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Air quality in Europe — 2020 report

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Brexit notice
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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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-28 urban population exposure to concentrations **above** EU standards (1)	Urban population exposure to concentrations **above** WHO AQG value (2)	Reporting stations that registered concentrations **above** EU standards (1)	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 µg/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.

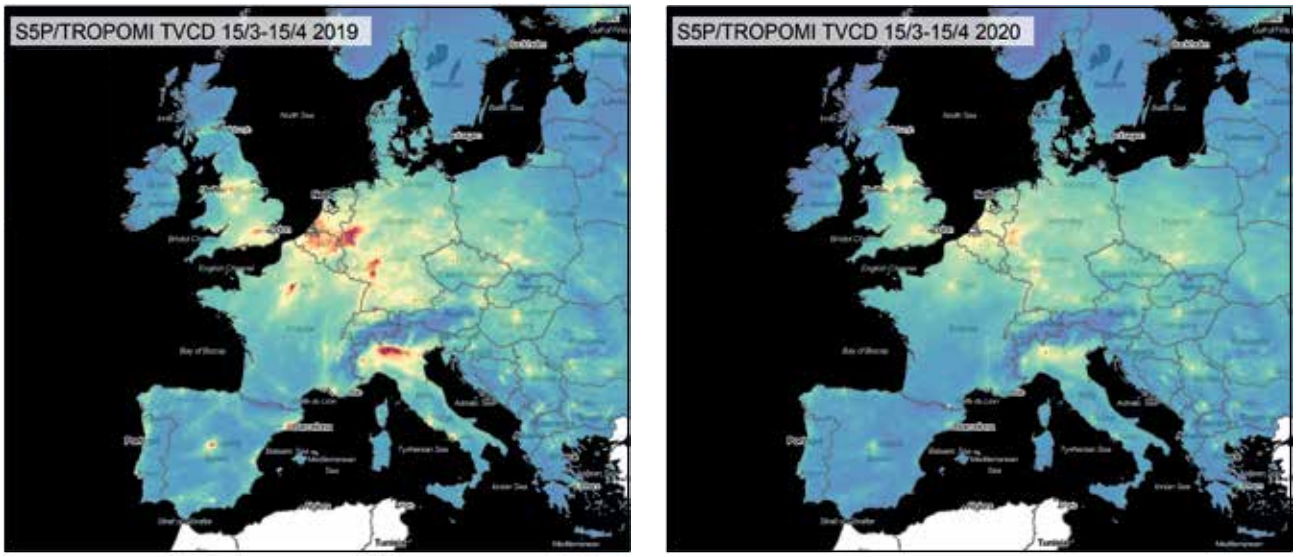
Cities were chosen according to their definition in Eurostat's city statistics database (formerly Urban Audit; Eurostat, 2020a). A daily value is obtained for each station in the city and then all daily values from stations in the city are averaged to get the weekly or monthly city concentration. Both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

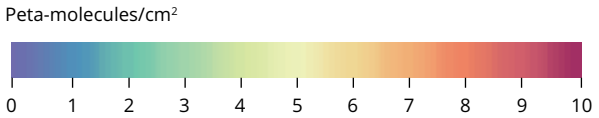
([9]) The gradient boosting regressor machine learning technique was used to simulate BAU NO_2 tropospheric columns satellite observations. Weather variables from the European Centre for Medium-Range Weather Forecasts (ECMWF) and CAMS operational forecasts at 9 km and 10 km resolutions, respectively, 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)



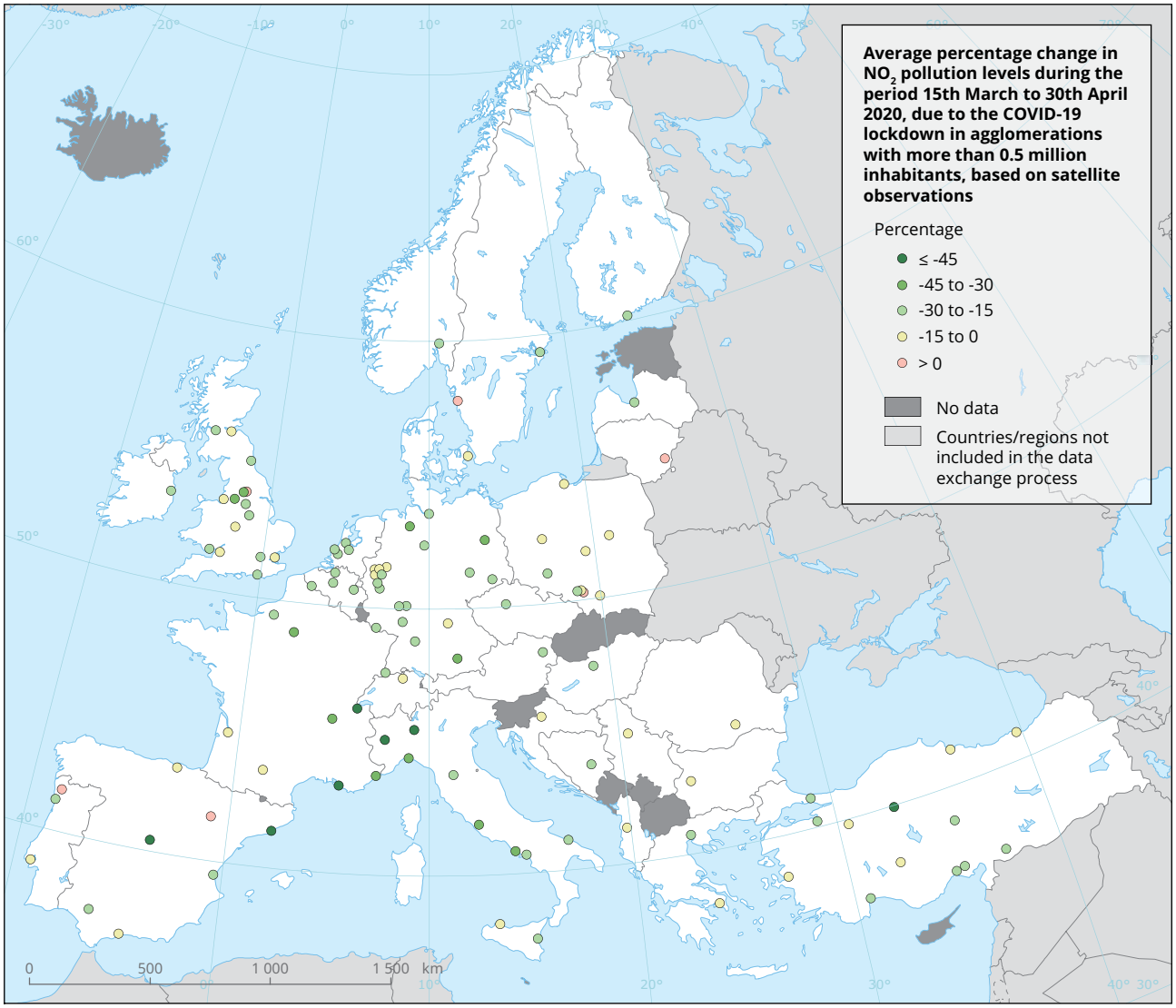
Note: Units are given in 10^{15} molecules per square centimetre.

(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).

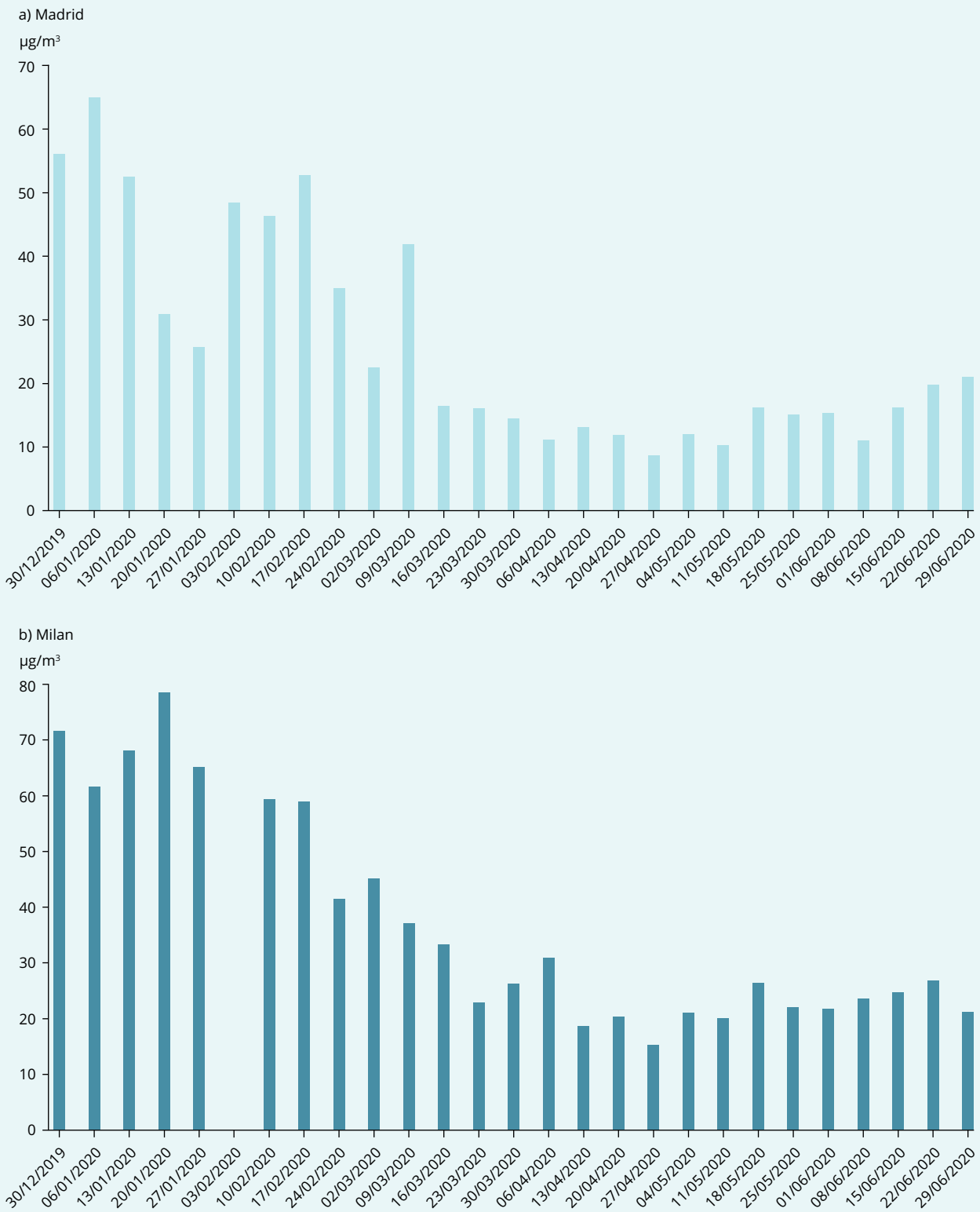
Map 2.2 **Average percentage change in NO_2 pollution levels during the period 15 March to 30 April, due to the COVID-19 lockdown in agglomerations with more than 0.5 million inhabitants, based on satellite observations**



Reference data: ©ESRI

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

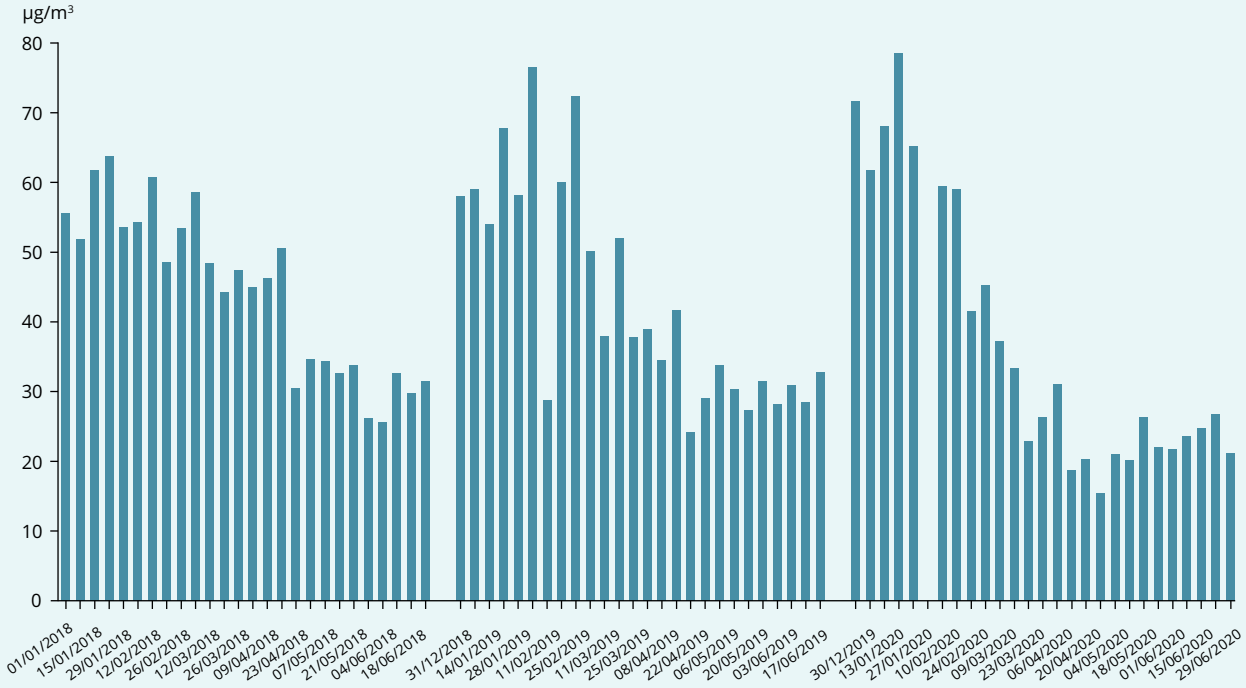
Figure 2.1 Development of weekly NO_2 concentrations in Madrid and Milan, January to June 2020



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).

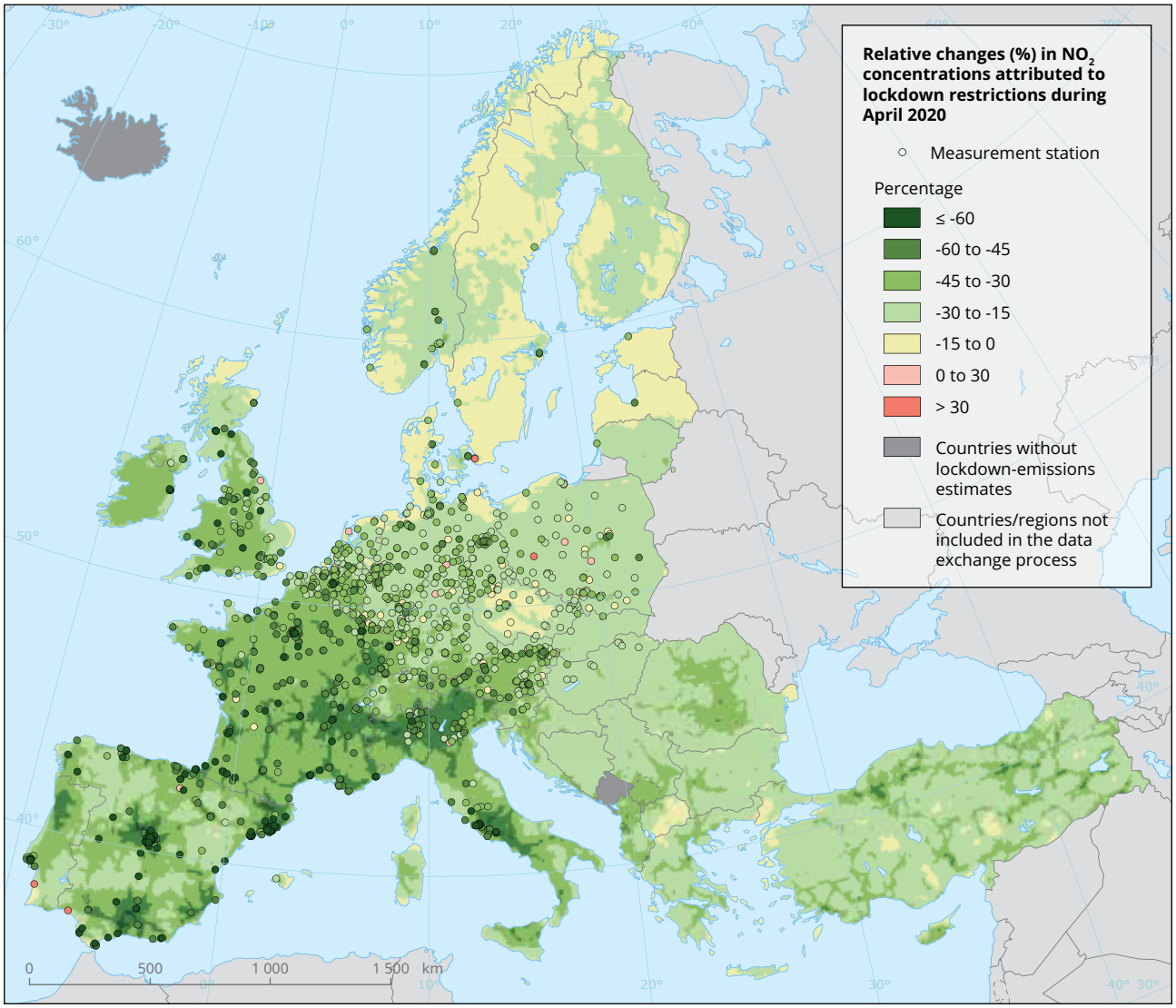
([11]) The GAM model is a non-linear regression model, which uses daily modelled meteorological data from ECMWF to predict daily air pollutant concentrations. Previously, the model needed to be 'trained' and in order to do so both modelled meteorological data and daily measured air pollutant concentrations 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

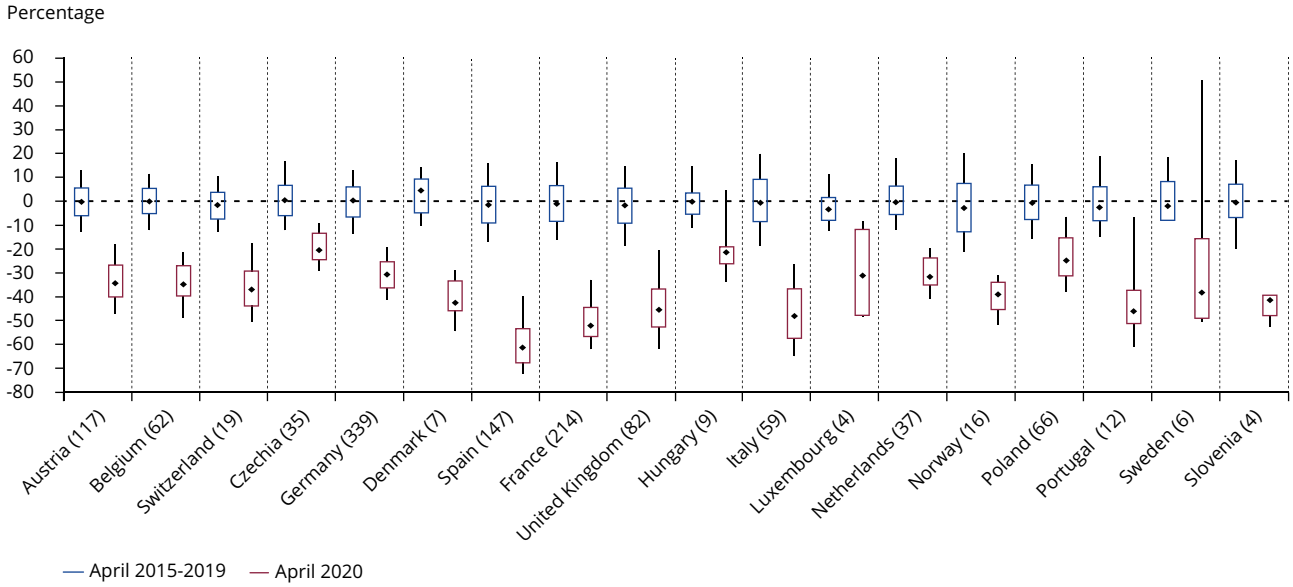
Note: The dots represent measurements stations, where the changes have been estimated using UTD monitoring data and the GAM. The background shading represents the changes estimated using CAMS chemical transport modelling with an emission inventory estimated for the lockdown conditions.

