline values for nitrogen dioxide

The European air quality standards, set by the Ambient Air Quality Directive (EU, 2008) for the protection of human health and the air quality guidelines (AQGs) set by the World Health Organization (WHO) for nitrogen dioxide (NO_2) are shown in Tables 1.1 and 1.3, respectively. For convenience, they are summarised in Table 6.1.

The Ambient Air Quality Directive (EU, 2008) also sets a critical level for nitrogen oxides (NO_X) for the protection of vegetation, shown in Table 1.2. The vegetation exposure to NO_X concentrations above this standard is assessed in Section 11.4.

6.2 Status of concentrations in 2018

All the 2018 37 reporting countries submitted NO_2 data in 2018 with a minimum coverage of 75 % of valid data from 3 411 stations (32 % of which are traffic stations) for the annual limit value and 3 160 stations (28 % of which are traffic stations) for the hourly limit value.

Sixteen of the EU Member States and three other reporting countries (Figure 6.1) recorded concentrations above the annual limit value (and the identical WHO AQG value). Concentrations were above the annual limit value at 8 % (285) of all stations measuring NO_2. Map 6.1 shows that stations with concentrations above the annual limit value continued to be widely distributed across Europe in 2018, as in previous years.

The highest concentrations, as well as 95 % of all values above the annual limit value, were observed at traffic stations, including two rural traffic stations, the only rural stations with concentrations above the annual limit value. Traffic is a major source of NO_2 and nitrogen monoxide (NO) (which reacts with ozone (O_3) to form NO_2). Therefore, measures to reduce NO_2 concentrations and exceedances are often focused on traffic and urban locations, as mentioned in Section 1.6.

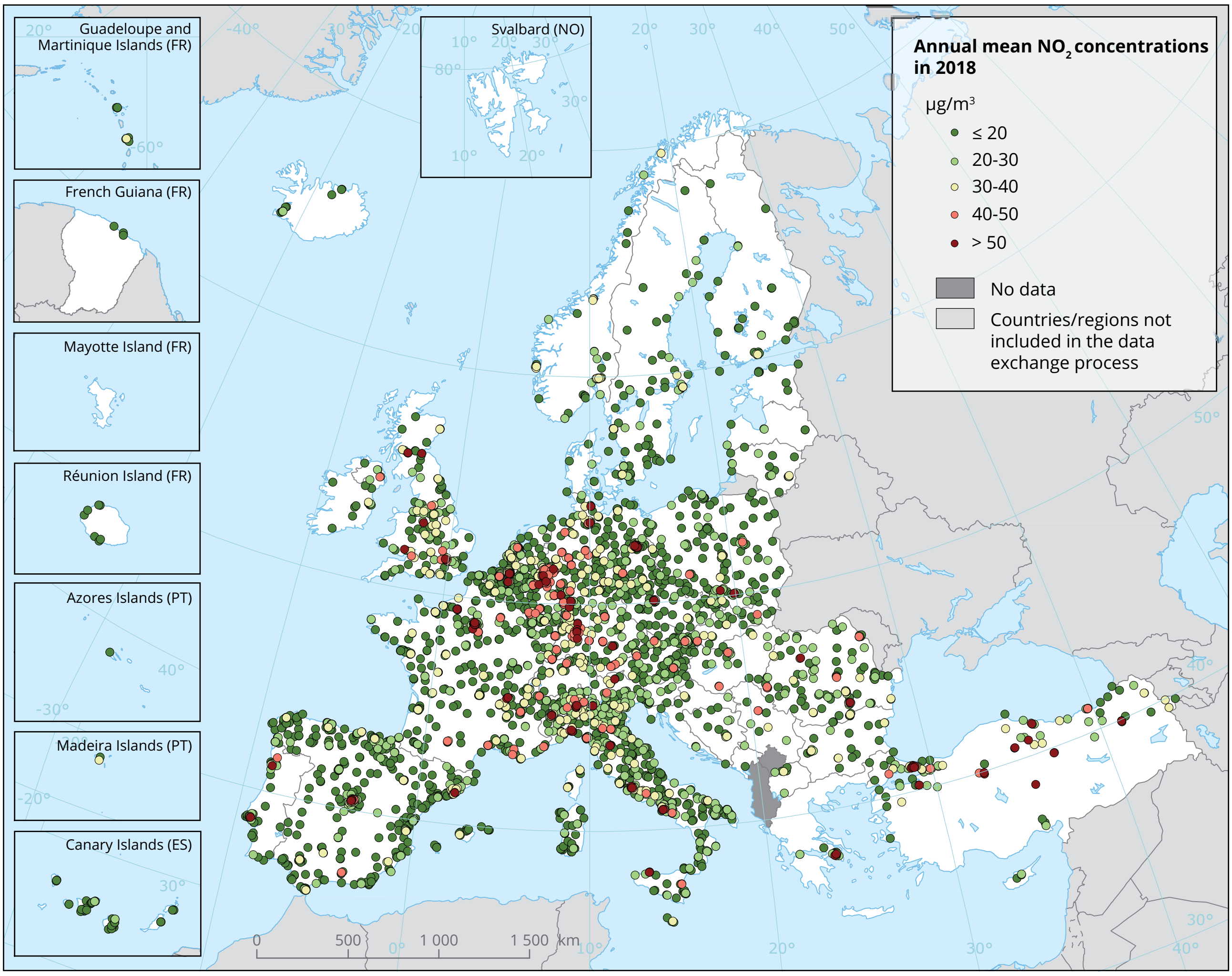
Annex 1 offers additional information on NO_2 annual concentrations, showing the frequency distributions (Figure A1.9), and the values by station and area type (Figure A1.10).

Apart from the measured concentrations, Belgium and the United Kingdom also reported exceedances of the annual limit value assessed using models. Belgium reported a modelled exceedance of 50 μg/m^3 in the air quality zone of 'Cities with more than 50 000 inhabitants' and of 57 μg/m^3 in the air quality zone of 'Flanders'. The United Kingdom reported modelled exceedances in 27 air quality zones. Here, the lowest modelled exceedance reported is 42 μg/m^3 in the

Table 6.1 Air quality standards for protecting human health from NO_2

Pollutant	Averaging period	Standard type and concentration	Comments
NO_2	1 hour	EU limit value: 200 μg/m^3	Not to be exceeded on more than 18 hours per year
		WHO AQG: 200 μg/m^3	
		EU alert threshold: 400 μg/m^3	To be measured over 3 consecutive hours over 100 km^2 or an entire zone
	Calendar year	EU limit value and WHO AQG: 40 μg/m^3	

Map 6.1 Concentrations of NO_2, 2018

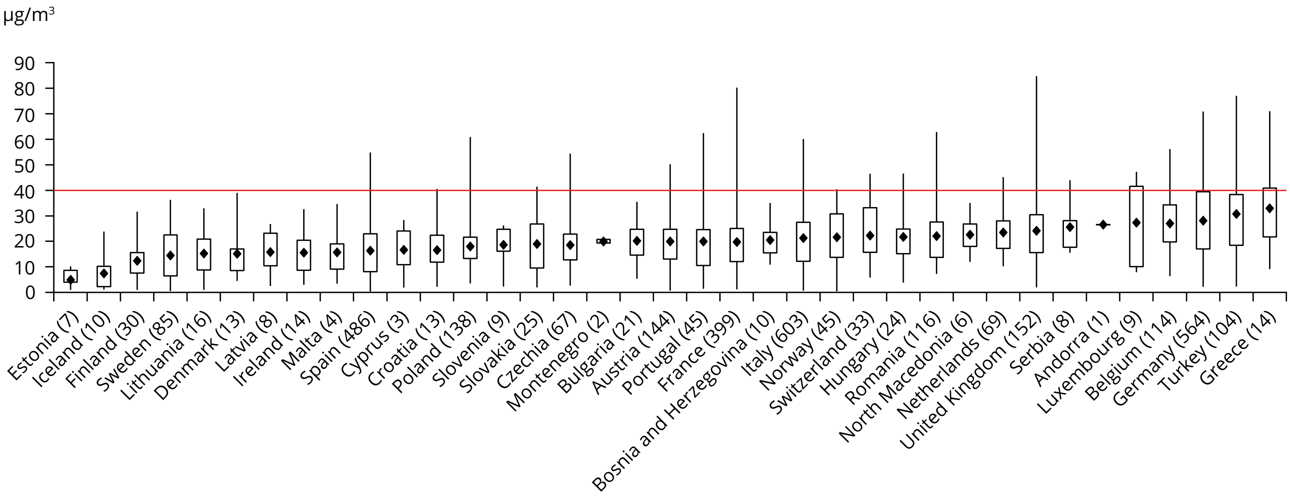


Reference data: ©ESRI | ©EuroGeographics

Note: Observed concentrations of NO_2 in 2018. Dots in the last two colour categories correspond to values above the EU annual limit value and the identical WHO AQG (40 µg/m³). Only stations with more than 75 % of valid data are included in the map. Belgium and the United Kingdom also reported exceedances of the annual limit value in 2018 assessed using models (please see main text).

Source: EEA (2020c).

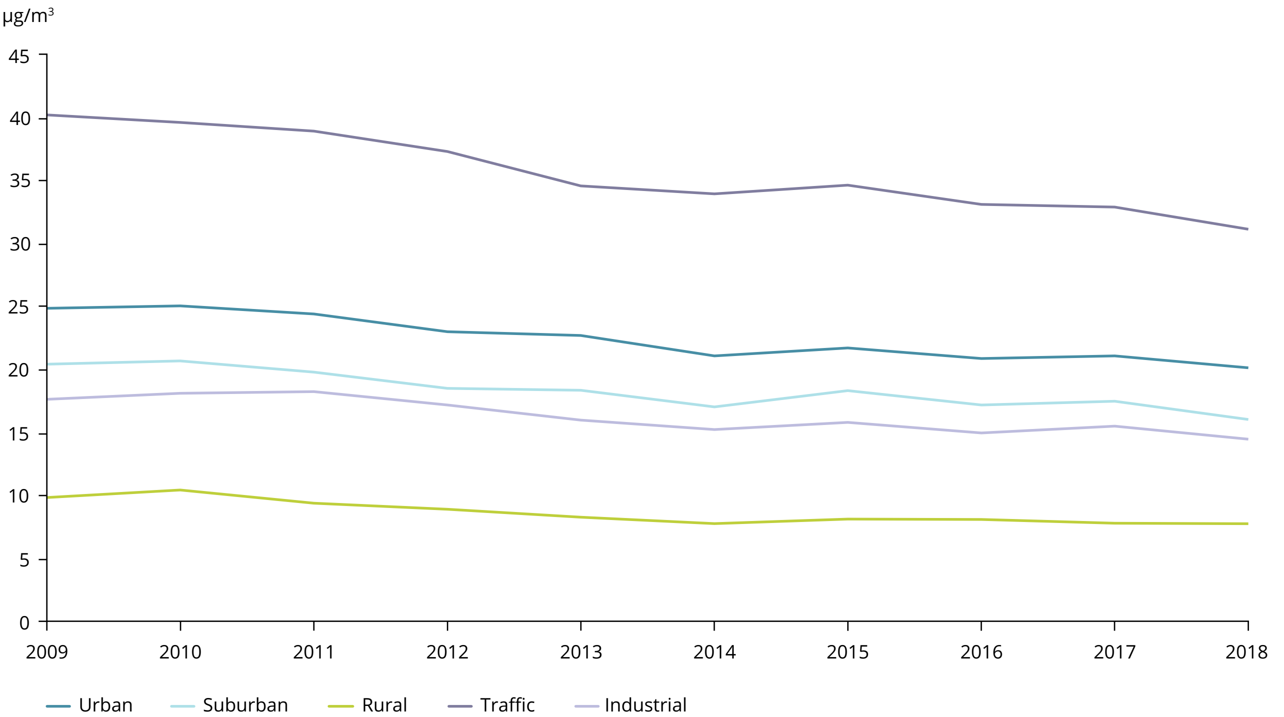
Figure 6.1 **NO_2 concentrations in relation to the annual limit value in 2018 and number of stations considered for each country**



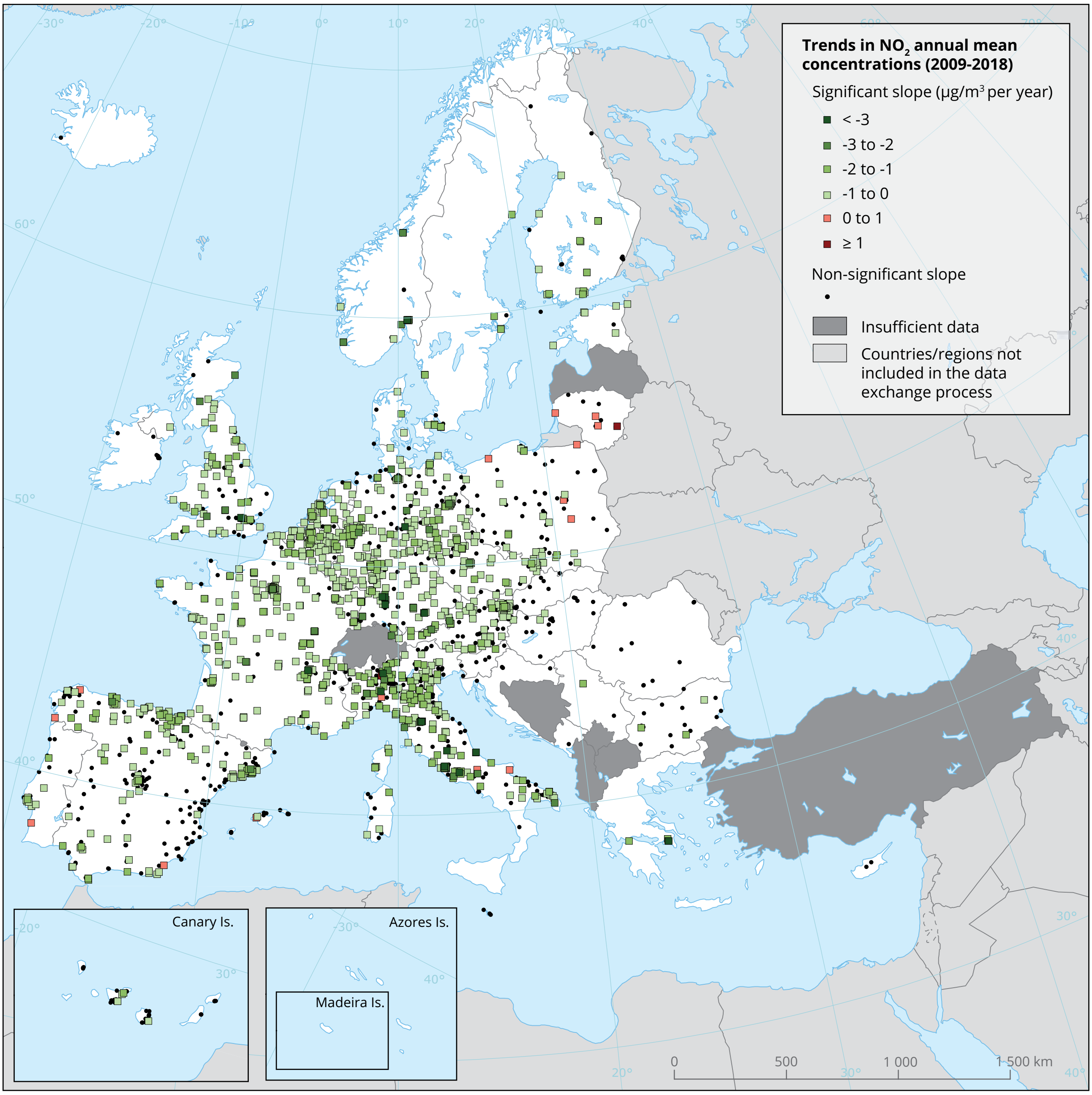
Note: The graph is based on the annual mean concentration values. For each country, the number of stations considered (in brackets) and the lowest, highest and average values (in µg/m³) recorded at its stations are given. The rectangles mark the 25th and 75th percentiles. At 25 % of the stations, levels are below the lower percentile; at 25 % of the stations, concentrations are above the upper percentile. The limit value set by EU legislation (which is equal to that set by the WHO AQG) is marked by the horizontal line. The graph should be read in relation to Map 6.1, as a country's situation depends on the number of stations considered. Belgium and the United Kingdom also reported exceedances of the annual limit value in 2018 assessed using models (please see main text).

Source: EEA (2020c).

Figure 6.2 **Average NO_2 annual mean concentrations by station type**



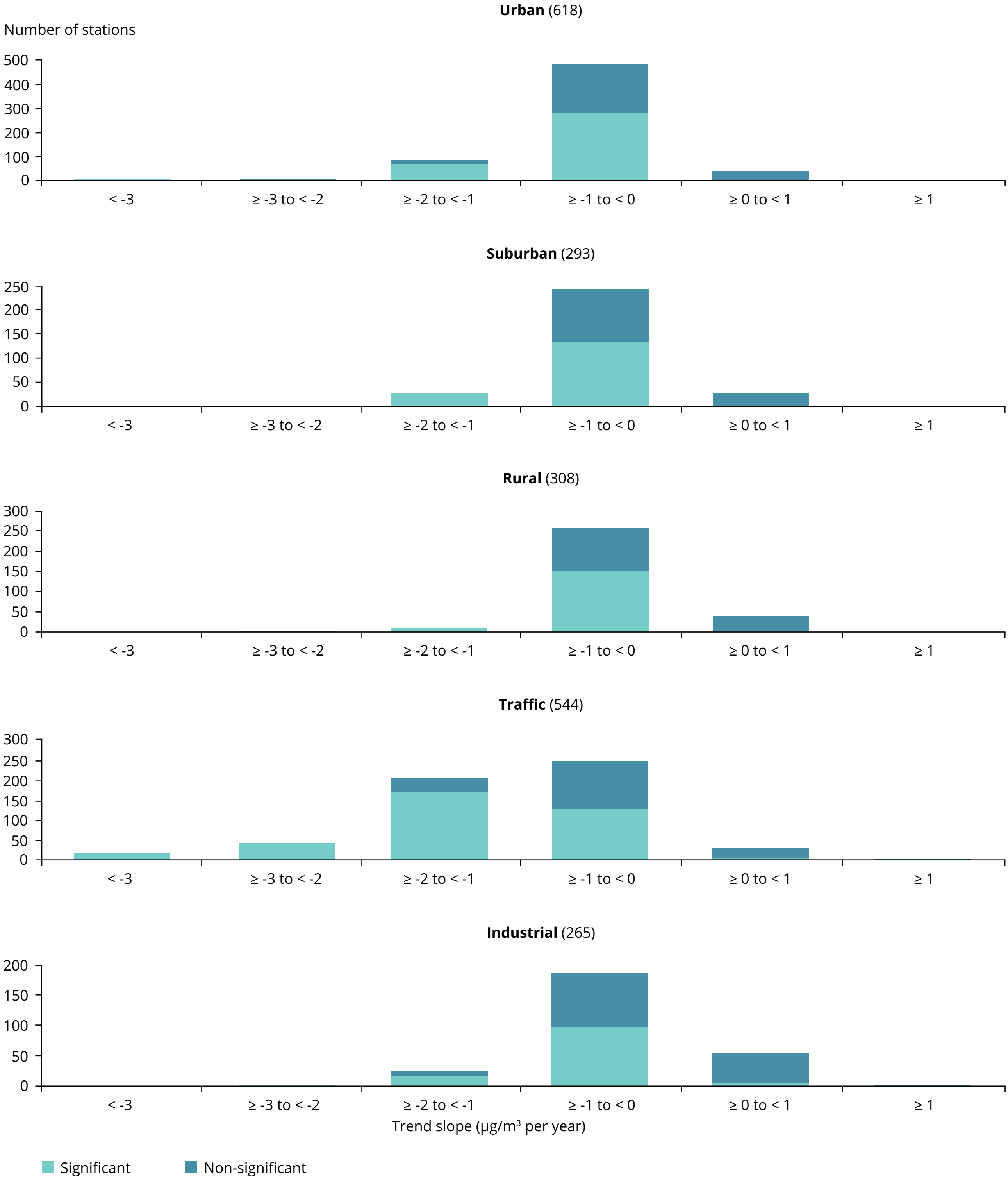
Map 6.2 **Trends in NO_2 annual mean concentrations (2009-2018)**



Reference data: ©ESRI

Note: For further information, please see Annex 2.

Figure 6.3 **Trend slope distribution (2009-2018) for NO_2 annual mean, per station type, for both significant and non-significant trends**



Note: The calculated trend slope represents the average change in concentration per year at each station in the period 2009-2018. The graphs should be read in relation to Map 6.2 and Table A2.6.

Swansea Urban Area, and the highest modelled exceedance is 58 μg/m^3 in the West Midlands Urban Area ([31]).

Concentrations above the hourly limit value were observed in 2018 in fewer than 1 % (15 stations) of all the reporting stations. They were observed in five countries ([32]), mostly at urban stations, except for two rural background stations (one in the Netherlands and one in Turkey).

6.3 Trends in concentrations

The average NO_2 annual mean concentrations from 2009 to 2018 are presented in Figure 6.2 for urban, suburban and rural background, traffic and industrial stations. NO_2 concentrations steadily decreased between 2009 and 2018. On average over the last decade (2009-2018), annual mean concentrations of NO_2 have fallen by 18 % at industrial stations, by 19 % in urban background stations, by 22 % in suburban and rural background stations and by 23 % in traffic stations. This decrease is lower than the decrease of 26 % in total NO_X emissions in the EEA-33 from 2009 to 2018 and lower than that of 34 % for road transport NO_X emissions (Figures 3.1 and 3.2 show the emission changes for the EU-28).

The trend analysis for the same period shows an overall decreasing trend. Map 6.2 shows the spatial distribution of the trends calculated for each station. More than half of the stations have a significant trend (58%). Most of the stations with a significant trend show a decreasing trend. Of the stations with non-significant trends, 21 % show an average increase in the NO_2 annual mean. The trend slopes, per station type, for significant and non-significant trends, are shown in Figure 6.3.

The trend analysis for the period 2009-2018 shows that the highest average decrease in NO_2 concentrations was observed in traffic stations, followed by (sub)urban background stations and industry, while the lowest decrease was in rural background stations. Table A2.6 (Annex 2) shows the results of the trend analysis per country and station type. While in Lithuania and Iceland there was an average increase in NO_2 concentrations (0.22 μg/m^3 per year, 10 stations, and 0.26 μg/m^3 per year, one station, respectively), and no change in Croatia (four stations), the other countries registered an average decrease. The highest average decrease was in Greece (-1.66 μg/m^3 per year, four stations), followed by Norway (-1.60 μg/m^3 per year, 18 stations), Serbia (-1.34 μg/m^3 per year, two stations), Sweden (-0.88 μg/m^3 per year, 18 stations) and Italy (-0.74 μg/m^3 per year, 337 stations).

A trend assessment study in Europe for the period between 2000 and 2017 shows that the average NO_2 annual mean concentration has decreased by 25 % at (sub)urban stations, by 28 % at traffic stations and by 34 % at industrial and rural stations ([33]) (ETC/ATNI, 2020c).

Figure 6.4 presents the average value for the 99.8 percentile (p99.8) of the hourly NO_2 concentrations in a year (19th highest hourly in a complete series, related to the hourly limit value) for urban, suburban and rural background, traffic and industrial stations. This percentile is highly impacted by meteorological variability. Map 6.3 shows the spatial distribution of stations, colour-coded according to their trend slope. Only 17 % of the stations show a significant trend, with most of these stations (96 %) showing a decreasing trend. Very few stations show a significant positive trend in the p99.8 (see Map 6.3). The trend slopes, per station type, for significant and non-significant trends, are shown in Figure 6.5. Table A2.7 (Annex 2) shows the results of the trend analysis per country and station type. While in Romania and Iceland there was an average increase in the p99.8 NO_2 concentrations (0.47 μg/m^3 per year, 10 stations, and 7.03 μg/m^3 per year, one station, respectively), the other countries registered an average decrease. The highest average decrease was in Slovakia (-6.34 μg/m^3 per year, nine stations), followed by Greece (-3.55 μg/m^3 per year, two stations) and Italy (-3.25 μg/m^3 per year, 335 stations).

([31]) The rest of reported modelled exceedances correspond to Leicester Urban Area (43 μg/m^3), South West (44 μg/m^3), North East Scotland (44 μg/m^3), Kingston upon Hull (45 μg/m^3), Nottingham Urban Area (46 μg/m^3), Bournemouth Urban Area (46 μg/m^3), Reading/Wokingham Urban Area (46 μg/m^3), Cardiff Urban Area (46 μg/m^3), Liverpool Urban Area (48 μg/m^3), Southend Urban Area (48 μg/m^3), East Midlands (48 μg/m^3), North Wales (49 μg/m^3), Greater Manchester Urban Area (50 μg/m^3), Portsmouth Urban Area (50 μg/m^3), Coventry/Bedworth (50 μg/m^3), North West Merseyside (50 μg/m^3), South East (51 μg/m^3), Central Scotland (51 μg/m^3), Sheffield Urban Area (53 μg/m^3), Yorkshire Humberside (53 μg/m^3), Tyneside (54 μg/m^3), West Midlands (54 μg/m^3), North East (54 μg/m^3), Teesside Urban Area (55 μg/m^3) and Southampton Urban Area (55 μg/m^3).

([32]) Turkey (nine stations), Spain and the United Kingdom (two stations each), and Portugal and the Netherlands (one station each).

([33]) The countries included in the analysis were Austria, Belgium, Bulgaria, Czechia, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Lithuania, Luxembourg, the Netherlands, Poland, Portugal, Slovakia, Slovenia, Spain, Sweden and United Kingdom.

6.4 Preliminary status of concentrations in 2019

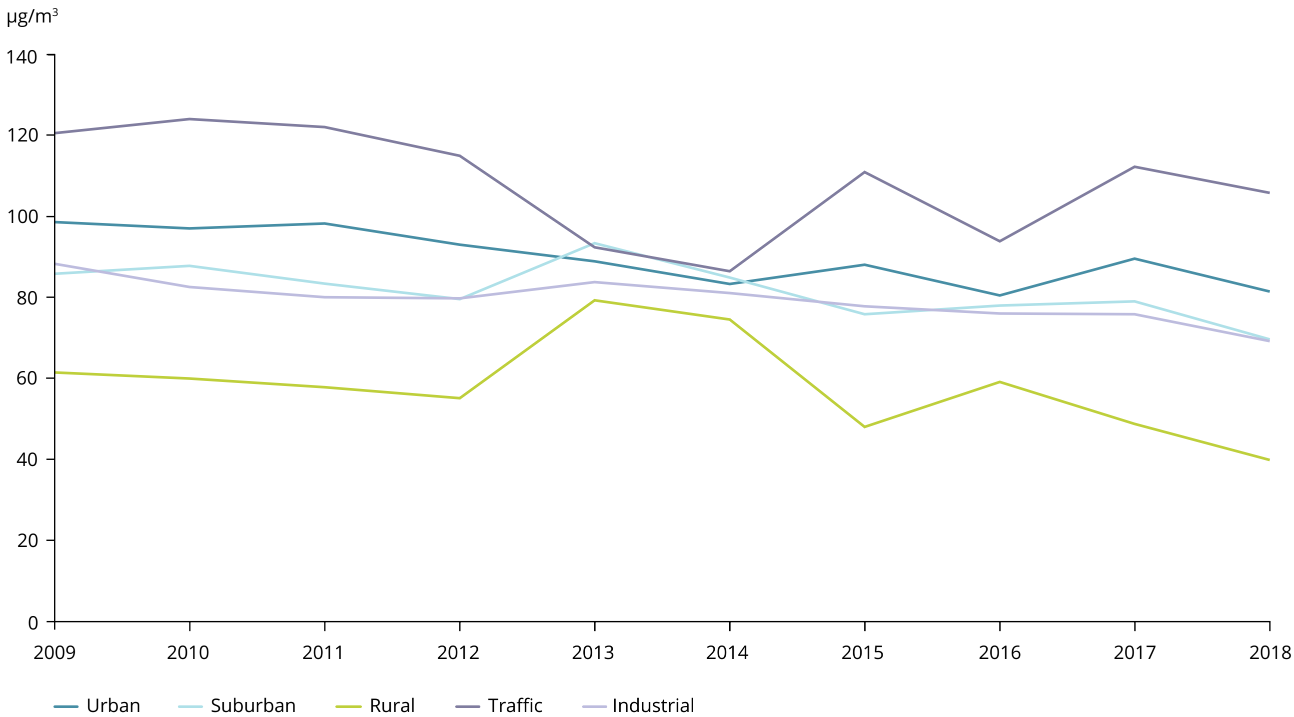
All the 2019 33 up-to-date (UTD) reporting countries submitted UTD NO_2 data in 2019 with a minimum coverage of 75 % of valid data from 2 427 stations (for the annual limit value) and 2 428 (for the hourly limit value).

Twelve of the EU Member States and one other reporting country (Map 6.4) recorded concentrations above the annual limit value (and the equal WHO AQG). This happened in 3 % (84) of all the stations measuring UTD NO_2. Of all values above the annual limit value, 98 % were observed at traffic stations. Furthermore, 98 % of the stations with values above the annual limit value were located in urban or suburban areas. Concentrations above the hourly limit value were preliminary observed in 2019 in 10 stations located in six countries: Italy (five stations), Croatia, France, Portugal, Sweden and the United Kingdom (one station each).

6.5 Contribution of emissions of nitrogen oxides and meteorology to ambient nitrogen dioxide concentrations

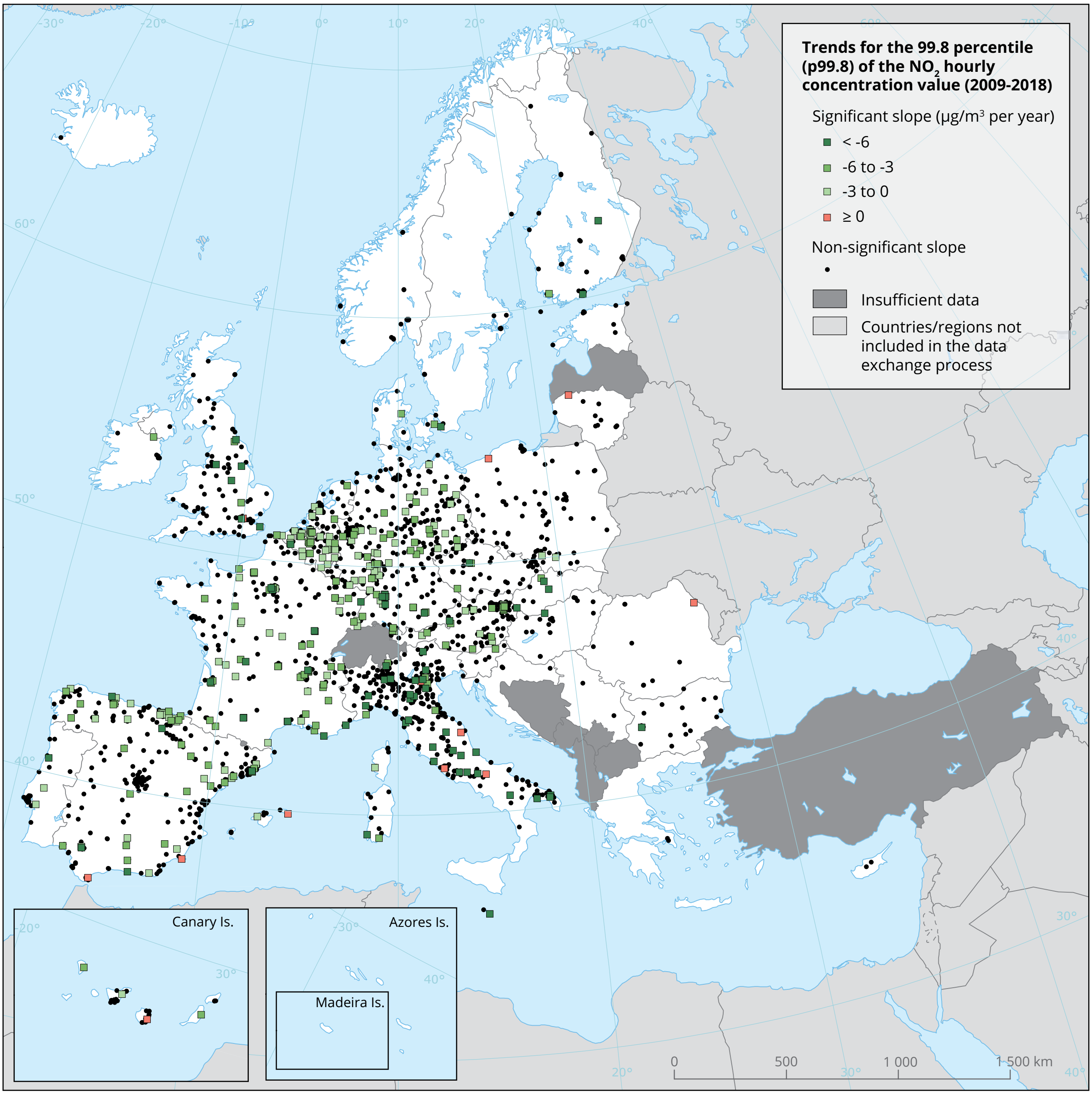
Contributions from different emission sources and sectors to ambient air concentrations depend not only on the amount of pollutant emitted but also on the emission conditions (e.g. height of emission points), meteorological conditions and distance to the receptor site. The transport sector continued to contribute the highest proportion of NO_X emissions (47 % in the EU-28; see Figure 3.4) in 2018, followed by the sectors energy supply, agriculture and manufacturing and extractive industry (see Section 3.2). However, the contribution of road transport (representing more than 80 % of the transport emissions) to population exposure to ambient NO_2 concentrations is considerably higher, especially in urban areas. This is because road transport emissions are close to the ground and are distributed across densely populated areas.

Figure 6.4 Average 99.8 percentile of the NO_2 hourly concentration values



Note: The 99.8 percentile of the NO_2 hourly concentrations represents the 19th highest value in a complete series and is related to the NO_2 hourly limit value.