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.

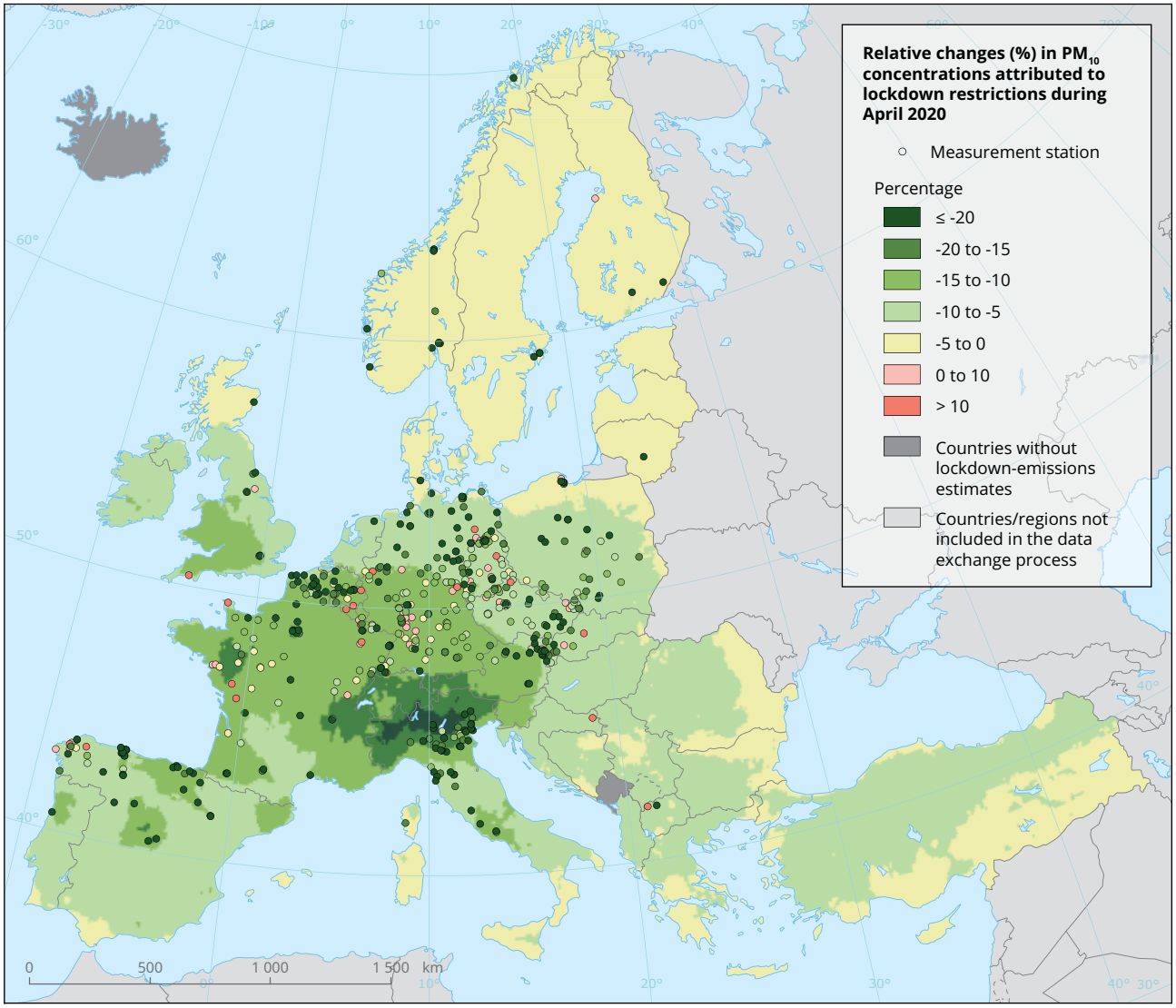
Rural stations also registered the highest uncertainties in the relative change estimations, partly because concentrations are lower in rural background areas and partly because of the complexity of the estimation, as secondary PM makes up a larger fraction of the measured PM mass and is more difficult 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

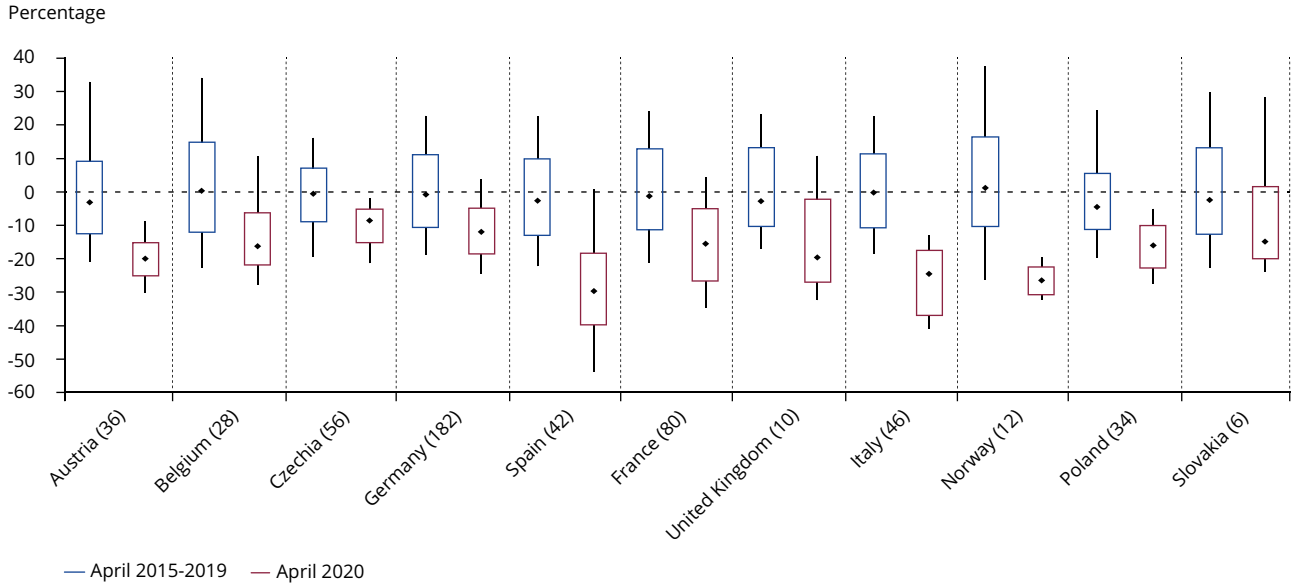
Map 2.4 Relative changes (%) in PM_{10} concentrations attributed to lockdown restrictions during April 2020



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

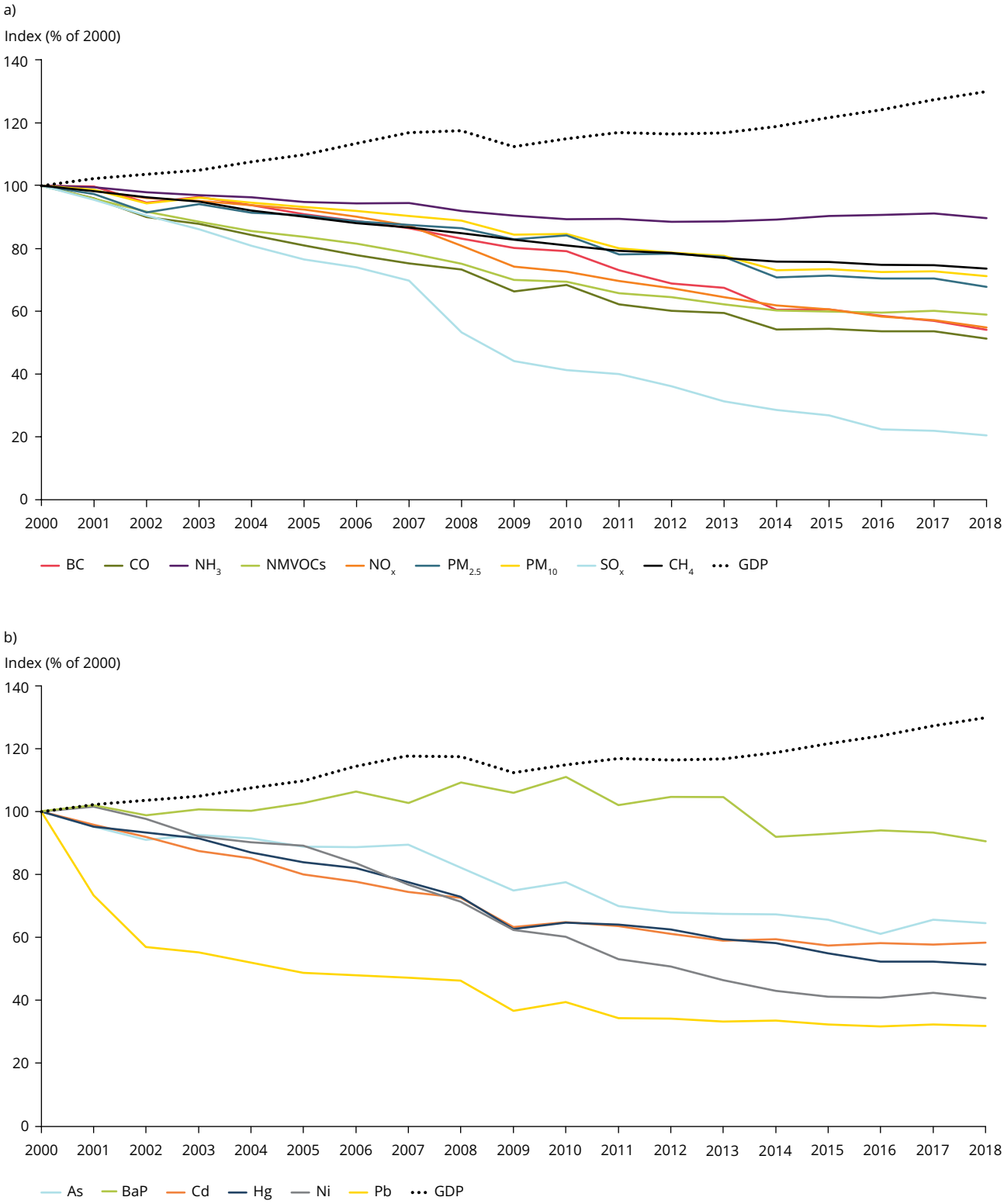
Figure 3.1 shows the total emissions of pollutants in the EU-28, indexed as a percentage of their value in the reference year 2000. Emissions for all primary and precursor pollutants contributing to ambient air concentrations of PM, O_3 and NO_2, as well as arsenic (As), cadmium (Cd), nickel (Ni), lead (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)**



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.

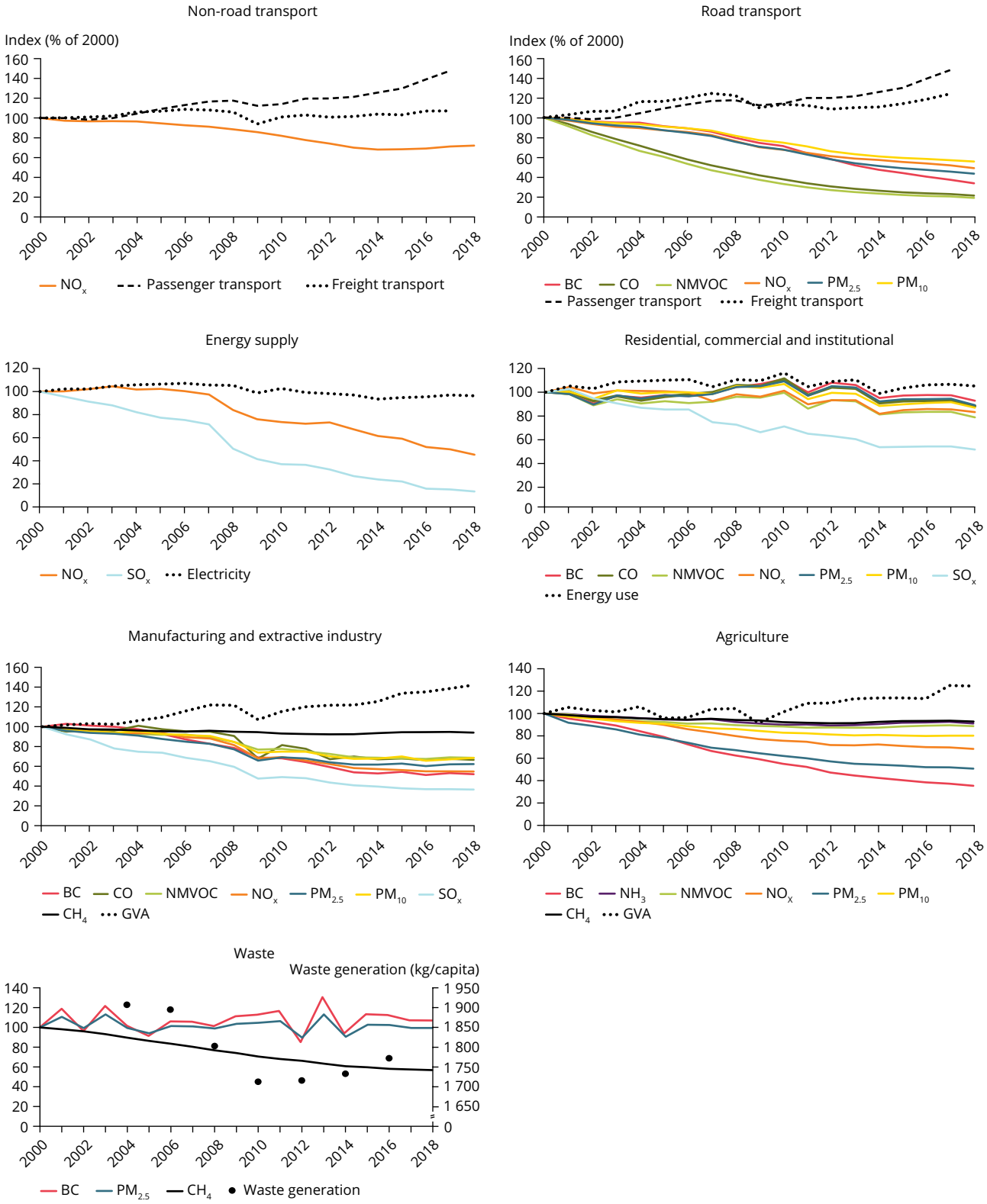
Sectoral activity key indicator for the residential, commercial and institutional is the energy use expressed in terms of the final energy consumption (described in units of toe) by the end users in the commercial and public services (Eurostat, 2020d) and by households (Eurostat, 2020e).

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))**

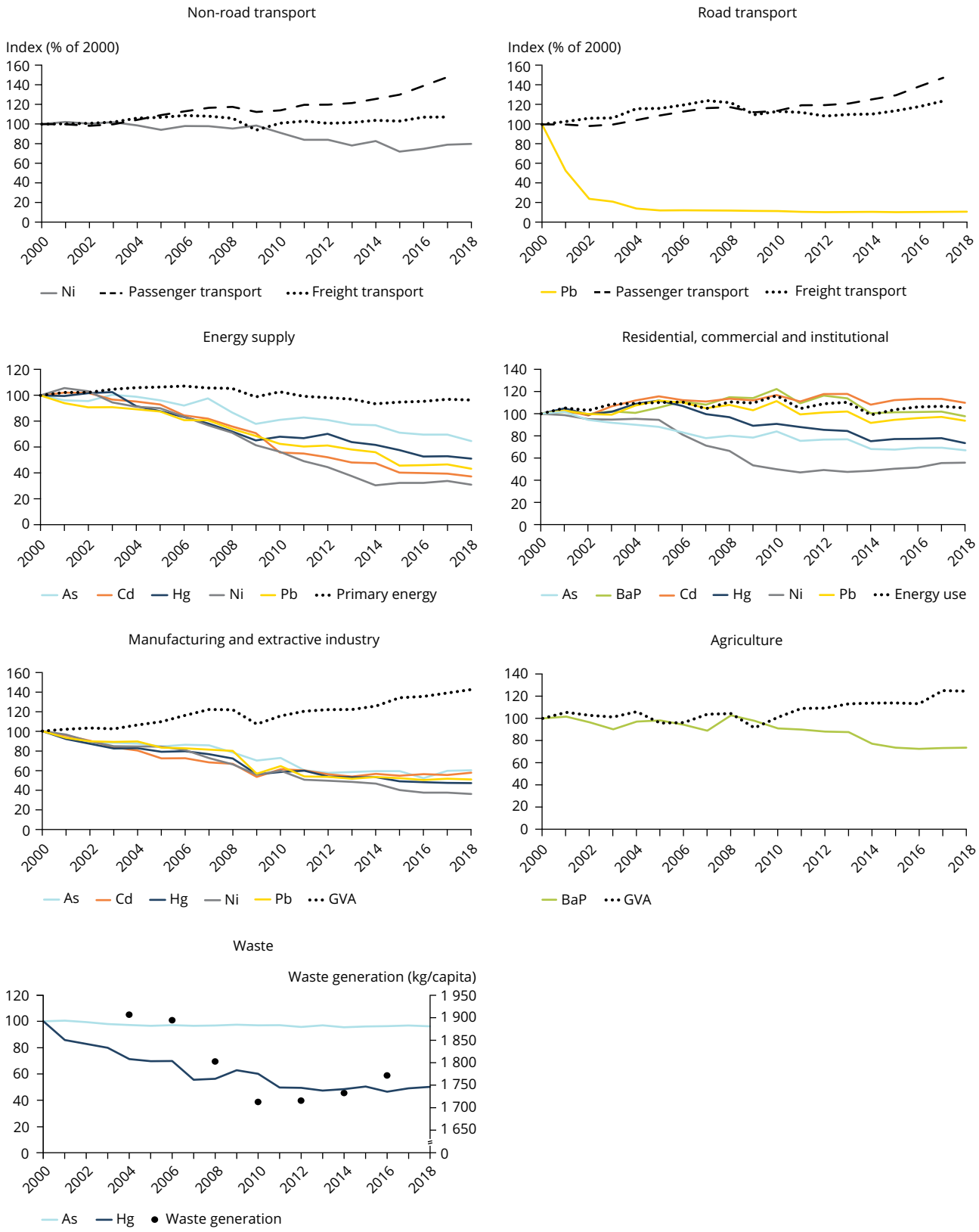


Notes: Only pollutants for which the sector contributes more than 5 % to the total pollutant emissions are shown in the figures.