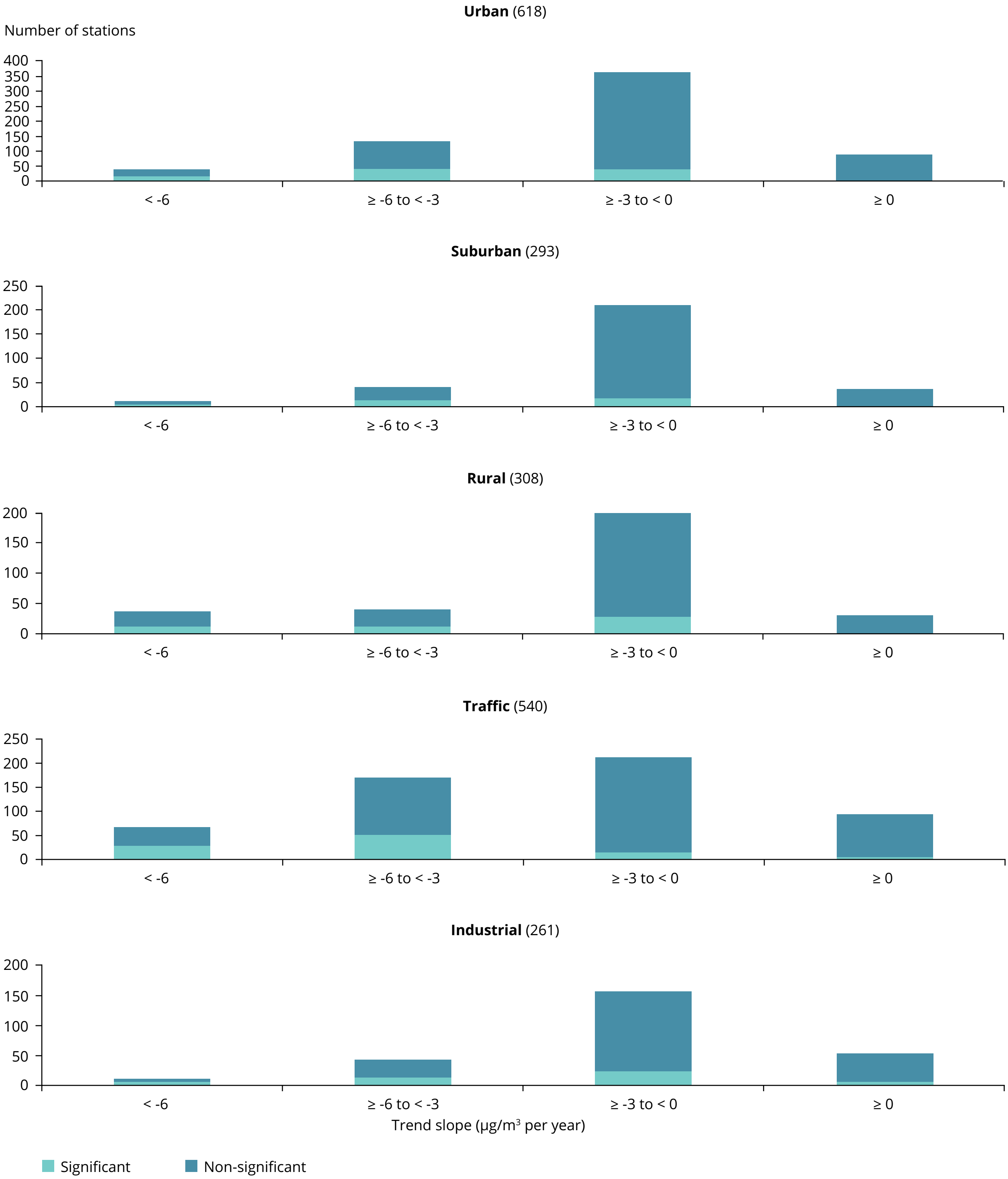
Map 6.3 **Trends in the 99.8 percentile of the NO_2 hourly concentration value (2009-2018)**



Reference data: ©ESRI

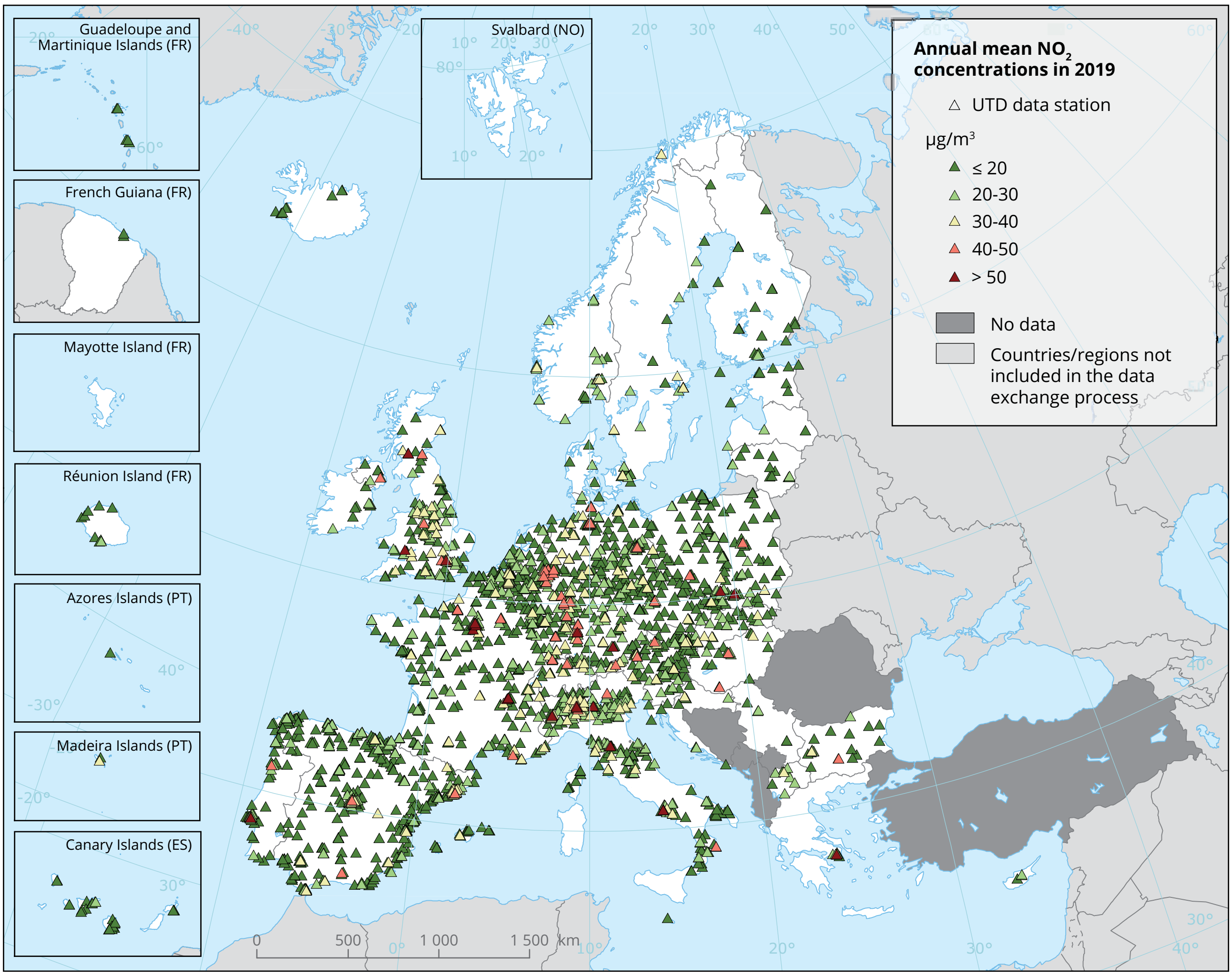
Note: The 99.8 percentile of the NO_2 hourly concentrations represents the 19th highest value in a complete series and is related to the NO_2 hourly limit value. For further information, please see Annex 2.

Figure 6.5 Trend slope distribution (2009-2018) for the 99.8 percentile of the NO_2 hourly concentration values, per station type, for both significant and non-significant trends



Notes: The 99.8 percentile of the NO_2 hourly concentrations represents the 19th highest value in a complete series and is related to the NO_2 hourly limit value. The calculated trend slope represents the average change in concentration per year at each station in the period 2009-2018. The graphs should be read in relation to Map 6.3 and Table A2.7.

Map 6.4 **Concentrations of NO_2, 2019**



Reference data: ©ESRI | ©EuroGeographics

Note: Observed concentrations of NO_2 in 2019. The data presented were reported as UTD data and therefore should be considered as not validated. They are used for the purpose of providing a preliminary assessment of the situation in 2019 in relation to the NO_2 annual limit value. Dots in the last two colour categories correspond to values above the EU annual limit value and the identical WHO AQG (40 µg/m³). Only stations with more than 75 % of valid UTD data are included in the map. A few French stations could not be processed due to errors in their metadata; therefore, they are not shown on the map.

7 Benzo[*a*]pyrene

7.1 European air quality standard and reference level for benzo[*a*]pyrene

The target value for benzo[*a*]pyrene (BaP) for the protection of human health and the estimated reference level (RL) ([34]) are presented in Tables 1.1 and 1.3. For convenience, they are summarised in Table 7.1.

7.2 Status of concentrations in 2018

Twenty-five Member States (all Member States except Greece, Malta and Portugal) and two other reporting countries (Norway and Switzerland) reported BaP data ([35]), with sufficient data coverage ([36]) for 2018, from a total of 722 ([37]) stations (67 % of which are urban and 18 % suburban).

Fourteen Member States ([38]) measured concentrations above 1.0 ng/m^3 in 2018 (Figure 7.1). As in previous years, values above 1.0 ng/m^3 are predominant in central and eastern Europe. The highest concentrations were recorded at many stations in Poland, where 136 out of 139 reporting stations had values above 1.0 ng/m^3.

Concentrations above 1.0 ng/m^3 were measured at 27 % (195) of the reported BaP measurement stations in 2018 (Map 7.1), mainly at urban (78 % of all stations with values above 1.0 ng/m^3) and suburban (16%) stations.

Regarding the RL, all reporting countries, except Cyprus, have at least one station with concentrations above 0.12 ng/m^3. This happened at 83 % of the reported stations in 2018.

Annex 1 offers additional information on BaP annual concentrations, showing the frequency distributions (Figure A1.11), and the values by station and area types (Figure A1.12).

Ambient air concentrations of BaP are high, mostly because of emissions from the domestic combustion of coal and wood (EEA, 2016), although for some specific countries (mostly in southern Europe) the contribution from burning agricultural waste is also relevant (EEA, 2017).

Table 7.1 Air quality standards for protecting human health from BaP

Pollutant	Averaging period	Standard type and concentration	Comments
BaP	Calendar year	EU target value: 1 ng/m^3	Measured as content in PM_{10}
		RL: 0.12 ng/m^3	

Note: PM_{10}, particulate matter with a diameter of 10 μm or less.

([34]) The estimated RL (0.12 ng/m^3) was estimated assuming WHO unit risk (WHO, 2010) for lung cancer for polycyclic aromatic hydrocarbon (PAH) mixtures and an acceptable risk of additional lifetime cancer risk of approximately 1 in 100 000 (ETC/ACM, 2011).

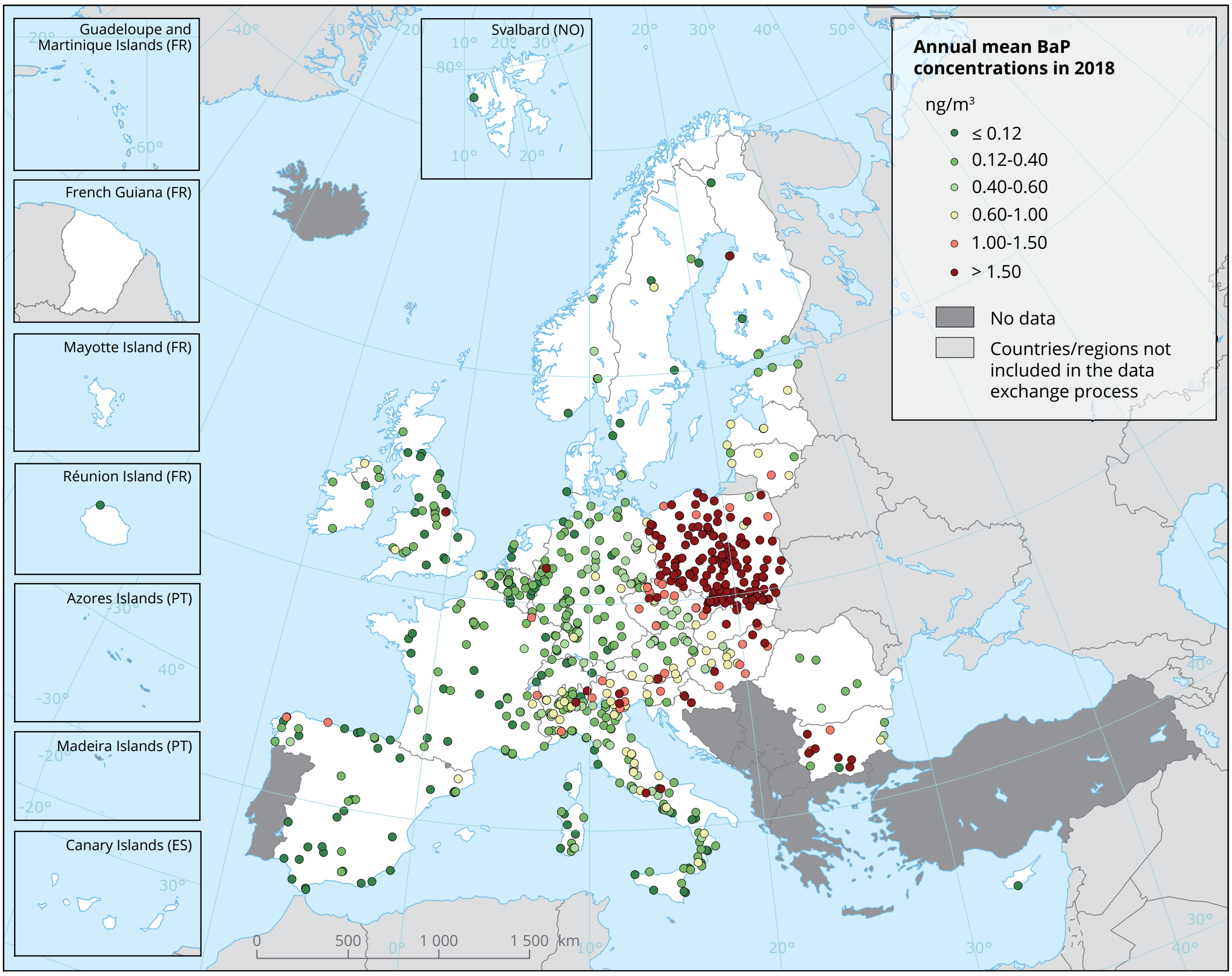
([35]) BaP is a PAH found mainly in fine particulate matter (PM). The Ambient Air Quality Directive (EU, 2004) prescribes that BaP concentration measurements should be made in the PM_{10} (particulate matter with a diameter of 10 μm or less) fraction. Going beyond this requirement, data available for any PM fraction were used in the current analysis. The justification is that most of the BaP is present in $PM_{2.5}$, not in the coarser fraction of PM_{10}, and the gaseous fraction of the total BaP is quite small. On the one hand, this may introduce some systematic differences in the measured data, but, on the other hand, the inclusion of additional measured data allows a broader analysis of BaP levels across Europe. For more information, see the discussion by ETC/ACM (2015).

([36]) A data coverage of 14 %, as required by the Ambient Air Quality Directive (EU, 2004) for indicative measurements, was used as a minimum requirement for the analysis of BaP data.

([37]) Italy reported data from one additional station, but it has not been considered because it was reported with the wrong units.

([38]) Austria, Bulgaria, Croatia, Czechia, Finland, France, Germany, Hungary, Italy, Lithuania, Poland, Slovakia, Spain and the United Kingdom.

Map 7.1 Concentrations of BaP, 2018



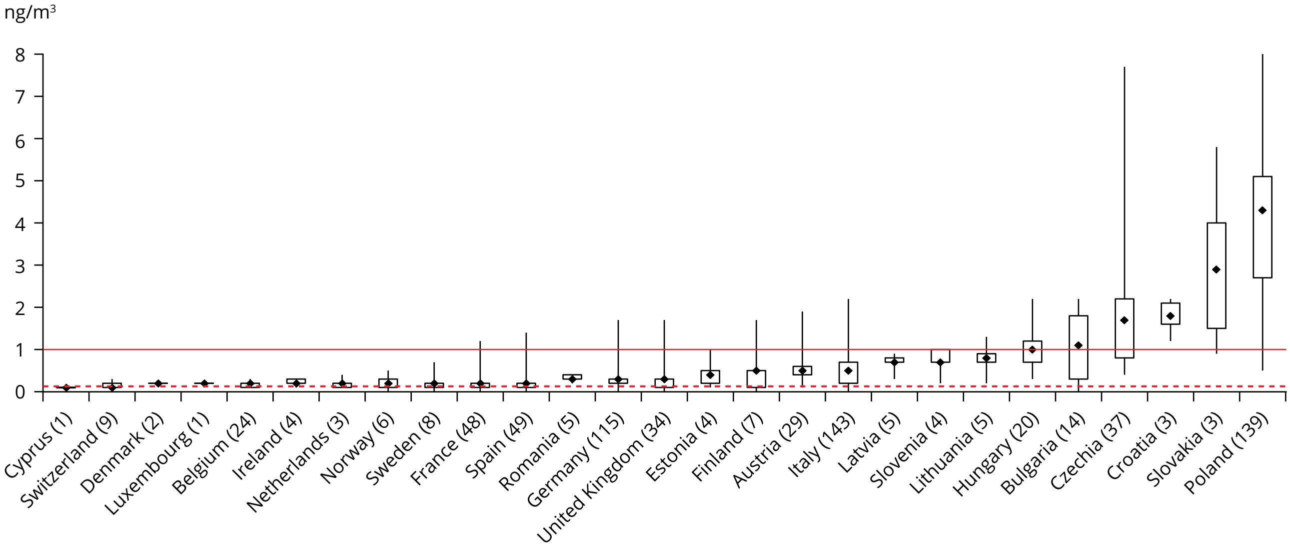
Reference data: ©ESRI | ©EuroGeographics

Note: Observed concentrations of BaP in 2018. Dots in the first colour category correspond to concentrations under the estimated RL (0.12 ng/m³, Table 1.3). Dots in the last colour category correspond to concentrations exceeding the 2004 Ambient Air Quality Directive target value of 1 ng/m³.

Only stations reporting more than 14 % of valid data, as daily, weekly or monthly measurements, are included in the map.

Source: EEA (2020c).

Figure 7.1 BaP concentrations in 2018 and number of stations considered for each country



Note: The graph is based on the annual mean concentration values. For each country, the number of stations considered (in brackets), and the lowest, highest and average values (in ng/m³) recorded at its stations are given. The rectangles mark the 25th and 75th percentiles. At 25 % of the stations, levels are below the lower percentile; at 25 % of the stations, concentrations are above the upper percentile. The upper horizontal line marks the concentration of 1.0 ng/m³. The lower horizontal line marks the estimated air quality RL. The graph should be read in relation to Map 7.1, as a country's situation depends on the number of stations considered. The highest value for Poland, 18.3 ng/m³, has not been included in the graph for representation purposes.

Source: EEA (2020c).

7.3 Concentrations of other polycyclic aromatic hydrocarbons

To assess the contribution of BaP in ambient air, the Ambient Air Quality Directive (EU, 2004) outlines an obligation for Member States to monitor other relevant polycyclic aromatic hydrocarbons (PAHs) at a limited number of measurement sites. The compounds to be measured must include, at least, benzo[*a*]anthracene, benzo[*b*]fluoranthene, benzo[*j*]fluoranthene, benzo[*k*]fluoranthene, indeno[1,2,3-*cd*]pyrene and dibenz[*a,h*]anthracene.

In 2018, 19 Member States reported measurements of at least one of the PAHs indicated in the Ambient Air Quality Directive (EU, 2004). The situation is summarised in Table 7.1 and the reported concentrations can be found in the EEA's 'Air quality statistics — Expert viewer' (EEA, 2020g).

7.4 Deposition of polycyclic aromatic hydrocarbons

The Ambient Air Quality Directive (EU, 2004) also includes the obligation of setting up at least one background station for the indicative measurement of the total deposition of BaP and the other PAHs referred to previously. In 2018, 14 Member States reported at least one of the listed PAHs. The situation is summarised in Table 7.2 and the reported concentrations can be found in the EEA's 'Air quality statistics — Expert viewer' (EEA, 2020g).

Table 7.2 Reporting of other PAHs in 2018

	AT	BE	HR	CY	DK	FI	FR	DE	HU	IT	LV	LT	MT	NL	PL	SI	ES	SE	UK
Benzo[*a*]anthracene	×	#	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	#	×
Benzo[*b*]fluoranthene	×		×	×		×	×	×		×	×	×	×		×		×	#	×
Benzo[*j*]fluoranthene	×	#	×				×	×		×			×		×		×	#	×
Benzo[*k*]fluoranthene	×		×	×	×	×	×	×		×	×	×	×		×		×	#	×
Indeno[1,2,3-*cd*]pyrene	×		×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	#	×
Dibenz[*a,h*]anthracene	×		×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	#	×

Notes: AT, Austria; BE, Belgium; HR, Croatia; CY, Cyprus; DK, Denmark; FI, Finland; FR, France; DE, Germany; HU, Hungary; IT, Italy; LV, Latvia; LT, Lithuania; MT, Malta; NL, Netherlands; PL, Poland; SI, Slovenia; ES, Spain; SE, Sweden; UK, United Kingdom.

× indicates that the pollutant was reported as measured in PM_{10} (aerosol).

# indicates that the pollutant was reported as measured in air + aerosol.

Table 7.3 Reporting of total deposition of BaP and other PAHs in 2018

	AT	BE	DK	FI	DE	HU	IE	LV	LT	PL	SI	ES	SE	UK
Benzo[*a*]pyrene	×	×	×	×	×	×	×	×, #	×	×	×	×	×	×
Benzo[*a*]anthracene	×	×	×	×	×	×		#		×	×	×	×	×
Benzo[*b*]fluoranthene	×				×			#		×			×	×
Benzo[*j*]fluoranthene	×				×					×				×
Benzo[*k*]fluoranthene	×				×			#		×		×	×	×
Indeno[1,2,3-*cd*]pyrene	×	×	×	×	×	×		#		×	×	×	×	×
Dibenz[*a,h*]anthracene	×	×	×		×	×		#		×	×	×	×	×

Notes: AT, Austria; BE, Belgium; DK, Denmark; FI, Finland; DE, Germany; HU, Hungary; IE, Ireland; LV, Latvia; LT, Lithuania; PL, Poland; SI, Slovenia; ES, Spain; SE, Sweden; UK, United Kingdom.

× indicates that the pollutant was reported as measured in precipitation and dry deposition.

# indicates that the pollutant was reported as measured in precipitation.

8 Other pollutants: sulphur dioxide, carbon monoxide, benzene and toxic metals

8.1 European air quality standards and World Health Organization guideline values

Table 1.1 presents the European air quality standards for sulphur dioxide (SO_2), carbon monoxide (CO), lead (Pb), benzene (C_6H_6), arsenic (As), cadmium (Cd) and nickel (Ni) for the protection of human health, as established in the Ambient Air Quality Directives (EU, 2004, 2008).

Table 1.3 shows the World Health Organization (WHO) air quality guidelines (AQGs) for SO_2, CO, Cd and Pb and the reference levels (RLs) for As, Ni and C_6H_6 ([39]).

For convenience, all the standards are summarised in Tables 8.1-8.4 in the corresponding sections below.

The Ambient Air Quality Directive (EU, 2008) also sets standards for SO_2 for the protection of vegetation, as shown in Table 1.2. The vegetation exposure to SO_2 levels above these standards is assessed in Section 11.4.

8.2 Status of concentrations

8.2.1 Sulphur dioxide

All of the 2018 37 reporting countries reported measurements of SO_2 with data coverage over 75 % in 2018, from 1 667 stations for the hourly limit value and from 1 666 stations for the daily limit value.

In general, SO_2 concentrations are generally well below the limit values for the protection of human health, although exceedance of the WHO daily mean guideline persists.

In 2018, 13 stations ([40]) registered concentrations above the hourly limit value and 16 stations ([41]) registered concentrations above the daily limit value for SO_2.

In contrast, 33 % (551) of all the stations reporting SO_2 levels measured concentrations above the WHO AQG of 20 μg/m³ for daily mean concentrations in 2018. They were located in 27 reporting countries ([42]).

Table 8.1 Air quality standards for protecting human health from SO_2

Pollutant	Averaging period	Standard type and concentration	Comments
SO_2	10 minutes	WHO AQG: 500 μg/m³	
	1 hour	EU limit value: 350 μg/m³	Not to be exceeded on more than 24 hours per year
		EU alert threshold: 500 μg/m³	To be measured over 3 consecutive hours over 100 km² or an entire zone
	1 day	EU limit value: 125 μg/m³	Not to be exceeded on more than 3 days per year
		WHO AQG: 20 μg/m³	

([39]) As WHO has not provided a guideline for As, Ni and C_6H_6, the RLs presented in Table 1.3 were estimated assuming the WHO unit risk for cancer and an acceptable risk of additional lifetime cancer risk of approximately 1 in 100 000 (ETC/ACM, 2011).

([40]) Six in Bosnia and Herzegovina, five in Turkey, one in Bulgaria and one in Serbia.

([41]) The same as for the hourly limit value plus two more in Turkey and one more in Bosnia and Herzegovina.

([42]) All of the 2018 37 reporting countries except Andorra, Cyprus, Estonia, Ireland, Latvia, Luxembourg, Malta, Slovenia, Sweden and Switzerland.

Map 8.1 shows annual mean SO_2 concentrations in 2018. Although the annual mean is not linked to any legal standard, it provides a comparison of the situation across Europe. Additional information on the different 2018 aggregations for SO_2 can be found in the EEA's 'Air quality statistics viewer' (EEA, 2020h).

All of the 2019 33 up-to-date (UTD) reporting countries, except Sweden, reported UTD measurements of SO_2 with data coverage over 75 % in 2019 from 1 124 stations for the hourly limit value and 1 116 stations for the daily limit value. In 2019, one station in Bulgaria registered concentrations above the hourly and daily limit values for SO_2. In contrast, 318 (28%) of all the stations reporting SO_2 levels, located in 22 reporting countries ([43]), measured SO_2 concentrations above the WHO AQG for daily mean concentrations in 2019.

8.2.2 Carbon monoxide

The highest CO levels are found in urban areas, during rush hour, or downwind from large industrial emission sources. All of the 2018 37 reporting countries, except Iceland, reported CO data from 970 ([44]) stations with more than 75 % of valid data. Only four stations registered concentrations above the CO limit value and the identical WHO AQG value in 2018: three urban background stations in Serbia and one urban traffic station in Sweden (Map 8.2).

When concentrations are below the 'lower assessment threshold' (LAT), air quality can be assessed only by means of modelling or objective estimates. At 96 % (936) of stations, maximum daily 8-hour mean concentrations of CO were below the LAT of 5 mg/m^3 in 2018 (first two categories of coloured dots in Map 8.2).

8.2.3 Benzene

C_6H_6 measurements in 2018 with at least 50 % data coverage were reported from 806 stations in 30 European countries (the EEA-33, except Iceland, Liechtenstein and Turkey).

Only four stations measured concentrations above 5.0 µg/m^3 — one suburban industrial station in France, one urban background station in Bulgaria, one urban traffic station in Greece and one urban industrial station in Czechia. At 87 % (703) of stations, annual mean concentrations of C_6H_6 were below the LAT of 2 µg/m^3 in 2018 (first two categories of coloured dots in Map 8.3).

Regarding the estimated WHO RL (Table 8.3), 18 % (144) of all stations reported concentrations above this RL in 2018, located in 16 European countries ([45]) (Map 8.3).

8.2.4 Toxic metals

The monitoring network for toxic metals is not as widespread as that for the rest of the pollutants. This is probably because concentrations are generally low and below the LAT, allowing assessment to be made by modelling or objective estimation. Concentrations of the toxic metals As, Cd, Pb and Ni above the EU standards are highly localised, as can be seen in Maps 8.4-8.7. The highest emissions are typically related to specific industrial plants.

Table 8.2 Air quality standards for protecting human health from CO

Pollutant	Averaging period	Standard type and concentration
CO	1 hour	WHO AQG: 30 mg/m^3
	Maximum daily 8-hour mean	EU limit value and WHO AQG: 10 mg/m^3

Table 8.3 Air quality standards for protecting human health from C_6H_6

Pollutant	Averaging period	Standard type and concentration
C_6H_6	Calendar year	EU limit value: 5 µg/m^3
		RL: 1.7 µg/m^3

([43]) All of the countries reporting SO_2 except Andorra, Cyprus, Denmark, Greece, Latvia, Luxembourg, Malta, the Netherlands, Slovenia and Switzerland.

([44]) Italy reported data from one additional station, but it was not considered because of its suspicious value.

([45]) In Austria, Bulgaria, Croatia, Czechia, France, Germany, Greece, Hungary, Italy, Latvia, Lithuania, Norway, Poland, Romania, Slovakia and Spain.

Table 8.4 Air quality standards for protecting human health from toxic metals

Pollutant	Averaging period	Standard type and concentration	Comments
Pb	Calendar year	EU limit value: 0.5 μg/m^3	Measured as content in PM_{10}
		WHO AQG: 0.5 μg/m^3	
As	Calendar year	EU target value: 6 ng/m^3	Measured as content in PM_{10}
		RL: 6.6 ng/m^3	
Cd	Calendar year	EU target value: 5 ng/m^3	Measured as content in PM_{10}
		WHO AQG: 5 ng/m^3	
Ni	Calendar year	EU target value: 20 ng/m^3	Measured as content in PM_{10}
		RL: 25 ng/m^3	

Note: PM_{10}, particulate matter with a diameter of 10 μm or less.

Data for As from 665 ([46]) stations in 28 European countries ([47]) were reported in 2018. Six stations in Belgium (two stations), Poland (two stations), Germany (one station) and Italy (one station) reported concentrations above the target value (6 ng/m^3) in both industrial suburban areas (one Belgian station and the German station) and background urban areas (the other four). Concentrations of As below the LAT (2.4 ng/m^3) were reported at 95 % of the stations in 2018 (Map 8.4).

Cd data from 699 ([48]) stations in 28 European countries ([49]) were reported in 2018 and, for the first time, no concentrations above the target value (5 ng/m^3) were measured. At the great majority of stations (684, 98 %), Cd concentrations were below or equal to the LAT (2 ng/m^3) (Map 8.5).

Pb data from 695 ([50]) stations in 27 European countries ([51]) were reported in 2018. Only one urban industrial station in Romania reported Pb concentrations above the 0.5 μg/m^3 limit value. Overall, only two stations reported Pb concentrations above the LAT of 0.25 μg/m^3 (see Map 8.6).

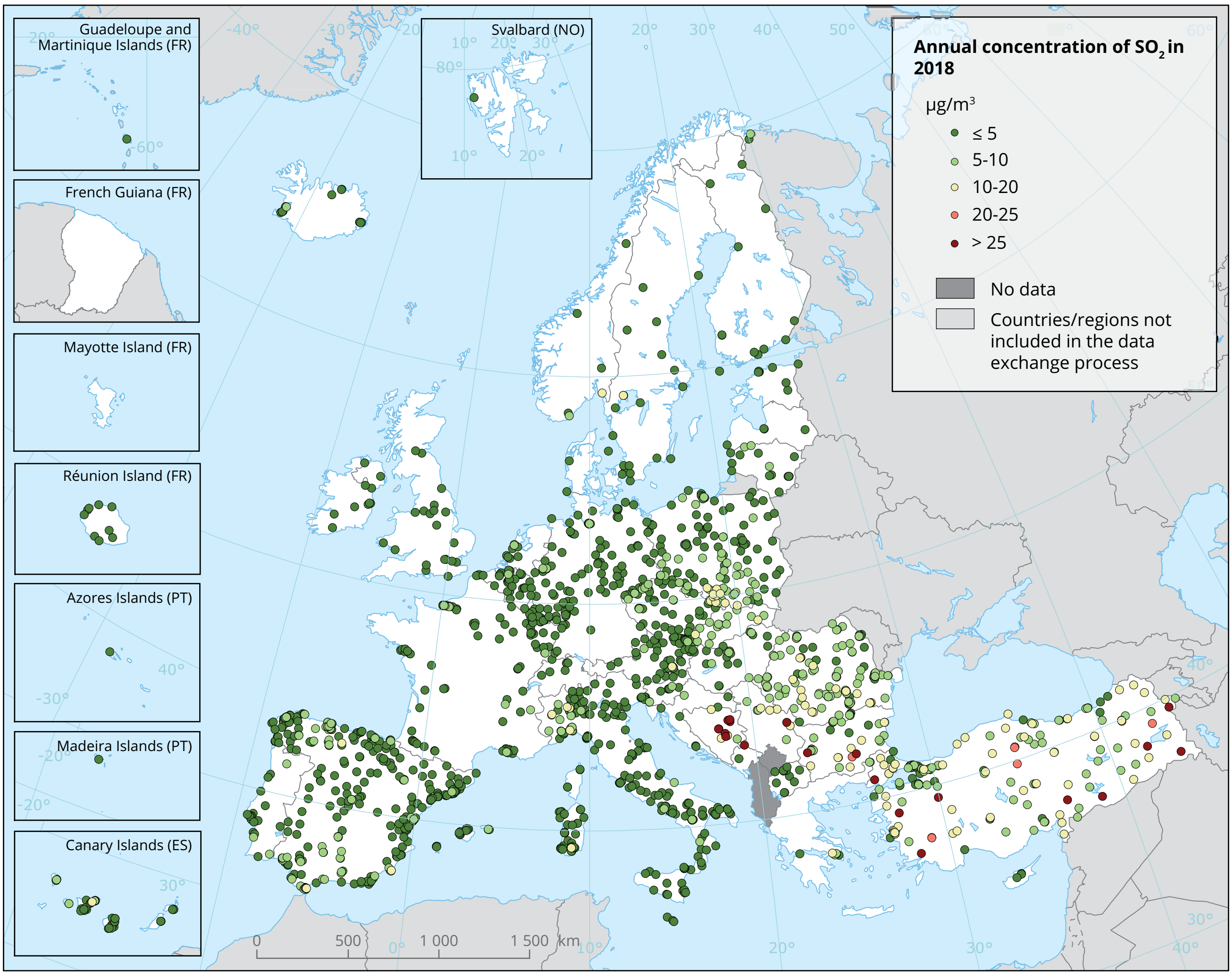
Ni data from 679 ([52]) stations in 29 European countries ([53]) were reported in 2018. Concentrations were above the target value of 20 ng/m^3 at three industrial stations in the United Kingdom, France and Norway (one station each). Of all the stations, 98 % (666) reported Ni concentrations below or equal to the LAT of 10 ng/m^3 (Map 8.7).

The Ambient Air Quality Directive (EU, 2004) also includes the obligation of setting up at least one background station per 100 000 km^2 for the indicative measurement of the total deposition of As, Cd and Ni. In 2018, 12 Member States ([54]) reported total deposition (as precipitation and dry deposition) of As, Cd and Ni. The concentrations can be found in the EEA's 'Air quality statistics — Expert viewer' (EEA, 2020g).

Mercury (Hg) concentrations recorded in the Air Quality e-Reporting Database are very sparse. The Ambient Air Quality Directive (EU, 2004) does not set any standard for Hg, but it calls on EU Member States to perform indicative measurements of total gaseous Hg and total deposition of Hg at one background station at least. It also recommends the measurement of particulate and gaseous divalent Hg. In 2018, Cyprus, France and Italy reported Hg in PM_{10} (particulate matter with a diameter of 10 μm or less); Sweden reported Hg in aerosol; Austria, Belgium and Malta reported elemental gaseous Hg; eight Member States ([55]) reported total gaseous Hg; and eight Member States ([56]) reported total deposition of Hg. The concentrations can be found in the EEA's 'Air quality statistics — Expert viewer' (EEA, 2020g).

([46]) Italy reported data from two additional stations, but they have not been considered because they were reported with the wrong units.
([47]) The EU-28 (except Greece, Malta and Portugal), Norway, Serbia and Switzerland.
([48]) Italy reported data from one additional station, but it has not been considered because it was reported with the wrong units.
([49]) The EU-28 (except Greece, Malta and Portugal), Norway, Serbia and Switzerland.
([50]) Ireland reported data from four stations and Italy reported data from two additional stations, but they have not been considered because they were reported with the wrong units.
([51]) The EU-28 (except Greece, Hungary, Malta and Portugal), Norway, Serbia and Switzerland.
([52]) Italy reported data from two additional stations, but they are not considered because they were reported with the wrong units.
([53]) The EU-28 (except Malta and Portugal), Norway, Serbia and Switzerland.
([54]) Austria, Denmark, Finland, Germany, Hungary, Ireland, Latvia, Lithuania, Poland, Slovenia, Spain and the United Kingdom.
([55]) Croatia, Finland, Germany, Lithuania, Poland, Slovenia, Sweden and the United Kingdom.
([56]) Austria, Finland, Germany, Hungary, Lithuania, Poland, Spain and the United Kingdom.