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.

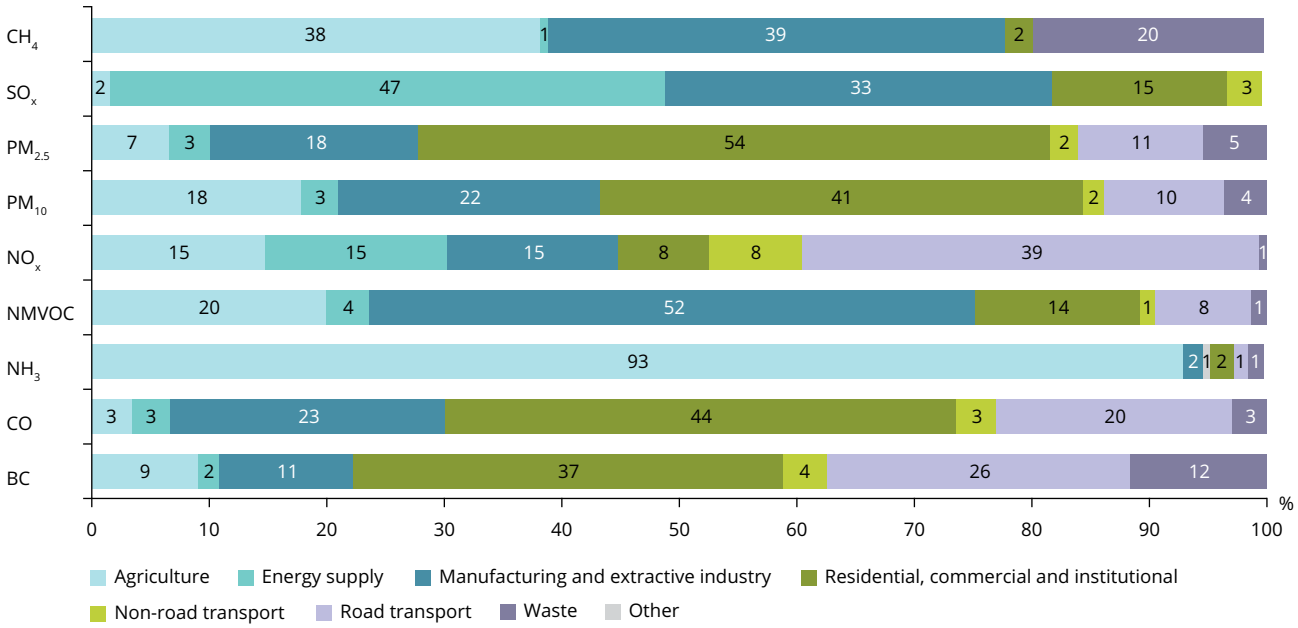
The sector with the least decoupling is the residential, commercial and institutional sector, where the energy use and respective emissions have been decoupling since 2014, but not substantially, except for SO_2. This is also the sector where emissions show the lowest decrease since 2000. Agriculture 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, CH_4, 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 emissions, as well as a significant amount of CH_4, BaP, NMVOC and NO_X emissions. The waste sector is the third largest contributor to CH_4, 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.

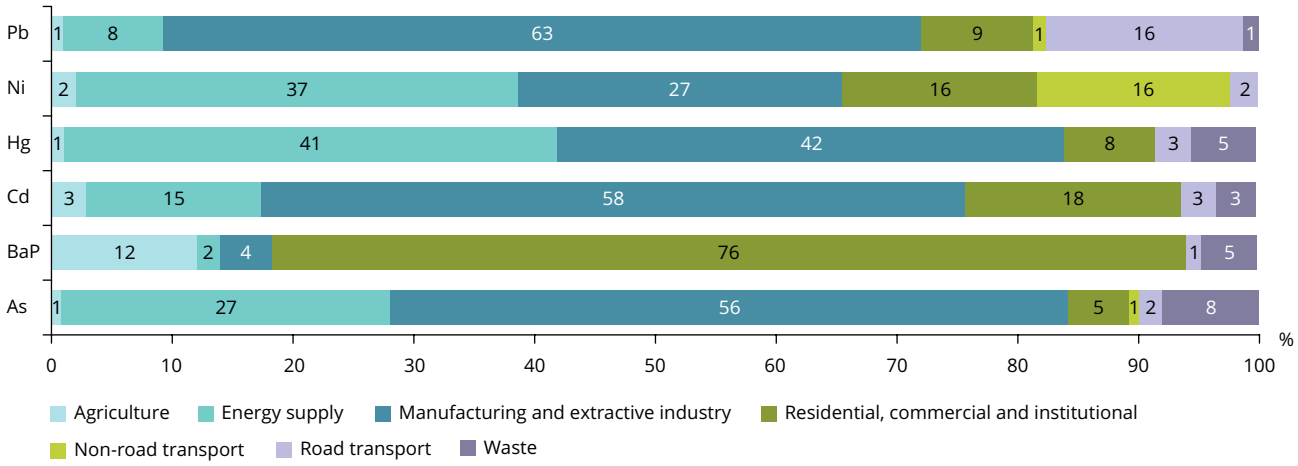
Figure 3.4 Contribution to EU-28 emissions from the main source sectors in 2018 of CH_4, SO_X, NO_X, primary PM_{10}, primary $PM_{2.5}$, NH_3, NMVOCs, CO and BC



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.

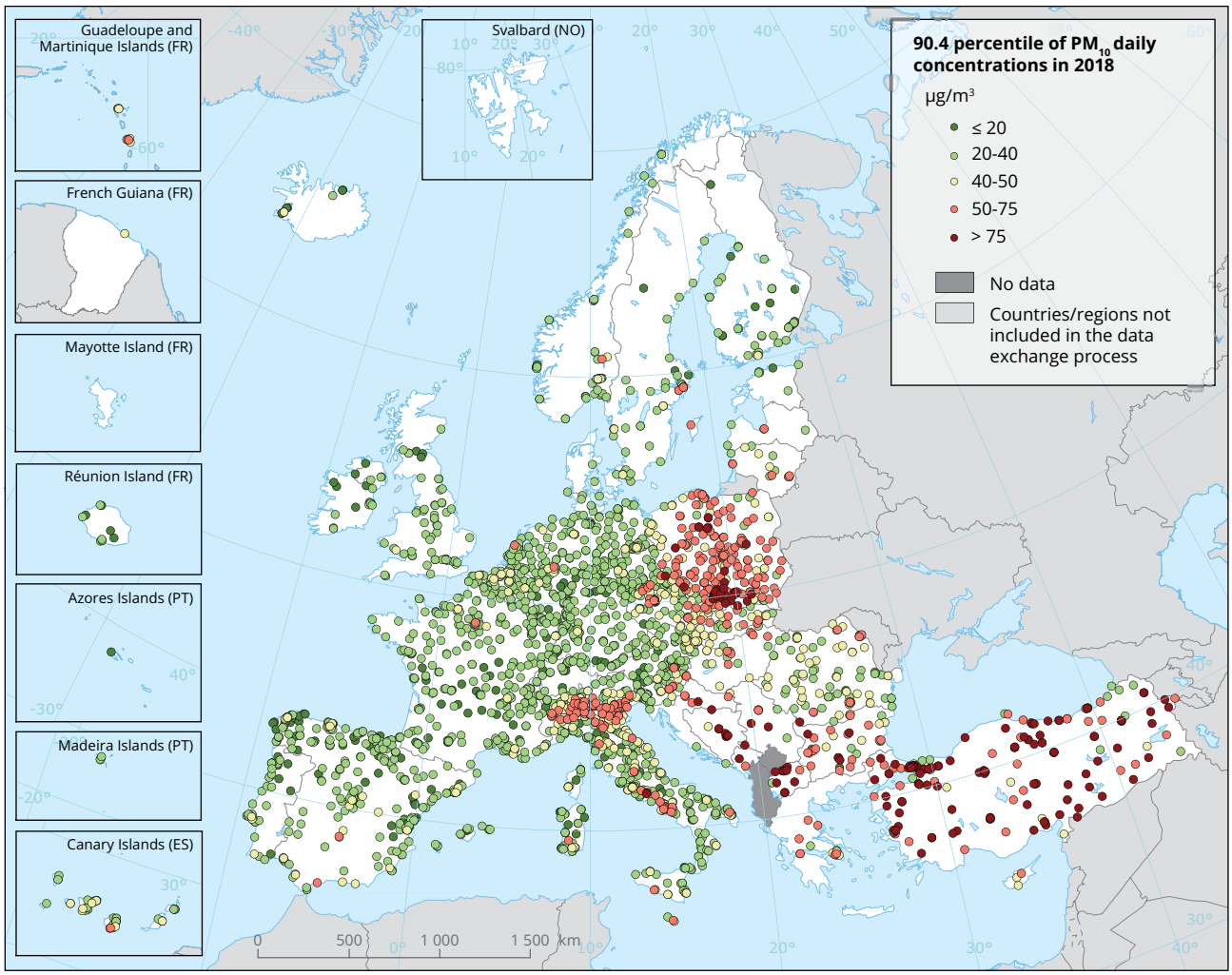
Table 4.1 Air quality standards for protecting human health from PM

Pollutant	Averaging period	Standard type and concentration	Comments
PM_{10}	1 day	EU limit value: 50 µg/m³	Not to be exceeded on more than 35 days per year
		WHO AQG: 50 µg/m³	99th percentile (3 days per year)
	Calendar year	Limit value: 40 µg/m³	
		WHO AQG: 20 µg/m³	
$PM_{2.5}$	1 day	WHO AQG: 25 µg/m³	99th percentile (3 days per year)
	Calendar year	EU limit value: 25 µg/m³	
		EU exposure concentration obligation: 20 µg/m³	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/m³	

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

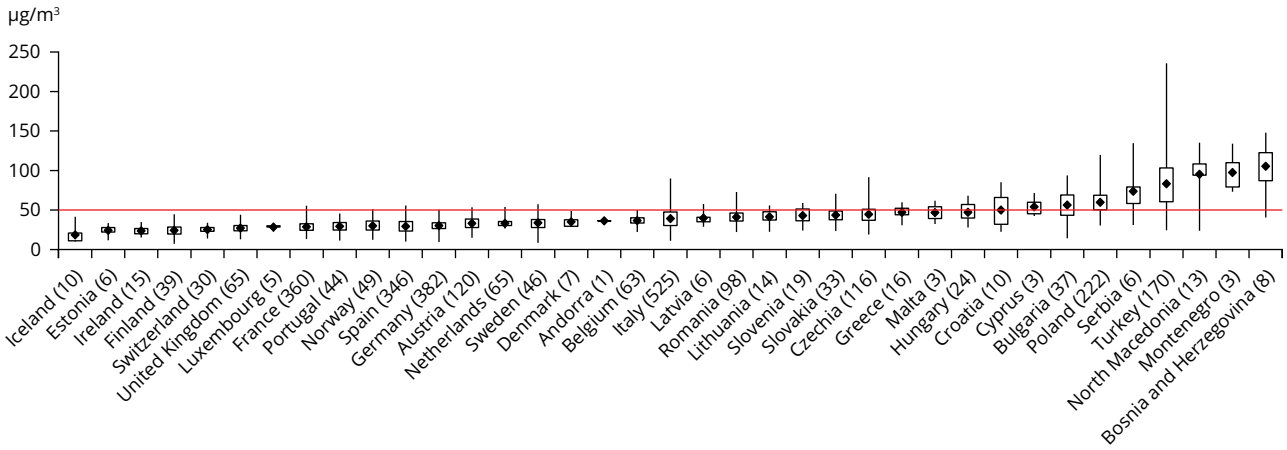


Reference data: ©ESRI | ©EuroGeographics

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

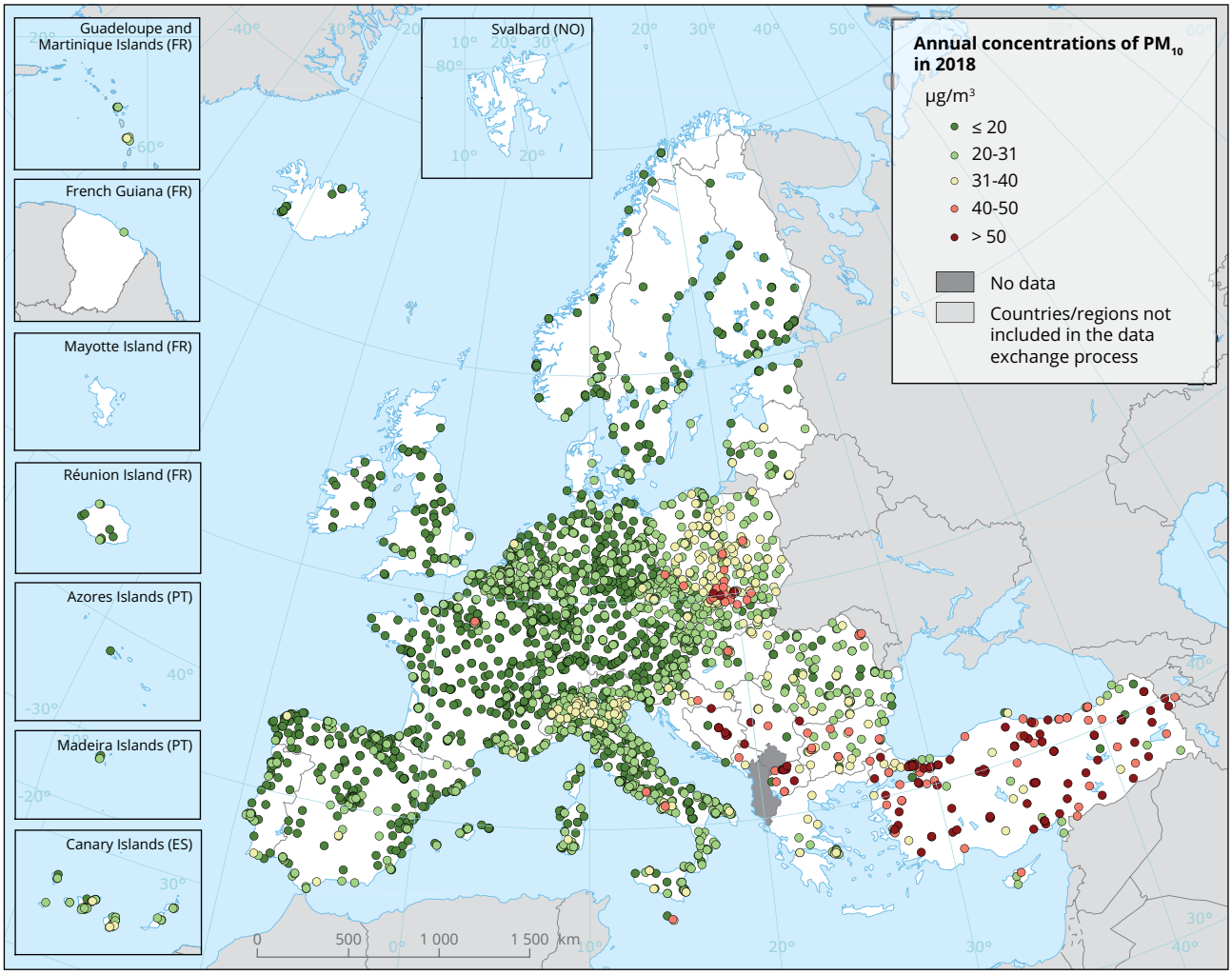


Note: The graph is based, for each country, on the 90.4 percentile of daily mean concentration values corresponding to the 36th highest daily mean. For each country, the number of stations considered (in brackets) and the lowest, highest and average 90.4 percentile values (in µg/m³) recorded at its stations 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

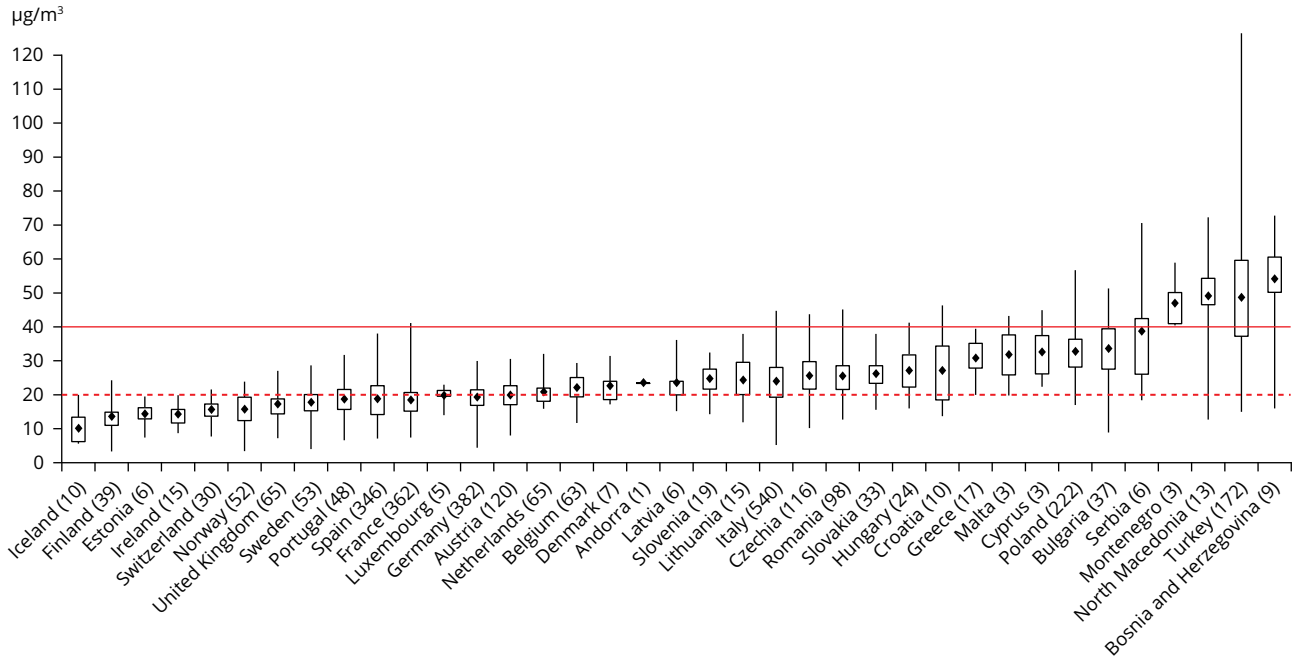


Reference data: ©ESRI | ©EuroGeographics

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.