Map 8.1 Concentrations of SO_2, 2018

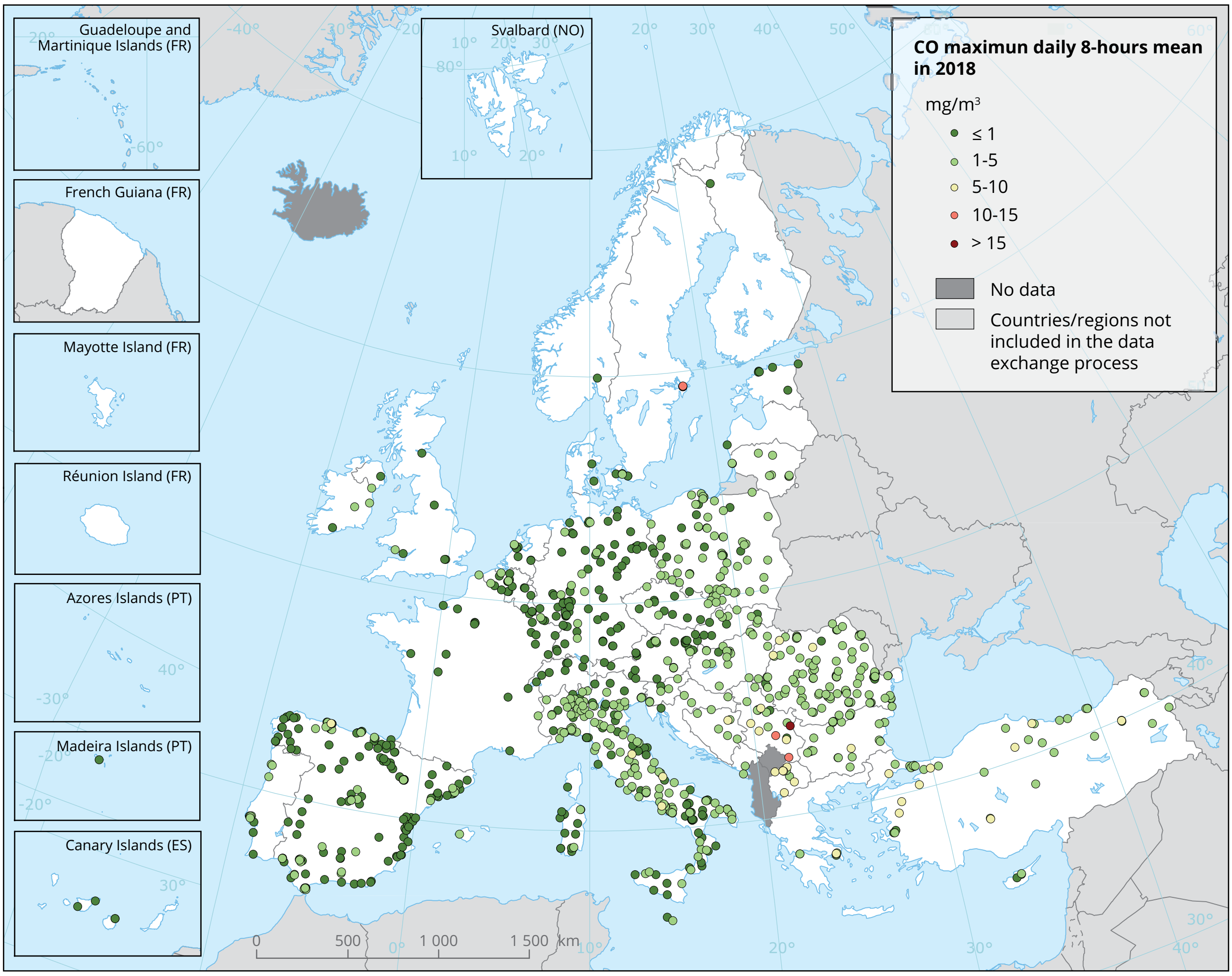


Reference data: ©ESRI | ©EuroGeographics

Note: Observed concentrations of SO_2 in 2018. The map shows the SO_2 annual mean, which is not related to any legal standard, for comparison purposes. Only stations with more than 75 % of valid data are included in the map.

Source: EEA (2020c).

Map 8.2 Concentrations of CO, 2018

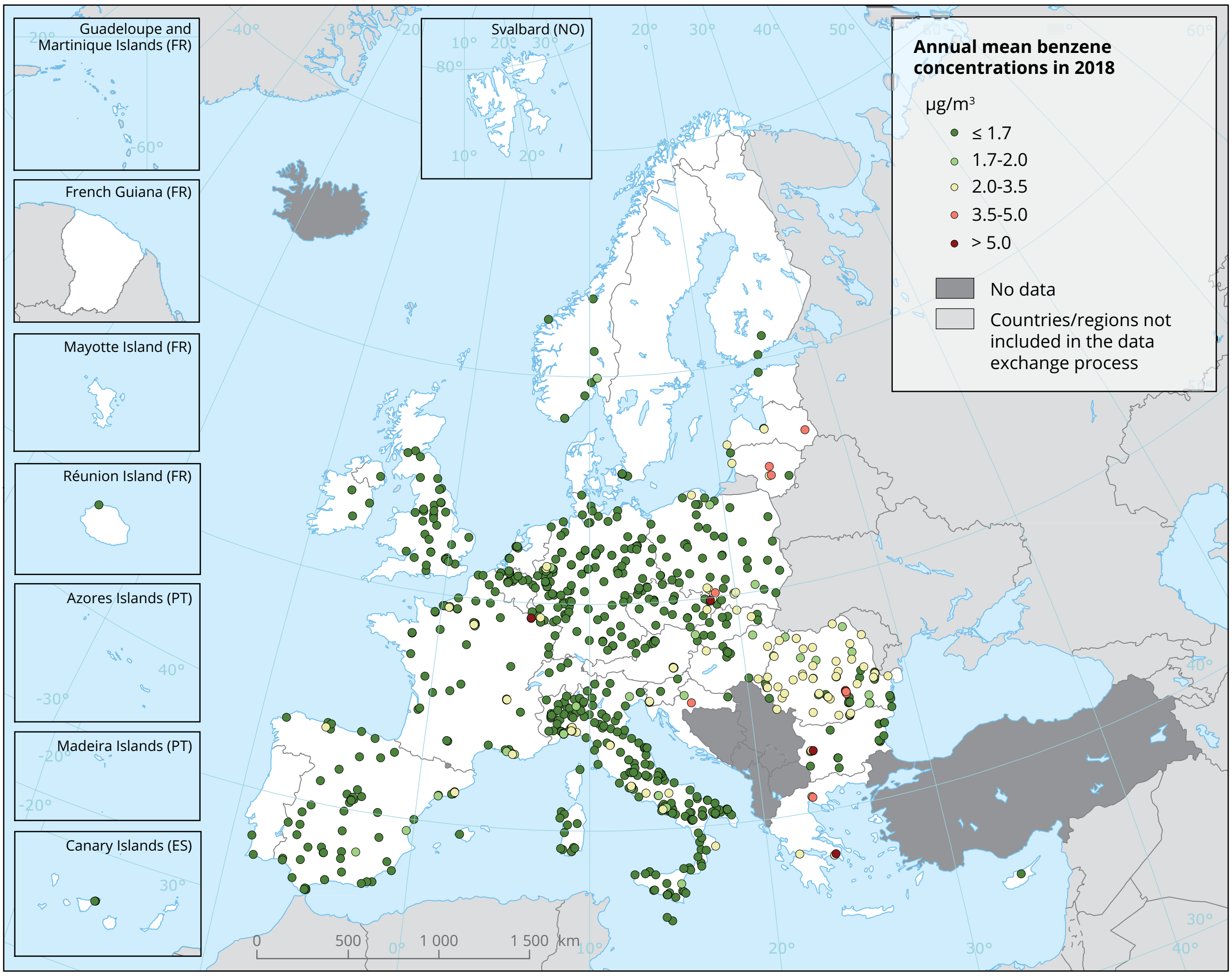


Reference data: ©ESRI | ©EuroGeographics

Note: Observed concentrations of CO in 2018. The map shows the CO maximum daily 8-hour mean. Dots in the last two colour categories correspond to values above the EU annual limit value and the WHO AQG (10 mg/m³). Only stations with more than 75 % of valid data are included in the map.

Source: EEA (2020c).

Map 8.3 **Concentrations of C_6H_6, 2018**

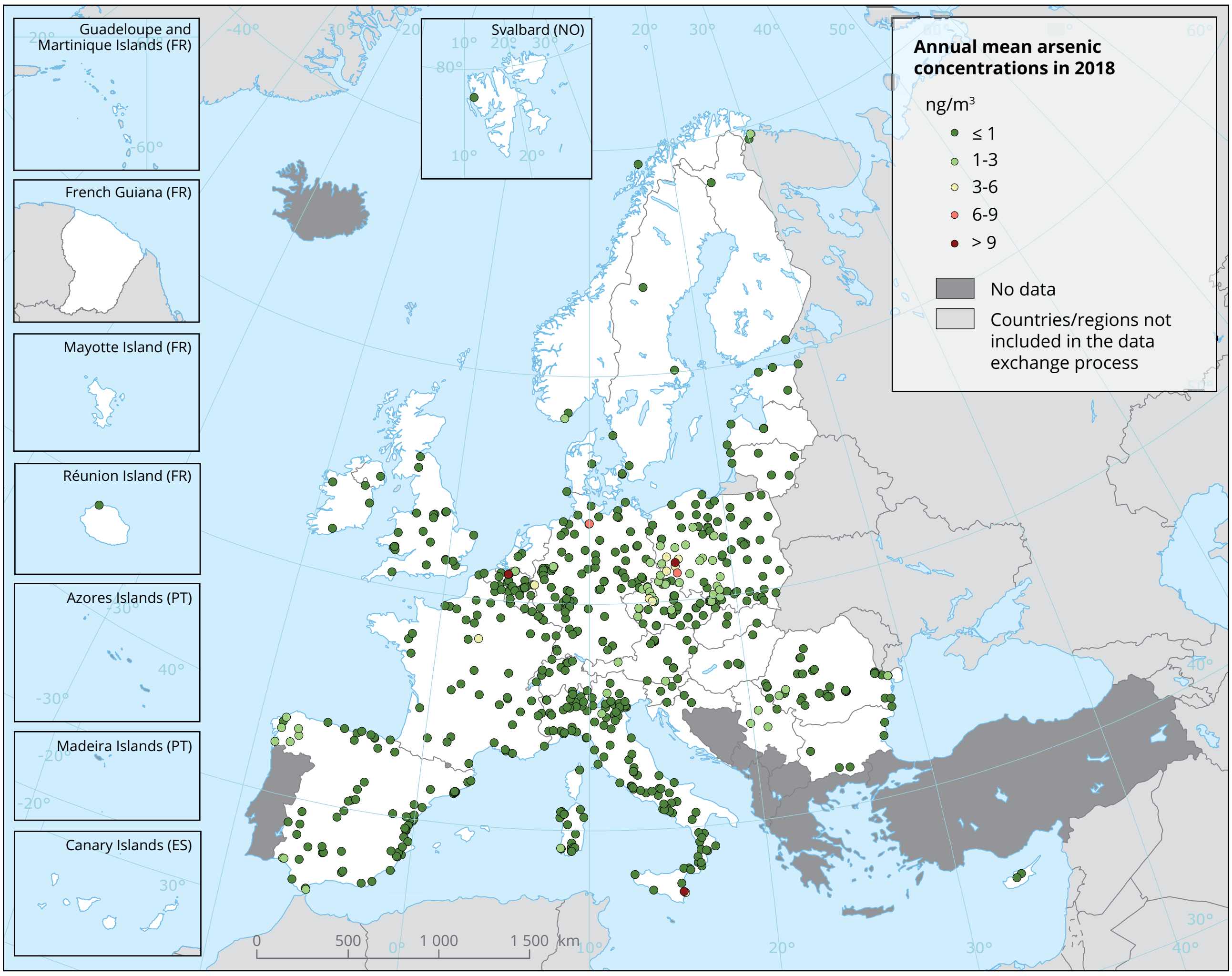


Reference data: ©ESRI | ©EuroGeographics

Note: Observed concentrations of C_6H_6 in 2018. Dots in the last colour category correspond to concentrations above the limit value of 5 µg/m³. Dots in the first colour category correspond to concentrations under the estimated WHO RL (1.7 µg/m³, Table 1.3). Only stations reporting more than 50 % of valid data are included in the map.

Source: EEA (2020c).

Map 8.4 Concentrations of As, 2018

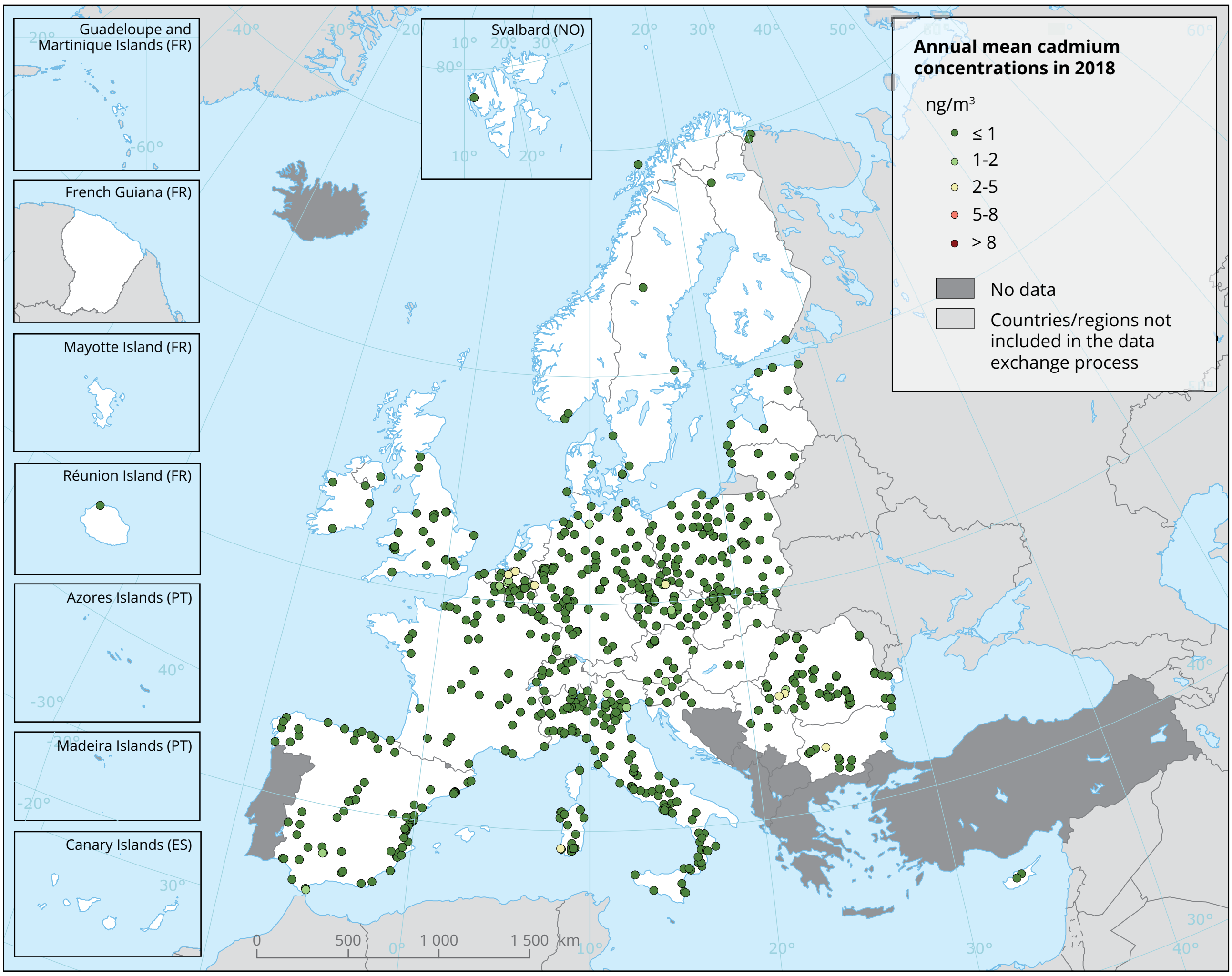


Reference data: ©ESRI | ©EuroGeographics

Note: Observed concentrations of As in 2018. Dots in the last two colour categories correspond to concentrations above the EU target value. Only stations reporting more than 14 % of valid data are included in the map.

Source: EEA (2020c).

Map 8.5 Concentrations of Cd, 2018

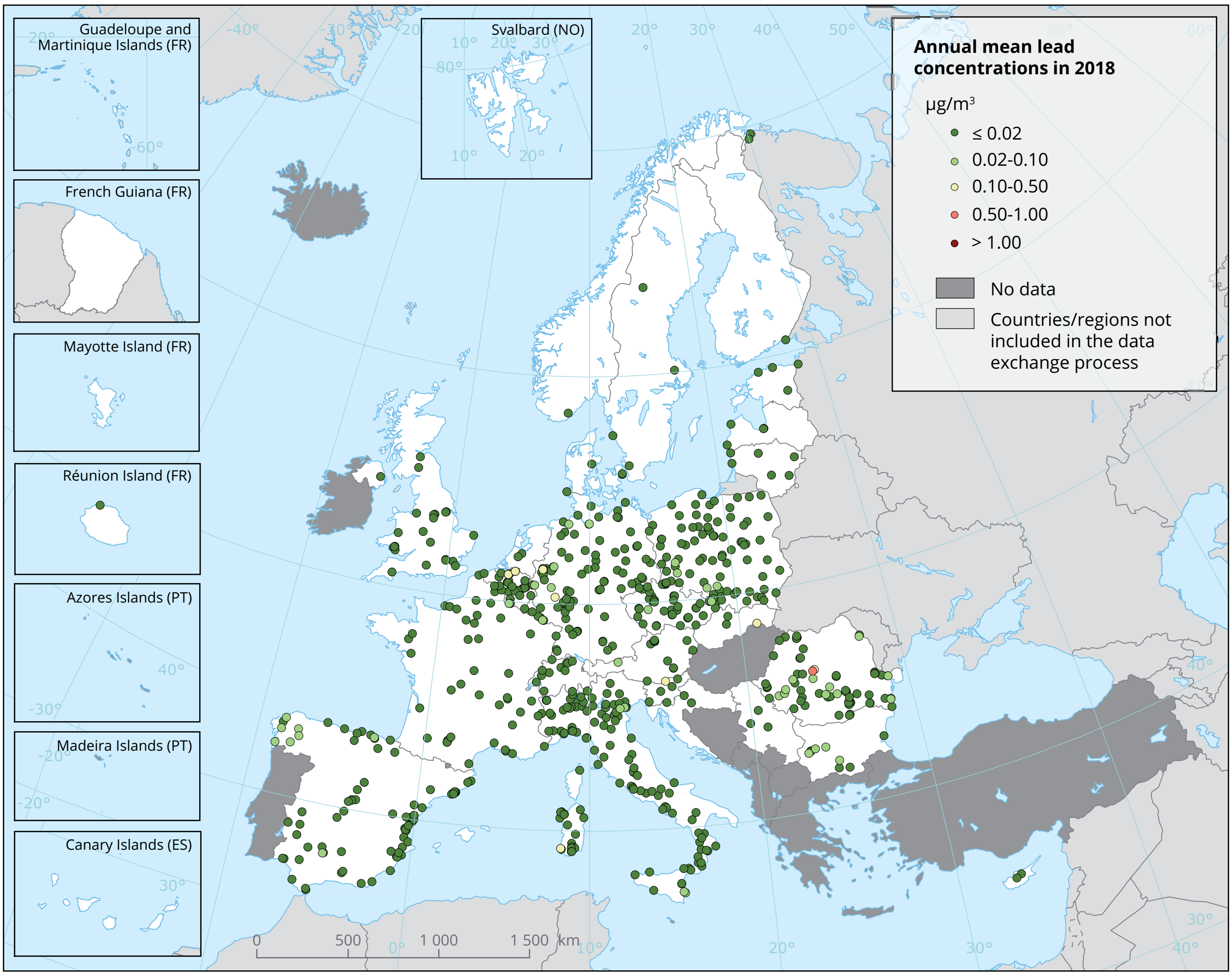


Reference data: ©ESRI | ©EuroGeographics

Note: Observed concentrations of Cd in 2018. Dots in the last two colour categories correspond to concentrations above the target value. Only stations reporting more than 14 % of valid data are included in the map.

Source: EEA (2020c).

Map 8.6 Concentrations of Pb, 2018

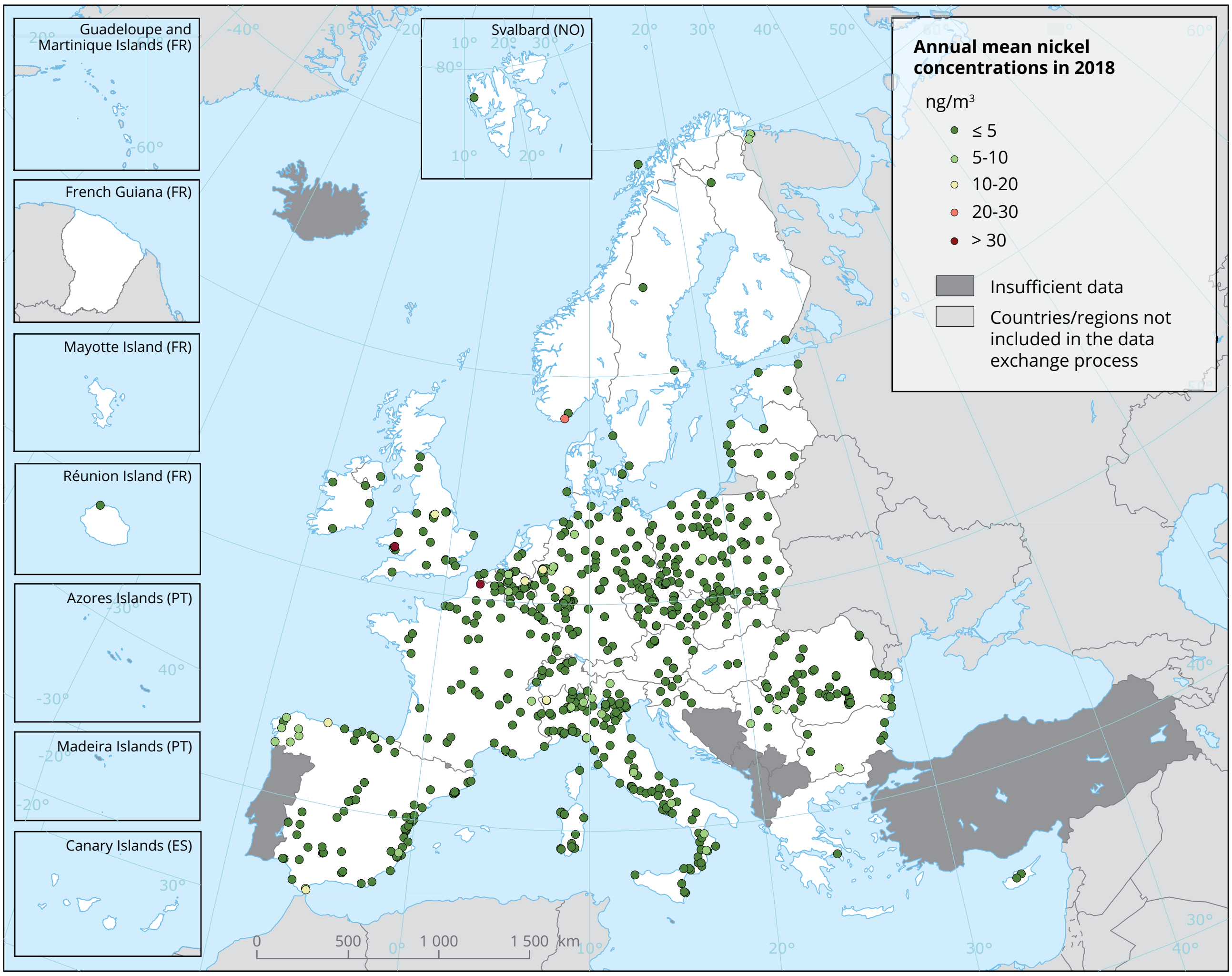


Reference data: ©ESRI | ©EuroGeographics

Note: Observed concentrations of Pb in 2018. Dots in the last two colour categories correspond to concentrations above the EU annual limit value. Only stations reporting more than 14 % of valid data are included in the map.

Source: EEA (2020c).

Map 8.7 Concentrations of Ni, 2018



Reference data: ©ESRI | ©EuroGeographics

Note: Observed concentrations of Ni in 2018. Dots in the last two colour categories correspond to concentrations above the target value. Only stations reporting more than 14 % of valid data are included in the map.

Source: EEA (2020c).

8.3 Trends in concentrations of SO_2

The average SO_2 annual mean concentrations from 2009 to 2018 are presented in Figure 8.1 for urban, suburban and rural background, traffic and industrial stations. SO_2 annual mean concentrations have been steadily decreasing since 2009, but there was an increase in average concentrations from 2016 to 2018 for all station types, except suburban. On average, there has been a reduction in annual mean concentrations of SO_2 for all station types, with the highest reduction for suburban (37 %) and lowest for urban (25%) stations, over the decade considered (2009-2018). The decrease in concentrations is lower than the decrease in emissions, as the total reported sulphur oxides (SO_X) emissions in the EU-28 (EEA-33) decreased by 54 % (35%) from 2009 to 2018 (Figure 3.1).

The trend analysis for the same period shows an overall decreasing trend. Map 8.8 shows the spatial distribution of the trends calculated for each station. Less than half of the stations (42 %) have a significant trend. Almost all of the stations with a significant trend show a decreasing trend, except 3 % of stations that show an increasing trend. Of the stations with non-significant trends, 32 % show an average increase in SO_2 annual mean. The distribution of the trend slopes, per station type, for significant and non-significant trends, are shown in Figure 8.2.

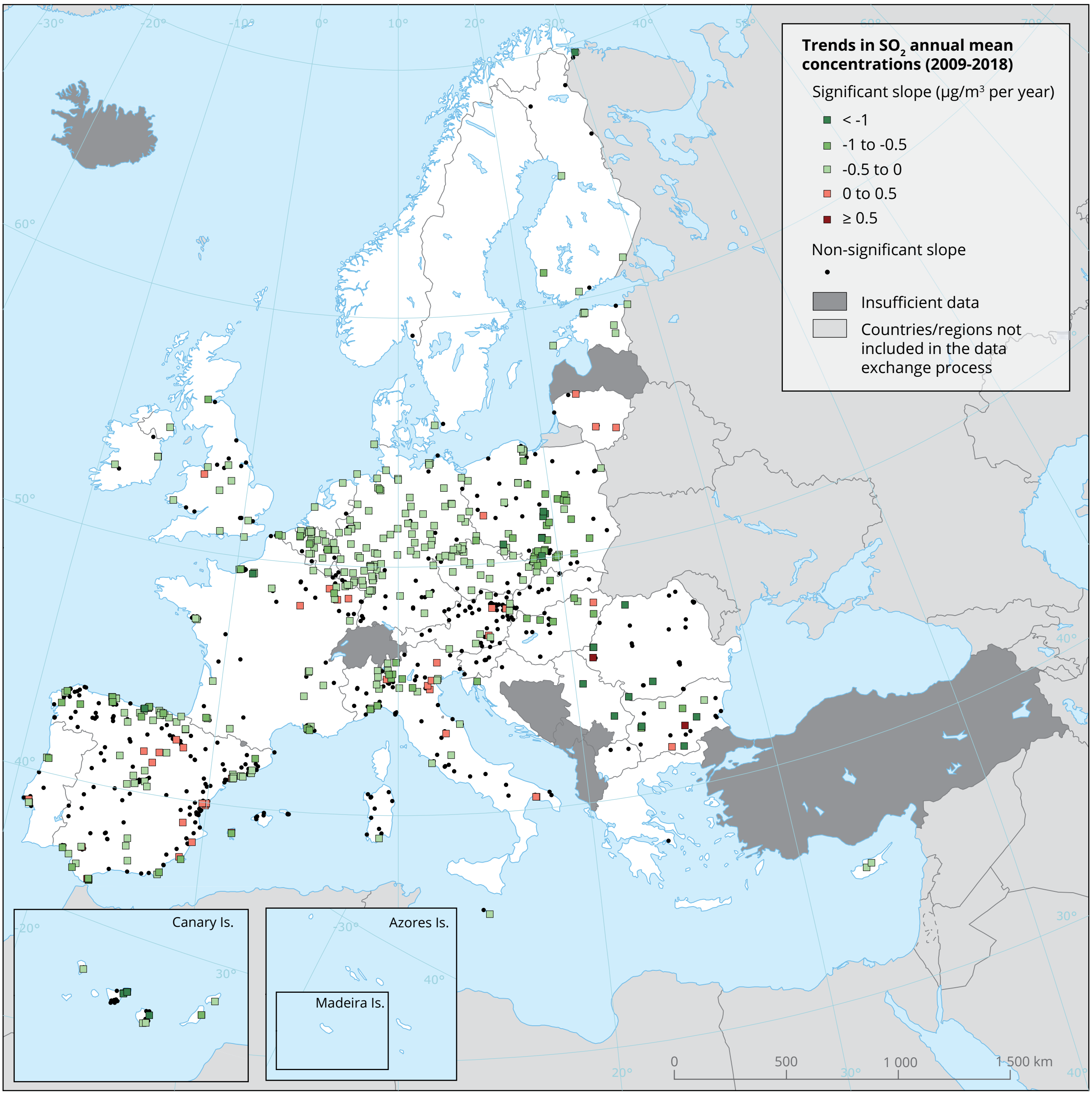
The trend analysis for the period 2009-2018 shows that the highest average decreases in SO_2 concentrations were observed in industrial stations, urban and suburban background stations, while the lowest decrease was observed in rural background stations. This is expected, as the concentrations are highest at industrial sites and lowest in rural areas, and the emission reduction was higher in industry-related sectors. Table A2.8 (Annex 2) shows the results of the trend analysis per country and station type. All countries show an overall negative trend, with Serbia (-1.58 µg/m^3 per year, two stations), North Macedonia (-1.53 µg/m^3 per year, two stations) and Norway (-0.95 µg/m^3 per year, three stations) being the countries with the most steeply declining slope, followed by Bulgaria (-0.49 µg/m^3 per year, 23 stations), Poland (-0.47 µg/m^3 per year, 82 stations) and Croatia (-0.46 µg/m^3 per year, two stations). The exceptions are the increase in slope for Lithuania (0.26 µg/m^3 per year, seven stations) and practically no change for Slovenia (0.07 µg/m^3 per year, five stations) and no change for Portugal (12 stations).

A trend assessment study in Europe for the period 2000-2017 shows that the average SO_2 annual mean concentration has decreased by more than 70 %, averaged across the stations with data available ([57]) (ETC/ATNI, 2020c). The assessment also indicates that SO_2 annual concentrations decreased faster between 2000 and 2008 than between 2009 and 2017.

Figure 8.1 Average SO_2 annual mean concentrations by station type

([57]) The countries included in the analysis were Austria, Belgium, Bulgaria, Czechia, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Lithuania, Luxembourg, the Netherlands, Poland, Portugal, Slovakia, Slovenia, Spain, Sweden and the United Kingdom.

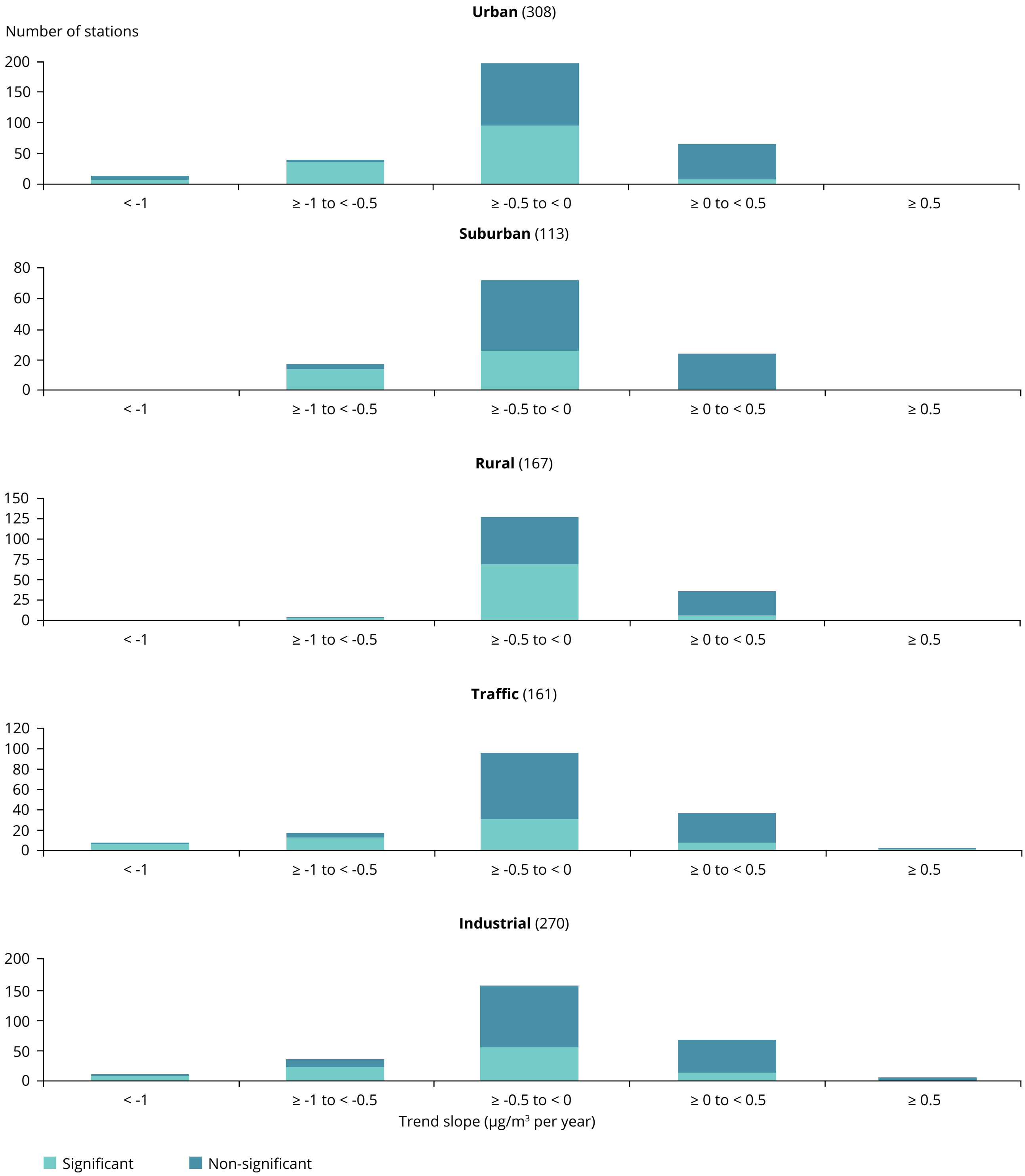
Map 8.8 Average trends in SO_2 annual mean concentrations (2009-2018)



Reference data: ©ESRI

Note: For further information, please see Annex 2.

Figure 8.2 **Trend slope distribution (2009-2018) for SO_2 concentration, per station type, for both significant and non-significant trends**



Note: The calculated trend slope represents the average change in concentration per year at each station in the period 2009-2018. The graphs should be read in relation to Map 8.8 and Table A2.8.

9 Population exposure to air pollutants

Health effects are related to both short- (over a few hours or days) and long-term (over months or years) exposure to air pollution. The EU Ambient Air Quality Directives and the World Health Organization (WHO) define, respectively, air quality standards and guidelines for the protection of human health from both short- and long-term effects, depending on the pollutant and its effects on health (Tables 1.1 and 1.3, respectively). These values differ from each other, and the WHO air quality guidelines (AQGs) are generally stricter (for nitrogen dioxide, NO_2, however, both the annual limit value and the long-term guideline are the same). The WHO AQGs are designed to offer guidance on reducing the health impacts of air pollution and are based on expert evaluation of current scientific evidence. The EU standards are a political compromise that also take into account what is technically and economically feasible and the cost versus the benefit.

9.1 Exposure of the EU-28 population in urban and suburban areas in 2018

The monitoring data reported by the EU-28 (EEA, 2020c) provide the basis for estimating the exposure of the urban population to values above the most stringent European air quality standards and the WHO AQGs. Exposure is estimated based on concentrations measured at all urban and suburban background monitoring stations for most of the urban population and at traffic stations for populations living within 100 metres of major roads. The methodology is described by the EEA (2020a).

Figure ES.1 shows the percentage of the EU-28 urban population exposed to concentrations above certain EU limit or target values and WHO AQG levels (or an estimated reference level, or RL, where no WHO AQG level exists) in 2018. There are some variations from year to year. This is due to changes in concentrations, variations attributable to meteorology and changes in the subset of cities and stations included in the year-to-year estimates.

In 2018, 15 % of the EU-28 urban population was exposed to PM_{10} (particulate matter with a diameter of 10 µm or less) above the EU daily limit value, decreasing again after the increase in 2017. The extent of exposure above this EU daily limit value fluctuated between 13 % and 42 % during the period 2000-2018, with 2003 identified as the year with the highest extent of exposure. Furthermore, 48 % of the same urban population was exposed to concentrations exceeding the stricter WHO AQG value for PM_{10} in 2018. The percentage of the urban population exposed to levels above the WHO annual AQG (20 µg/m^3) ranged between 43 % and 91 % (maximum also reached in 2003) during the period 2000-2018.

About 4 % of the EU-28 urban population was exposed to $PM_{2.5}$ (particulate matter with a diameter of 2.5 µm or less) above the EU limit value in 2018. The percentage is half the value in 2017 and represents a new minimum since the beginning of the time series in 2006. The urban population's exposure to levels above the more stringent WHO AQG for $PM_{2.5}$ was 74 % in 2018, also reaching a new minimum from the initial maximum of 97 % in 2006.

In 2018, about 34 % of the EU-28 population in urban areas was exposed to ozone (O_3) concentrations above the EU target value threshold. The percentage represents a relative maximum since 2006 and the third-highest value in the series, which started in 2000 and reached a minimum of 7 % in 2014 and a maximum of 55 % in 2003. In 2018, the percentage of the EU-28 urban population exposed to O_3 levels exceeding the WHO AQG reached the maximum of 99 % for the third time, and it has fluctuated very little since the 94 % exposure recorded in 2000.

A little less than 4 % of the EU-28 urban population was exposed to NO_2 concentrations above the EU annual limit value and the WHO AQG value in 2018, almost halving the percentage in 2017 and setting a new minimum record. The percentage of the urban population exposed to concentrations above the annual limit value has gradually decreased since the maximum of 31 % in 2003.

In 2018, 15 % of the urban population in the EU-28 was exposed to benzo[*a*]pyrene (BaP) annual concentrations above the EU target value (1.0 ng/m^3) and 75 % was exposed to concentrations above the estimated RL (0.12 ng/m^3), in both cases reaching new minimum values since 2008, the starting year of the BaP series (with maxima of 24 % and 90 %, respectively).

Exposure to sulphur dioxide (SO_2) has decreased over the past few decades and, since 2007, the exposure of the urban population to concentrations above the EU daily limit value has remained under 0.5 %. The EU-28 urban population exposed to SO_2 levels exceeding the WHO AQG decreased from 85 % of the total urban population in 2000 to 19 % in 2018, which constitutes a new minimum value in the series (EEA, 2020a).

Based on the available measurements for 2018 and previous years, it can be concluded that the European population's exposure to carbon monoxide (CO) and benzene (C_6H_6) ambient concentrations above the EU limit values is very localised and infrequent (Sections 8.2.2 and 8.2.3), as there are very few exceedances. Concentrations above the estimated C_6H_6 WHO RL are more current and widespread.

Human exposure to arsenic (As), cadmium (Cd), lead (Pb) and nickel (Ni) ambient air concentrations above the EU limit or target values is restricted to a few areas in Europe and exposure happens mainly at industrial areas. However, atmospheric deposition of toxic metals contributes to the exposure of ecosystems and organisms to toxic metals and to bioaccumulation and biomagnification in the food chain, affecting human health (EEA, 2019).

9.2 Exposure of total European population in 2018 and changes over time

To estimate the exposure of the total European population ([58]) to the various pollutant standards, an interpolation of annual statistics of reported monitoring data from 2018 has been used. It combines the monitoring data from rural and urban background stations (and traffic stations in the case of PM and NO_2 to take into account hotspots, since traffic is an important source of PM and especially NO_2) with results from the European Monitoring and Evaluation Programme (EMEP) chemical transport model and other supplementary data, such as altitude and meteorology (for further details, see ETC/ACM, 2017a; ETC/ATNI, 2020d). The maps of spatially interpolated air pollutant concentrations (annual mean concentration for PM_{10}, $PM_{2.5}$ and NO_2, and accumulated O_3 concentration (8-hour daily maximum) in excess of 35 parts per billion (ppb), known as SOMO35, for O_3) are presented in Map 9.1. The population exposure is estimated by combining these concentration maps with the population density (based on the Geostat 2011 grid data set; Eurostat, 2014), which is the basis for the health impact estimates in 2018 presented in Chapter 10 ([59]).

Figure 9.1 shows the European population frequency distribution for different exposure classes in 2018. In 2018, about 49 % of the European population (and 42 % of the EU-28 population) was exposed to PM_{10} annual average concentrations above the WHO AQG (bars to the right of the line at 20 μg/m^3 in Figure 9.1a). The population exposure exceeding the EU limit value (bars to the right of the line at 40 μg/m^3 in Figure 9.1a) was 9 % for the population of the total European area considered and about 1 % for the EU-28.

When it comes to $PM_{2.5}$, in 2018, around 76 % of the population of the total European area considered (excluding Turkey) and 77 % of the EU-28 population were exposed to annual mean concentrations above the WHO AQG (bars to the right of the line at 10 μg/m^3 in Figure 9.1b). In addition, almost 5 % of the total population and 3 % of the EU-28 population were exposed to concentrations above the EU limit value (bars to the right of the line at 25 μg/m^3 in Figure 9.1b).

For O_3 (Figure 9.1c), it has been estimated that, in 2018, about 32 % of the European population and 31 % of the EU-28 population lived in areas with SOMO35 values above 6 000 μg/m^3·days ([60]).

Finally, for NO_2, it has been estimated that, in 2018, about 4 % of the European population and about 2 % of the EU-28 population lived in areas with annual average concentrations above the EU limit value (bars to the right of the line at 40 μg/m^3 in Figure 9.1d).

The results from the maps prepared in previous years enable an analysis of changes in total European population exposure over time (Figure 9.2). Exposure to both PM_{10} and $PM_{2.5}$ shows a steady decrease over time, with a slight increase in 2011 as an exception. For exposure to O_3 (expressed as SOMO35), a slight decrease is also observed until 2014. Following that

([58]) All European countries (not only EU-28) and all populations (not only urban).

([59]) More detailed information on population exposure to $PM_{2.5}$, NO_2 and O_3 at country level can be found in Tables 3.1, 5.1 and 4.2 in ETC/ATNI (2020d), respectively.

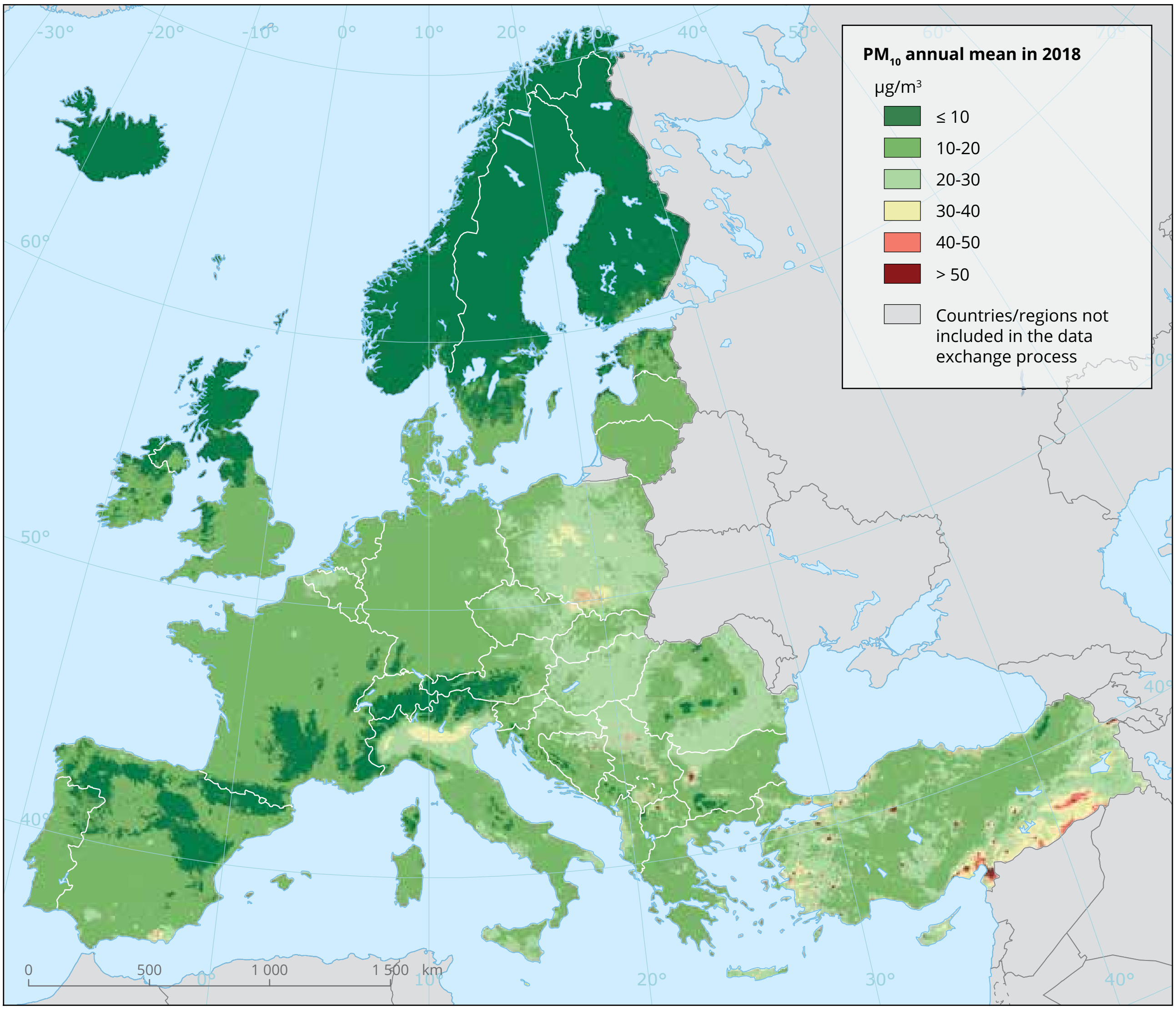
([60]) The comparison of the 93.2 percentile of maximum daily 8-hour means with the SOMO35 results for all background stations shows that there is no simple relationship between the two indicators; however, it seems that the O_3 target value threshold (120 μg/m^3) is related, to some extent, to SOMO35 in the range 6 000-8 000 μg/m^3·days (ETC/ATNI, 2020d).

year, values increased, reflecting the effect of more favourable meteorological conditions for O_3 formation. For NO_2, exposures in the last 6 years are well below the values observed in the previous years and show a slight but constant decrease (ETC/ATNI, 2020d).

Although the spatial distributions of PM, O_3 and NO_2 concentrations differ widely, the possibility of an accumulation of risks resulting from high exposures to all three pollutants cannot be excluded. Combining the maps for the three most frequently exceeded EU standards (PM_{10} daily limit value, O_3 target value and NO_2 annual limit value) yields the following results: out of the total population of 621 million in the model area, 7.4 % (46.2 million) live in areas where two or three of these air quality standards are exceeded and 0.7 % (4.5 million) live in areas where all three standards are exceeded. The worst situation is observed in Turkey, where 4.2 % of the population lives in areas where all three standards are exceeded, followed by Italy (in particular the Po valley), where this is also the case for 1.8 % of the population.

Map 9.1 Concentration interpolated maps of (a) PM_{10} (annual mean, μg/m³), (b) $PM_{2.5}$ (annual mean, μg/m³), (c) O_3 (SOMO35, μg/m³·days) and (d) NO_2 (annual mean, μg/m³) for 2018

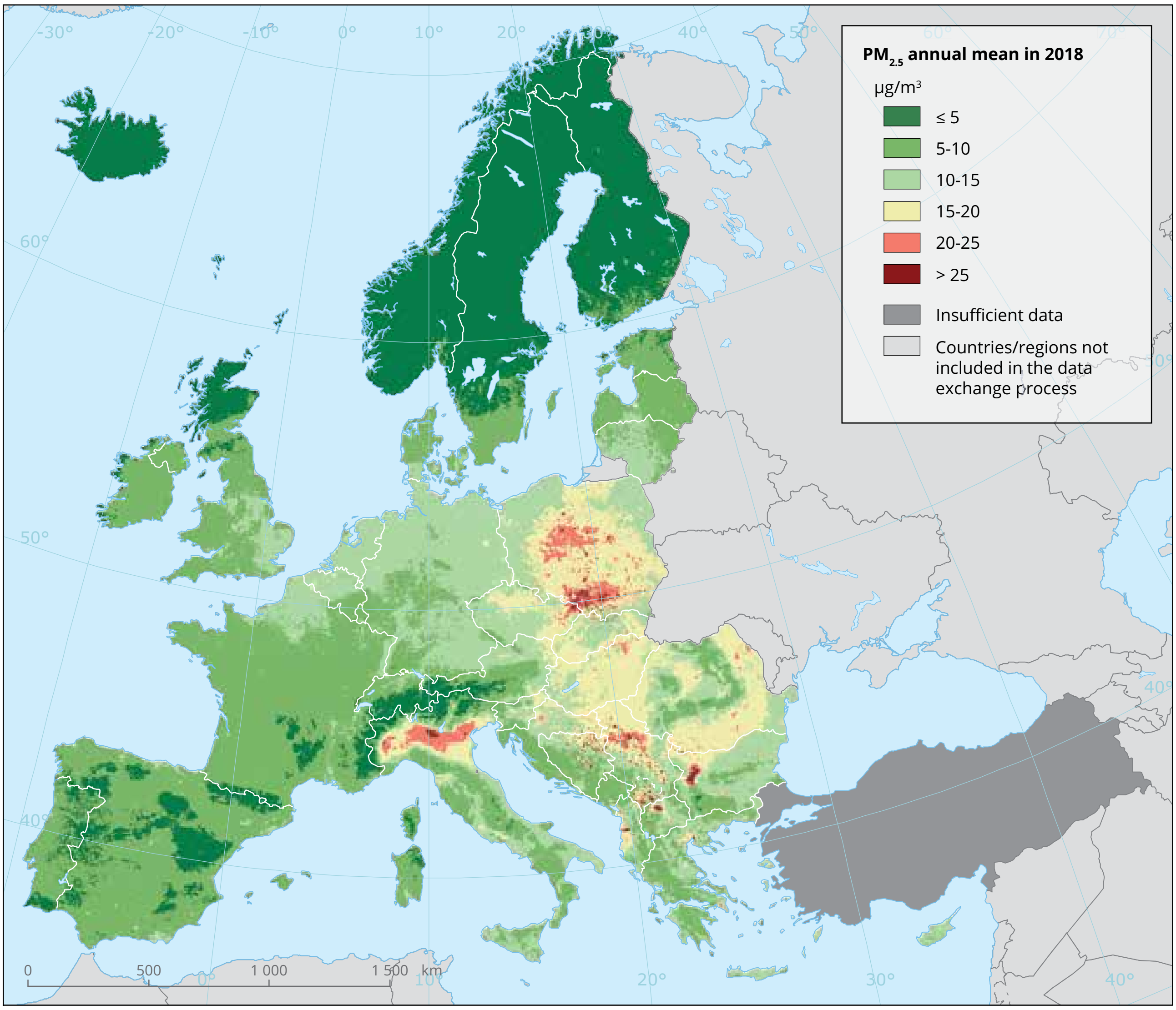
a)



Reference data: ©ESRI

Map 9.1 **Concentration interpolated maps of (a) PM_{10} (annual mean, µg/m³), (b) $PM_{2.5}$ (annual mean, µg/m³), (c) O_3 (SOMO35, µg/m³·days) and (d) NO_2 (annual mean, µg/m³) for 2018 (cont.)**

b)

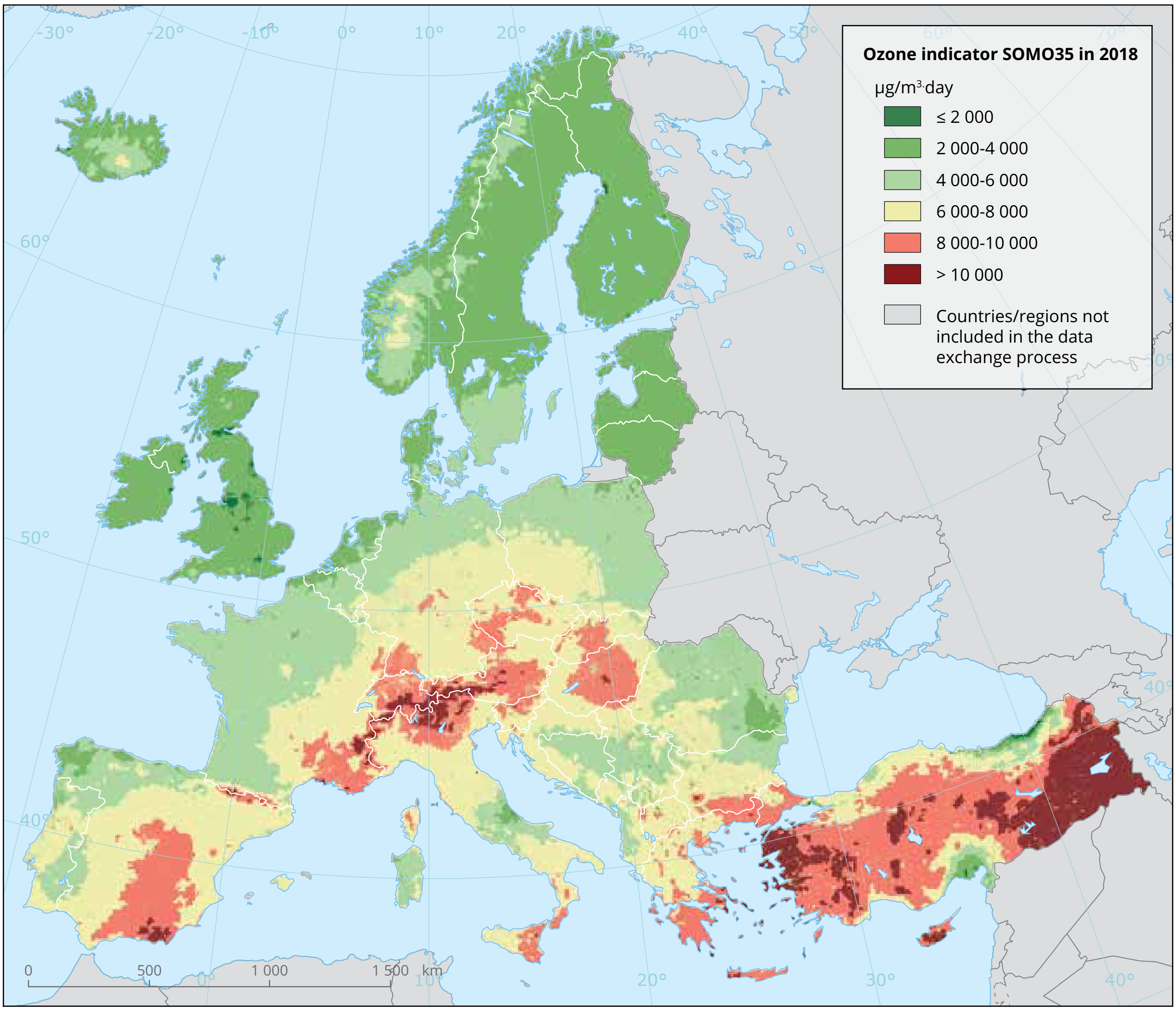


Reference data: ©ESRI

Note: Turkey is not included in the map of annual average $PM_{2.5}$, because there was large uncertainty in the modelling results due to the lack of data from rural background stations in the country.

Map 9.1 **Concentration interpolated maps of (a) PM_{10} (annual mean, µg/m³), (b) $PM_{2.5}$ (annual mean, µg/m³), (c) O_3 (SOMO35, µg/m³·days) and (d) NO_2 (annual mean, µg/m³) for 2018 (cont.)**

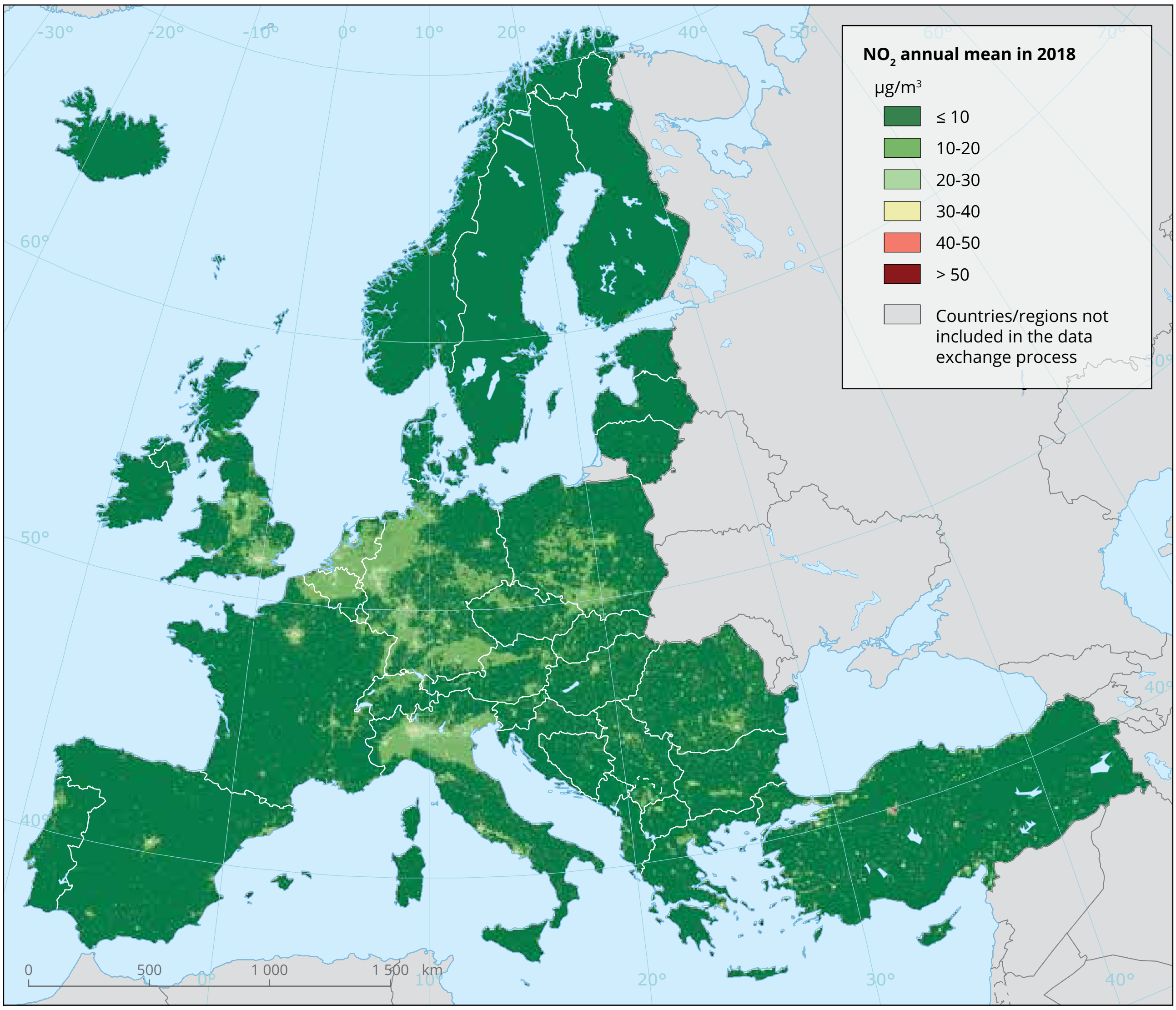
c)



Reference data: ©ESRI

Map 9.1 **Concentration interpolated maps of (a) PM_{10} (annual mean, µg/m³), (b) $PM_{2.5}$ (annual mean, µg/m³), (c) O_3 (SOMO35, µg/m³·days) and (d) NO_2 (annual mean, µg/m³) for 2018 (cont.)**

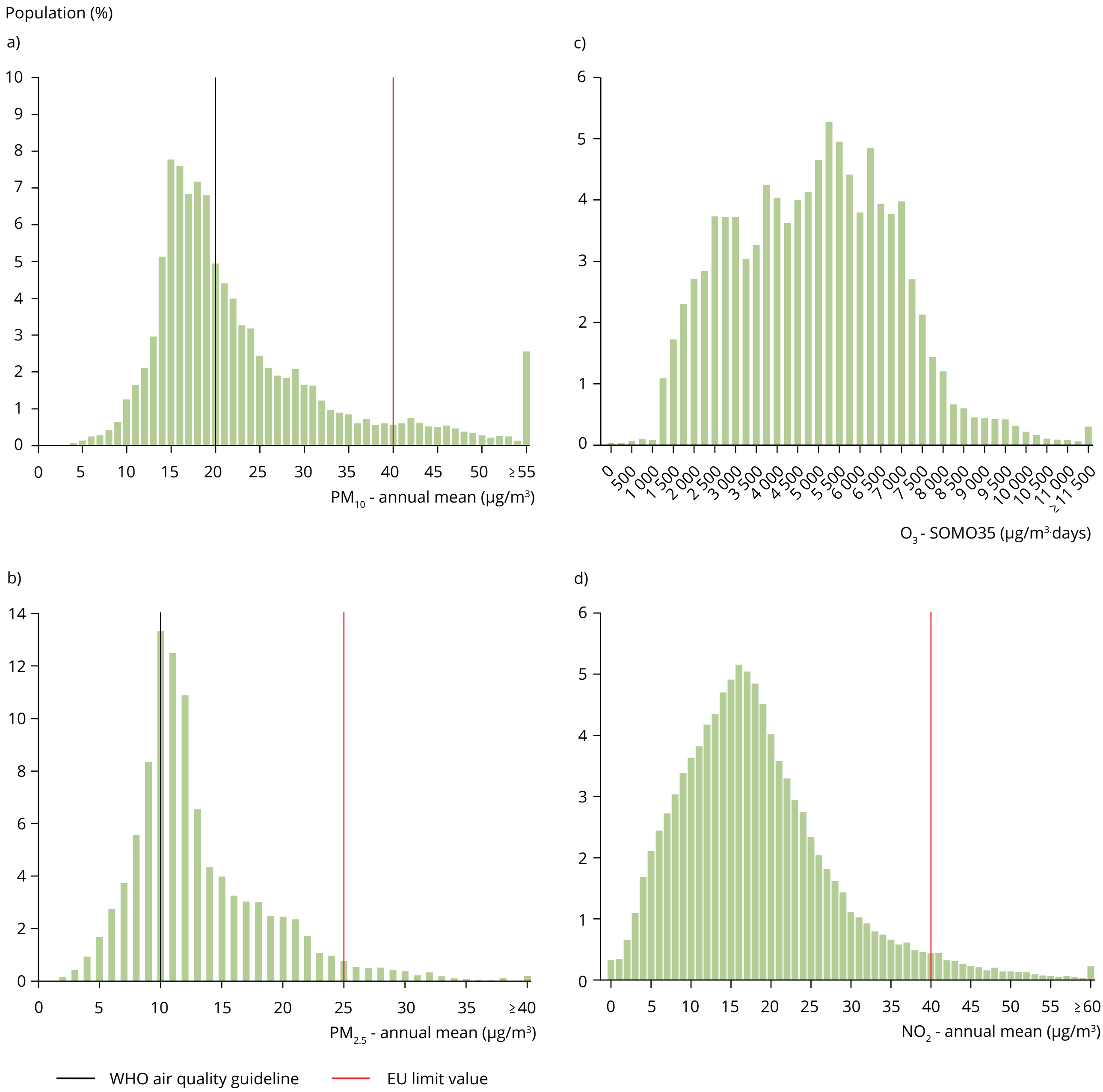
d)



Reference data: ©ESRI

Source: ETC/ATNI (2020d).

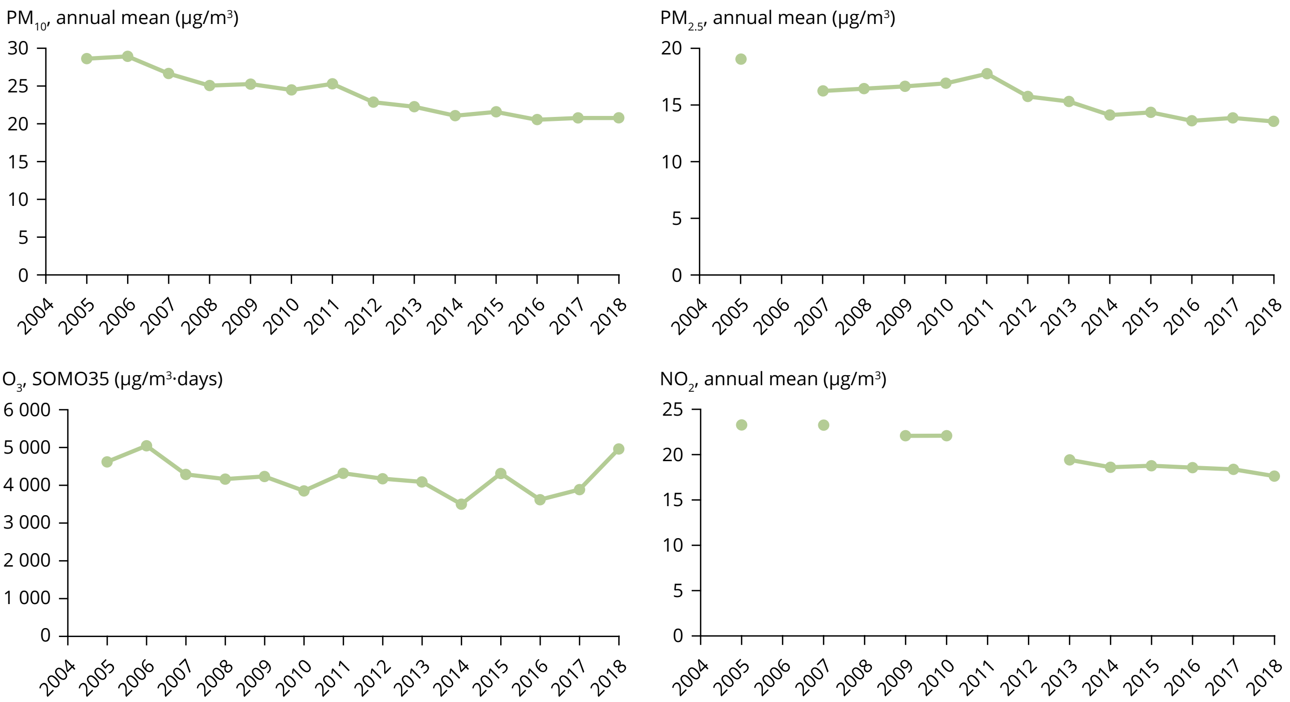
Figure 9.1 Frequency distribution of the total population exposure to PM_{10} (annual mean), $PM_{2.5}$ (annual mean), O_3 (SOMO35) and NO_2 (annual mean) in 2018



Note: The graphs should be read in combination with Map 9.1.

Source: ETC/ATNI (2020d).

Figure 9.2 Evolution in total European population exposure to PM_{10} (annual mean), $PM_{2.5}$ (annual mean), O_3 (SOMO35) and NO_2 (annual mean) from 2005 to 2018



Note: Exposure is expressed as population-averaged concentrations. The total European population does not include Turkey, because, in the years before 2016, it was not included in the interpolated maps. For PM, for the years 2005 and 2009 and the period 2015-2018 the most recent mapping methodology (ETC/ACM, 2017a; ETC/ATNI, 2020d), considering urban traffic stations, has been used. For NO_2, all years apart from 2007 are calculated using the most recent methodology.

Source: ETC/ATNI (2020d).

10 Health impacts of exposure to fine particulate matter, nitrogen dioxide and ozone

It is well documented that exposure to air pollution may lead to adverse health effects, such as premature mortality and morbidity, mainly related to respiratory and cardiovascular diseases (WHO, 2006b, 2008, 2013b). Mortality reflects a reduction in life expectancy owing to premature death as a result of exposure to air pollution, whereas morbidity relates to the occurrence of illness and years lived with a disease or disability, ranging from subclinical effects (e.g. inflammation) and symptoms such as coughing to chronic conditions that may require hospitalisation. Even less severe effects might have considerable public health implications, because air pollution affects the whole population on a daily basis.

Methods to quantify mortality and morbidity effects are available, and they are based on air pollution concentrations, basic demographic and health data, and the relationship between the ambient concentrations and each specific health outcome. This can be translated into number of human lives lost or costs associated with mortality and morbidity. A number of studies (e.g. WHO and OECD, 2015) also show that, after monetising the health effects, the total external costs caused by mortality outweigh those arising from morbidity. In this report, the focus is, as in previous years, on estimating the premature mortality related to air pollution, focusing on particulate matter (PM), nitrogen dioxide (NO_2) and ozone (O_3). Exposure to other air pollutants, such as benzene (C_6H_6) or polycyclic aromatic hydrocarbons (PAHs) (in particular benzo[*a*]pyrene, BaP), also has health impacts; however, under the current European air quality conditions, those pollutants' impact on total air pollution-related mortality is small compared with PM, NO_2, and O_3, and may, in part, be already included in estimates of the effects of PM.

Estimates are produced for 2018, in line with most of the information presented in this report, and also for the year 2009, using the air quality data published in 2011 in the first *Air quality in Europe* report and the most up-to-date methodology for the production of concentration maps and for the calculations of health impacts, as described in the following section.

10.1 Methodology used to estimate health impacts of air pollution

The impacts attributable to exposure to $PM_{2.5}$, NO_2 and O_3 in Europe presented in this report are based on two different mortality endpoints (see Box 10.1). This assessment required information on air pollution, demographic data, health/mortality data and the relationship between exposure to ambient pollutant concentrations and a health outcome. The 2018 maps of annual mean concentrations for $PM_{2.5}$ (particulate matter with a diameter of 2.5 μm or less), NO_2 and SOMO35 (accumulated O_3 concentration (8-hour daily maximum) in excess of 35 ppb (parts per billion)), used in the assessment, are presented in Section 9.2; those for 2009 are published in ETC/ATNI (2020e). The demographic data and life expectancy data were taken from Eurostat (2020i, 2020j) and the mortality data were taken from WHO (2019b). The exposure-response relationship and the population at risk have been selected following a recommendation from the Health Risks of Air Pollution in Europe (HRAPIE) project (WHO, 2013b). For $PM_{2.5}$, all-cause (natural) mortality is considered in people aged over 30 years for all concentrations (i.e. concentrations above 0 μg/m^3), assuming a linear increase in the risk of mortality of 6.2 % for a 10 μg/m^3 increase in $PM_{2.5}$. For NO_2, all-cause (natural) mortality is considered in people aged over 30 for concentrations above 20 μg/m^3, assuming a linear increase in the risk of mortality of 5.5 % for a 10 μg/m^3 increase in NO_2. For O_3, all-cause (natural) mortality is considered for all ages, assuming a linear increase in the risk of mortality of 0.29 % for a 10 μg/m^3 increase in O_3 values over 35 ppb ([61]). A detailed description of the methodology can be found in EEA (2018b) and ETC/ATNI (2020f).

([61]) In previous years, a sensitivity analysis was performed using various concentrations above which to consider the health impacts (or counterfactual values), namely the effects from 2.5 μg/m^3 for $PM_{2.5}$, from 10 μg/m^3 for NO_2 and from 10 ppb for O_3. The results of a similar analysis are shown in Annex 3.

Box 10.1

Premature deaths are deaths that occur before a person reaches an expected age. This expected age is typically the life expectancy for a country stratified by sex and age. Premature deaths are considered preventable if their causes can be eliminated.

Years of life lost (YLL) is defined as the years of potential life lost as a result of premature death. It is an estimate of the average number of years that a person would have lived if they had not died prematurely. YLL takes into account the age at which the death occurs and is greater for deaths at a younger age and lower for deaths at an older age. Therefore, it gives, more nuanced information than the number of premature deaths alone.

The relative risks described in the previous paragraph have an uncertainty that is expressed as confidence intervals (CIs). These CIs provide the upper and lower boundaries of the 95 % CI of the estimate, considering only the uncertainty in the relative risks. These CIs are 4.0-8.3 % for $PM_{2.5}$, 3.1-8.0 % for NO_2 and 0.14-0.43 % for O_3.

Quantifications of health impacts are done individually for these air pollutants and they cannot be added together, as they exhibit some degree of correlation — positive or negative. For example, when adding together the results for $PM_{2.5}$ and NO_2, this may lead to the double counting of the effects of NO_2 up to 30 % (WHO, 2013b).

10.2 Health impact, results for 2018

The results of the health impact calculations for 2018 related to $PM_{2.5}$, NO_2, and O_3 exposure are presented in Tables 10.1 and 10.2 for 41 European countries. These tables show the population-weighted concentrations and the estimated number of attributable premature deaths (Table 10.1), the number of years of life lost (YLL) and the YLL per 100 000 inhabitants (Table 10.2) associated with exposure to $PM_{2.5}$, NO_2 and O_3 concentration levels in 2018.

In the 41 countries listed, 417 000 premature deaths are attributed to $PM_{2.5}$ exposure, 55 000 to NO_2 exposure and 20 600 to O_3 exposure. In the EU-28, the premature deaths attributed to $PM_{2.5}$, NO_2 and O_3 exposure are 379 000, 54 000 and 19 400, respectively. In line with the changes in concentrations, the estimated deaths attributable to $PM_{2.5}$ are slightly lower than those estimated for 2017, while those for NO_2 decreased by slightly more than 20%. In contrast, the high O_3 concentrations in 2018 implied an increase of more than 25 % in the deaths attributed to exposure to O_3.