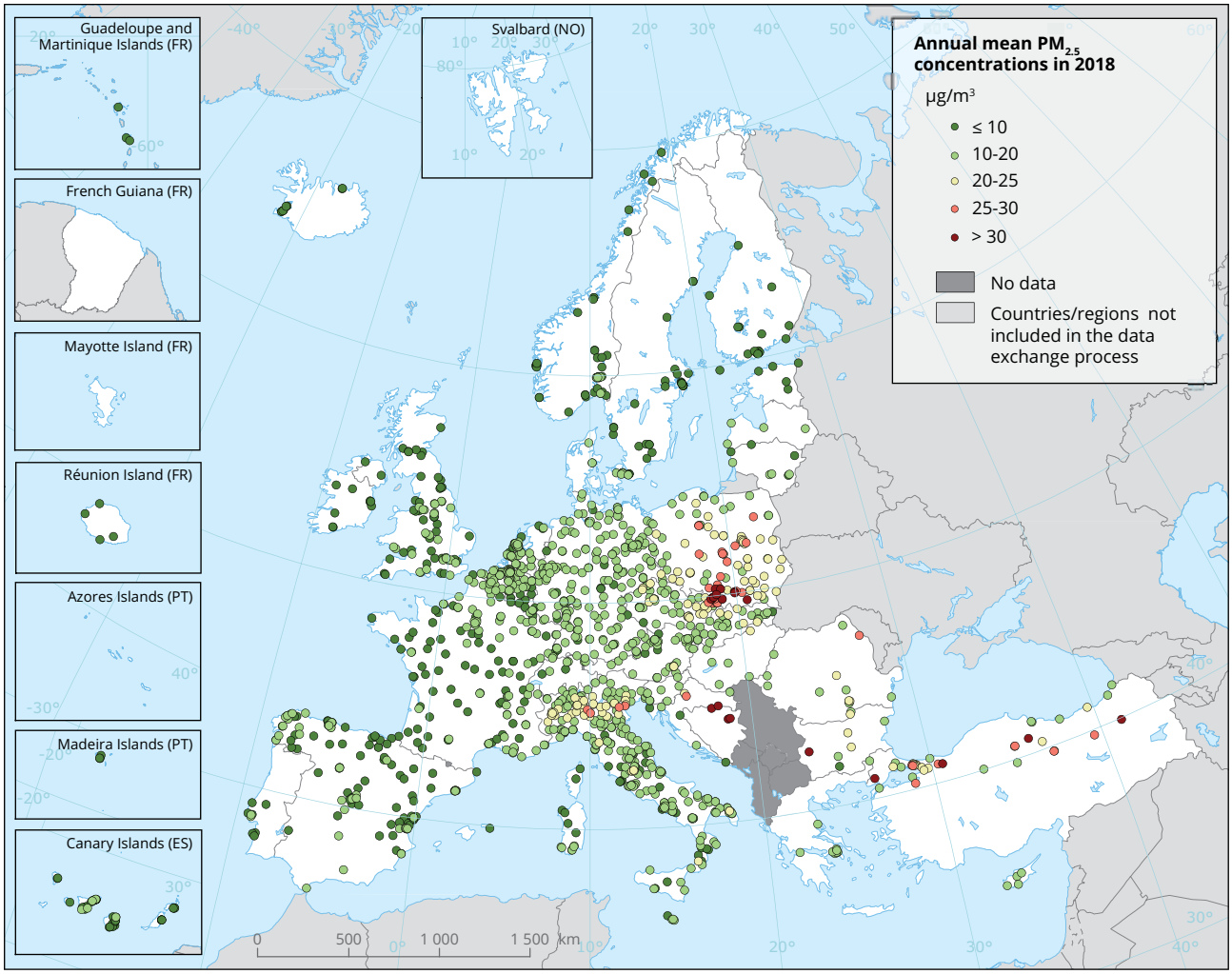
Source: EEA (2020c).

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

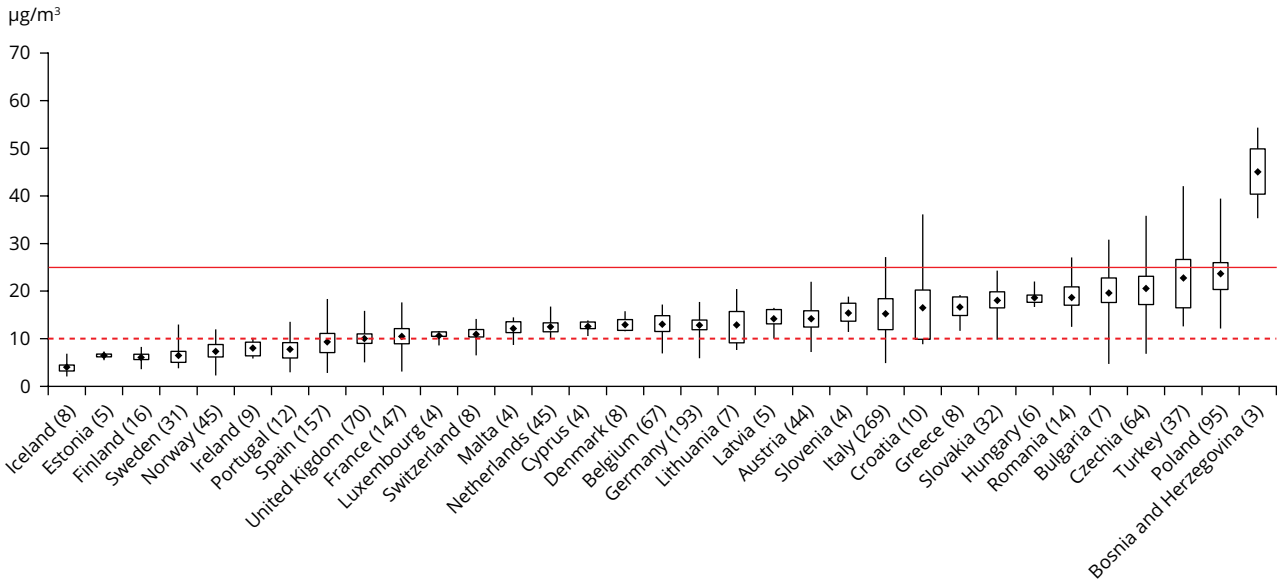


Reference data: ©ESRI | ©EuroGeographics

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/m^3 per year (-1.6 µg/m^3 per year for (sub) urban background stations), over the last decade. Only North Macedonia (-2.5 µg/m^3 per year, three stations) and Cyprus (-1.6 µg/m^3 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/m^3 per year, two stations) and Denmark (0.1 µg/m^3 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).

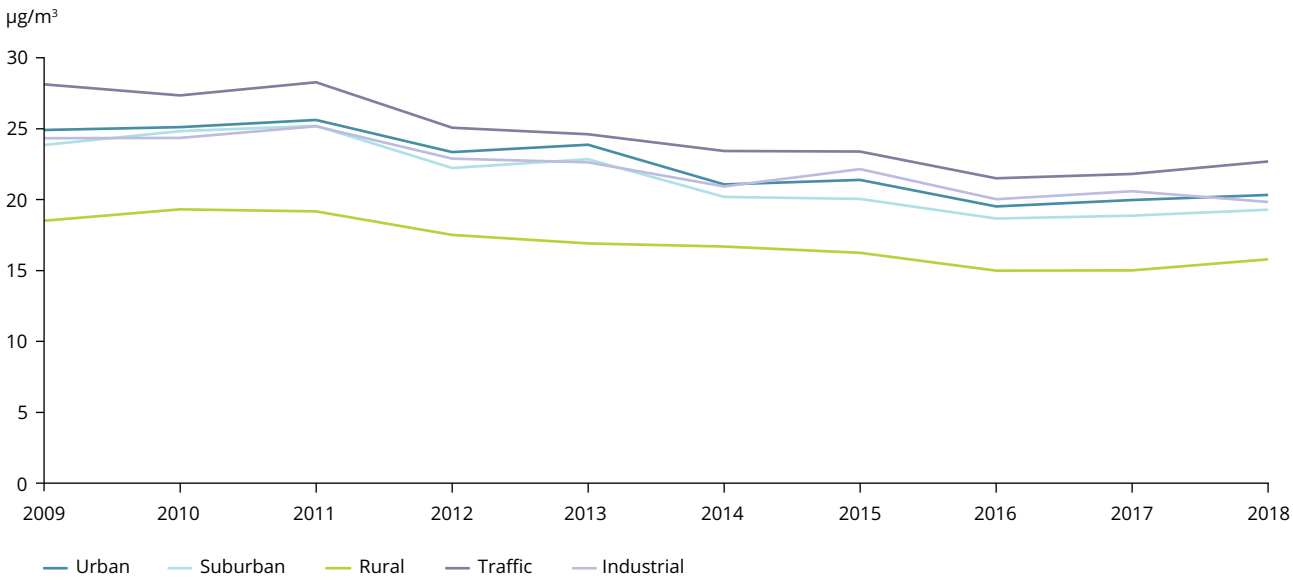
Figure 4.6 presents the average value for the 90.4 percentile (p90.4) of the daily PM_{10} concentrations (36th highest daily) in a year for urban, suburban and rural background, traffic and industrial stations. The time series indicate a similar behaviour as shown for the annual average in Figure 4.4, 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 $PM_{2.5}$

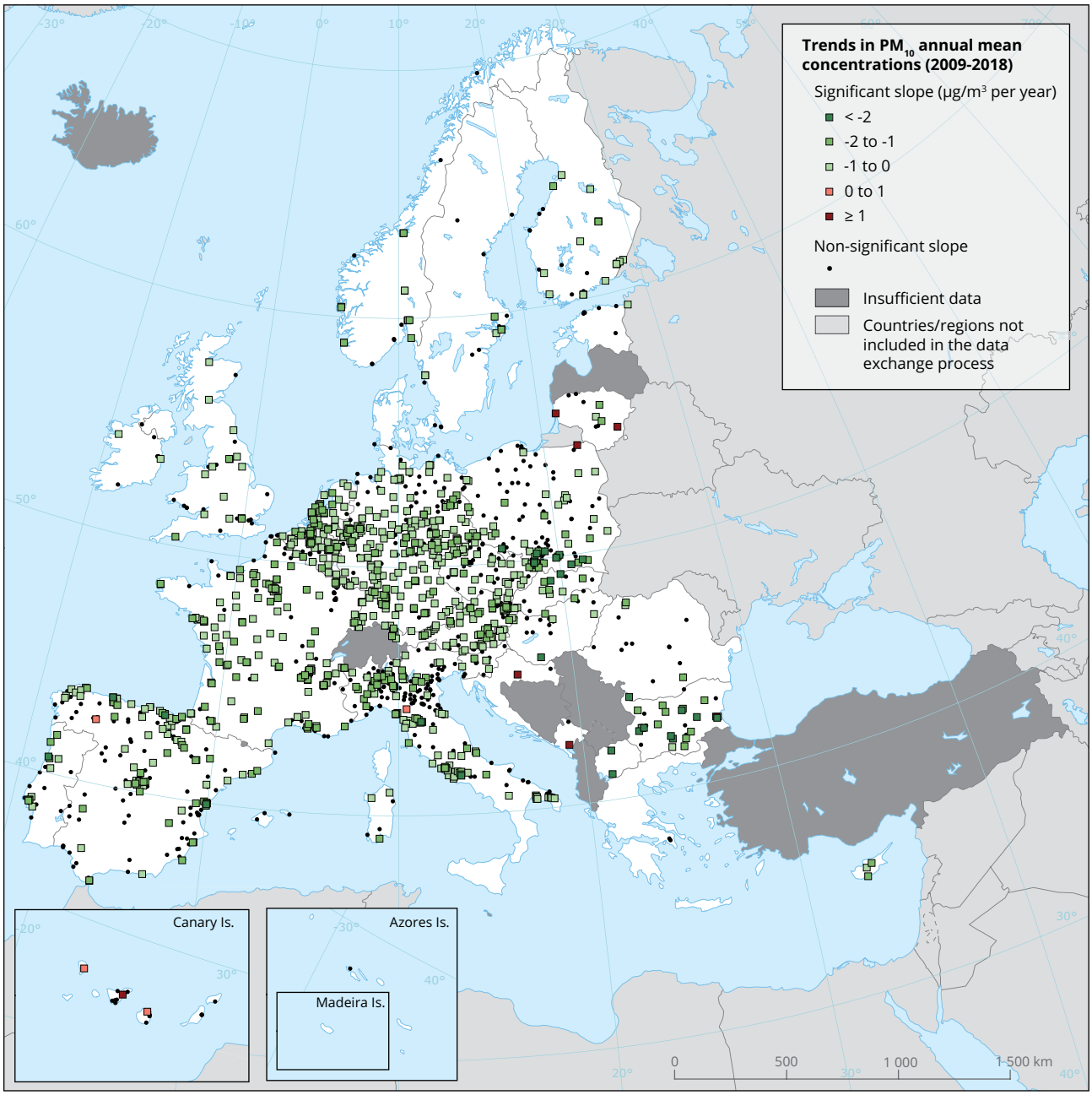
The development in average $PM_{2.5}$ annual mean concentrations from 2009 to 2018 is presented in Figure 4.8 for urban, suburban and rural background, traffic and industrial stations. $PM_{2.5}$ concentrations mainly decreased between 2011 and 2016, but, as for PM_{10}, there was an increase in average 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.

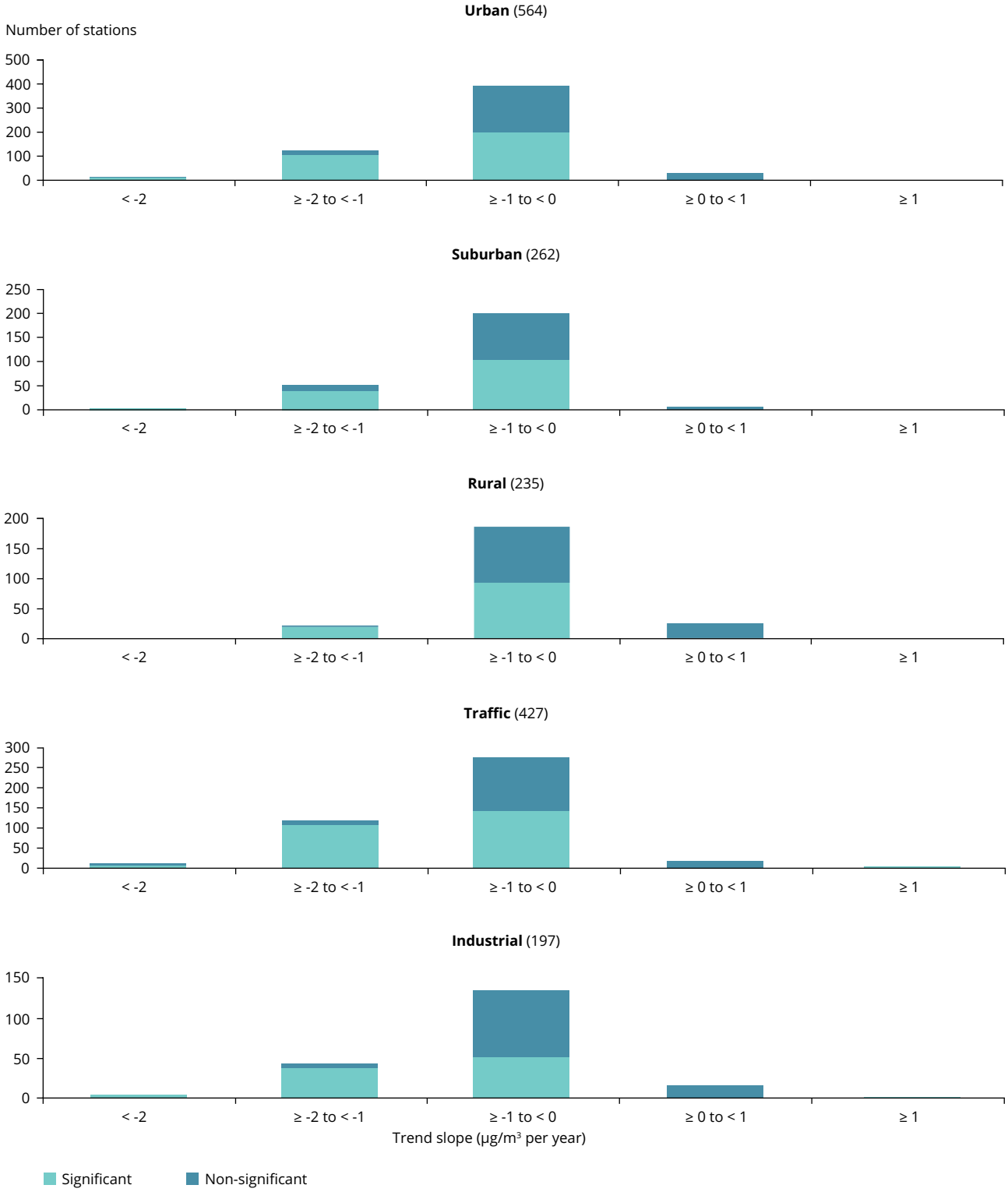
Map 4.4 Trends in PM_{10} annual mean concentrations (2009-2018)



Reference data: ©ESRI

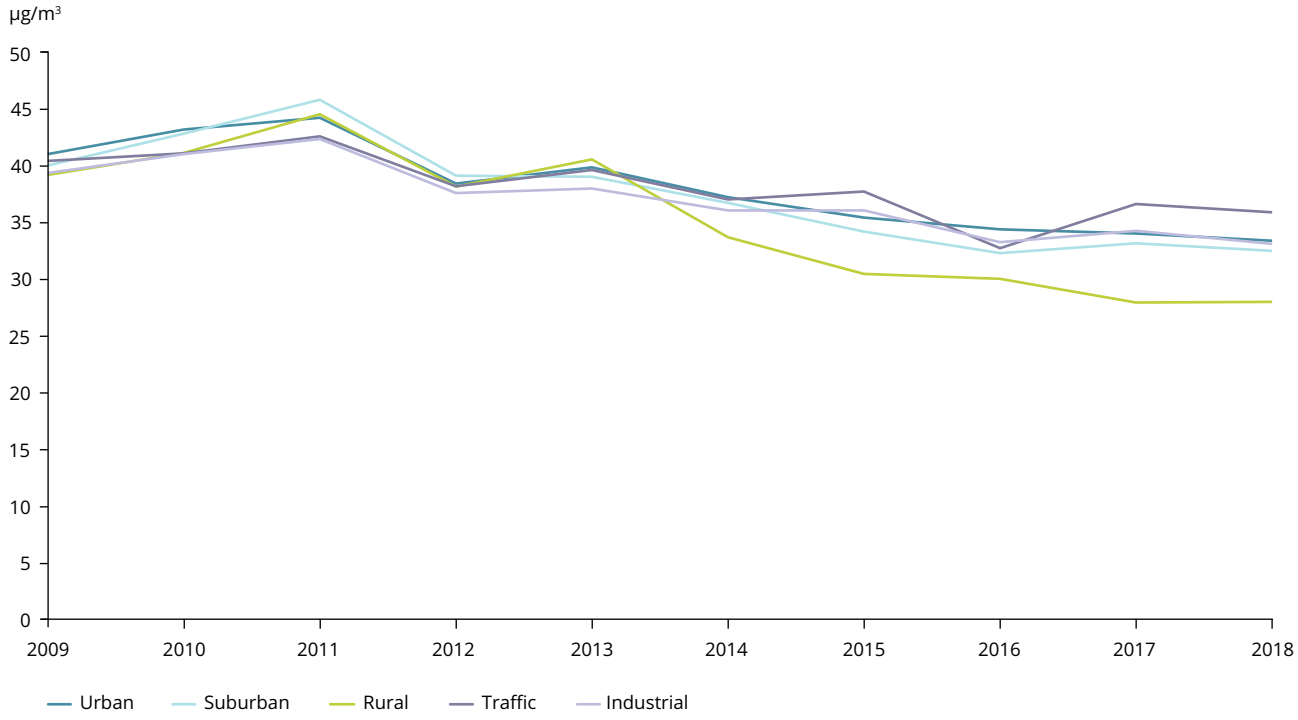
Note: For further information, please see Annex 2.