In the 41 countries assessed, 4 805 800 YLL are attributed to $PM_{2.5}$ exposure, 623 600 to NO_2 exposure, and 246 700 to O_3 exposure (Table 10.2). In the EU-28, the YLL attributed to $PM_{2.5}$, NO_2 and O_3 exposure are 4 380 800, 610 300, and 232 200, respectively.

The largest contribution to the uncertainties in the estimates of premature deaths and YLL is related to the choice of the relative risk coefficients. In the results presented below, the uncertainties in health outcomes (expressed as 95 % CIs) are estimated as follows:

- for the EU-28 estimates of attributable premature deaths, 251 000-495 000 for $PM_{2.5}$, 31 000-76 000 for NO_2 and 9 400-28 900 for O_3;
- for the 41 European countries estimates of attributable premature deaths, 276 000-543 500 for $PM_{2.5}$, 32 000-78 000 for NO_2 and 10 000-30 700 for O_3.

The largest health impacts in terms of premature deaths and YLL attributable to $PM_{2.5}$ are estimated for the countries with some of the largest populations, namely Germany, Italy, Poland, France and the United Kingdom. However, in relative terms, when considering YLL per 100 000 inhabitants, the largest impacts are observed in central and eastern European countries where the highest concentrations of $PM_{2.5}$ are also observed, namely Kosovo, Serbia, Albania, Bulgaria and North Macedonia. The smallest relative impacts are found in countries situated in the north and north-west of Europe, namely Iceland, Norway, Sweden, Ireland and Finland.

For NO_2, the largest impacts from exposure are seen in Italy, Germany, Spain, the United Kingdom and France. When considering YLL per 100 000 inhabitants, the highest rates are found in Greece, Monaco, Romania, Cyprus, Italy and Spain. The smallest relative impacts are found in San Marino, Liechtenstein, Iceland, Malta, Finland, Estonia and Sweden.

Regarding O_3, the countries with the largest impacts are Germany, Italy, France, Spain and Poland. The countries with the highest rates of YLL per 100 000 inhabitants are Monaco, Albania, Hungary, Croatia and Czechia. The countries with the smallest impacts are Iceland, Ireland, the United Kingdom, Finland and Norway

Table 10.1 Premature deaths attributable to $PM_{2.5}$, NO_2 and O_3 exposure in 41 European countries and the EU-28, 2018

		$PM_{2.5}$		NO_2		O_3	
Country	**Population (1 000)**	**Annual mean ([a])**	**Premature deaths ([b])**	**Annual mean ([a])**	**Premature deaths ([b])**	**SOMO35 ([a])**	**Premature deaths ([b])**
Austria	8 822	13.6	6 100	17.7	790	6 731	420
Belgium	11 399	12.7	7 400	20.4	1 200	4 298	350
Bulgaria	7 050	21	12 500	19.0	1 100	3 765	320
Croatia	4 105	18	5 100	13.8	90	6 342	250
Cyprus	1 216	14.5	620	23.5	210	6 844	40
Czechia	10 610	18.3	10 900	15.5	300	6 946	580
Denmark	5 781	10.5	3 100	9.8	10	3 866	150
Estonia	1 319	7	610	7.1	< 1	2 793	30
Finland	5 513	5.9	1 700	8.6	< 1	2 351	90
France	64 456	10.6	33 100	15.9	5 900	5 274	2 300
Germany	82 792	12.3	63 100	19.1	9 200	5 674	4 000
Greece	10 741	18.3	11 800	21.0	3 000	7 157	650
Hungary	9 778	18.3	13 100	17.0	850	5 892	590
Ireland	4 830	7.8	1 300	11.0	50	2 556	60
Italy	60 484	15.5	52 300	20.1	10 400	6 490	3 000
Latvia	1 934	12.1	1 800	11.9	70	2 732	60
Lithuania	2 809	12.8	2 700	12.3	10	3 096	90
Luxembourg	602	10	210	20.2	40	4 604	10
Malta	476	12.5	230	10.4	< 1	5 498	10
Netherlands	17 181	12	9 900	20.4	1 600	3 620	410
Poland	37 977	21.7	46 300	15.6	1 900	5 095	1 500
Portugal	9 794	8.4	4 900	15.4	750	4 672	370
Romania	19 531	17.6	25 000	19.3	3 500	3 683	730
Slovakia	5 443	18.2	4 900	14.8	40	6 129	230
Slovenia	2 067	15.8	1 700	14.5	50	6 494	100
Spain	44 452	10.2	23 000	19.4	6 800	5 841	1 800
Sweden	10 120	6.1	3 100	8.7	< 1	3 465	240
United Kingdom	66 274	10	32 900	18.9	6 000	2 307	1 000
Albania	2 870	21.6	5 000	14.7	100	5 601	180
Andorra	75	8.5	30	18.1	< 1	6 593	< 1
Bosnia and Herzegovina	3 503	26.4	5 100	13.9	90	5 218	150
Iceland	348	4.7	60	10.4	< 1	1 999	< 1
Kosovo	1 799	28.2	4 000	17.0	90	3 922	80
Liechtenstein	38	8.6	20	16.5	< 1	7 045	< 1
Monaco	38	12.6	20	25.0	10	7 686	< 1
Montenegro	622	20.5	640	15.0	10	5 630	30
North Macedonia	2 075	30.7	3 000	19.0	130	3 533	50
Norway	5 296	6.4	1 400	10.0	40	3 128	90
San Marino	34	13.3	30	14.4	< 1	6 700	< 1
Serbia	7 001	26.3	14 600	17.3	430	3 500	280
Switzerland	8 484	9.8	3 500	17.6	270	7 214	350
EU-28 total	**507 558**	**13.2**	**379 000**	**17.8**	**54 000**	**4 970**	**19 400**
All countries total	**539 742**	**13.5**	**417 000**	**17.6**	**55 000**	**4 962**	**20 600**

Notes: ([a]) The annual mean (in μg/m³) and the SOMO35 (in μg/m³·days), expressed as population-weighted concentration, is obtained according to the methodology described by ETC/ATNI (2020d) and references therein and not only from monitoring stations.

([b]) Total and EU-28 premature deaths are rounded to the nearest thousand (except for O_3, nearest hundred). The national totals are rounded to the nearest hundred or ten.

Table 10.2 Years of life lost (YLL) attributable to $PM_{2.5}$, NO_2 and O_3 exposure in 41 European countries and the EU-28, 2018

Country	$PM_{2.5}$		NO_2		O_3	
	YLL ([a])	YLL/10^5 inhabitants ([b])	YLL ([a])	YLL/10^5 inhabitants ([b])	YLL ([a])	YLL/10^5 inhabitants ([b])
Austria	65 100	738	8 400	95	4 600	52
Belgium	83 000	728	13 700	120	4 000	35
Bulgaria	139 600	1 980	11 800	167	3 700	52
Croatia	54 900	1 337	950	23	2 800	68
Cyprus	7 000	576	2 400	197	480	39
Czechia	125 800	1 186	3 400	32	6 900	65
Denmark	35 300	611	110	2	1 900	33
Estonia	7 000	531	< 5	< 1	380	29
Finland	20 400	370	< 5	< 1	1 100	20
France	424 700	659	76 400	119	30 400	47
Germany	710 900	859	103 500	125	46 600	56
Greece	128 800	1 199	32 200	300	7 400	69
Hungary	152 400	1 559	9 900	101	7 000	72
Ireland	16 200	335	580	12	780	16
Italy	556 700	920	110 400	183	33 500	55
Latvia	21 300	1 101	810	42	690	36
Lithuania	30 000	1 068	90	3	1 000	36
Luxembourg	2 500	415	500	83	170	28
Malta	2 900	610	< 5	< 1	190	40
Netherlands	109 600	638	17 400	101	4 700	27
Poland	592 400	1 560	23 800	63	20 600	54
Portugal	53 000	541	8 200	84	4 100	42
Romania	297 300	1 522	41 300	211	9 200	47
Slovakia	64 200	1 179	520	10	3 200	59
Slovenia	21 000	1 016	600	29	1 200	58
Spain	254 700	573	75 400	170	20 600	46
Sweden	30 800	304	20	< 1	2 500	25
United Kingdom	373 300	563	67 900	102	12 500	19
Albania	57 400	2 000	1 200	42	2 200	77
Andorra	400	535	30	40	40	53
Bosnia and Herzegovina	60 500	1 727	1 100	31	1800	51
Iceland	670	192	< 5	< 1	40	11
Kosovo	44 200	2 458	960	53	920	51
Liechtenstein	180	472	< 5	< 1	20	52
Monaco	300	783	110	287	30	78
Montenegro	8 600	1 382	110	18	360	58
North Macedonia	37 200	1 793	1 600	77	700	34
Norway	15 200	287	450	8	1 100	21
San Marino	280	813	< 5	< 1	20	58
Serbia	161 200	2 302	4 800	69	3 200	46
Switzerland	38 900	459	3 000	35	4 100	48
EU-28 total	**4 381 000**	**863**	**610 000**	**120**	**232 000**	**46**
All countries total	**4 806 000**	**890**	**624 000**	**116**	**247 000**	**46**

Notes: ([a]) Total and EU-28 figures are rounded to the nearest thousand. National data are rounded to the nearest hundred or ten.

([b]) Total and EU-28 values per 100 000 inhabitants are not rounded.

10.3 Changes in health impact over time (2009 and 2018)

Quantifications of health impacts have been produced for 2009, the year analysed in the first *Air quality in Europe* report in 2011. The methodology described in Section 10.1 (including the concentration-response functions) was used for the calculations with 2009 air quality, population and health data. In 2009, in the 41 countries considered, 477 000 premature deaths are attributed to $PM_{2.5}$ exposure, 120 000 to NO_2 exposure and 17 100 to O_3 exposure. In the EU-28, the premature deaths attributed to $PM_{2.5}$, NO_2 and O_3 exposure are 437 000, 117 000, and 15 700, respectively.

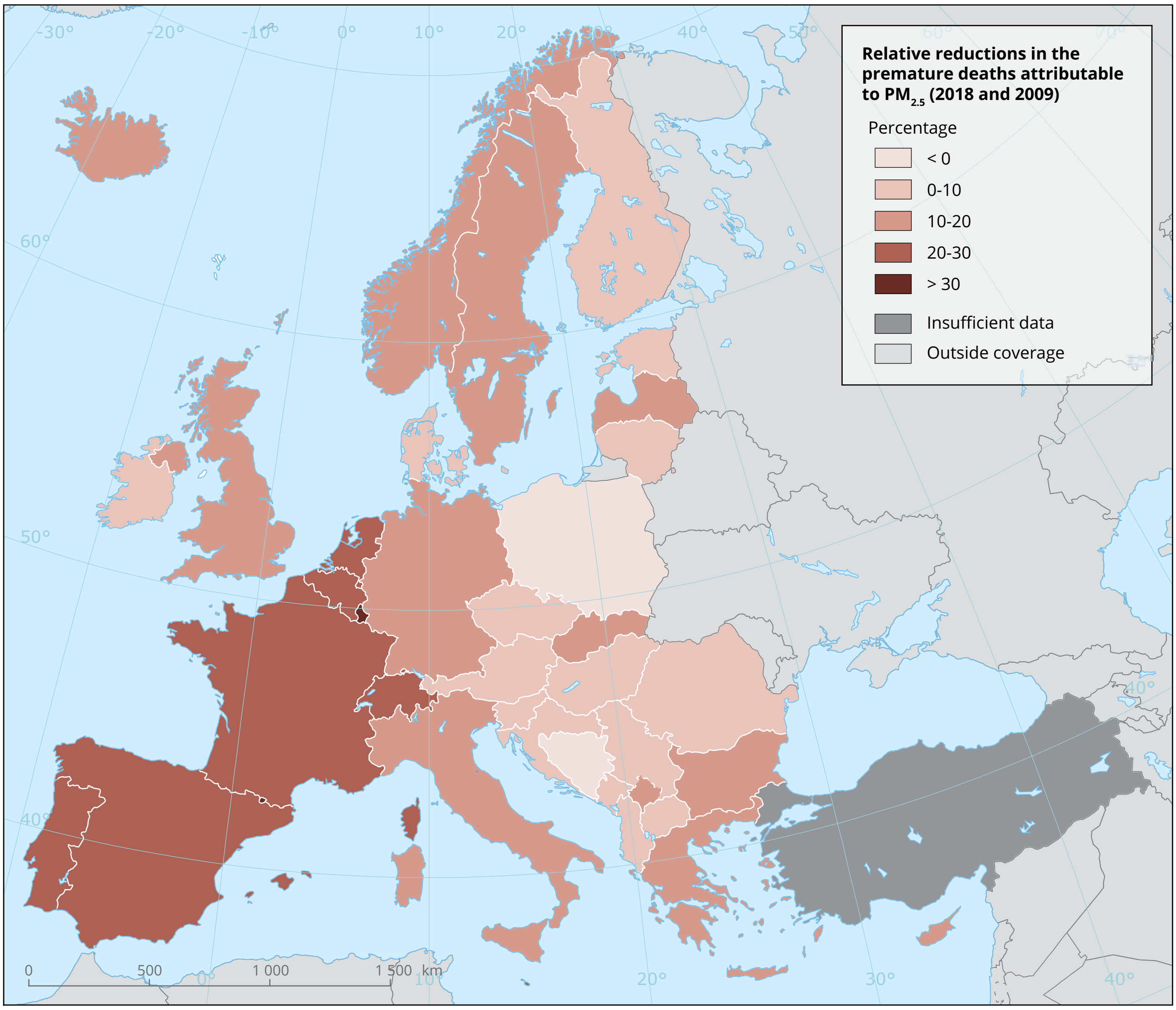
If the estimations for 2018 are compared with these figures, they show a relative reduction from 2009 to 2018 of 13 % in both the total European and the EU-28 mortality attributed to exposure to $PM_{2.5}$. This reduction partly reflects the reduction in $PM_{2.5}$ concentrations analysed in Section 4.3. The changes are also driven by population structure and changes in numbers of deaths in the 2 years considered. Map 10.1 shows the reduction by country ([62]).

For NO_2, the decrease in attributable deaths in the decade studied reaches an impressive 54 % for both the 41 European countries and the EU-28. This is again the consequence of the steady decreases in NO_2 concentrations shown in Section 6.3, certainly due to emission control measures adopted in all countries and also because, in many places, annual mean values have fallen below 20 µg/m^3, the threshold above which health impacts are calculated.

Finally, for O_3 an increment in attributable deaths of 20 % and 24 %, for the 41 European countries and the EU-28, respectively, is found. This is due to the effect of the high temperatures in 2018, which favoured the photochemical formation of O_3, increasing its concentrations and, therefore, its impacts on health.

([62]) This decrease in mortality might be underestimated. The increasing results found for $PM_{2.5}$ in Poland seem unrealistic and contradict the decreasing trends found in the corresponding analysis. This may be due to an underestimation of the concentrations in 2009. For the production of the 2009 concentration map, only 24 $PM_{2.5}$ stations were considered, complemented with information from 151 PM_{10} stations; for the production of the 2018 map, 88 $PM_{2.5}$ and 123 complementary PM_{10} stations were used, increasing the quality of the final result. Furthermore, some of the complementary PM_{10} stations show increasing trends and, finally, the ratio used for estimating $PM_{2.5}$ from the PM_{10} stations could also lead to an underestimation.

Map 10.1 Relative reductions in the premature deaths attributable to $PM_{2.5}$ (2018 and 2009)



Reference data: ©ESRI

11 Exposure of ecosystems to air pollution

Air pollution leads to environmental degradation and has impacts on natural ecosystems and biodiversity. Ground-level ozone (O_3) can damage crops, forests and other vegetation, impairing their growth and affecting biodiversity.

The deposition of nitrogen compounds can cause eutrophication, an oversupply of nutrients. Like sulphur compounds, nitrogen compounds also have acidifying effects. Both eutrophication and acidification can affect terrestrial and aquatic ecosystems and may lead to changes in species diversity and invasions by new species (Duprè et al., 2010). Acidification may also lead to increased mobilisation of toxic metals in water or soils, which increases the risk of uptake in the food chain.

Toxic metals and persistent organic compounds (POPs), in addition to their environmental toxicity, tend to bioaccumulate in animals and plants and to biomagnify, implying that concentrations in the tissues of organisms increase at successively higher levels in the food chain.

11.1 Ozone concentrations, trends and vegetation exposure to ground-level ozone

High levels of O_3 damage plant cells, impairing plants' reproduction and growth, thereby reducing agricultural crop yields, forest growth and biodiversity ([63]). In many parts of central and southern Europe, EU Natura 2000 grasslands are at risk as a result of exposure to current O_3 levels, which can change plant community composition and change flowering and seed production in some species (Harmens et al., 2016).

Changing climatic conditions and the increase in emissions of carbon dioxide (CO_2) and other pollutants, such as reactive nitrogen, modify the responses of vegetation to O_3. In addition to affecting plant growth, these modifiers influence the amount of O_3 taken up by leaves, thus altering the magnitude of effects on plant growth, crop yields and ecosystem services (Harmens et al., 2015).

The standards set by the EU to protect vegetation from high O_3 concentrations are shown in Table 1.2. In addition, the United Nations Economic Commission for Europe (UNECE) Convention on Long-range Transboundary Air Pollution (CLRTAP) (UNECE, 1979) defines a critical level (CL) for the protection of forests. For convenience, the standards are summarised in Table 11.1.

In 2018, the AOT40 (see Table 11.1) for the protection of vegetation could be calculated for 2 196 stations in 36 countries (the 2018 37 reporting countries, except Iceland): 1 794 were background stations and 564 were rural background stations (located in all the 36 countries except Greece and Montenegro). Of the total stations, 44 % (960) exceeded the AOT40 target value threshold in 2018; 49 % (881) of the background stations and 57 % (323) of the background rural stations exceeded the AOT40 target value threshold. In this last case they were located in 22 countries ([64]) (Map 11.1). Of all the stations, 82 % (1 797) show values above the long-term objective; 87 % (1 552) of the background stations and 91 % (515) of the rural background stations show values above the long-term objective. In this last case they were located in 32 countries (all with rural background stations except Bosnia and Herzegovina and Estonia)

In 2018 it was possible to calculate the AOT40 for protection of forests in 2 197 stations from 36 countries (the 2018 37 reporting countries, except Iceland); 1 798 were background and 564 were rural background stations (located in all the 36 countries except Greece and Montenegro). Of all the stations, 83 % (1 824) exceeded the CL for the protection of forests; 87 % (1 572) of the background and 93 % (523) of the rural background stations exceeded the CL for the protection

([63]) Several effects of damage to vegetation by ground-level O_3 were described in *Air quality in Europe — 2015 report* (EEA, 2015b).
([64]) Andorra, Austria, Belgium, Bulgaria, Croatia, Cyprus, Czechia, France, Germany, Hungary, Italy, Luxembourg, Malta, the Netherlands, North Macedonia, Poland, Portugal, Slovakia, Slovenia, Spain, Switzerland and Turkey.

Table 11.1 Air quality standards for protecting vegetation and forests from O_3

Pollutant	Averaging period	Standard type and concentration	Comments
O_3	AOT40 ([a]) accumulated over May to July	EU target value: 18 000 μg/m³·hours	Averaged over 5 years ([b])
		EU long-term objective: 6 000 μg/m³·hours	
	AOT40 ([a]) accumulated over April to September	CL for the protection of forests: 10 000 μg/m³·hours	Defined by the CLRTAP

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.

of forests; in the latter case these were located in all 34 countries with rural background stations, except Estonia.

To calculate vegetation exposure to O_3, concentration (AOT40) maps are annually produced (the latest are published in ETC/ATNI, 2020d and reproduced in the following section). Whereas the maps up to 2015 did not include Turkey, the maps produced from 2016 onwards do. The following two analyses will therefore be carried out: one excluding Turkey (which will be named EEA-32), so that a comparison can be made with years before 2016, and one including Turkey (named EEA-33), to obtain the complete picture.

Since 2000, the AOT40 value of 18 000 μg/m³·hours has been exceeded in a substantial part of the European agricultural area, as shown in Figure 11.1a (highest parts of the bars), albeit with large year-to-year variations. In 2018, the AOT40 value of 18 000 μg/m³·hours was exceeded in about 40 % of all agricultural land in the EEA-32 and 45 % of all agricultural land in the EEA-33. The situation for the EEA-32 has fluctuated between the minimum 15 % observed in 2016 and a maximum of 69 %, which was observed in 2006. The long-term objective was exceeded in 2018 in 95 % of the agricultural area of the EEA-32 and 96 % of the agricultural area of the EEA-33 (all bars in Figure 11.1a, except the green bars). This value also fluctuated for the EEA-32 between the minimum 72 % observed in 2017 and a maximum of 98 %, observed in 2006.

When it comes to all of the European countries considered in the 2018 calculations and the EU-28 (Map 11.1; ETC/ATNI, 2020d), the total agricultural area is 2 430 470 km² and 1 997 169 km², respectively. Of these, 45 % (1 090 133 km²) and 40 % (793 103 km²), respectively, were exposed to AOT40 values above the target value threshold and 96 % and 95 % were exposed to AOT40 values above the long-term objective.

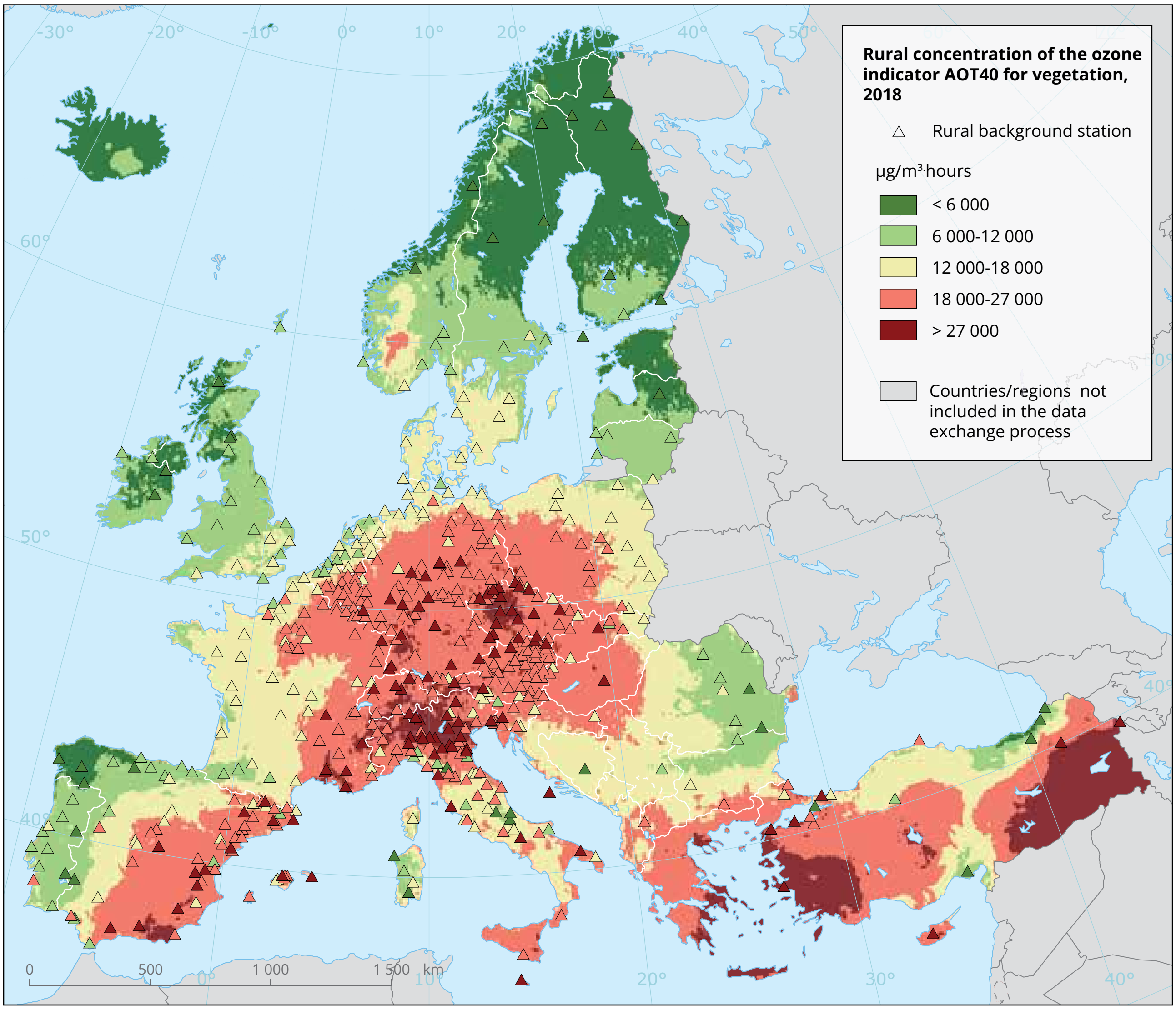
The exceedances of the CL for the protection of forest areas are even more pronounced than in the case of the target value for the protection of vegetation, as shown in Figure 11.1b (note that only the lowest parts of the bars correspond to exposures below the CL). In 2018, the CL was exceeded in 86 % of the total forest area in the EEA-32 and 87 % of the total forest area in the EEA-33. For the EEA-32, this is the third-highest value observed during the time series.

The CL was also exceeded in 88 % of the total forest area in all European countries and in 87 % of the EU-28 forest area (i.e. 1 485 119 out of 1 696 767 km² and 1 209 120 out of 1 393 819 km², respectively) in 2018 (Map 11.2; ETC/ATNI, 2020d.

The high levels of AOT40 in 2018 do not, however, directly relate to such a large effect of O_3 on vegetation, since the extreme drought in central and northern Europe was most likely to have reduced the vegetation's uptake of O_3, thus reducing the impact on vegetation. According to current scientific knowledge, the so-called phytotoxic O_3 dose flux approach is a better indicator of O_3 damage to vegetation, as it estimates the amount of O_3 that actually enters the plant via small pores (stomata) on the leaf surface. This amount depends on the opening and closing of the stomata under, for example, different temperature, humidity and light intensity conditions (ICP Vegetation, 2017).

The AOT40 for crops measured at rural stations from 2009 to 2018 shows a high interannual variability (Figure 11.2). Only 10 % of rural stations show a significant trend in AOT40 for crops, mostly increasing (Figure 11.3). Map 11.3 shows that the stations with significant increasing trends are mostly located over central-eastern Europe, while significant decreasing trends were mostly found in southern European countries (Table A2.9, Annex 2).

Map 11.1 Rural background concentration of the O_3 indicator AOT40 for vegetation and crops, 2018

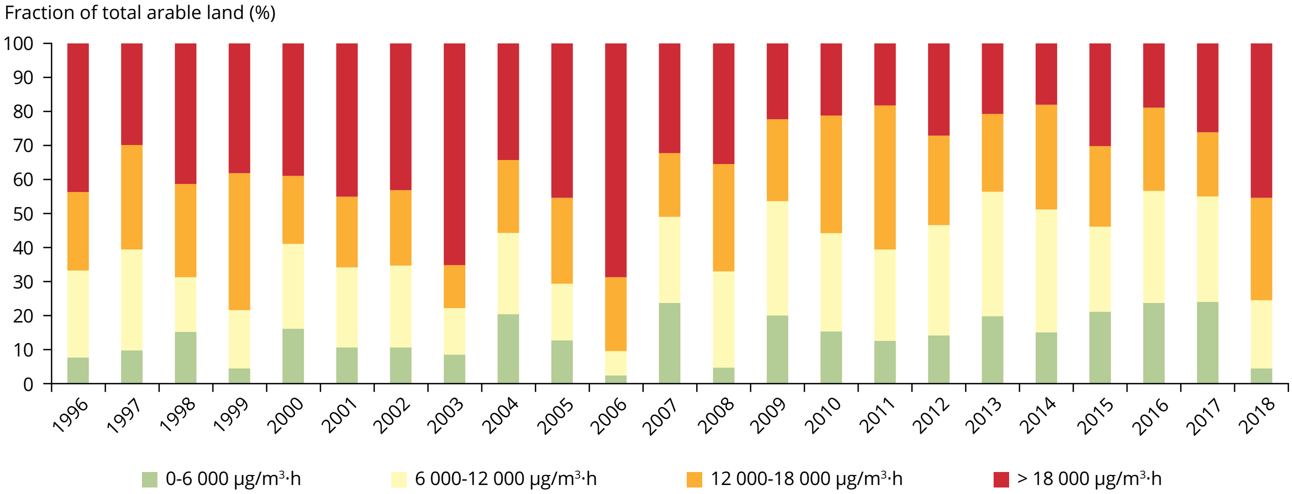


Reference data: ©ESRI

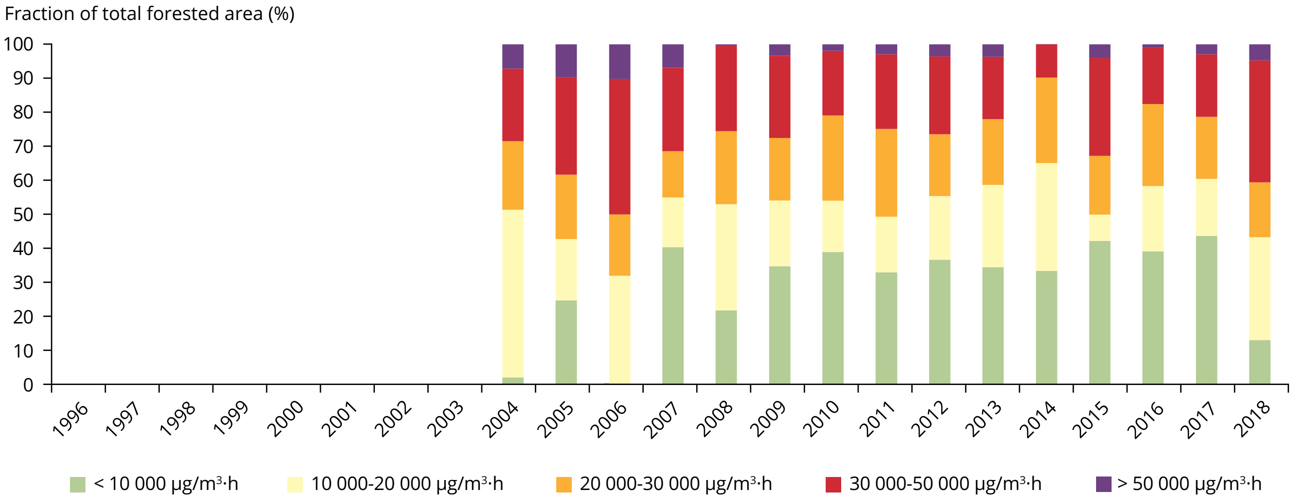
Source: ETC/ATNI (2020d).

Figure 11.1 Exposure of (a) agricultural area and (b) forest area to O_3 (AOT40) in the EEA member countries, from 1996 (a) and 2004 (b) to 2018

a)



b)



Notes: (a) In the Ambient Air Quality Directive (EU, 2008), the target value for protection of vegetation is set at 18 000 µg/m³·hours, averaged over 5 years, whereas the long-term objective is set at 6 000 µg/m³·hours. Only yearly values of the AOT40 are considered in the graph, without any averaging over years.

Owing to a lack of detailed land cover data and/or rural O_3 data, Iceland and Norway were included in the calculations in 2007; Switzerland was included in 2008 and Turkey in 2016; therefore, only data from 2016 onwards correspond to the EEA-33.

(b) The UNECE CLRTAP (UNECE, 1979) has set a CL for the protection of forests at 10 000 µg/m³·hours.

Bulgaria, Greece and Romania were added to the calculations in 2005, Iceland and Norway in 2007, and Switzerland in 2008. Turkey has been included only since 2016; therefore, only data from 2016 onwards correspond to the EEA-33.

Source: EEA (2020d).

In the period 2000-2017, the AOT40 for crops was reduced by 21 %, but interannual variability is so large that the trend is not significant. In the case of the AOT40 for forest, the trend was significant and the reduction was 32 % (ETC/ATNI, 2020c).

11.2 Eutrophication

Air pollution contributes to eutrophication (an excess of nutrient nitrogen), as the nitrogen emitted to the air as nitrogen oxides (NO_X) and ammonia (NH_3) is deposited on soils, vegetation surfaces and waters.

Eutrophication (and acidification) effects due to deposition of air pollution are estimated using the 'critical load' concept. This term describes the ecosystem's ability to absorb eutrophying nitrogen pollutants (or acidifying pollutants, in the case of acidification) deposited from the atmosphere, without the potential to cause negative effects on the natural environment. Exceedances of these spatially determined critical loads are estimated using ecosystem classification methods and model calculations.

EMEP (2020a) estimated that critical loads for eutrophication were exceeded in virtually all European countries and over about 65 % of the European ecosystem area (3 million km^2) in 2018. As in previous years, the highest exceedances in 2018 were modelled in the Po valley (Italy), in the Dutch-German-Danish border areas and in north-eastern Spain.

11.3 Acidification

Air pollution contributes to acidification through the emission of nitrogen and sulphur compounds into the atmosphere, which transform into nitric acid and sulphuric acid, respectively. When these airborne acids fall onto the Earth' surface and its waters as acid deposition, they reduce the pH levels of soil and water.

Owing to the considerable reductions in emissions of sulphur oxides (SO_X) over the past three decades, nitrogen compounds emitted as NO_X have become the principal acidifying components in both terrestrial and aquatic ecosystems, in addition to their role in causing eutrophication. However, emissions of SO_X, which have a higher acidifying potential than NO_X, still contribute to acidification.

Similar to eutrophication effects, acidification effects are estimated using the concept of 'critical load' (Section 11.2). EMEP (2020a) estimated that exceedances of the critical loads for acidification occurred over about 6 % of the European ecosystem area in 2018. Hotspots of exceedances occurred, as usual, in the Netherlands and its borders with Germany and Belgium and in small parts of southern Germany and Czechia. However, most of Europe did not exceed the critical loads for acidification in 2018.

11.4 Vegetation exposure to nitrogen oxides and sulphur dioxide

CLs for NO_X and sulphur dioxide (SO_2) for the protection of vegetation are set by the Ambient Air Quality Directive (EU, 2008), as shown in Table 1.2. For convenience, they are summarised in Table 11.2. The sampling points targeting the protection of vegetation must be situated more than 20 km away from agglomerations or more than 5 km away from other built-up areas, major industrial sites and major roads, which corresponds to rural background stations (Box 1.1).

The NO_X annual CL for the protection of vegetation (30 µg/m^3) was exceeded in 2018 at eight rural background stations in the Netherlands (four), Italy (three) and Germany (one) (EEA, 2020g).

ETC/ATNI (2020d) estimated that in most areas of Europe the annual NO_X means are below 20 µg/m^3. However, in the Po valley, the southern part of the Netherlands, northern Belgium, the German Ruhr region and a few rural areas close to major cities, NO_X concentrations above the CL were estimated for 2018 (Map 5.2 in ETC/ATNI, 2020d). Vegetation in those areas would be exposed to concentrations above the CL.