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.

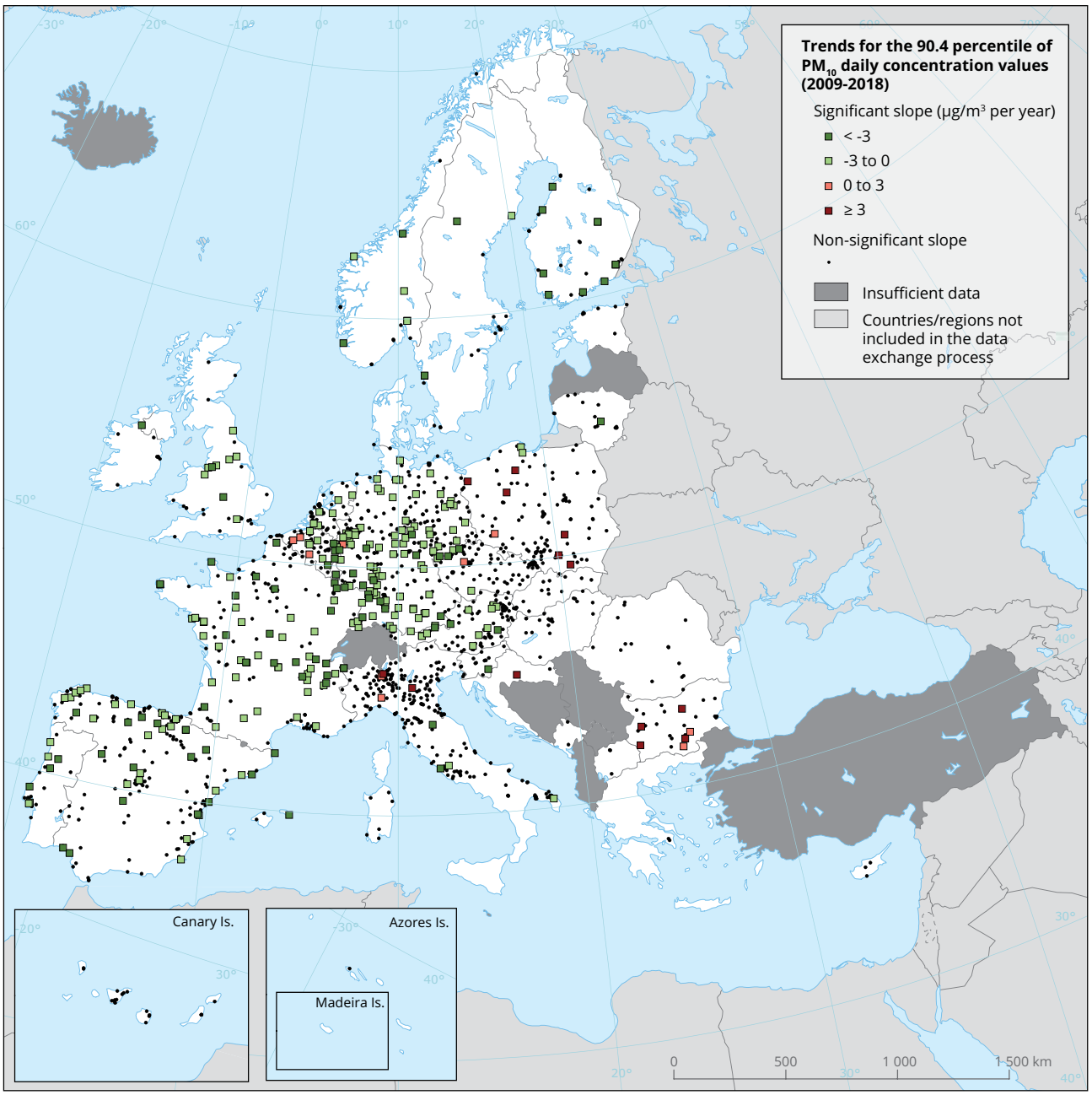
Map 4.6 shows the spatial distribution of the trend significance and slope from the trend analysis for the same period. The analysis shows that 58 % of the stations have a significant trend and most of the stations with a significant trend have a decreasing trend (92 %). The trend slopes, per station 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.

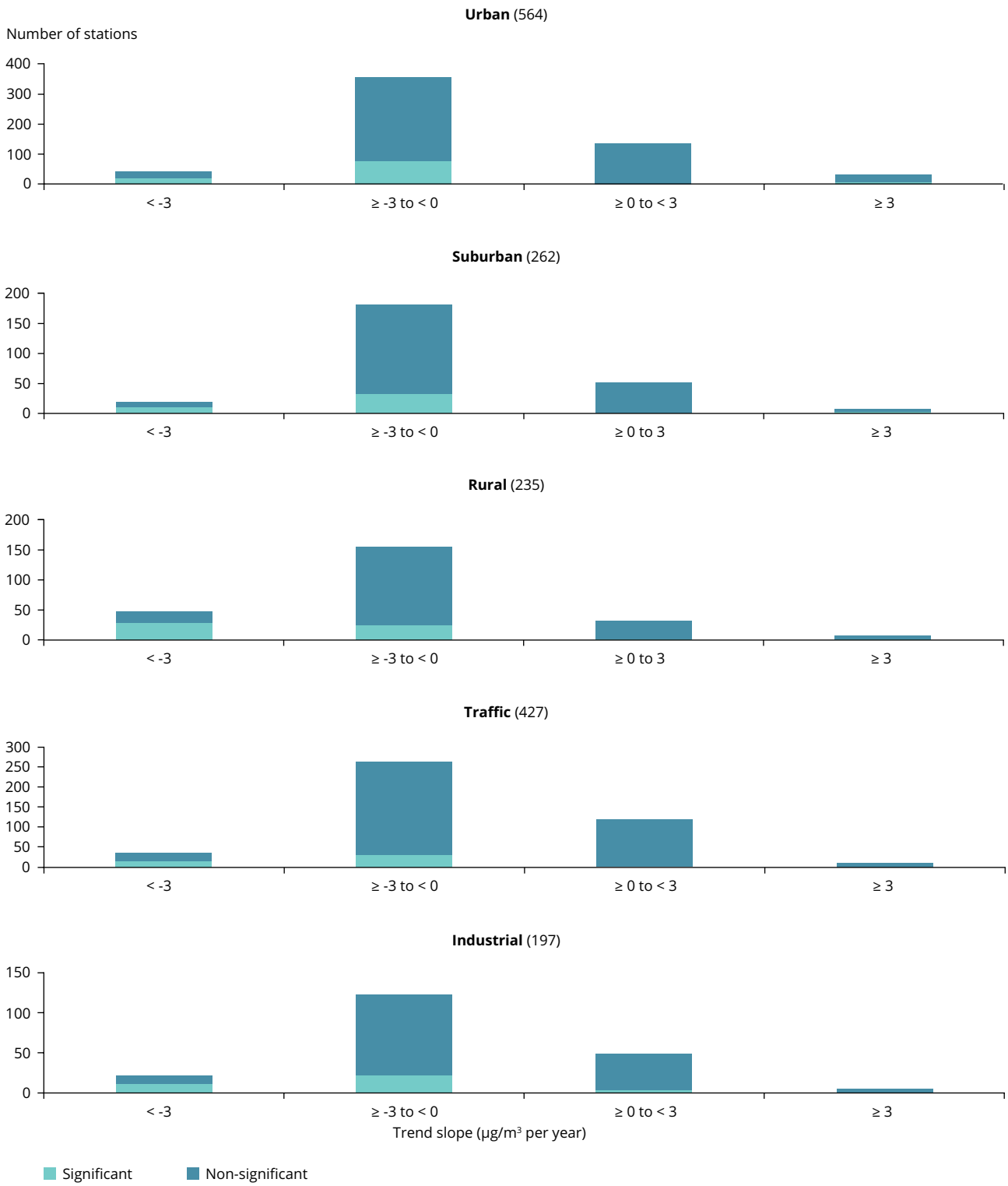
Map 4.5 Trends for the 90.4 percentile of PM_{10} daily concentration values (2009-2018)



Reference data: ©ESRI

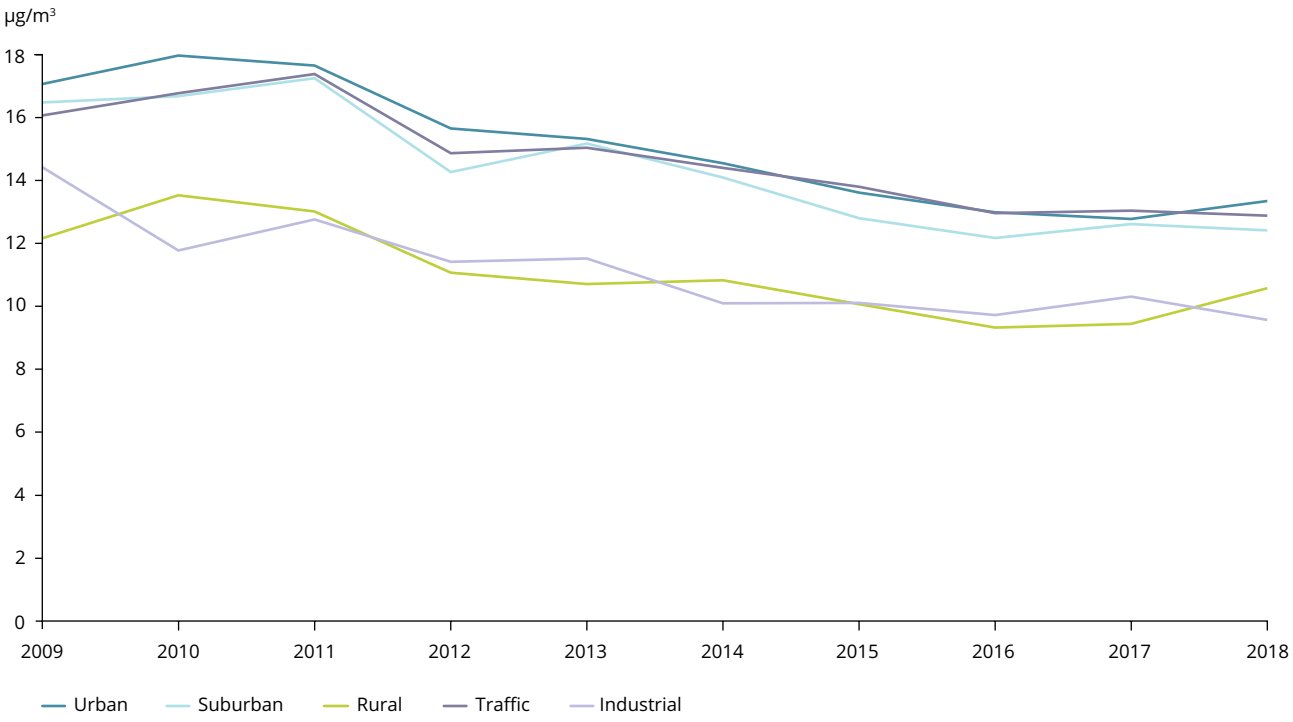
Note: The 90.4 percentile of the PM_{10} daily mean concentrations represents the 36th highest value in a complete series and is related to the PM_{10} daily limit value. For further information on the trend analysis, please see Annex 2.

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



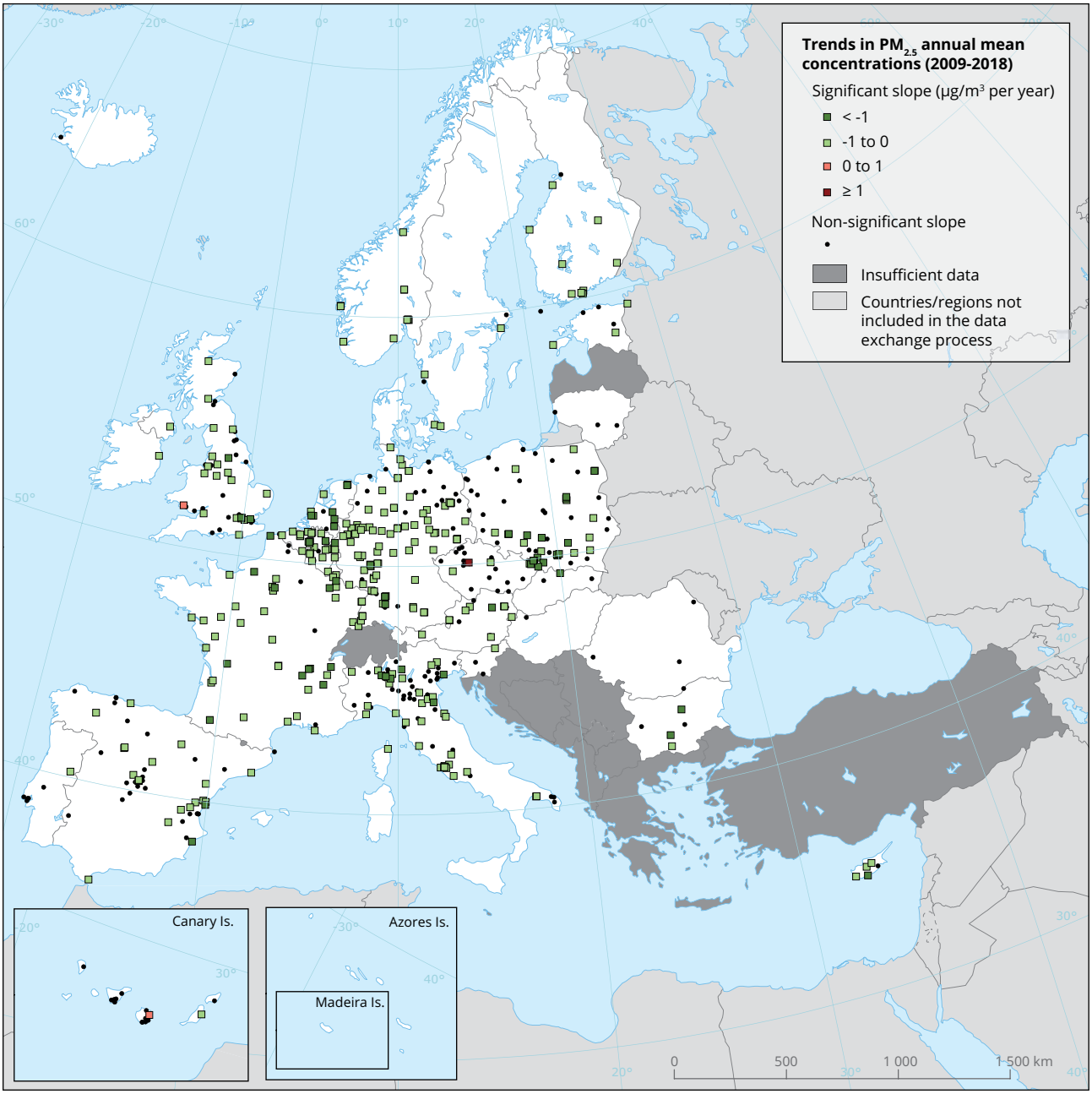
4.4 $PM_{2.5}$ average exposure indicator

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.

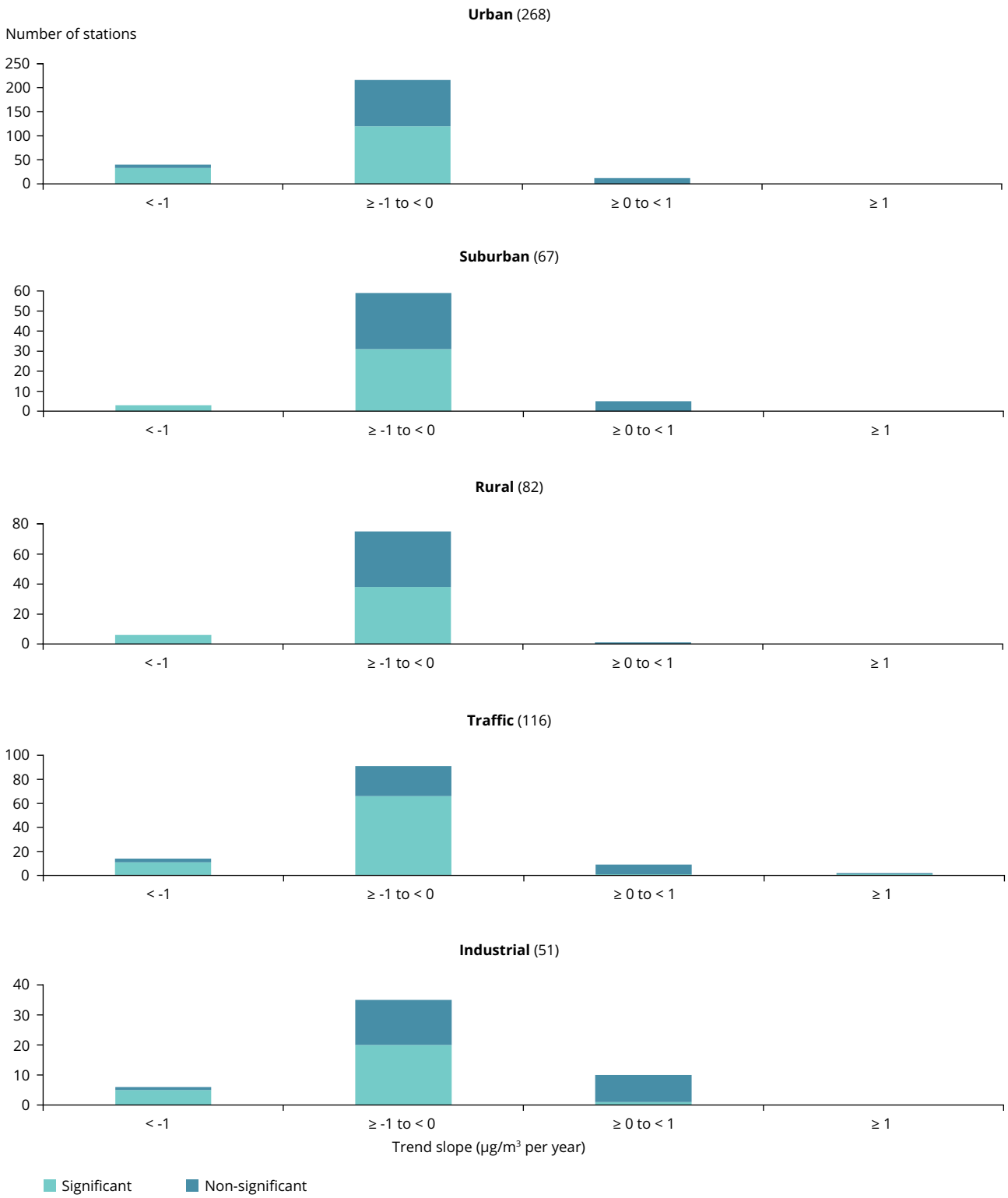
Map 4.6 Trends in $PM_{2.5}$ annual mean concentrations (2009-2018)



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 %).

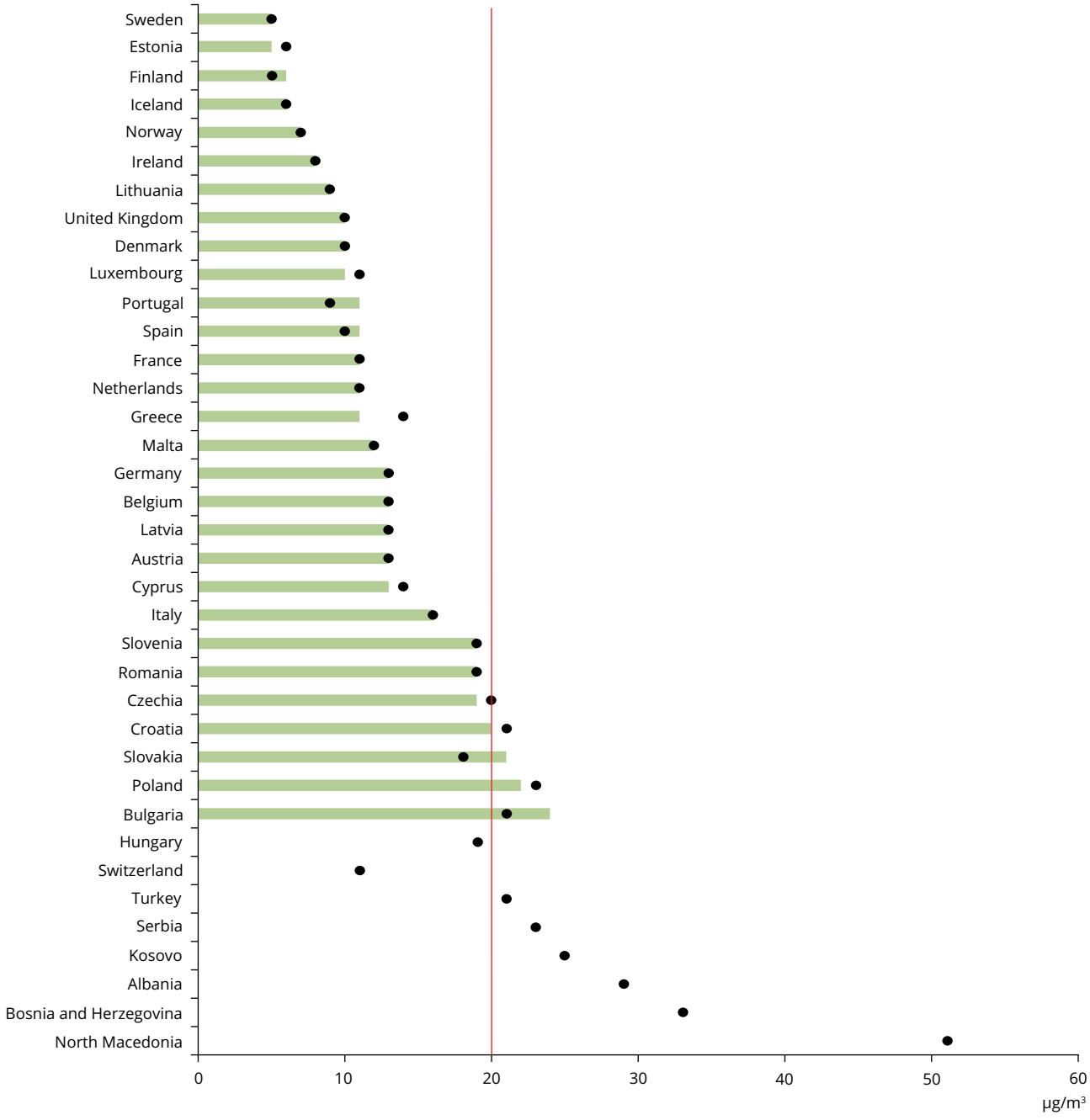
UTD concentrations above the PM_{10} annual limit value in 2019 were monitored in 0.5 % (10 stations) of all the reporting stations, located in four countries: North Macedonia (five), Poland (three), Bulgaria (one) and Italy (one). The stricter value of the WHO AQG for PM_{10} annual mean was exceeded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

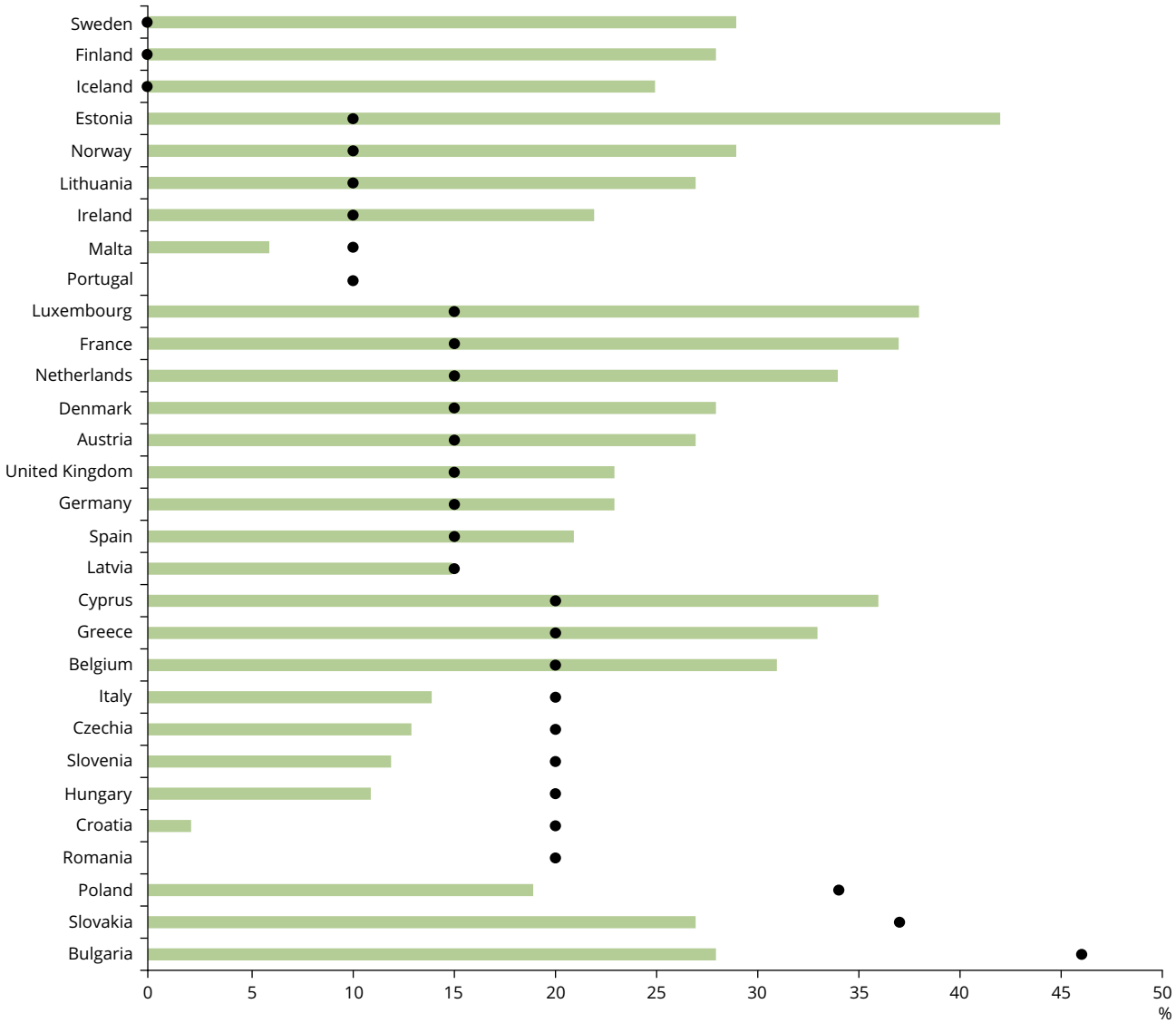
The dots show all urban and suburban background $PM_{2.5}$ concentrations (for stations with at least 75 % of data coverage) in all reporting countries presented as 3-year (2016-2018) averages, as an approximation of the AEI in 2018 and to facilitate comparison with information provided in previous *Air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

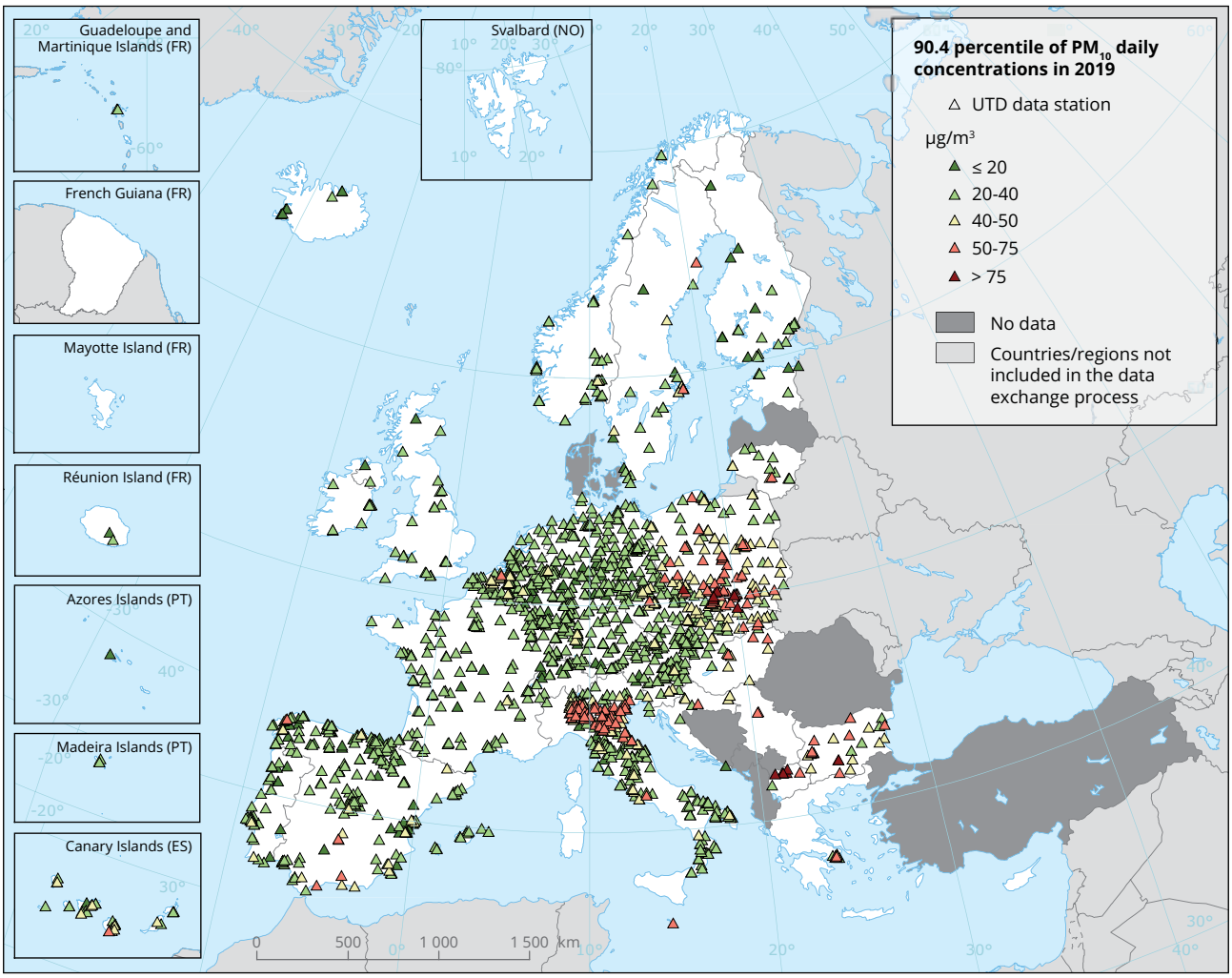


Notes: Bars indicate the reduction in the AEI 2018 as a percentage of the AEI 2011 (AEI 2015 in the case of Croatia — see the main text). Dots indicate the reduction to be obtained in the AEI 2020 as a percentage of the AEI 2011 (AEI 2015 in the case of Croatia). If the end of the bar is to the right 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

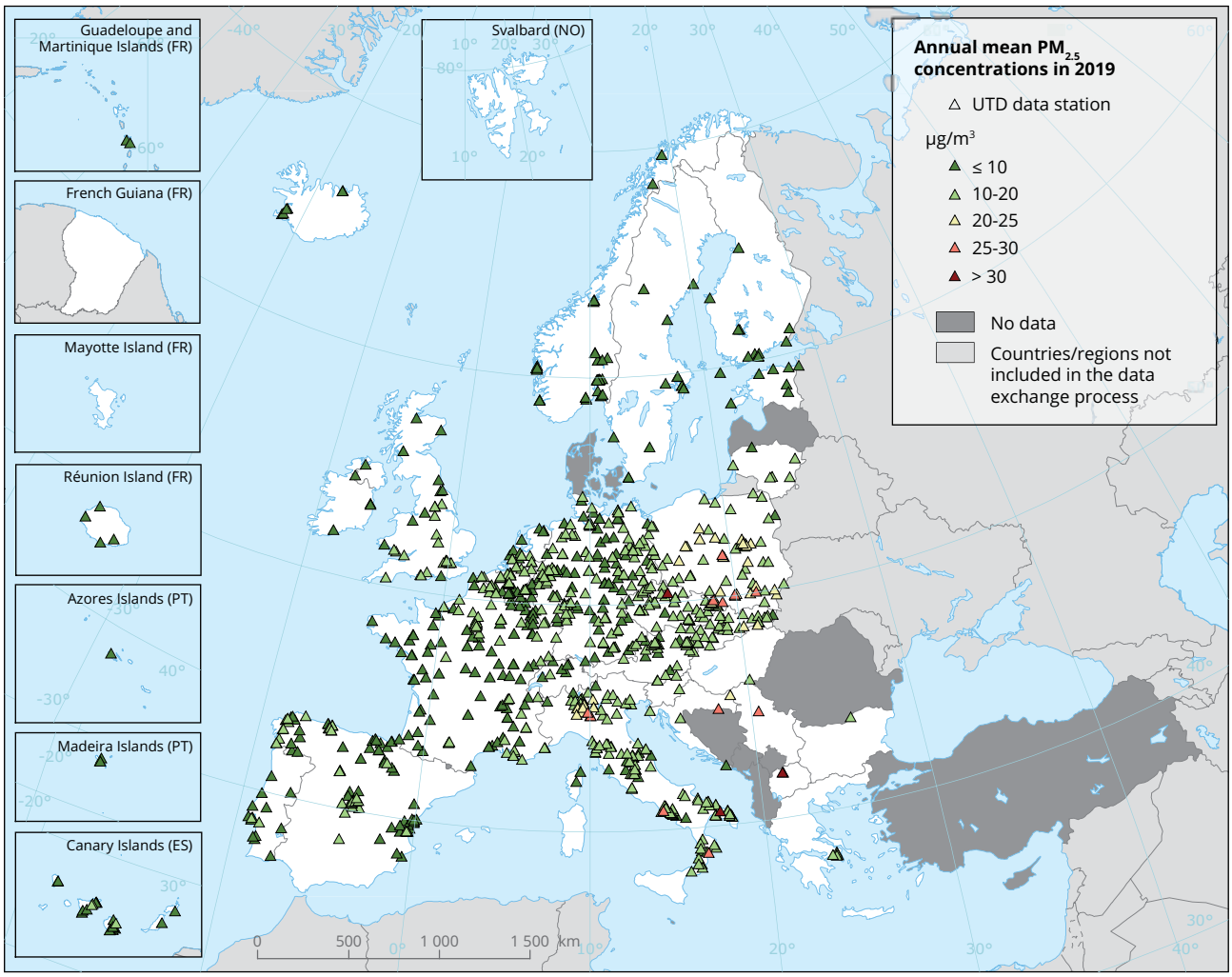


Reference data: ©ESRI | ©EuroGeographics

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

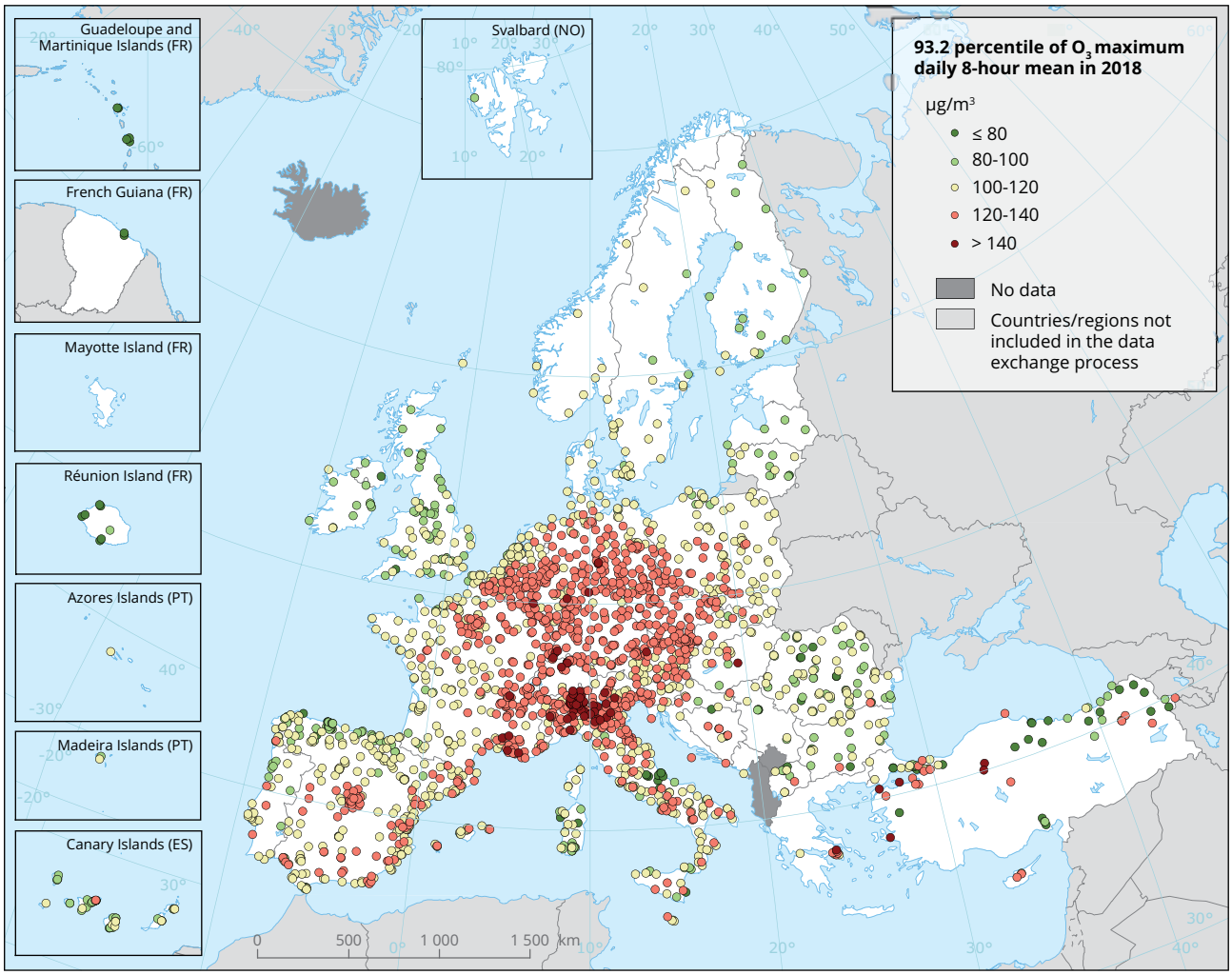
Table 5.1 Air quality standards for protecting human health from O_3