Table 11.2 Air quality standards for protecting vegetation from NO_X and SO_2

Pollutant	Averaging period	Standard type and concentration	Comments
NO_X	Calendar year	EU CL: 30 µg/m³	
SO_2	Winter	EU CL: 20 µg/m³	1 October to 31 March
	Calendar year	EU CL: 20 µg/m³	

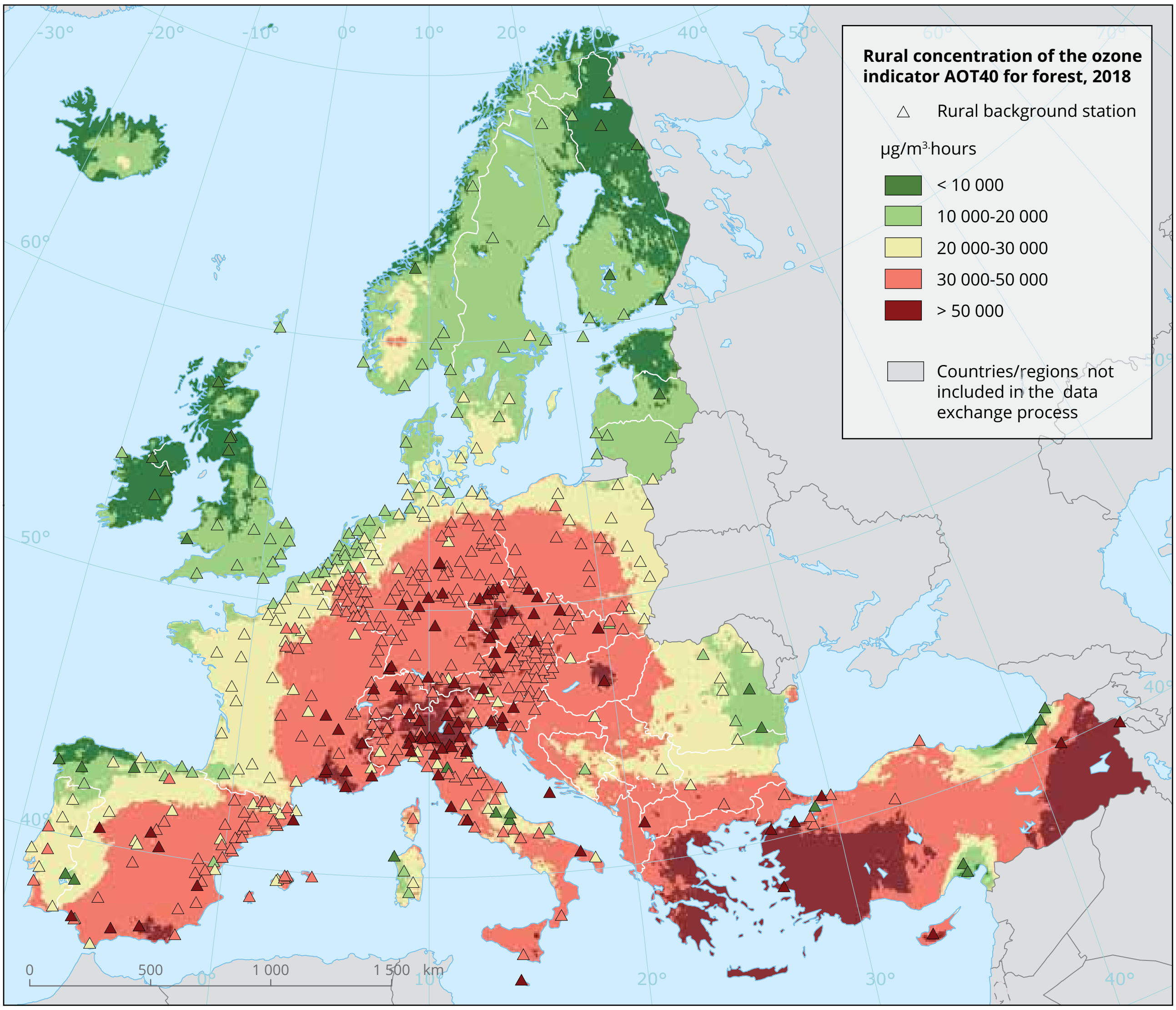
In 2018, there were no exceedances of the SO_2 CLs in any of the reported rural background stations (EEA, 2020g).

11.5 Environmental impacts of toxic metals

Toxic metal pollutants can cause harmful effects in plants and animals, in addition to humans. Although their atmospheric concentrations may be low, they still contribute to the deposition and build-up of toxic metals in soils, sediments and organisms. For instance, lead (Pb) and cadmium (Cd) affect the biodiversity of soil species and reduce plant growth. In addition, these metals tend to accumulate in plant tissues and transfer to human organisms through food chains. Mercury (Hg) in water bodies accumulates in fish and affects human health through fish consumption (EMEP, 2018). More information can be found in Chapter 8 of the *Air quality in Europe — 2019 report* (EEA, 2019).

The EMEP model (EMEP, 2020b) estimated the 2018 deposition of heavy metals. It found that the highest deposition of Pb, Cd and Hg took place in central and southern Europe. Elevated Hg deposition was also predicted in the High Arctic as a result of intensive Hg oxidation during springtime. Finally, the lowest deposition fluxes were found in northern Europe.

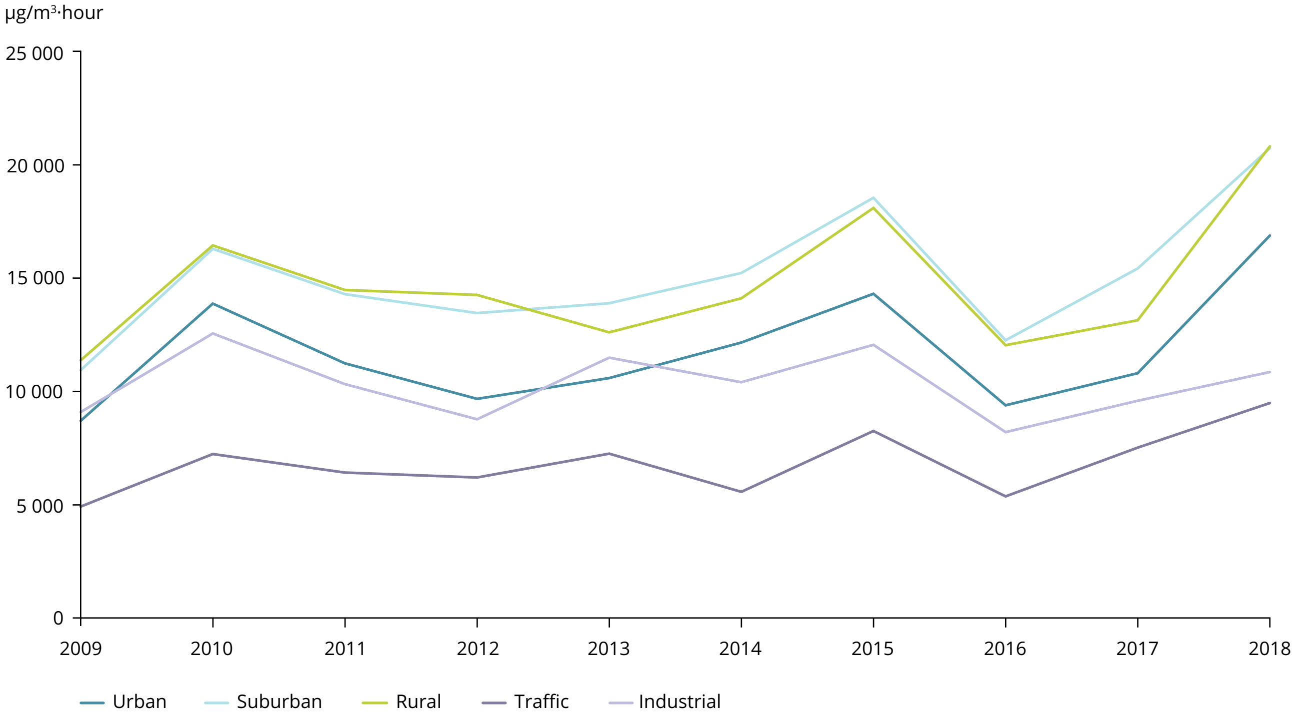
Map 11.2 **Rural background concentration of the O_3 indicator AOT40 for forests, 2018**



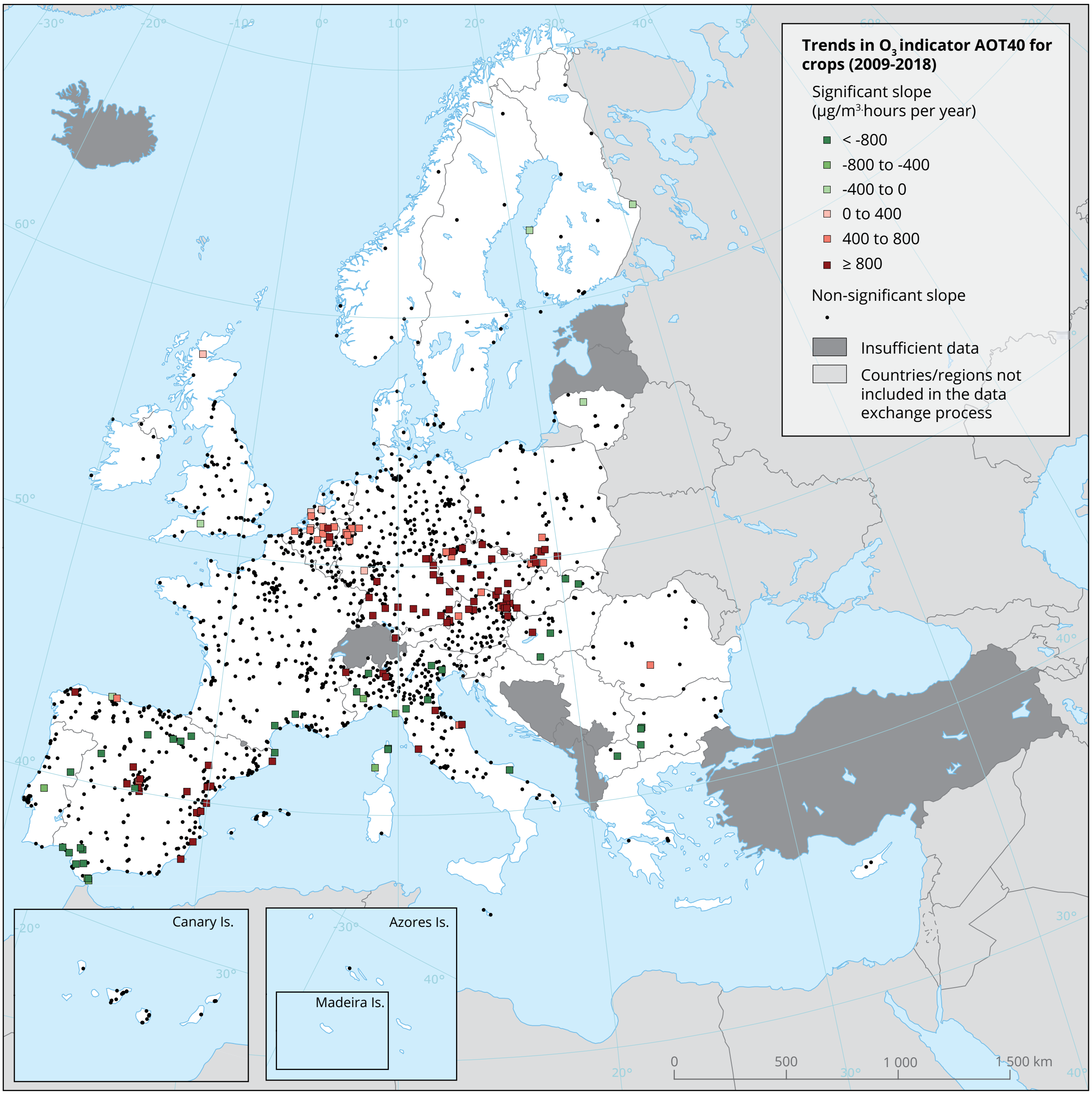
Reference data: ©ESRI

Source: ETC/ATNI (2020d).

Figure 11.2 Average O_3 indicator AOT40 for vegetation and crops per station type



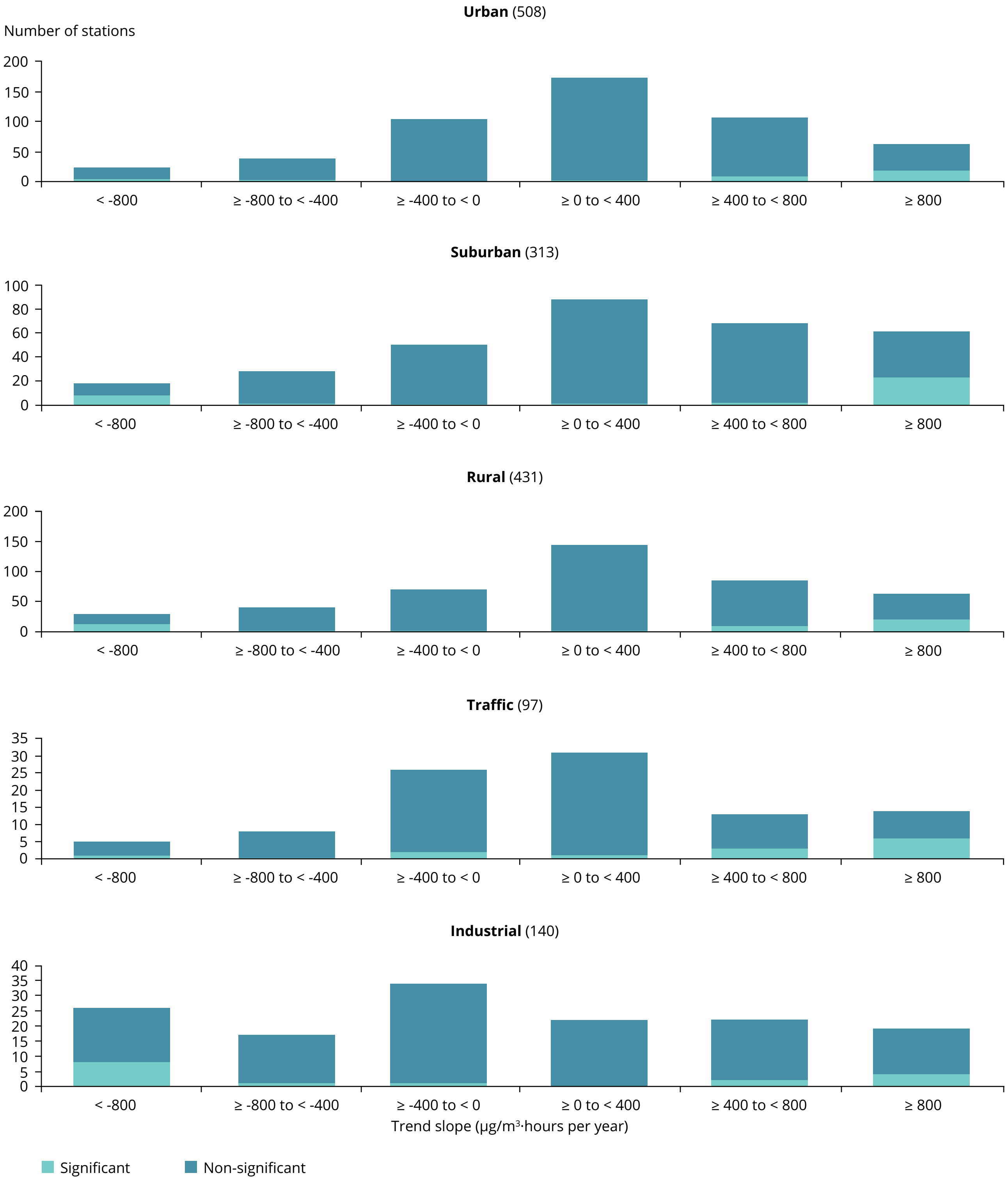
Map 11.3 Trends in O_3 indicator AOT40 for vegetation and crops (2009-2018)



Reference data: ©ESRI

Note: For further information, please see Annex 2.

Figure 11.3 Trend slope distribution (2009-2018) for O_3 indicator AOT40 for vegetation and crops, per station type, for both significant and non-significant trends



Note: The calculated trend slope represents the average change in AOT40 per year at each station in the period 2009-2018. The graphs should be read in relation to Map 11.3 and Table A2.9.

Abbreviations, units and symbols

μg/m^3	Microgram(s) per cubic metre
AEI	Average exposure indicator for $PM_{2.5}$ concentrations
AOT40	Accumulated exposure over a threshold of 40 ppb. This represents the sum of the differences between hourly concentrations > 80 μg/m^3 (40 ppb) and 80 μg/m^3 accumulated over all hourly values measured between 08.00 and 20.00 Central European Time
AQG	Air quality guideline
As	Arsenic
BaP	Benzo[*a*]pyrene
BAU	Business as usual
BC	Black carbon
CAMS	Copernicus Atmosphere Monitoring Service
C_6H_6	Benzene
Cd	Cadmium
CH_4	Methane
CI	Confidence interval
CL	Critical level
CLRTAP	Convention on Long-range Transboundary Air Pollution
CO	Carbon monoxide
COVID-19	Coronavirus disease 2019
CTM	Chemical transport model
ECO	Exposure concentration obligation
EEA	European Environment Agency
EMEP	European Monitoring and Evaluation Programme
ETC/ACM	European Topic Centre for Air Pollution and Climate Change Mitigation
ETC/ATNI	European Topic Centre on Air Pollution, Noise, Transport and Industrial Pollution

EU	European Union
GAM	Generalised additive model
GDP	Gross domestic product
GVA	Gross value added
Hg	Mercury
HRAPIE	Health Risks of Air Pollution in Europe
LAT	Lower assessment threshold
mg/m^3	Milligram(s) per cubic metre
NEC	National Emission reduction Commitments (Directive)
NERT	National exposure reduction target
ng/m^3	Nanogram(s) per cubic metre
NGO	Non-governmental organisation
NH_3	Ammonia
Ni	Nickel
NMVOC	Non-methane volatile organic compound
NO	Nitrogen monoxide
NO_2	Nitrogen dioxide
NO_X	Nitrogen oxides
O_3	Ozone
PAH	Polycyclic aromatic hydrocarbon
Pb	Lead
PM	Particulate matter
$PM_{2.5}$	Particulate matter with a diameter of 2.5 µm or less
PM_{10}	Particulate matter with a diameter of 10 µm or less
POP	Persistent organic pollutant
ppb	Parts per billion
RL	Reference level
SDG	Sustainable Development Goal
SO_2	Sulphur dioxide

SOMO35	Accumulated O_3 concentration (8-hour daily maximum) in excess of 35 ppb
SO_x	Sulphur oxides
TOE	Tonnes of oil equivalent
TROPOMI	Tropospheric Monitoring Instrument
UN	United Nations
UNECE	United Nations Economic Commission for Europe
UNEP	United Nations Environment Programme
UTD	Up-to-date
VOC	Volatile organic compound
WHO	World Health Organization
YLL	Years of life lost

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Annex 1 Air quality monitoring stations reporting 2018 data

This annex presents additional information on the stations with 2018 data considered for the assessment and officially reported by the 37 reporting countries (Box 1.1). For the main pollutants, for each aggregation metrics, one graph shows the frequency distribution of all the concentrations reported and one graph shows the increasing concentrations by station type and area type. The definition of station type and area type can be found in Box 1.1.

Particulate matter with a diameter of 10 μm or less (PM_{10})

Figure A1.1 Frequency distribution of the 90.4 percentile concentrations of PM_{10}, 2018

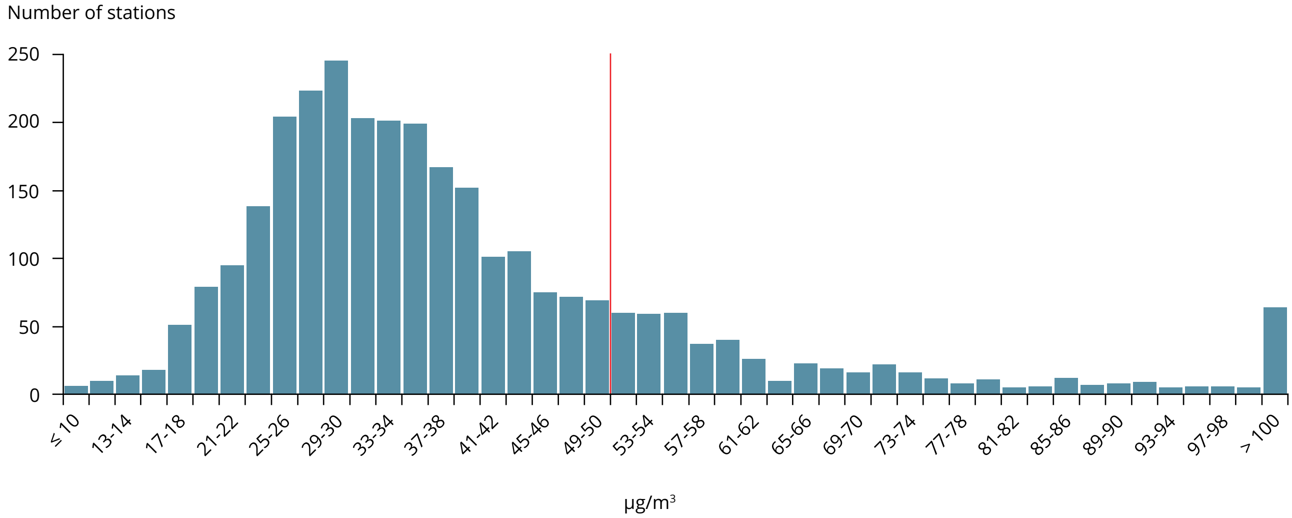


Figure A1.2 90.4 percentile of PM_{10} concentrations by station and area type, 2018

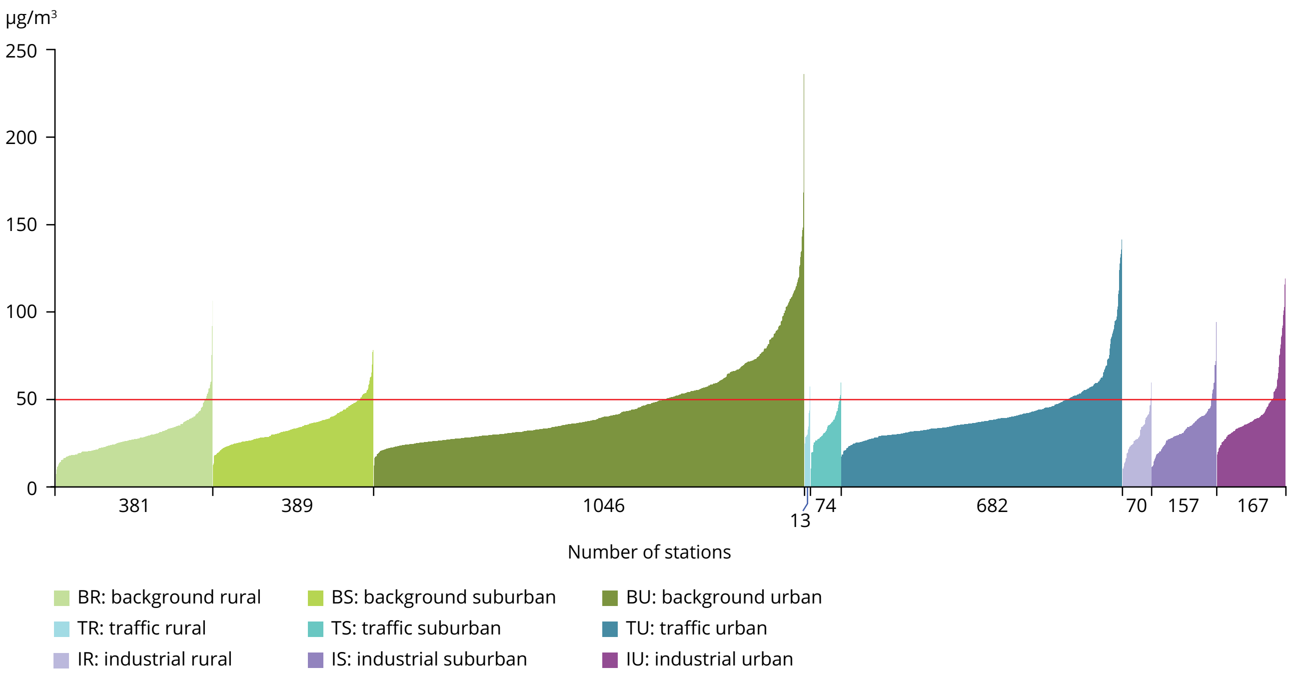


Figure A1.3 Frequency distribution of the annual mean concentrations of PM_{10}, 2018

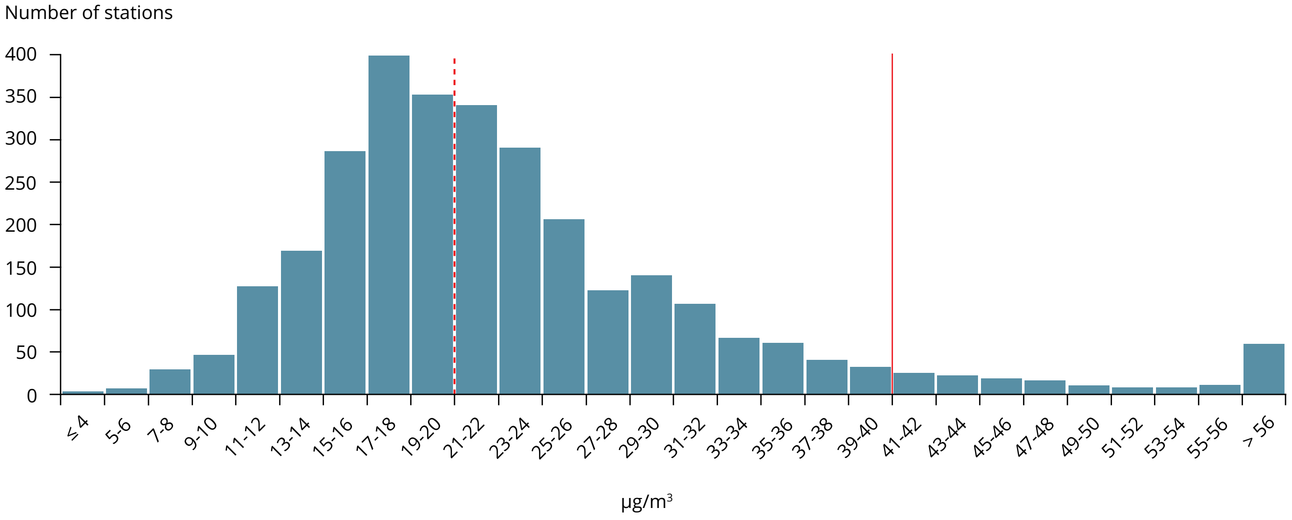
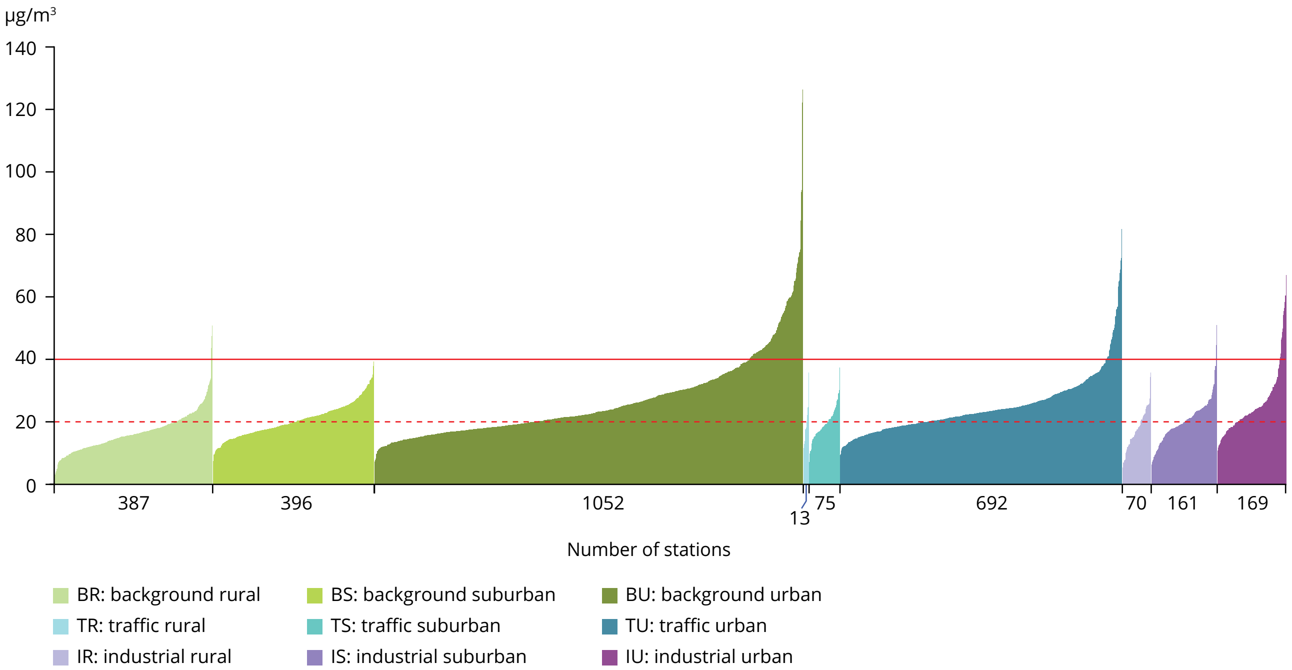


Figure A1.4 Annual mean concentrations of PM_{10} by station and area type, 2018



Particulate matter with a diameter of 2.5 µm or less ($PM_{2.5}$)

Figure A1.5 Frequency distribution of the annual mean concentrations of $PM_{2.5}$, 2018

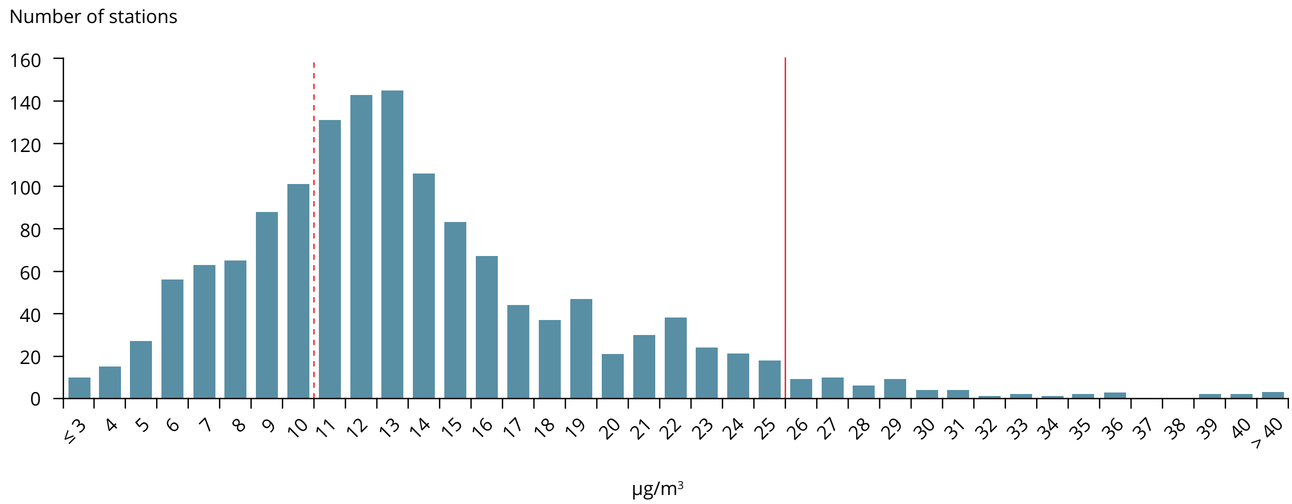
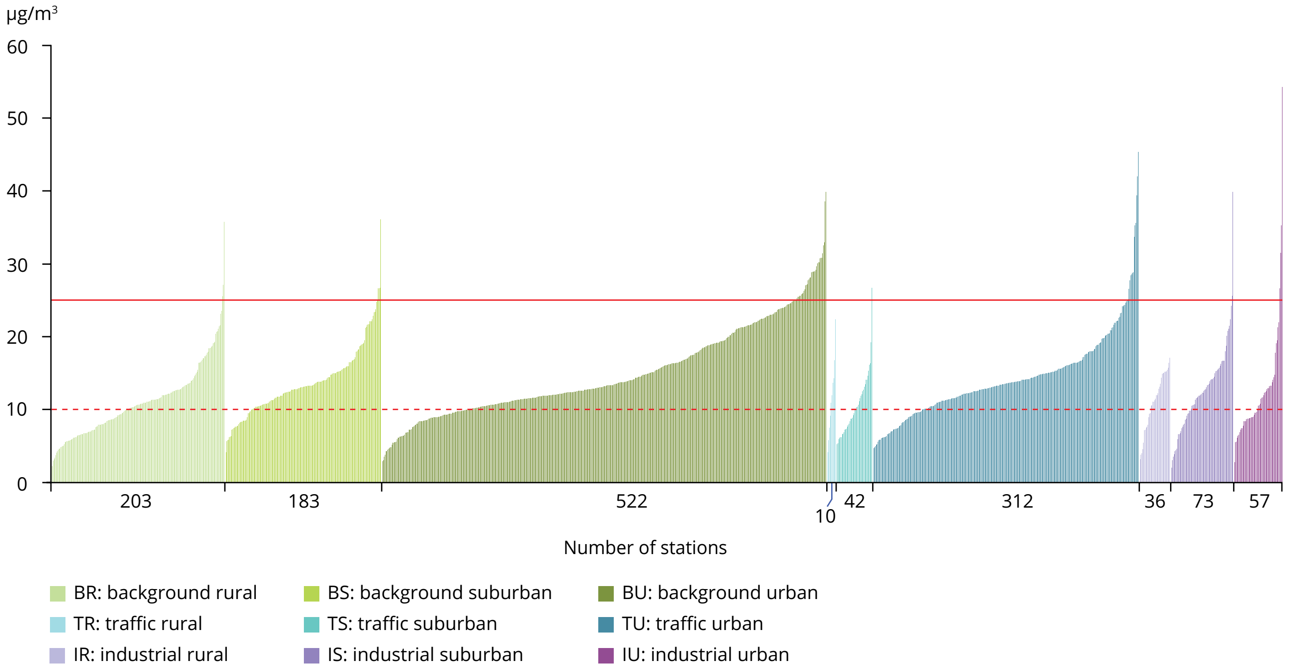


Figure A1.6 Annual mean concentrations of $PM_{2.5}$ by station and area type, 2018



Ozone (O_3)

Figure A1.7 Frequency distribution of the 93.2 percentile concentrations of O_3, 2018

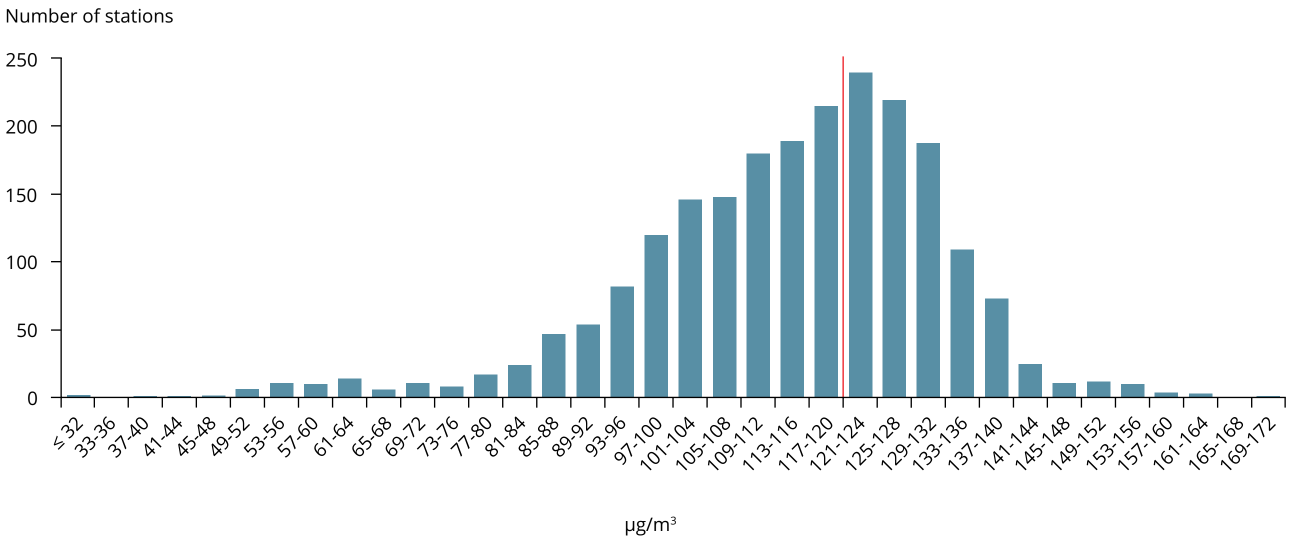
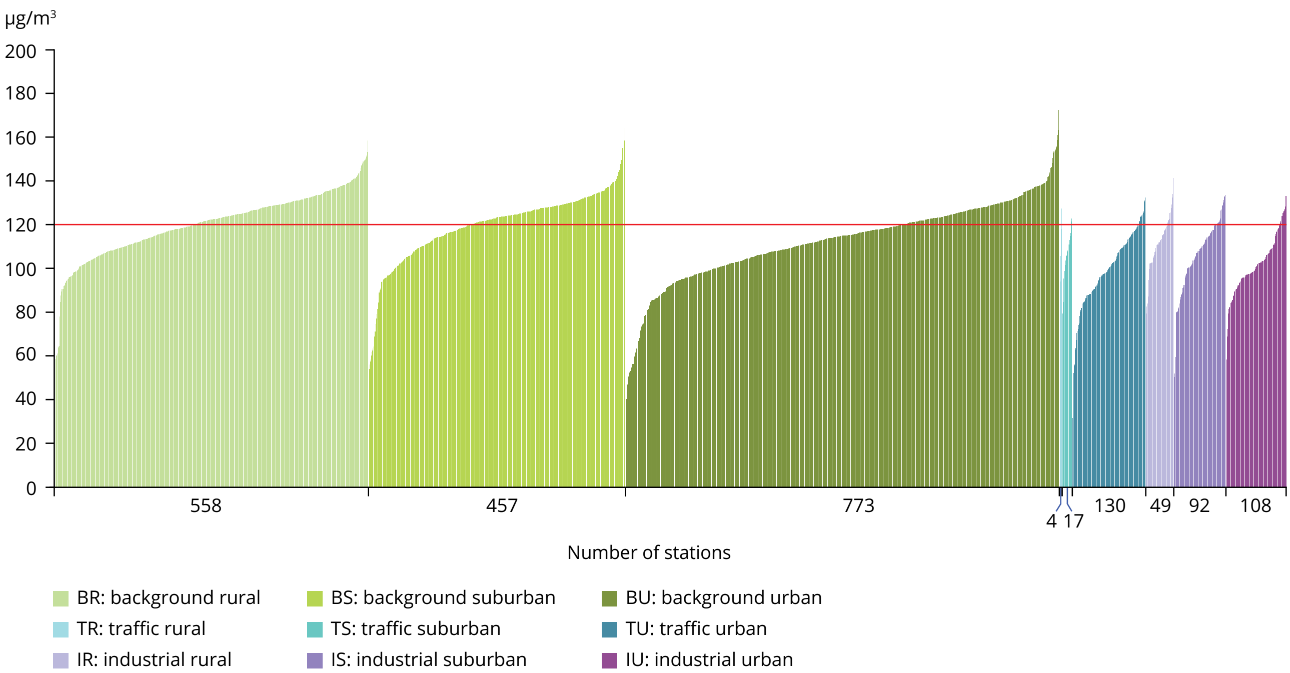


Figure A1.8 93.2 percentile of O_3 concentrations by station and area type, 2018



Nitrogen dioxide (NO_2)

Figure A1.9 Frequency distribution of the annual mean concentrations of NO_2, 2018

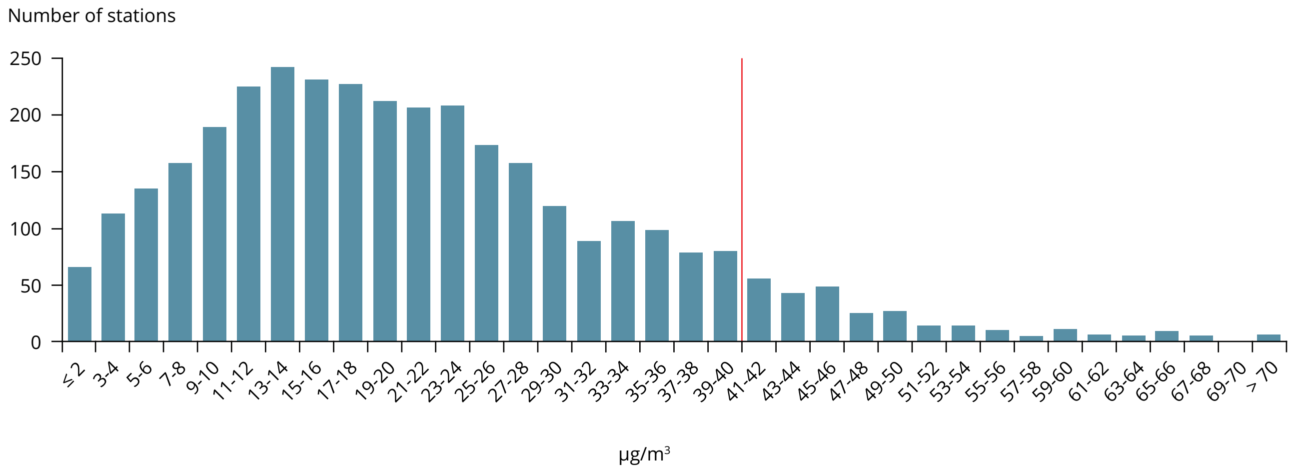
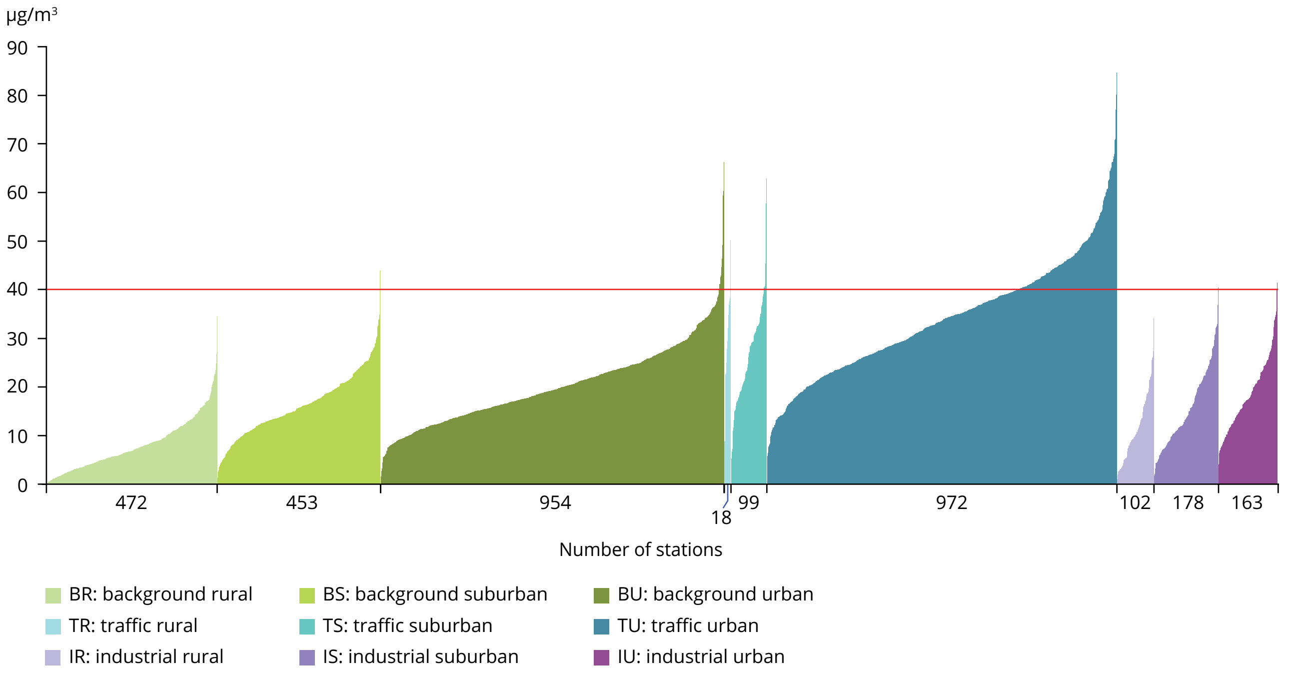


Figure A1.10 Annual mean concentrations of NO_2 by station and area type, 2018



Benzo[*a*]pyrene (BaP)

Figure A1.11 Frequency distribution of the annual mean concentrations of BaP, 2018

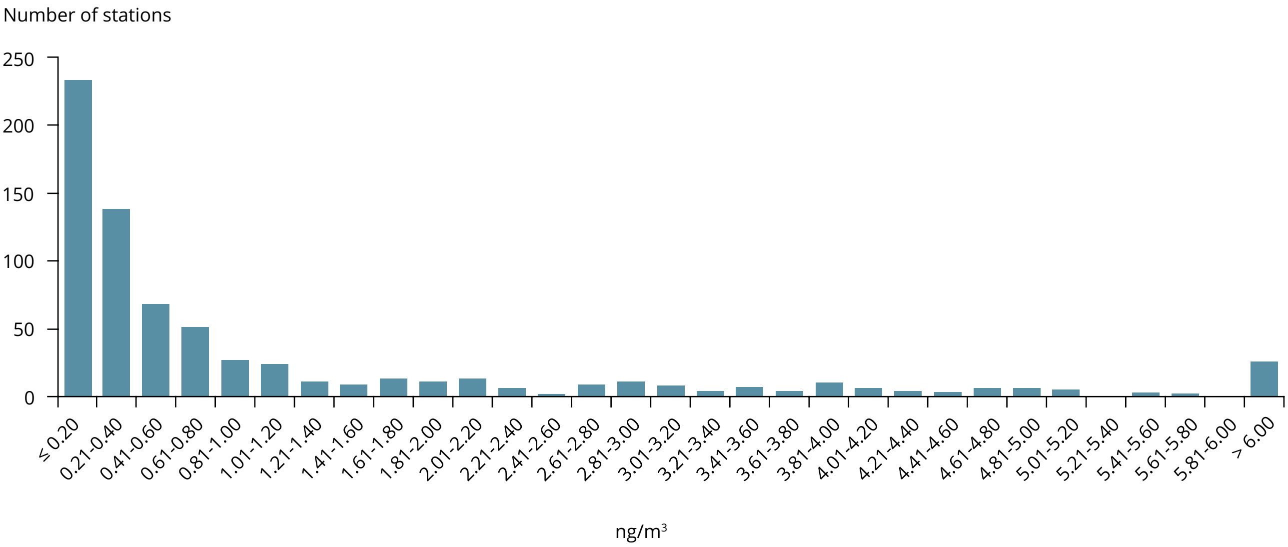
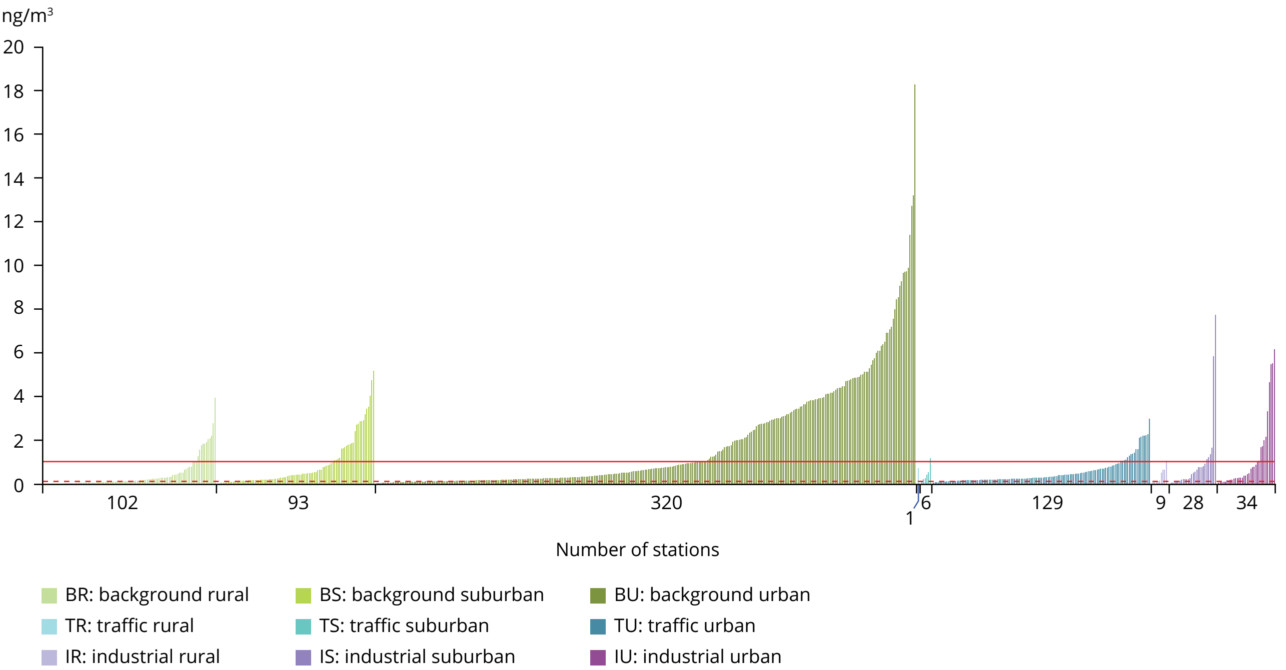


Figure A1.12 Annual mean concentrations of BaP by station and area type, 2018



Annex 2 Trends in air pollutant concentrations at country level

A trend analysis considering observations at the monitoring sites across Europe and officially reported by the EEA member and cooperating countries from 2009 to 2018 and available from the EEA (2020c) is presented here. Metrics relevant to the EU Ambient Air Quality Directive (EU, 2008), and for impacts on human health and ecosystems were estimated for each year and for each given station. All the data included in the EEA database that complied with data completeness criteria were used in the present study. The first criterion for data completeness is that any station with less than 75 % of the records available for a year is discarded; the second is to remove any station with less than 8 years of data available (75 % of the years in the period analysed). Furthermore, metadata on the station and area types have to be available for the stations to be considered. The analysis differentiates background station type in urban, suburban and rural areas and considered traffic and industrial stations as unique categories, irrespective of their area types.

The statistical method applied for the trend detection is the Mann-Kendall test (Gilbert, 1987) (with an α of 0.05) and the actual slope is estimated using the Sen-Theil approach. A trend is considered significant when the significance of the Mann-Kendall test, the p-value, is lower than 0.05 (α). That means that there is a 95 % probability of the existence of a monotonic trend. If, on the contrary, there is less than 95 % probability of the existence of a monotonic trend, there is no trend. In this report, and in order to account for the average change in concentrations per year over the period assessed, we refer to it as a 'non-significant' trend and it is taken into account when calculating the trend slopes presented in the tables below. (Nevertheless, in the maps, only significant trends appear with their value.)

In the tables, the following abbreviations are used:

- nsta: number of stations fulfilling the data completeness criteria and included in the analysis;
- nsig: number of stations with statistically significant trends;
- slope: average slope for all the stations;
- 2stddev: standard deviation;
- NA: not available.

Table A2.1 Particulate matter with a diameter of 10 µm or less (PM_{10}) annual mean

Country	All stations				Urban and suburban background				Traffic				Industrial				Rural background			
	nsta	nsig	slope	2stddev	nsta	nsig	slope	2stddev	nsta	nsig	slope	2stddev	nsta	nsig	slope	2stddev	nsta	nsig	slope	2stddev
All	1 685	938	-0.67	1.13	826	469	-0.70	1.07	427	261	-0.79	1.10	197	95	-0.61	1.57	235	113	-0.40	0.75
EU-28	1 653	920	-0.67	1.07	815	462	-0.70	1.07	409	252	-0.79	1.07	194	93	-0.61	1.20	235	113	-0.40	0.75
AT	113	82	-0.81	0.66	71	53	-0.84	0.70	14	10	-0.87	0.44	6	4	-0.87	0.67	22	15	-0.60	0.47
BE	52	40	-0.80	0.75	22	16	-0.83	0.93	1	1	-1.04	NA	16	11	-0.76	0.71	13	12	-0.75	0.45
BG	31	22	-1.40	2.29	20	15	-1.63	1.71	6	4	-1.29	2.65	3	2	0.53	3.22	2	1	-0.65	0.23
CY	3	3	-1.60	0.83	1	1	-1.60	NA	1	1	-1.60	NA	0	0	NA	NA	1	1	-0.88	NA
CZ	84	42	-0.53	1.00	47	28	-0.62	1.05	13	6	-0.46	0.58	1	1	-1.64	NA	23	7	-0.38	0.91
DE	324	236	-0.62	0.69	140	99	-0.59	0.61	105	90	-0.84	0.66	22	13	-0.63	0.63	57	34	-0.38	0.42
DK	1	0	0.10	NA	0	0	NA	NA	1	0	0.10	NA	0	0	NA	NA	0	0	NA	NA
EE	7	1	-0.25	0.72	3	1	-0.25	1.02	1	0	-0.18	NA	2	0	-0.61	0.62	1	0	-0.24	NA
EL	2	0	-1.19	1.48	2	0	-1.19	1.48	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA
ES	228	87	-0.49	1.19	68	24	-0.39	1.28	59	27	-0.71	1.03	74	30	-0.53	1.27	27	6	-0.21	0.65
FI	31	17	-0.49	0.68	6	4	-0.46	0.18	21	10	-0.49	0.80	4	3	-0.44	0.40	0	0	NA	NA
FR	209	144	-0.90	0.75	147	101	-0.89	0.70	29	24	-1.00	0.83	22	12	-0.87	0.87	11	7	-0.80	0.59
HR	2	1	1.10	1.91	0	0	NA	NA	2	1	1.10	1.91	0	0	NA	NA	0	0	NA	NA
HU	22	7	-0.60	1.24	12	5	-0.67	0.95	7	1	-0.58	1.61	1	0	0.51	NA	2	1	-0.42	0.98
IE	7	2	-0.18	0.47	5	2	-0.38	0.53	1	0	-0.18	NA	0	0	NA	NA	1	0	-0.14	NA
IT	243	104	-0.66	0.94	109	42	-0.64	0.80	83	42	-0.75	0.94	19	10	-0.59	1.19	32	10	-0.29	0.97
LT	14	5	-0.58	2.00	5	1	-0.09	1.48	5	2	-0.64	2.74	4	2	-0.60	2.01	0	0	NA	NA
LU	1	1	-0.89	NA	1	1	-0.89	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA
LV	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA
MT	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA
NL	40	35	-0.90	0.53	10	7	-0.81	0.62	12	11	-1.01	0.63	0	0	NA	NA	18	17	-0.89	0.38
PL	114	41	-0.66	1.56	99	38	-0.67	1.53	6	1	-0.73	1.57	3	1	-0.56	3.16	6	1	-0.21	1.01
PT	30	11	-0.55	1.28	11	5	-0.75	1.00	5	4	-1.08	1.53	4	1	-0.87	1.37	10	1	-0.13	0.42
RO	14	3	-0.29	1.24	3	2	-1.26	1.40	5	1	-0.31	1.29	6	0	-0.07	0.59	0	0	NA	NA
SE	20	7	-0.35	0.90	3	2	-0.32	0.30	14	5	-0.76	0.90	0	0	NA	NA	3	0	-0.03	0.30
SI	13	5	-0.66	0.59	10	5	-0.68	0.62	1	0	-0.66	NA	0	0	NA	NA	2	0	-0.37	0.08

Table A2.1 Particulate matter with a diameter of 10 µm or less (PM_{10}) annual mean *(cont.)*

	All stations				Urban and suburban background				Traffic				Industrial				Rural background			
Country	nsta	nsig	slope	2stddev	nsta	nsig	slope	2stddev	nsta	nsig	slope	2stddev	nsta	nsig	slope	2stddev	nsta	nsig	slope	2stddev
SK	14	8	-0.90	1.51	7	4	-0.91	1.72	5	4	-1.21	1.05	0	0	NA	NA	2	0	-0.25	1.25
UK	36	18	-0.55	0.78	14	7	-0.51	0.59	13	8	-0.66	1.02	7	3	-0.49	0.50	2	0	-0.19	0.80
AL	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA
BA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA
CH	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA
IS	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA
ME	2	1	-0.81	5.90	1	0	-2.90	NA	1	1	1.28	NA	0	0	NA	NA	0	0	NA	NA
MK	3	2	-2.50	7.11	0	0	NA	NA	1	0	-0.75	NA	2	2	-5.05	7.20	0	0	NA	NA
NO	25	13	-0.53	1.21	9	6	-0.53	0.62	15	7	-0.54	1.49	1	0	-0.39	NA	0	0	NA	NA
RS	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA
TR	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA
XK	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA

Table A2.2 PM_{10} 90.4 percentile of the daily concentrations

	All stations				Urban and suburban background				Traffic				Industrial				Rural background			
Country	nsta	nsig	slope	2stddev	nsta	nsig	slope	2stddev	nsta	nsig	slope	2stddev	nsta	nsig	slope	2stddev	nsta	nsig	slope	2stddev
All	1 685	295	-1.0	3.7	826	156	-1.1	3.7	427	46	-0.7	3.5	197	38	-1.1	3.8	235	55	-1.5	3.5
EU-28	1 653	289	-1.0	3.7	815	151	-1.0	3.7	409	45	-0.7	3.6	194	38	-1.1	3.7	235	55	-1.5	3.5
AT	113	14	-1.0	2.3	71	8	-1.0	2.2	14	2	-0.6	2.8	6	0	-1.2	2.2	22	4	-1.3	2.1
BE	52	11	-0.8	2.6	22	5	-0.9	2.3	1	0	-1.4	NA	16	2	-0.1	1.7	13	4	-2.0	2.4
BG	31	6	2.4	4.2	20	5	3.0	3.8	6	0	1.8	4.3	3	1	2.0	0.8	2	0	-1.7	0.5
CY	3	0	2.6	3.0	1	0	2.6	NA	1	0	3.1	NA	0	0	NA	NA	1	0	0.3	NA
CZ	84	4	-0.6	3.5	47	2	-0.6	3.5	13	0	-0.3	2.2	1	0	-3.8	NA	23	2	-1.0	3.5
DE	324	94	-1.2	2.2	140	57	-1.3	1.7	105	13	-0.7	2.3	22	6	-1.1	2.2	57	18	-1.9	2.1
DK	1	0	-0.1	NA	0	0	NA	NA	1	0	-0.1	NA	0	0	NA	NA	0	0	NA	NA
EE	7	0	-3.8	4.0	3	0	-2.0	5.1	1	0	-0.8	NA	2	0	-4.1	0.3	1	0	-3.8	NA
EL	2	0	1.9	3.5	2	0	1.9	3.5	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA
ES	228	40	-1.2	3.3	68	9	-1.1	2.7	59	6	-1.0	3.1	74	14	-1.2	3.6	27	11	-2.4	3.1
FI	31	10	-3.0	3.3	6	1	-3.9	4.3	21	7	-2.4	3.0	4	2	-3.3	3.2	0	0	NA	NA
FR	209	60	-1.7	2.4	147	45	-1.8	2.3	29	7	-1.4	2.7	22	5	-2.0	2.8	11	3	-1.4	2.2
HR	2	1	4.3	5.2	0	0	NA	NA	2	1	4.3	5.2	0	0	NA	NA	0	0	NA	NA
HU	22	0	-1.3	3.3	12	0	-1.5	2.5	7	0	-0.2	4.4	1	0	-1.3	NA	2	0	0.3	1.4
IE	7	0	-0.6	3.4	5	0	-0.6	4.0	1	0	-0.6	NA	0	0	NA	NA	1	0	-1.0	NA
IT	243	8	0.2	3.8	109	2	0.1	3.6	83	3	0.2	3.8	19	0	0.8	3.5	32	3	0.2	4.4
LT	14	1	-0.3	3.3	5	0	-0.5	2.8	5	0	0.7	4.3	4	1	-0.5	3.1	0	0	NA	NA
LU	1	1	-3.8	NA	1	1	-3.8	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA
LV	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA
MT	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA
NL	40	8	-1.6	1.2	10	1	-1.9	1.7	12	2	-1.3	1.1	0	0	NA	NA	18	5	-1.6	1.1
PL	114	9	1.2	4.6	99	7	1.2	4.3	6	0	0.6	8.9	3	1	3.2	3.7	6	1	1.4	5.3
PT	30	7	-1.3	2.6	11	1	-1.2	2.3	5	1	-1.1	2.2	4	3	-1.4	1.3	10	2	-1.2	3.6
RO	14	0	-0.7	3.8	3	0	-1.3	3.5	5	0	-1.4	3.6	6	0	-0.2	4.6	0	0	NA	NA
SE	20	4	-1.0	3.8	3	1	-0.3	3.4	14	2	-1.0	3.8	0	0	NA	NA	3	1	-2.1	5.2
SI	13	1	-1.5	3.1	10	1	-1.1	3.1	1	0	-3.8	NA	0	0	NA	NA	2	0	-1.0	1.2

Table A2.2 PM_{10} 90.4 percentile of the daily concentrations (cont.)

	All stations				Urban and suburban background				Traffic				Industrial				Rural background			
Country	**nsta**	**nsig**	**slope**	**2stddev**	**nsta**	**nsig**	**slope**	**2stddev**	**nsta**	**nsig**	**slope**	**2stddev**	**nsta**	**nsig**	**slope**	**2stddev**	**nsta**	**nsig**	**slope**	**2stddev**
SK	14	0	-0.2	3.2	7	0	-0.4	3.0	5	0	0.0	2.2	0	0	NA	NA	2	0	-1.2	7.2
UK	36	10	-1.9	2.9	14	5	-2.2	2.0	13	1	-0.8	3.0	7	3	-2.7	3.4	2	1	-2.9	3.4
AL	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA
BA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA
CH	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA
IS	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA
ME	2	0	-0.2	3.3	1	0	-1.4	NA	1	0	0.9	NA	0	0	NA	NA	0	0	NA	NA
MK	3	0	1.8	7.0	0	0	NA	NA	1	0	1.8	NA	2	0	3.3	9.6	0	0	NA	NA
NO	25	6	-1.4	2.2	9	5	-1.8	2.5	15	1	-1.0	1.7	1	0	-0.3	NA	0	0	NA	NA
RS	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA
TR	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA
XK	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA

Table A2.3 Particulate matter with a diameter of 2.5 µm or less ($PM_{2.5}$) annual mean

	All stations				Urban and suburban background				Traffic				Industrial				Rural background			
Country	**nsta**	**nsig**	**slope**	**2stddev**	**nsta**	**nsig**	**slope**	**2stddev**	**nsta**	**nsig**	**slope**	**2stddev**	**nsta**	**nsig**	**slope**	**2stddev**	**nsta**	**nsig**	**slope**	**2stddev**
All	584	336	-0.50	0.83	335	187	-0.52	0.79	116	79	-0.52	0.94	51	26	-0.43	0.97	82	44	-0.33	0.70
EU-28	567	324	-0.51	0.84	330	183	-0.52	0.79	105	71	-0.54	0.98	50	26	-0.44	0.97	82	44	-0.33	0.70
AT	14	10	-0.65	0.48	10	7	-0.65	0.43	2	2	-0.82	0.18	0	0	NA	NA	2	1	-0.37	0.67
BE	30	28	-0.71	0.47	16	16	-0.75	0.42	0	0	NA	NA	6	5	-0.79	0.49	8	7	-0.60	0.46
BG	6	3	-0.67	1.65	5	2	-0.84	1.75	0	0	NA	NA	0	0	NA	NA	1	1	-0.39	NA
CY	5	4	-0.97	0.32	4	3	-0.98	0.37	0	0	NA	NA	0	0	NA	NA	1	1	-0.86	NA
CZ	27	8	-0.36	1.08	18	5	-0.35	0.80	4	1	0.07	1.39	1	1	-1.51	NA	4	1	-0.37	0.93
DE	119	90	-0.52	0.45	63	46	-0.49	0.38	32	31	-0.70	0.39	7	3	-0.49	0.36	17	10	-0.27	0.50
DK	1	1	-0.40	NA	0	0	NA	NA	1	1	-0.40	NA	0	0	NA	NA	0	0	NA	NA
EE	6	3	-0.28	0.47	3	2	-0.45	0.65	0	0	NA	NA	0	0	NA	NA	3	1	-0.18	0.27
EL	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA
ES	76	22	-0.18	0.69	25	2	-0.16	0.62	15	6	-0.35	0.67	23	9	-0.11	0.92	13	5	-0.15	0.27
FI	13	10	-0.41	0.21	7	6	-0.43	0.19	4	3	-0.38	0.24	1	1	-0.45	NA	1	0	-0.20	NA
FR	46	40	-0.80	0.56	42	36	-0.82	0.57	1	1	-0.64	NA	0	0	NA	NA	3	3	-0.78	0.54
HR	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA
HU	1	0	-0.88	NA	0	0	NA	NA	1	0	-0.88	NA	0	0	NA	NA	0	0	NA	NA
IE	1	1	-0.43	NA	1	1	-0.43	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA
IT	77	37	-0.56	0.76	43	17	-0.54	0.71	14	9	-0.67	0.81	5	3	-0.94	0.61	15	8	-0.49	0.92
LT	3	0	0.32	1.60	0	0	NA	NA	3	0	0.32	1.60	0	0	NA	NA	0	0	NA	NA
LU	2	2	-0.86	0.16	2	2	-0.86	0.16	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA
LV	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA
MT	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA
NL	12	10	-1.03	0.55	6	4	-0.91	0.34	3	3	-1.35	0.39	0	0	NA	NA	3	3	-1.13	0.62
PL	55	26	-0.74	1.14	45	20	-0.70	1.05	5	3	-1.05	1.38	1	1	-2.09	NA	4	2	-0.27	0.56
PT	6	1	-0.05	0.60	3	0	0.11	0.82	1	0	0.03	NA	0	0	NA	NA	2	1	-0.23	0.26
RO	3	0	0.04	1.71	3	0	0.04	1.71	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA
SE	8	3	-0.22	0.26	2	1	-0.30	0.37	4	2	-0.22	0.20	0	0	NA	NA	2	0	-0.24	0.46
SI	4	1	-0.34	0.40	2	1	-0.24	0.66	1	0	-0.34	NA	0	0	NA	NA	1	0	-0.35	NA

Table A2.3 Particulate matter with a diameter of 2.5 µm or less ($PM_{2.5}$) annual mean (cont.)

	All stations				Urban and suburban background				Traffic				Industrial				Rural background			
Country	nsta	nsig	slope	2stddev	nsta	nsig	slope	2stddev	nsta	nsig	slope	2stddev	nsta	nsig	slope	2stddev	nsta	nsig	slope	2stddev
SK	2	0	-0.71	1.65	1	0	-0.12	NA	1	0	-1.29	NA	0	0	NA	NA	0	0	NA	NA
UK	51	25	-0.43	0.66	29	12	-0.43	0.37	14	10	-0.51	1.00	6	3	-0.40	0.59	2	0	-0.32	1.30
AD	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA
AL	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA
BA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA
CH	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA
IS	1	0	-0.09	NA	0	0	NA	NA	0	0	NA	NA	1	0	-0.09	NA	0	0	NA	NA
ME	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA
MK	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA
NO	15	11	-0.31	0.27	5	4	-0.31	0.30	10	7	-0.32	0.26	0	0	NA	NA	0	0	NA	NA
TR	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA
XK	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA

Table A.2.4 Accumulated ozone (O_3) concentration (8-hour daily maximum) in excess of 35 ppb (SOMO35)

	All stations				Urban and suburban background				Traffic				Industrial				Rural background			
Country	nsta	nsig	slope	2stddev	nsta	nsig	slope	2stddev	nsta	nsig	slope	2stddev	nsta	nsig	slope	2stddev	nsta	nsig	slope	2stddev
All	1 513	180	21	353	832	91	28	324	101	20	22	334	145	28	-43	489	435	41	19	345
EU-28	1 500	180	21	351	831	91	28	325	100	20	23	320	144	28	-38	490	425	41	20	342
AT	90	3	101	167	41	1	114	170	4	2	205	207	1	0	23	NA	44	0	85	155
BE	38	11	43	129	14	2	35	119	1	0	-51	NA	5	3	103	122	18	6	66	126
BG	17	4	-188	728	10	2	-328	487	3	1	-182	473	2	0	-62	357	2	1	-503	2 227
CY	2	0	69	113	0	0	NA	NA	1	0	109	NA	0	0	NA	NA	1	0	29	NA
CZ	51	6	94	225	26	5	84	232	3	0	104	69	0	0	NA	NA	22	1	90	236
DE	242	27	28	206	148	20	37	210	7	1	27	53	13	0	59	84	74	6	1	214
DK	7	0	7	122	3	0	9	94	1	0	24	NA	0	0	NA	NA	3	0	-59	67
EL	4	0	76	430	1	0	36	NA	2	0	-93	589	1	0	183	NA	0	0	NA	NA
ES	338	66	-21	448	118	20	3	443	59	12	43	307	98	23	-98	525	63	11	-38	392
FI	12	3	-78	115	5	2	-105	118	0	0	NA	NA	0	0	NA	NA	7	1	-55	113
FR	238	13	23	215	197	12	25	206	0	0	NA	NA	0	0	NA	NA	41	1	17	256
HR	2	0	-35	85	2	0	-35	85	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA
HU	17	3	-92	592	13	2	-54	533	1	0	-195	NA	1	1	-783	NA	2	0	-30	491
IE	6	0	45	82	3	0	-7	65	0	0	NA	NA	0	0	NA	NA	3	0	59	52
IT	174	22	-19	481	111	13	10	451	5	0	-232	233	3	0	-245	464	55	9	-44	532
LT	11	1	-88	142	2	0	-121	94	4	1	-123	57	2	0	16	187	3	0	-40	131
LU	5	0	94	105	2	0	40	177	0	0	NA	NA	0	0	NA	NA	3	0	94	56
LV	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA
MT	2	1	120	421	1	0	-29	NA	0	0	NA	NA	0	0	NA	NA	1	1	269	NA
NL	29	6	65	131	8	1	99	84	4	3	83	77	0	0	NA	NA	17	2	48	143
PL	53	4	51	246	35	4	59	221	0	0	NA	NA	1	0	63	NA	17	0	36	299
PT	29	3	-109	408	18	2	-115	461	0	0	NA	NA	2	0	-137	232	9	1	-109	338
RO	26	1	29	408	14	1	18	402	2	0	52	390	9	0	82	462	1	0	-71	NA
SE	14	1	-3	105	5	0	-27	100	1	0	15	NA	0	0	NA	NA	8	1	-3	119
SI	11	0	29	237	6	0	23	111	1	0	105	NA	0	0	NA	NA	4	0	1	374
SK	11	1	-220	384	7	1	-220	416	0	0	NA	NA	0	0	NA	NA	4	0	-185	368
UK	62	3	29	148	38	3	26	147	0	0	NA	NA	4	0	-34	58	20	0	50	155

Table A.2.4 Accumulated ozone (O_3) concentration (8-hour daily maximum) in excess of 35 ppb (SOMO35) (cont.)

	All stations				Urban and suburban background				Traffic				Industrial				Rural background			
Country	nsta	nsig	slope	2stddev	nsta	nsig	slope	2stddev	nsta	nsig	slope	2stddev	nsta	nsig	slope	2stddev	nsta	nsig	slope	2stddev
AD	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA
AL	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA
BA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA
CH	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA
CH	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA
ME	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA
MK	2	0	-339	402	0	0	NA	NA	1	0	-481	NA	1	0	-197	NA	0	0	NA	NA
NO	10	0	-2	94	1	0	-8	NA	0	0	NA	NA	0	0	NA	NA	9	0	4	100
RS	1	0	-675	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA	1	0	-675	NA
TR	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA
XK	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA

Note: Data for Estonia do not appear because 2018 data could not be properly processed.