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



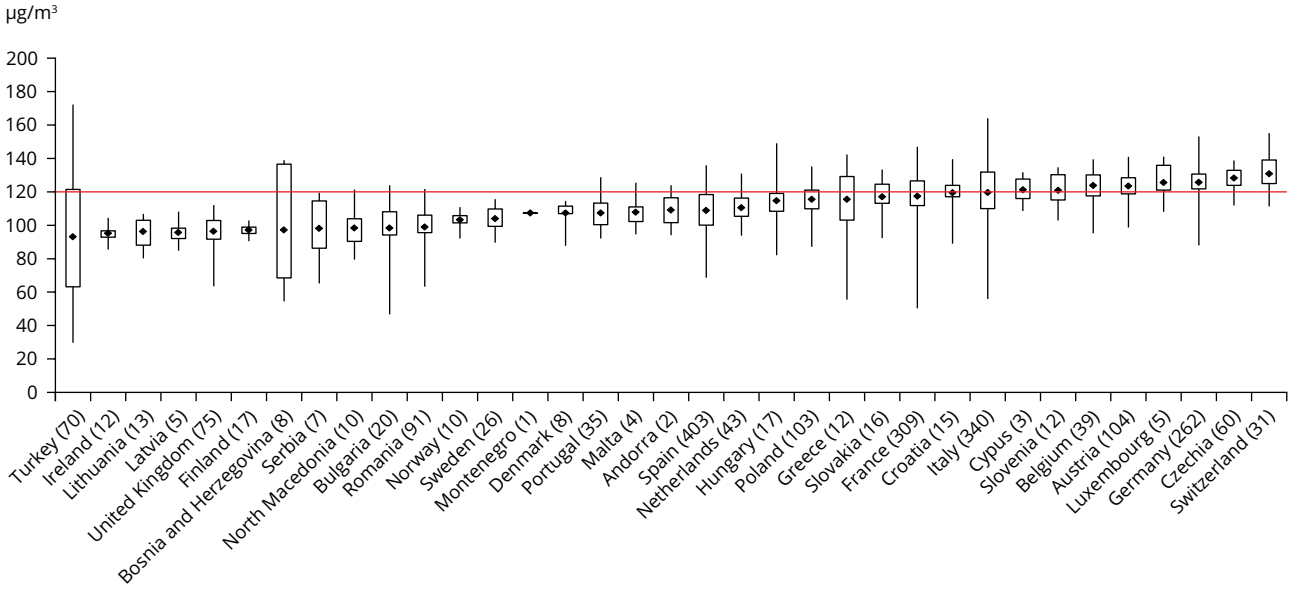
Reference data: ©ESRI | ©EuroGeographics

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

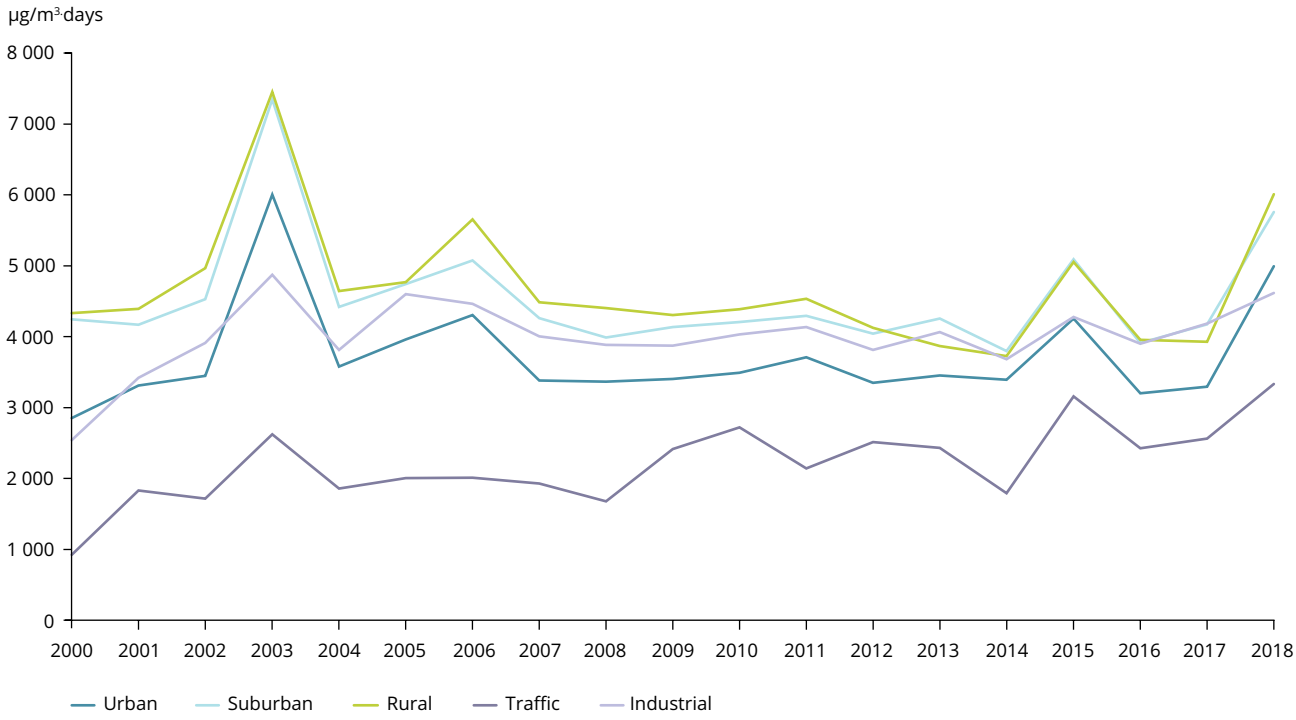


Notes: The graph is based, for each country, on the 93.2 percentile of the maximum daily 8-hour mean concentration values, corresponding to the 26th highest daily maximum of the running 8-hour mean. For each country, the number of stations considered (in brackets), and the lowest, highest and average 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

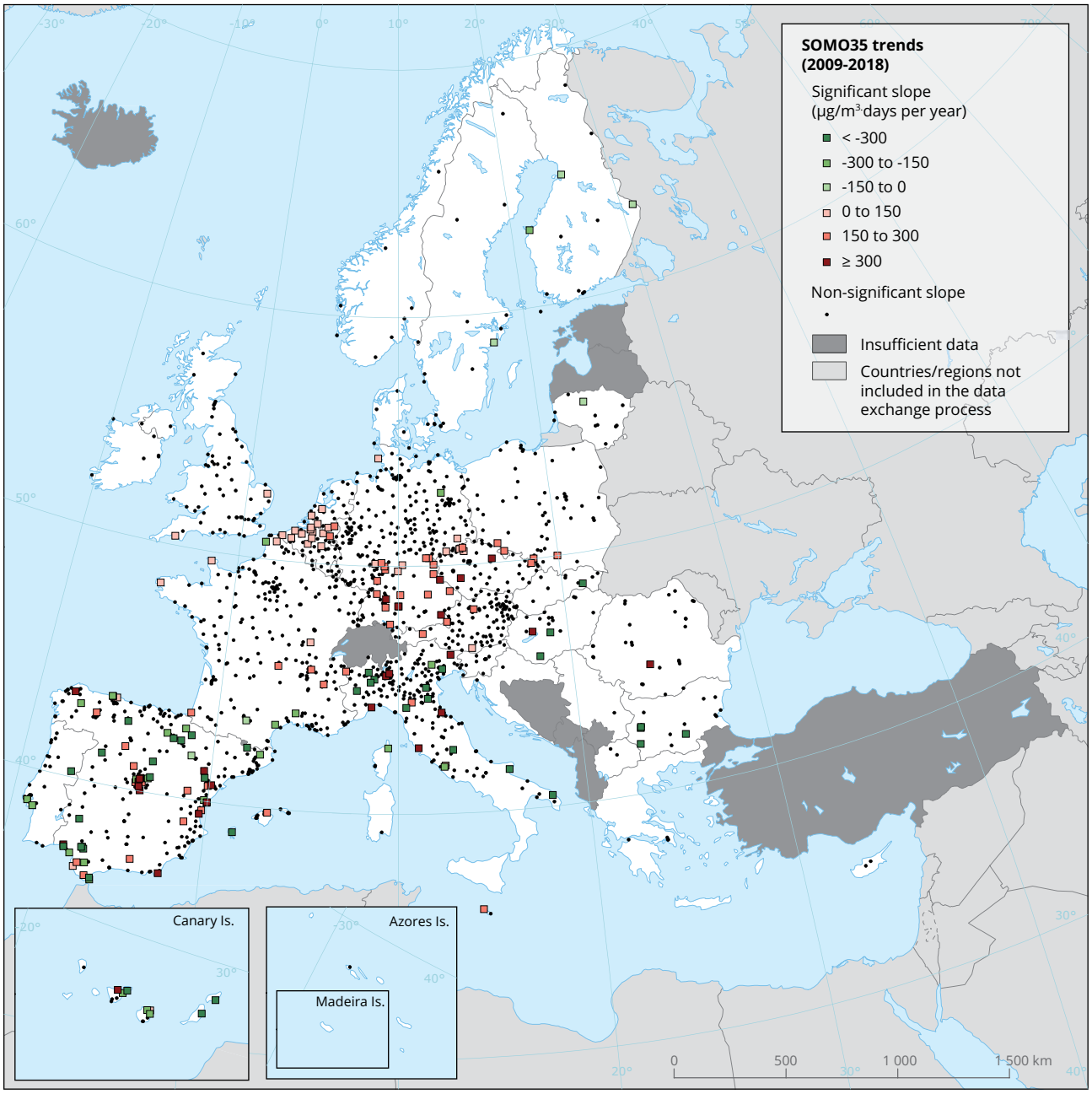
The average SOMO35 ([30]) O_3 concentrations from 2000 to 2018 are presented in Figure 5.2 for urban, suburban and rural background, traffic and industrial stations. Following the extreme values measured in 2003 and 2006, SOMO35 was relatively constant from 2009 to 2013 and varied more in the last 5 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.

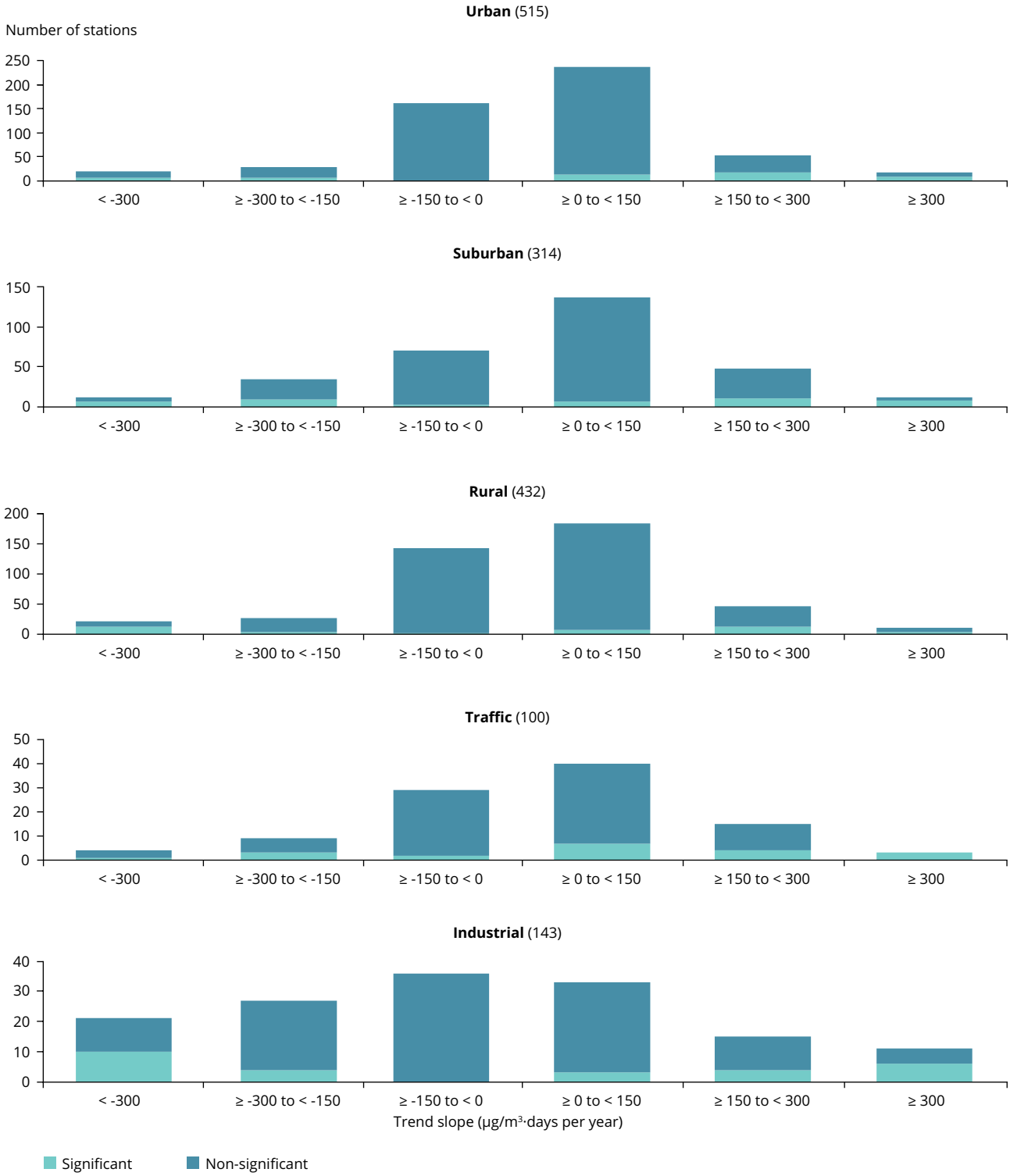
Map 5.2 SOMO35 trends (2009-2018)



Reference data: ©ESRI

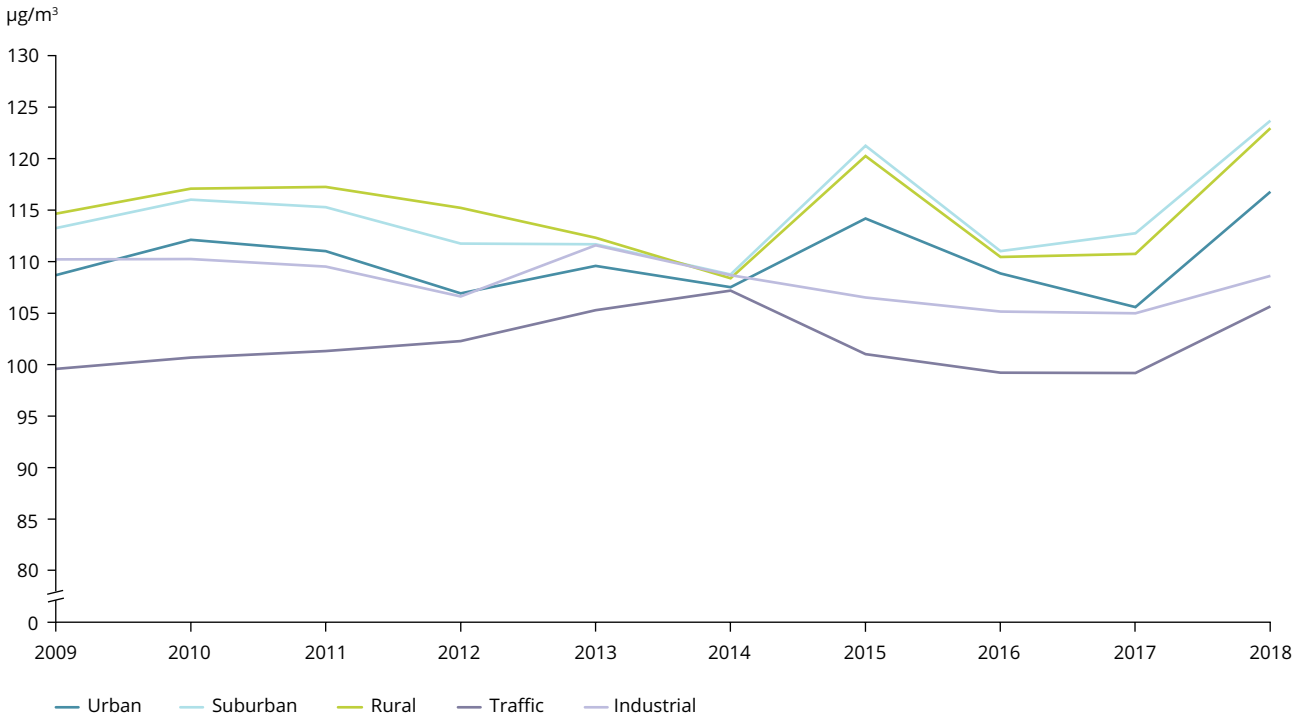
Note: For further information, please see Annex 2.

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).

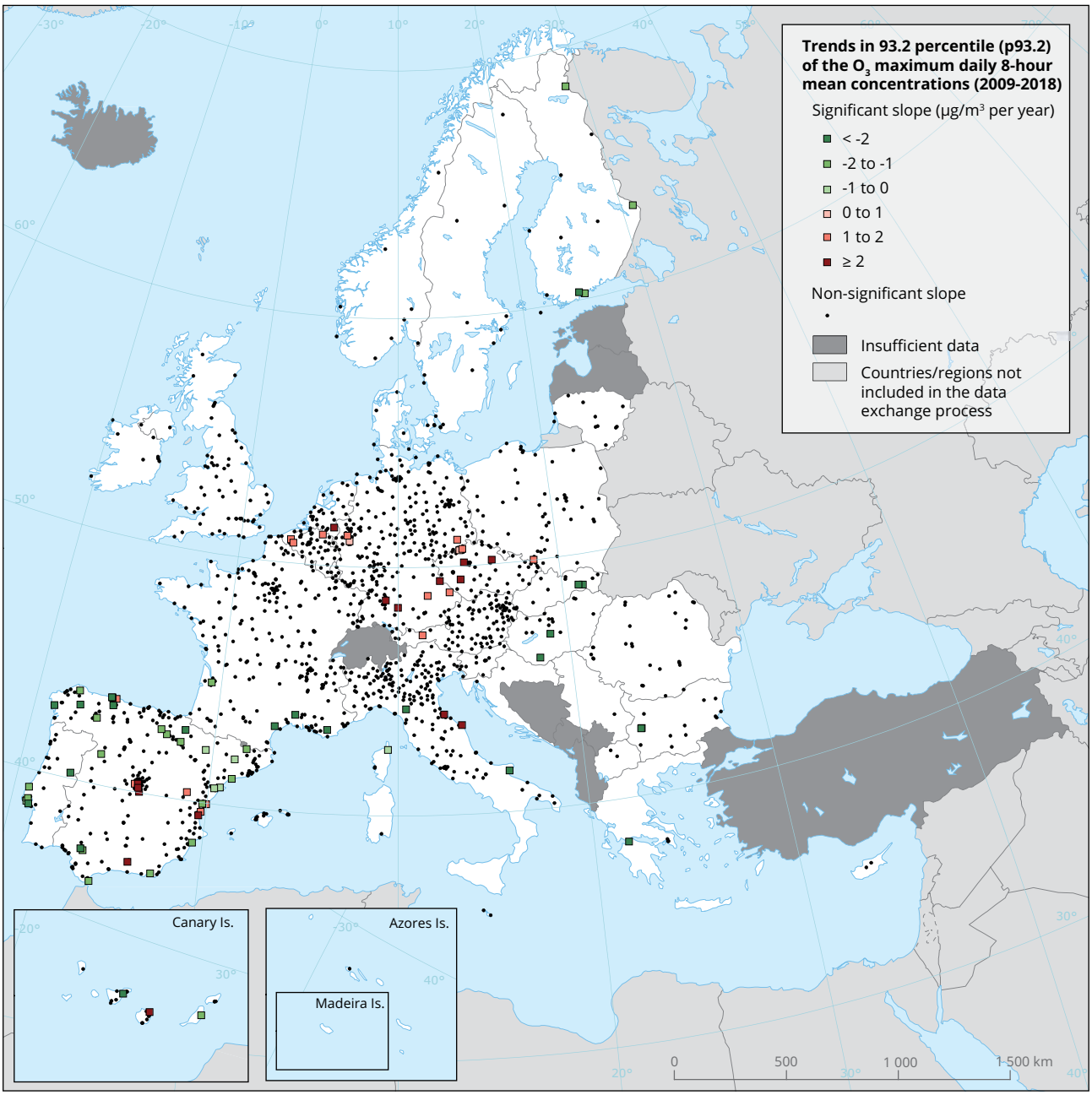
The analysis of trends in O_3 peaks from 2000 to 2017 looked at the fourth highest maximum daily 8-hour mean (p98.9) O_3 concentrations. This analysis indicates a clearer decreasing trend from 2000 to 2008 for all station types, except traffic, which shows no clear trend, and a flattening for all station 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.