Table A.2.5 Ozone (O_3) 93.2 percentile of the maximum daily 8-hour mean

	All stations				Urban and suburban background				Traffic				Industrial				Rural background			
Country	nsta	nsig	slope	2stddev	nsta	nsig	slope	2stddev	nsta	nsig	slope	2stddev	nsta	nsig	slope	2stddev	nsta	nsig	slope	2stddev
All	1 519	82	0.11	2.38	837	38	0.20	2.21	102	11	0.41	3.00	145	14	-0.50	3.32	435	19	0.04	2.05
EU-28	1 505	81	0.12	2.36	835	37	0.20	2.21	101	11	0.41	2.74	144	14	-0.49	3.29	425	19	0.05	2.06
AT	90	1	0.33	1.15	41	0	0.56	1.09	4	1	1.00	1.17	1	0	-0.44	NA	44	0	0.10	1.02
BE	38	3	0.83	1.66	14	1	0.63	1.79	1	0	-0.51	NA	5	1	1.54	1.33	18	1	0.90	1.57
BG	17	2	-1.17	3.74	10	1	-1.33	3.29	3	1	-0.16	2.67	2	0	0.63	2.80	2	0	-2.56	7.89
CY	2	0	-0.13	0.32	0	0	NA	NA	1	0	-0.02	NA	0	0	NA	NA	1	0	-0.24	NA
CZ	51	5	0.71	1.68	26	4	0.93	1.84	3	0	1.53	1.09	0	0	NA	NA	22	1	0.48	1.53
DE	242	8	0.45	1.48	148	5	0.56	1.52	7	1	0.82	1.24	13	0	0.70	1.23	74	2	0.29	1.43
DK	7	0	0.25	2.79	3	0	1.09	1.61	1	0	2.63	NA	0	0	NA	NA	3	0	-0.69	1.85
EL	4	1	0.28	5.03	1	0	-0.02	NA	2	1	-1.01	8.28	1	0	0.58	NA	0	0	NA	NA
ES	337	36	-0.37	2.48	118	14	-0.27	2.38	59	7	0.20	2.34	97	10	-0.86	2.68	63	5	-0.41	2.00
FI	12	4	-0.95	1.75	5	1	0.11	1.93	0	0	NA	NA	0	0	NA	NA	7	3	-1.10	1.36
FR	240	5	0.05	1.83	199	4	0.11	1.84	0	0	NA	NA	0	0	NA	NA	41	1	-0.01	1.69
HR	2	0	1.21	1.62	2	0	1.21	1.62	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA
HU	17	2	-0.31	3.59	13	1	-0.27	3.12	1	0	-2.26	NA	1	1	-5.18	NA	2	0	-0.06	0.89
IE	9	0	0.15	1.19	6	0	0.13	0.90	0	0	NA	NA	0	0	NA	NA	3	0	0.99	1.62
IT	175	4	-0.12	2.80	112	2	-0.03	2.74	5	0	-1.30	2.87	3	0	-1.05	1.41	55	2	-0.26	2.90
LT	11	0	0.66	3.17	2	0	0.83	0.48	4	0	1.00	4.68	2	0	0.80	3.16	3	0	-0.69	1.86
LU	5	0	0.44	2.63	2	0	1.37	2.91	0	0	NA	NA	0	0	NA	NA	3	0	0.44	2.12
LV	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA
MT	2	0	-0.36	0.29	1	0	-0.26	NA	0	0	NA	NA	0	0	NA	NA	1	0	-0.46	NA
NL	29	1	0.29	1.76	8	0	0.34	1.57	4	0	1.26	2.03	0	0	NA	NA	17	1	0.24	1.84
PL	53	1	0.33	1.89	35	1	0.33	1.96	0	0	NA	NA	1	0	0.48	NA	17	0	0.23	1.85
PT	30	5	-1.03	3.22	18	2	-1.05	2.26	0	0	NA	NA	3	1	-0.63	8.47	9	2	-0.86	1.80
RO	26	0	0.75	4.02	14	0	0.37	3.76	2	0	1.52	6.28	9	0	1.66	4.63	1	0	0.20	NA
SE	14	0	-0.07	0.90	5	0	-0.39	0.53	1	0	0.57	NA	0	0	NA	NA	8	0	0.09	0.88
SI	11	0	-0.37	2.12	6	0	-0.32	1.34	1	0	1.85	NA	0	0	NA	NA	4	0	-1.00	2.38
SK	11	2	-0.83	3.61	7	1	-0.83	3.89	0	0	NA	NA	0	0	NA	NA	4	1	-0.31	3.44
UK	62	1	0.36	1.55	37	1	0.58	1.54	1	0	0.20	NA	4	0	-0.07	1.72	20	0	0.24	1.57

Table A.2.5 Ozone (O_3) 93.2 percentile of the maximum daily 8-hour mean (cont.)

	All stations				Urban and suburban background				Traffic				Industrial				Rural background			
Country	nsta	nsig	slope	2stddev	nsta	nsig	slope	2stddev	nsta	nsig	slope	2stddev	nsta	nsig	slope	2stddev	nsta	nsig	slope	2stddev
AD	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA
AL	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA
BA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA
CH	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA
ME	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA
MK	2	0	-4.82	3.47	0	0	NA	NA	1	0	-6.04	NA	1	0	-3.59	NA	0	0	NA	NA
NO	10	0	-0.16	1.50	1	0	0.53	NA	0	0	NA	NA	0	0	NA	NA	9	0	-0.22	1.55
RS	1	0	-1.46	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA	1	0	-1.46	NA
TR	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA
XK	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA

Note: Data for Estonia do not appear because 2018 data could not be properly processed.

Table A.2.6 Nitrogen dioxide (NO_2) annual mean

	All stations				Urban and suburban background				Traffic				Industrial				Rural background			
Country	nsta	nsig	slope	2stddev	nsta	nsig	slope	2stddev	nsta	nsig	slope	2stddev	nsta	nsig	slope	2stddev	nsta	nsig	slope	2stddev
All	2 028	1 170	-0.55	1.28	911	524	-0.54	0.94	544	363	-0.96	1.63	265	119	-0.37	1.01	308	164	-0.26	0.64
EU-28	2 003	1 155	-0.55	1.25	904	522	-0.54	0.94	528	350	-0.94	1.60	264	119	-0.37	1.01	307	164	-0.27	0.64
AT	125	82	-0.50	0.87	56	37	-0.49	0.53	35	29	-0.82	1.05	7	2	-0.37	0.27	27	14	-0.24	0.52
BE	65	61	-0.67	0.53	18	16	-0.95	0.43	2	2	-0.74	0.33	28	27	-0.62	0.46	17	16	-0.56	0.39
BG	19	3	-0.32	1.09	11	2	-0.32	1.03	4	1	-0.75	1.13	2	0	-0.84	1.34	2	0	0.14	0.10
CY	2	0	-0.29	0.49	0	0	NA	NA	1	0	-0.47	NA	0	0	NA	NA	1	0	-0.12	NA
CZ	51	40	-0.50	0.88	24	19	-0.50	0.48	15	11	-0.75	1.35	1	1	-0.60	NA	11	9	-0.34	0.21
DE	349	251	-0.52	1.31	155	102	-0.45	0.60	107	91	-1.13	1.65	20	13	-0.30	0.52	67	45	-0.25	0.43
DK	9	7	-0.51	1.38	3	3	-0.51	0.35	3	3	-1.69	0.39	0	0	NA	NA	3	1	-0.14	0.33
EE	8	6	-0.47	0.53	3	2	-0.49	0.13	1	1	-0.86	NA	2	2	-0.48	0.56	2	1	-0.12	0.00
EL	4	4	-1.66	2.49	1	1	-1.44	NA	2	2	-2.62	3.80	1	1	-1.87	NA	0	0	NA	NA
ES	391	132	-0.38	1.11	122	37	-0.44	0.96	94	49	-0.77	1.15	124	34	-0.18	1.08	51	12	-0.08	0.65
FI	27	17	-0.56	1.10	7	5	-0.55	0.65	14	10	-0.93	1.20	2	1	-0.29	0.15	4	1	-0.01	0.47
FR	279	219	-0.64	0.92	198	155	-0.62	0.55	49	40	-1.23	1.39	19	16	-0.56	0.61	13	8	-0.33	0.65
HR	4	0	0.00	0.93	2	0	-0.15	0.03	2	0	0.48	1.00	0	0	NA	NA	0	0	NA	NA
HU	21	3	-0.14	0.75	12	1	-0.10	0.89	7	1	-0.28	0.48	1	0	0.21	NA	1	1	-0.59	NA
IE	8	0	-0.35	1.18	4	0	-0.13	0.56	3	0	-1.12	1.11	0	0	NA	NA	1	0	-0.04	NA
IT	337	170	-0.74	1.63	141	72	-0.76	1.48	111	58	-1.08	1.89	30	11	-0.49	1.20	55	29	-0.36	0.95
LT	10	4	0.22	0.89	3	0	0.00	0.34	4	3	0.51	1.38	3	1	0.16	0.55	0	0	NA	NA
LU	3	3	-0.50	0.35	1	1	-0.50	NA	0	0	NA	NA	0	0	NA	NA	2	2	-0.39	0.46
LV	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA
MT	3	0	-0.17	0.34	1	0	-0.34	NA	1	0	-0.17	NA	0	0	NA	NA	1	0	0.00	NA
NL	49	45	-0.64	0.90	14	14	-0.65	0.40	15	15	-1.32	0.65	2	1	-0.56	1.19	18	15	-0.42	0.41
PL	80	27	-0.21	0.79	58	21	-0.18	0.68	7	4	-0.59	1.60	4	1	-0.36	0.38	11	1	-0.12	0.37
PT	25	11	-0.58	0.77	12	5	-0.58	0.75	5	2	-0.67	0.40	4	2	-0.62	1.00	4	2	-0.21	0.60
RO	11	0	-0.06	1.34	4	0	0.37	1.62	3	0	-0.26	1.40	4	0	0.18	0.81	0	0	NA	NA
SE	18	10	-0.88	1.13	5	2	-0.52	0.50	12	8	-0.98	1.16	0	0	NA	NA	1	0	0.02	NA
SI	7	1	-0.37	0.91	5	0	-0.37	0.80	1	1	-1.01	NA	0	0	NA	NA	1	0	-0.20	NA
SK	9	0	-0.43	1.88	4	0	-0.38	1.02	5	0	-0.43	2.45	0	0	NA	NA	0	0	NA	NA

Table A.2.6 Nitrogen dioxide (NO_2) annual mean (cont.)

	All stations				Urban and suburban background				Traffic				Industrial				Rural background			
Country	nsta	nsig	slope	2stddev	nsta	nsig	slope	2stddev	nsta	nsig	slope	2stddev	nsta	nsig	slope	2stddev	nsta	nsig	slope	2stddev
UK	92	60	-0.63	1.28	41	27	-0.65	0.89	27	20	-1.08	1.66	10	6	-0.54	0.50	14	7	-0.31	0.36
AL	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA
BA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA
CH	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA
IS	1	0	0.26	NA	0	0	NA	NA	0	0	NA	NA	1	0	0.26	NA	0	0	NA	NA
ME	1	0	-0.57	NA	0	0	NA	NA	1	0	-0.57	NA	0	0	NA	NA	0	0	NA	NA
MK	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA
NO	18	13	-1.60	2.17	5	2	-0.83	1.45	12	11	-2.07	1.96	0	0	NA	NA	1	0	-0.11	NA
RS	2	1	-1.34	0.85	1	0	-1.05	NA	1	1	-1.64	NA	0	0	NA	NA	0	0	NA	NA
TR	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA
XK	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA

Table A2.7 Nitrogen dioxide (NO_2) 99.8 percentile of the hourly means

	All stations				Urban and suburban background				Traffic				Industrial				Rural background			
Country	nsta	nsig	slope	2stddev	nsta	nsig	slope	2stddev	nsta	nsig	slope	2stddev	nsta	nsig	slope	2stddev	nsta	nsig	slope	2stddev
All	2 020	338	-1.92	6.39	911	134	-1.81	5.28	540	102	-2.52	7.52	261	50	-1.34	6.00	308	52	-1.75	7.21
EU-28	1 996	338	-1.93	6.30	904	134	-1.80	5.28	525	102	-2.58	7.29	260	50	-1.36	5.92	307	52	-1.75	7.17
AT	125	25	-1.91	3.12	56	8	-1.87	2.34	35	16	-3.89	2.96	7	0	-1.05	0.67	27	1	-0.71	1.54
BE	65	33	-2.38	1.84	18	9	-2.48	1.99	2	1	-3.09	0.85	28	14	-1.90	1.79	17	9	-1.67	1.40
BG	19	1	-2.23	13.59	11	1	-2.23	15.15	4	0	-8.13	13.56	2	0	-1.76	4.65	2	0	0.64	1.35
CY	2	0	-0.11	0.37	0	0	NA	NA	1	0	0.02	NA	0	0	NA	NA	1	0	-0.24	NA
CZ	51	3	-1.47	3.93	24	0	-1.02	2.20	15	2	-2.22	6.06	1	0	-1.61	NA	11	1	-1.99	1.39
DE	349	68	-1.72	3.77	155	29	-1.66	2.07	107	21	-2.33	5.54	20	4	-1.10	2.43	67	14	-1.57	2.79
DK	9	2	-2.53	4.56	3	0	-1.93	2.12	3	2	-5.08	2.33	0	0	NA	NA	3	0	-0.56	3.11
EE	8	0	-1.18	4.96	3	0	-1.82	1.90	1	0	-2.85	NA	2	0	0.46	9.10	2	0	1.69	0.55
EL	2	0	-3.55	0.66	1	0	-3.78	NA	1	0	-3.31	NA	0	0	NA	NA	0	0	NA	NA
ES	389	59	-1.40	5.36	122	13	-1.41	5.45	94	17	-1.58	5.01	122	20	-1.15	5.39	51	9	-1.27	5.51
FI	27	3	-2.12	9.31	7	0	-0.30	3.45	14	3	-3.20	8.10	2	0	-2.03	0.49	4	0	6.40	6.53
FR	279	73	-2.19	4.28	198	49	-2.04	3.24	49	19	-3.98	6.51	19	5	-1.95	2.79	13	0	-1.67	1.56
HR	4	0	-0.75	4.26	2	0	-2.56	2.28	2	0	0.85	1.72	0	0	NA	NA	0	0	NA	NA
HU	21	1	-0.76	3.30	12	1	-0.80	3.82	7	0	-0.76	2.90	1	0	-0.51	NA	1	0	-2.31	NA
IE	8	1	-1.38	6.95	4	0	0.60	5.72	3	0	-3.05	8.82	0	0	NA	NA	1	1	-4.74	NA
IT	335	39	-3.25	9.75	141	13	-3.36	8.45	109	9	-2.33	9.44	30	4	-2.64	10.31	55	13	-6.05	9.56
LT	10	1	-1.01	9.35	3	0	-0.76	6.32	4	0	-3.52	4.11	3	1	3.75	6.47	0	0	NA	NA
LU	3	0	-1.28	0.43	1	0	-1.28	NA	0	0	NA	NA	0	0	NA	NA	2	0	-1.43	0.56
LV	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA
MT	3	1	-2.49	33.25	1	0	-2.49	NA	1	1	-25.12	NA	0	0	NA	NA	1	0	7.30	NA
NL	49	6	-2.03	4.66	14	1	-1.78	2.08	15	3	-3.51	3.81	2	0	-1.85	4.37	18	2	-1.66	5.44
PL	80	3	-1.11	3.02	58	2	-0.96	3.05	7	1	-1.66	4.43	4	0	-1.27	1.72	11	0	-1.10	2.13
PT	25	3	-1.66	4.20	12	1	-2.32	4.82	5	0	-2.51	4.41	4	0	-1.59	2.60	4	2	-1.07	2.64
RO	10	1	0.47	8.93	4	1	2.45	11.83	3	0	-1.76	7.36	3	0	1.63	6.45	0	0	NA	NA
SE	18	1	-2.59	4.03	5	0	-2.31	3.26	12	1	-2.84	4.06	0	0	NA	NA	1	0	0.19	NA
SI	7	1	-2.21	3.33	5	0	-2.21	3.59	1	1	-3.43	NA	0	0	NA	NA	1	0	-0.83	NA
SK	9	4	-6.34	8.40	4	2	-3.88	5.85	5	2	-6.48	9.41	0	0	NA	NA	0	0	NA	NA

Table A2.7 Nitrogen dioxide (NO_2) 99.8 percentile of the hourly means (cont.)

	All stations				Urban and suburban background				Traffic				Industrial				Rural background			
Country	nsta	nsig	slope	2stddev	nsta	nsig	slope	2stddev	nsta	nsig	slope	2stddev	nsta	nsig	slope	2stddev	nsta	nsig	slope	2stddev
UK	92	9	-2.77	8.00	41	4	-2.95	7.71	27	3	-2.36	9.07	10	2	-2.24	6.09	14	0	-3.57	7.54
AL	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA
BA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA
CH	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA
IS	1	0	7.03	NA	0	0	NA	NA	0	0	NA	NA	1	0	7.03	NA	0	0	NA	NA
ME	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA
MK	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA
NO	18	0	-1.24	11.31	5	0	-3.83	4.32	12	0	2.89	10.06	0	0	NA	NA	1	0	-10.04	NA
RS	2	0	-1.85	11.98	1	0	-6.09	NA	1	0	2.38	NA	0	0	NA	NA	0	0	NA	NA
TR	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA
XK	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA

Table A.2.8 Sulphur dioxide (SO_2) annual mean

Country	All stations				Urban and suburban background				Traffic				Industrial				Rural background			
	nsta	nsig	slope	2stddev	nsta	nsig	slope	2stddev	nsta	nsig	slope	2stddev	nsta	nsig	slope	2stddev	nsta	nsig	slope	2stddev
All	1 019	428	-0.13	0.72	421	187	-0.15	0.73	161	61	-0.13	0.82	270	102	-0.18	0.79	167	78	-0.07	0.32
EU-28	1 011	424	-0.13	0.68	420	186	-0.15	0.72	158	59	-0.12	0.67	266	101	-0.18	0.77	167	78	-0.07	0.32
AT	60	10	-0.04	0.23	23	3	-0.03	0.21	0	0	NA	NA	17	4	-0.07	0.32	20	3	-0.05	0.15
BE	40	28	-0.24	0.36	12	9	-0.20	0.48	2	1	-0.32	0.09	17	11	-0.30	0.31	9	7	-0.11	0.14
BG	23	11	-0.49	1.87	12	5	-0.41	2.35	6	5	-0.58	1.28	3	0	-0.70	0.21	2	1	0.19	0.42
CY	2	2	-0.22	0.10	0	0	NA	NA	1	1	-0.25	NA	0	0	NA	NA	1	1	-0.19	NA
CZ	36	23	-0.30	0.29	21	12	-0.29	0.23	1	0	-0.11	NA	1	0	-0.35	NA	13	11	-0.36	0.38
DE	119	87	-0.14	0.23	56	46	-0.15	0.23	13	8	-0.15	0.27	14	7	-0.18	0.15	36	26	-0.09	0.21
DK	1	1	-0.26	NA	0	0	NA	NA	1	1	-0.26	NA	0	0	NA	NA	0	0	NA	NA
EE	8	7	-0.11	0.19	3	3	-0.09	0.10	1	1	-0.12	NA	2	1	-0.25	0.31	2	2	-0.10	0.02
EL	1	0	-0.21	NA	0	0	NA	NA	1	0	-0.21	NA	0	0	NA	NA	0	0	NA	NA
ES	312	94	-0.08	0.67	86	19	-0.06	0.54	70	24	-0.13	0.50	116	39	-0.15	0.88	40	12	-0.01	0.26
FI	9	4	-0.12	0.36	0	0	NA	NA	0	0	NA	NA	5	3	-0.21	0.41	4	1	-0.03	0.13
FR	98	35	-0.15	0.59	45	14	-0.11	0.46	1	0	-0.20	NA	45	18	-0.20	0.70	7	3	-0.03	0.32
HR	2	1	-0.46	0.57	1	1	-0.66	NA	1	0	-0.26	NA	0	0	NA	NA	0	0	NA	NA
HU	21	7	-0.33	0.59	12	4	-0.38	0.64	7	3	-0.33	0.58	1	0	-0.33	NA	1	0	-0.09	NA
IE	7	3	-0.13	0.32	4	2	-0.16	0.18	1	0	-0.08	NA	1	1	-0.49	NA	1	0	-0.08	NA
IT	95	31	-0.03	0.55	39	12	-0.04	0.41	28	9	-0.03	0.65	21	9	-0.06	0.68	7	1	-0.01	0.30
LT	7	3	0.26	0.19	3	3	0.26	0.13	2	0	0.16	0.28	2	0	0.22	0.09	0	0	NA	NA
LU	3	0	-0.14	0.17	2	0	-0.17	0.09	0	0	NA	NA	0	0	NA	NA	1	0	-0.03	NA
LV	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA
MT	2	1	-0.13	0.31	0	0	NA	NA	1	1	-0.24	NA	0	0	NA	NA	1	0	-0.02	NA
NL	5	4	-0.07	0.16	1	1	-0.07	NA	0	0	NA	NA	0	0	NA	NA	4	3	-0.10	0.18
PL	82	50	-0.47	0.67	64	41	-0.47	0.67	4	1	-0.36	0.98	4	3	-0.50	0.76	10	5	-0.39	0.48
PT	12	5	0.00	0.44	5	3	0.01	0.60	2	0	-0.03	0.08	3	2	-0.13	0.41	2	0	0.05	0.08
RO	28	5	-0.04	1.49	8	1	-0.03	1.75	9	3	-0.05	1.52	9	1	-0.03	1.44	2	0	0.01	0.18
SE	1	0	-0.06	NA	1	0	-0.06	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA
SI	5	0	0.07	0.48	4	0	0.08	0.21	1	0	-0.38	NA	0	0	NA	NA	0	0	NA	NA

Table A.2.8 Sulphur dioxide (SO_2) annual mean (cont.)

	All stations				Urban and suburban background				Traffic				Industrial				Rural background			
Country	nsta	nsig	slope	2stddev	nsta	nsig	slope	2stddev	nsta	nsig	slope	2stddev	nsta	nsig	slope	2stddev	nsta	nsig	slope	2stddev
SK	8	1	-0.22	0.70	5	1	-0.48	0.69	3	0	0.03	0.38	0	0	NA	NA	0	0	NA	NA
UK	25	12	-0.18	0.44	13	6	-0.18	0.17	3	2	-0.02	1.04	5	2	-0.26	0.58	4	2	-0.17	0.12
AL	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA
BA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA
CH	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA
IS	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA
ME	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA
MK	2	0	-1.53	2.80	0	0	NA	NA	1	0	-2.52	NA	1	0	-0.54	NA	0	0	NA	NA
NO	3	1	-0.95	1.30	0	0	NA	NA	0	0	NA	NA	3	1	-0.95	1.30	0	0	NA	NA
RS	2	2	-1.58	1.52	1	1	-1.04	NA	1	1	-2.11	NA	0	0	NA	NA	0	0	NA	NA
TR	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA
XK	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA

Table A2.9 Ozone (O_3) ATO40 for crops

	All stations				Urban and suburban background				Traffic				Industrial				Rural background			
Country	nsta	nsig	slope	2stddev	nsta	nsig	slope	2stddev	nsta	nsig	slope	2stddev	nsta	nsig	slope	2stddev	nsta	nsig	slope	2stddev
All	1 498	149	179	1 388	824	74	204	1 318	98	13	73	1 155	142	16	-42	1 627	434	46	201	1 444
EU-28	1 484	147	182	1 382	822	73	205	1 318	97	12	79	1 133	141	16	-40	1 623	424	46	209	1 428
AT	90	17	662	913	41	9	709	882	4	1	867	1 072	1	0	-110	NA	44	7	498	932
BE	38	6	373	597	14	0	239	538	1	0	-84	NA	5	1	526	541	18	5	483	553
BG	16	3	-731	2 377	10	2	-903	1 692	2	0	-993	1 394	2	0	-339	823	2	1	-1805	6 802
CY	2	0	-169	1 373	0	0	NA	NA	1	0	317	NA	0	0	NA	NA	1	0	-654	NA
CZ	51	12	699	936	26	6	711	857	3	0	741	986	0	0	NA	NA	22	6	533	1 050
DE	242	23	474	845	148	19	482	866	7	0	225	548	13	1	531	473	74	3	415	855
DK	7	0	34	692	3	0	124	581	1	0	34	NA	0	0	NA	NA	3	0	-69	768
EL	4	0	507	1 857	1	0	705	NA	2	0	-426	2 079	1	0	885	NA	0	0	NA	NA
ES	336	35	18	1 584	118	9	85	1 675	58	7	73	1 023	97	13	-178	1 683	63	6	75	1 531
FI	12	2	-249	473	5	1	-264	338	0	0	NA	NA	0	0	NA	NA	7	1	-233	574
FR	238	5	121	900	197	4	140	913	0	0	NA	NA	0	0	NA	NA	41	1	58	823
HR	2	0	221	1 144	2	0	221	1 144	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA
HU	17	3	-330	2 197	13	2	-330	2 113	1	0	-1049	NA	1	1	-2649	NA	2	0	-85	559
IE	6	0	138	329	3	0	-6	145	0	0	NA	NA	0	0	NA	NA	3	0	299	137
IT	172	16	-34	2 041	110	10	-1	1892	4	0	-630	964	3	0	-995	1 588	55	6	-49	2 300
LT	11	1	-35	543	2	0	-77	140	4	1	-20	239	2	0	347	810	3	0	-286	136
LU	5	0	355	706	2	0	343	296	0	0	NA	NA	0	0	NA	NA	3	0	355	904
LV	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA
MT	2	0	778	2 110	1	0	32	NA	0	0	NA	NA	0	0	NA	NA	1	0	1524	NA
NL	29	7	321	539	8	1	384	673	4	3	356	583	0	0	NA	NA	17	3	303	422
PL	53	9	437	856	35	8	440	879	0	0	NA	NA	1	0	704	NA	17	1	307	847
PT	29	2	-452	946	18	0	-448	951	0	0	NA	NA	2	0	-602	584	9	2	-452	1049
RO	17	1	46	1 087	7	1	101	988	2	0	30	1 686	7	0	46	1 261	1	0	-79	NA
SE	14	0	41	319	5	0	34	339	1	0	104	NA	0	0	NA	NA	8	0	68	346
SI	11	0	-188	566	6	0	-149	489	1	0	-166	NA	0	0	NA	NA	4	0	-397	757
SK	11	3	-171	1 787	7	1	-171	1 809	0	0	NA	NA	0	0	NA	NA	4	2	-532	1 808
UK	61	3	75	421	38	1	94	320	0	0	NA	NA	4	0	16	169	19	2	63	612

Table A2.9 Ozone (O_3) ATO40 for crops (cont.)

	All stations				Urban and suburban background				Traffic				Industrial				Rural background			
Country	nsta	nsig	slope	2stddev	nsta	nsig	slope	2stddev	nsta	nsig	slope	2stddev	nsta	nsig	slope	2stddev	nsta	nsig	slope	2stddev
AD	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA
AL	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA
BA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA
CH	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA
ME	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA
MK	2	1	-1120	108	0	0	NA	NA	1	1	-1082	NA	1	0	-1159	NA	0	0	NA	NA
NO	10	0	9	303	1	0	6	NA	0	0	NA	NA	0	0	NA	NA	9	0	12	318
RS	1	0	-2931	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA	1	0	-2931	NA
TR	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA
XK	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA

Note: Data for Estonia do not appear because 2018 data could not be properly processed.

Annex 3 Additional information on the health impacts of air pollution

Health impact, results for 2009

The following tables show the population-weighted concentration and the estimated number of attributable premature deaths (Table A3.1), and the number of years of life lost (YLL) and the YLL per 100 000 inhabitants (Table A3.2) as a result of exposure to particulate matter with a diameter of 2.5 µm or less ($PM_{2.5}$), nitrogen dioxide (NO_2) and ozone (O_3) concentration levels in 2009. They have been calculated, as in Tables 10.1 and 10.2 for 2018, following the methodology described in Section 10.1.

Table A3.1 Premature deaths attributable to $PM_{2.5}$, NO_2 and O_3 exposure in 41 European countries and the EU-28, 2009

Country	Population (1 000)	$PM_{2.5}$ Annual mean ([a])	$PM_{2.5}$ Premature deaths ([b])	NO_2 Annual mean ([a])	NO_2 Premature deaths ([b])	O_3 SOMO35 ([a])	O_3 Premature deaths ([b])
Austria	8 335	16.0	6 600	21.2	1 400	5 062	290
Belgium	10 753	18.6	10 200	25.9	3 200	2 688	210
Bulgaria	7 467	27.2	15 500	22.2	2 400	5 248	430
Croatia	4 310	20.1	5 600	16.9	330	5 858	230
Cyprus	1 081	20.6	760	18.8	70	9 866	50
Czechia	10 426	19.0	10 900	18.6	820	4 461	360
Denmark	5 511	10.9	3 300	12.7	90	2 446	100
Estonia	1 336	7.5	640	9.3	< 1	1 790	20
Finland	5 326	6.7	1 800	10.9	30	1 576	60
France	62 466	16.1	45 400	21.2	12 300	4 018	1 600
Germany	82 002	15.5	72 800	23.3	20 500	3 536	2 300
Greece	11 095	23.1	14 700	24.0	4 500	8 293	750
Hungary	10 031	20.2	14 000	19.2	1 400	6 838	670
Ireland	4 521	8.7	1 400	13.9	150	1 650	40
Italy	59 001	19.2	60 900	28.6	27 800	6 908	3 100
Latvia	2 163	13.3	2 100	12.4	80	1 843	40
Lithuania	3 184	12.7	2 800	11.9	< 1	2 293	70
Luxembourg	494	16.3	310	23.0	70	2 712	10
Malta	411	16.5	290	12.7	0	6 152	20
Netherlands	16 486	17.1	12 400	26.1	4 500	2 343	240
Poland	38 136	21.6	43 200	17.0	2 600	3 695	1 100
Portugal	10 046	12.4	6 800	19.0	1 400	4 898	370
Romania	20 440	20.1	27 400	20.9	4 600	4 938	960
Slovakia	5 382	20.4	5 700	19.5	490	6 341	250
Slovenia	2 032	18.8	1 800	17.1	130	5 633	80
Spain	44 194	14.5	29 200	23.6	10 700	5 636	1 600
Sweden	9 256	7.5	3 700	12.6	110	2 050	140

Table A3.1 Premature deaths attributable to $PM_{2.5}$, NO_2 and O_3 exposure in 41 European countries and the EU-28, 2009 (cont.)

Country	Population (1 000)	$PM_{2.5}$ Annual mean ([a])	$PM_{2.5}$ Premature deaths ([b])	NO_2 Annual mean ([a])	NO_2 Premature deaths ([b])	O_3 SOMO35 ([a])	O_3 Premature deaths ([b])
United Kingdom	62 042	12.0	37 100	24.7	16 900	1 494	640
Albania	2 936	23.3	5 200	17.7	370	6 513	210
Andorra	84	13.4	50	14.1	< 1	9 211	< 5
Bosnia and Herzegovina	3 844	23.9	4 700	15.1	80	5 183	150
Iceland	319	6.0	70	13.7	0	1 138	< 5
Kosovo	2 181	27.5	4 500	15.7	60	5 909	140
Liechtenstein	36	13.3	20	22.0	< 1	4 970	< 5
Monaco	29	15.9	20	35.6	20	7 567	< 5
Montenegro	617	21.0	650	15.9	20	6 097	30
North Macedonia	2 049	33.0	3 200	19.6	190	6 062	90
Norway	4 799	7.4	1 700	15.1	390	1 903	60
San Marino	31	16.7	30	21.4	< 1	5 663	< 5
Serbia	7 335	26.5	14 600	18.7	970	6 165	490
Switzerland	7 702	14.6	4 900	23.1	1 300	5 119	240
EU-28 total	**497 927**		**437 000**		**117 000**		**15 700**
All countries total	**529 890**		**477 000**		**120 000**		**17 100**

Note: The results found for $PM_{2.5}$ in Poland seem unrealistically low and might be due to an underestimation of the concentrations in 2009. For the production of the 2009 concentration map, only 24 $PM_{2.5}$ stations were considered, complemented with information from 151 PM_{10} stations, while, for the production of the 2018 map, 88 $PM_{2.5}$ and 123 complementary PM_{10} stations were used, increasing the quality of the final result. Furthermore, the ratio used for estimating $PM_{2.5}$ from the PM_{10} stations could also lead to an underestimation.

Table A3.2 Years of life lost (YLL) attributable to $PM_{2.5}$, NO_2 and O_3 exposure in 41 European countries and the EU-28, 2009

	$PM_{2.5}$		NO_2		O_3	
Country	**YLL**	**YLL/10^5 inhabitants**	**YLL**	**YLL/10^5 inhabitants**	**YLL**	**YLL/10^5 inhabitants**
Austria	77 600	931	16 900	203	3 600	43
Belgium	120 200	1 118	38 300	356	2 600	24
Bulgaria	182 400	2 443	27 700	371	5 400	72
Croatia	63 800	1 480	3 800	88	2 700	63
Cyprus	9 200	851	910	84	670	62
Czechia	130 000	1 247	9 800	94	4 400	42
Denmark	38 200	693	1 000	18	1 200	22
Estonia	7 900	591	< 5	< 1	270	20
Finland	22 400	421	350	7	740	14
France	585 400	937	158 000	253	21 600	35
Germany	861 300	1 050	242 000	295	28 200	34
Greece	153 700	1 385	47 000	424	8 200	74
Hungary	177 900	1 774	17 600	175	8 800	88
Ireland	17 300	383	1 900	42	490	11
Italy	663 300	1 124	302 800	513	35 000	59
Latvia	25 500	1 179	960	44	520	24
Lithuania	34 100	1 071	50	2	890	28
Luxembourg	3 900	790	910	184	90	18
Malta	3 500	852	10	2	190	46
Netherlands	151 300	918	54 500	331	3 100	19
Poland	571 500	1 499	34 700	91	14 700	39
Portugal	82 800	824	17 500	174	4 700	47
Romania	360 000	1 761	60 200	295	13 400	66
Slovakia	71 300	1 325	6 200	115	3 400	63
Slovenia	23 500	1 156	1 700	84	1 000	49
Spain	347 600	787	127 500	289	19 700	45
Sweden	38 100	412	1 100	12	1 500	16
United Kingdom	444 300	716	201 900	325	8 100	13
Albania	59 700	2 033	4 300	146	2 500	85
Andorra	670	793	< 5	< 1	70	83
Bosnia and Herzegovina	53 100	1 381	870	23	1 700	44
Iceland	740	232	30	9	20	6
Kosovo	51 800	2 375	650	30	1700	78
Liechtenstein	290	815	50	140	20	56
Monaco	270	917	240	815	20	68
Montenegro	8 500	1 377	290	47	380	62
North Macedonia	38 700	1 889	2 300	112	1 200	59
Norway	17 800	371	4 100	85	660	14
San Marino	310	991	30	96	20	64
Serbia	168 200	2 293	11 200	153	5 900	80
Switzerland	55 500	721	14 800	192	2 900	38
EU-28 total	**5 268 000**	**1 058**	**1 375 300**	**276**	**195 200**	**39**
All countries total	**5 723 600**	**1 080**	**1 414 100**	**267**	**212 300**	**40**

Sensitivity analysis of the health impact estimates in 2018

The recommendations from the *Health risks of air pollution in Europe* (HRAPIE) report (WHO, 2013b) indicate that the quantification of long-term effects of particulate matter with a diameter of 2.5 µm or less ($PM_{2.5}$), nitrogen dioxide (NO_2) and ozone (O_3) should be estimated for all concentration levels, annual levels above 20 µg/m³ and concentrations above 35 parts per billion (ppb), respectively. The results for 2018 using those recommendations are presented in Section 10.2.

To assess how sensitive the estimations are, additional calculations were undertaken, following the same methodology as that described in Section 10.1 but with different starting thresholds (or counterfactual concentrations). Table A3.3 summarises the estimated health impacts in 2018 of concentrations equal to or above 2.5 and 10 µg/m³ for $PM_{2.5}$ and NO_2, respectively, and of SOMO10 (the annual average of daily maximum running 8-hour average O_3 concentrations above 10 ppb) for O_3. These values should be compared with the values in Tables 10.1 and 10.2. The rationale for choosing 2.5 µg/m³ for $PM_{2.5}$ is that the European $PM_{2.5}$ background concentration level is estimated to be, on average, 2.5 µg/m³ (ETC/ACM, 2017b).

For NO_2, Raaschou-Nielsen et al. (2012) showed an increase in all-cause mortality when NO_2 concentrations were lower than 20 µg/m³, with 10 µg/m³ being the lowest value observed affecting their study participants. Finally, for O_3, the HRAPIE project (WHO, 2013b) recommends using SOMO10 as an alternative to the assessment of only SOMO35. The Review of evidence on health aspects of air pollution (REVIHAAP) (WHO, 2013a) also suggests that there is no specific threshold for effects and that small O_3 concentrations might affect human health.

The number of premature deaths attributable to $PM_{2.5}$ exposure when including the full range of concentration for $PM_{2.5}$ is around 22 % higher than estimated, based on concentrations equal to or above 2.5 µg/m³. For NO_2, the estimations considering only concentrations above 20 µg/m³ are at least four times lower than when assuming a threshold of 10 µg/m³. The results in Tables 10.1 and 10.2 indicate that in many countries concentrations do not exceed 20 µg/m³ and, therefore, the estimations of premature deaths and YLL attributable to NO_2 above that concentration are zero. Finally, for O_3, estimating health effects based on SOMO10 provides a number of premature deaths that are about four times higher than an estimation based on SOMO35.

Table A3.3 Estimated number of premature deaths and years of life lost attributable to $PM_{2.5}$ (from a concentration of 2.5 µg/m³), NO_2 (from a concentration of 10 µg/m³) and O_3 (for SOMO10), reference year 2018

		Pollutant and concentration threshold		
		$PM_{2.5}$ 2.5 µg/m³	NO_2 10 µg/m³	O_3 SOMO10
Total	Premature deaths	344 000	244 000	80 600
	Years of life lost	3 971 000	2 522 000	963 000
EU-28	Premature deaths	311 000	222 000	75 700
	Years of life lost	3 595 000	2 397 000	905 000

European Environment Agency

Air quality in Europe — 2020 report

2020 — 160 pp. — 21 x 29.7 cm

ISBN 978-92-9480-292-7
doi:10.2800/786656

TH-AL-20-023-EN-N
doi:10.2800/786656

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of the European Union

European Environment Agency