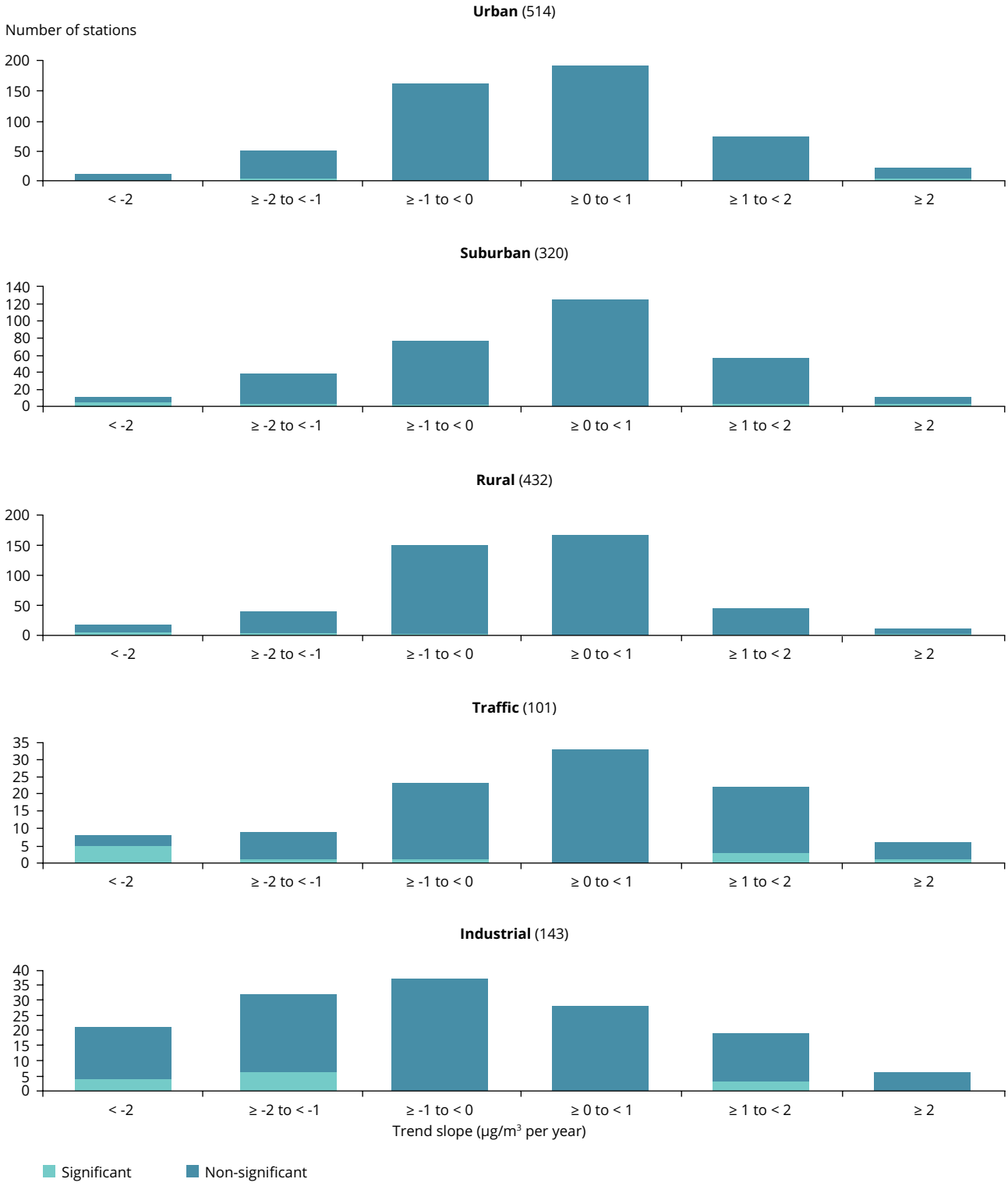
Map 5.3 **Trends for the 93.2 percentile of the O_3 maximum daily 8-hour mean concentrations (2009-2018)**



Reference data: ©ESRI

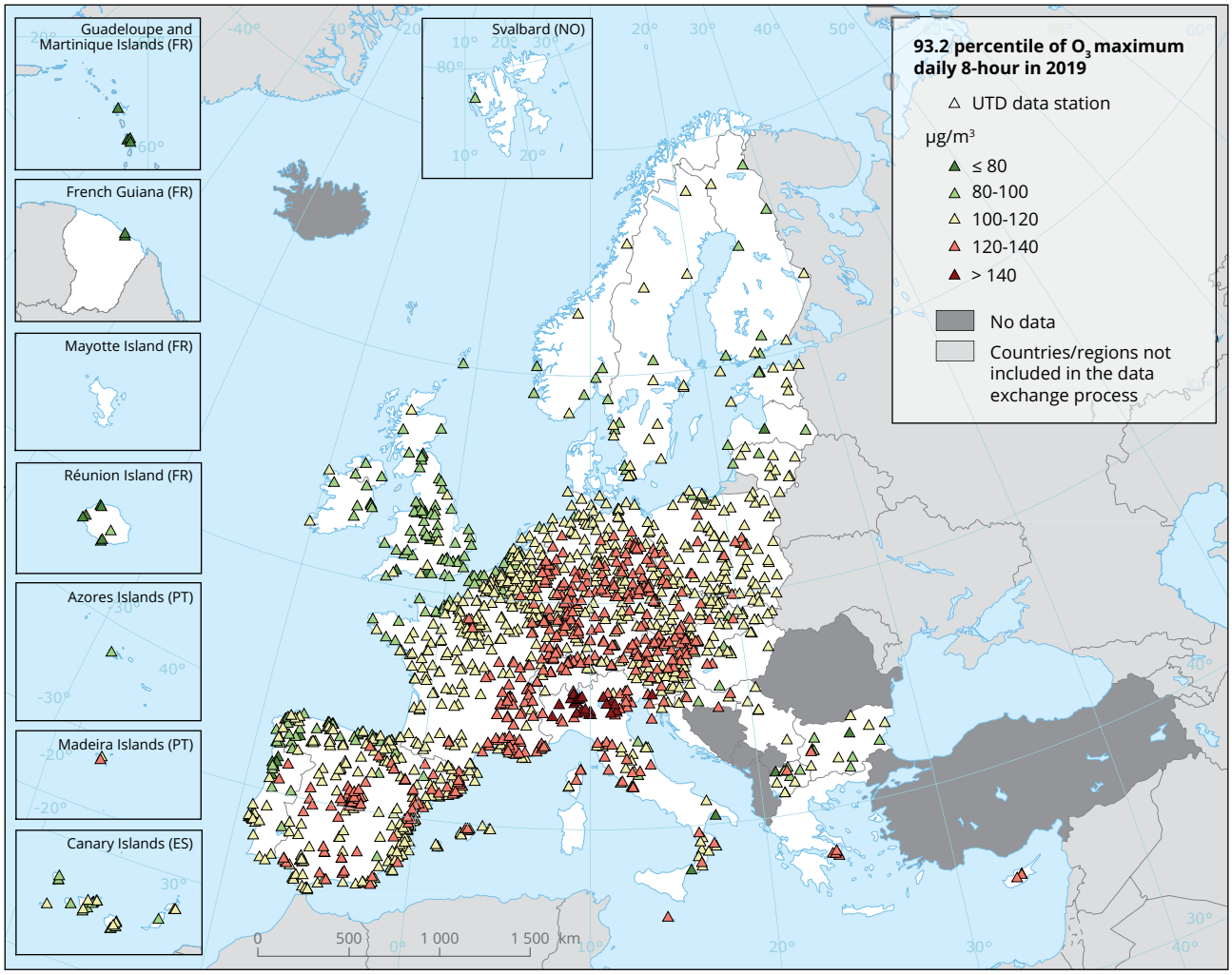
Note: The 93.2 percentile of the O_3 maximum daily 8-hour mean represents the 26th highest value in a complete series and is related to the O_3 target value. For further information, please see Annex 2.

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.

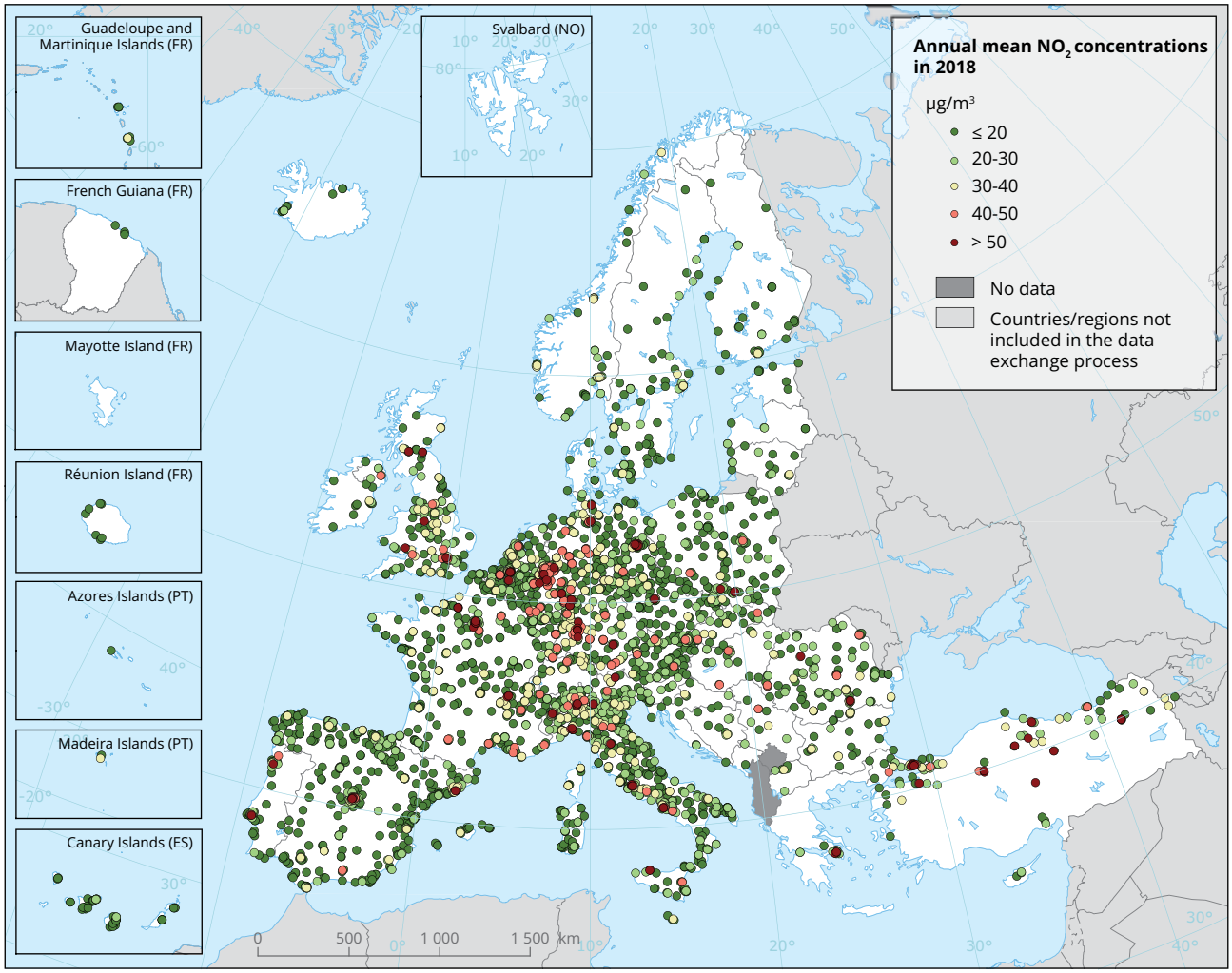
Annex 1 offers additional information on NO_2 annual concentrations, showing the frequency distributions (Figure A1.9), and the values by station and area type (Figure A1.10).

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/m³ in the air quality zone of 'Cities with more than 50 000 inhabitants' and of 57 µg/m³ 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/m³ 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/m³	Not to be exceeded on more than 18 hours per year
		WHO AQG: 200 µg/m³	
		EU alert threshold: 400 µg/m³	To be measured over 3 consecutive hours over 100 km² or an entire zone
	Calendar year	EU limit value and WHO AQG: 40 µg/m³	

Map 6.1 Concentrations of NO_2, 2018

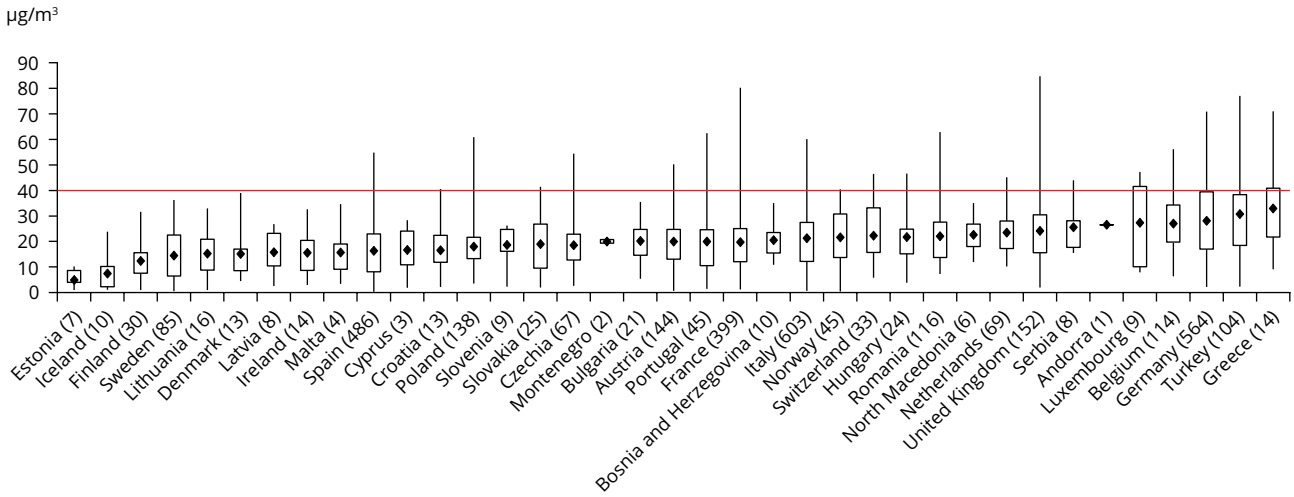


Reference data: ©ESRI | ©EuroGeographics

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).

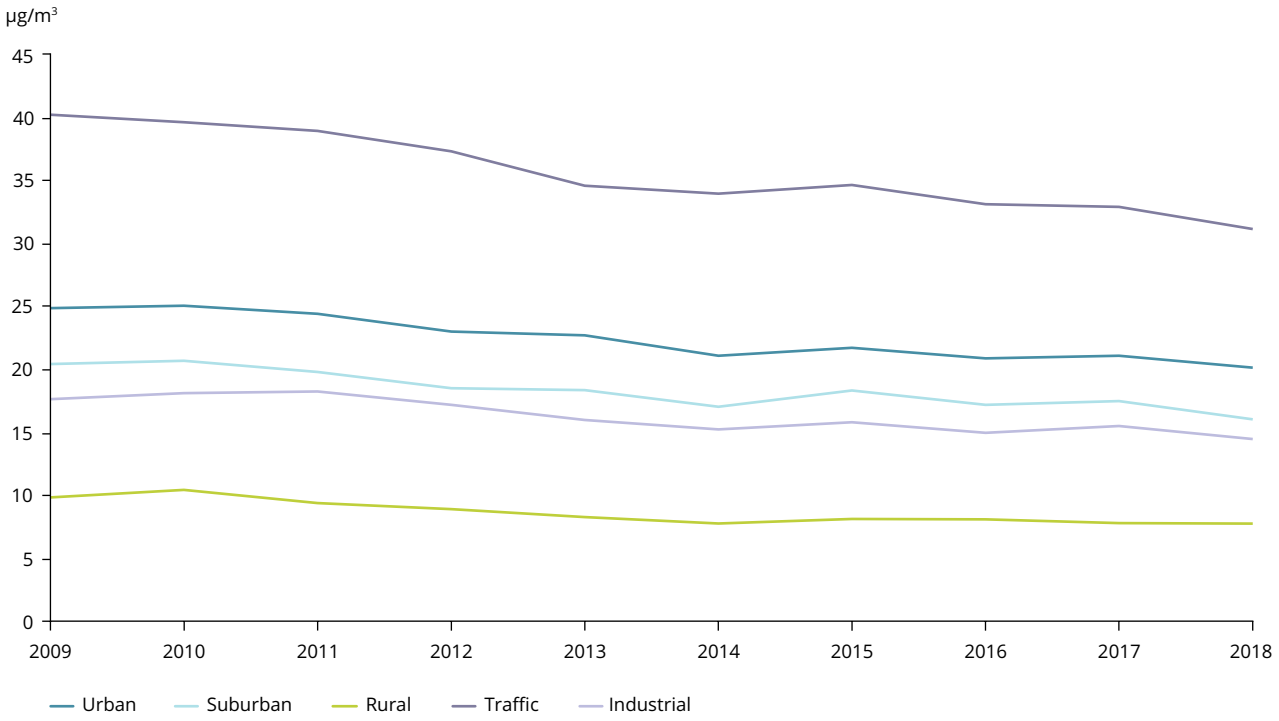
Figure 6.1 NO_2 concentrations in relation to the annual limit value in 2018 and number of stations considered for each country



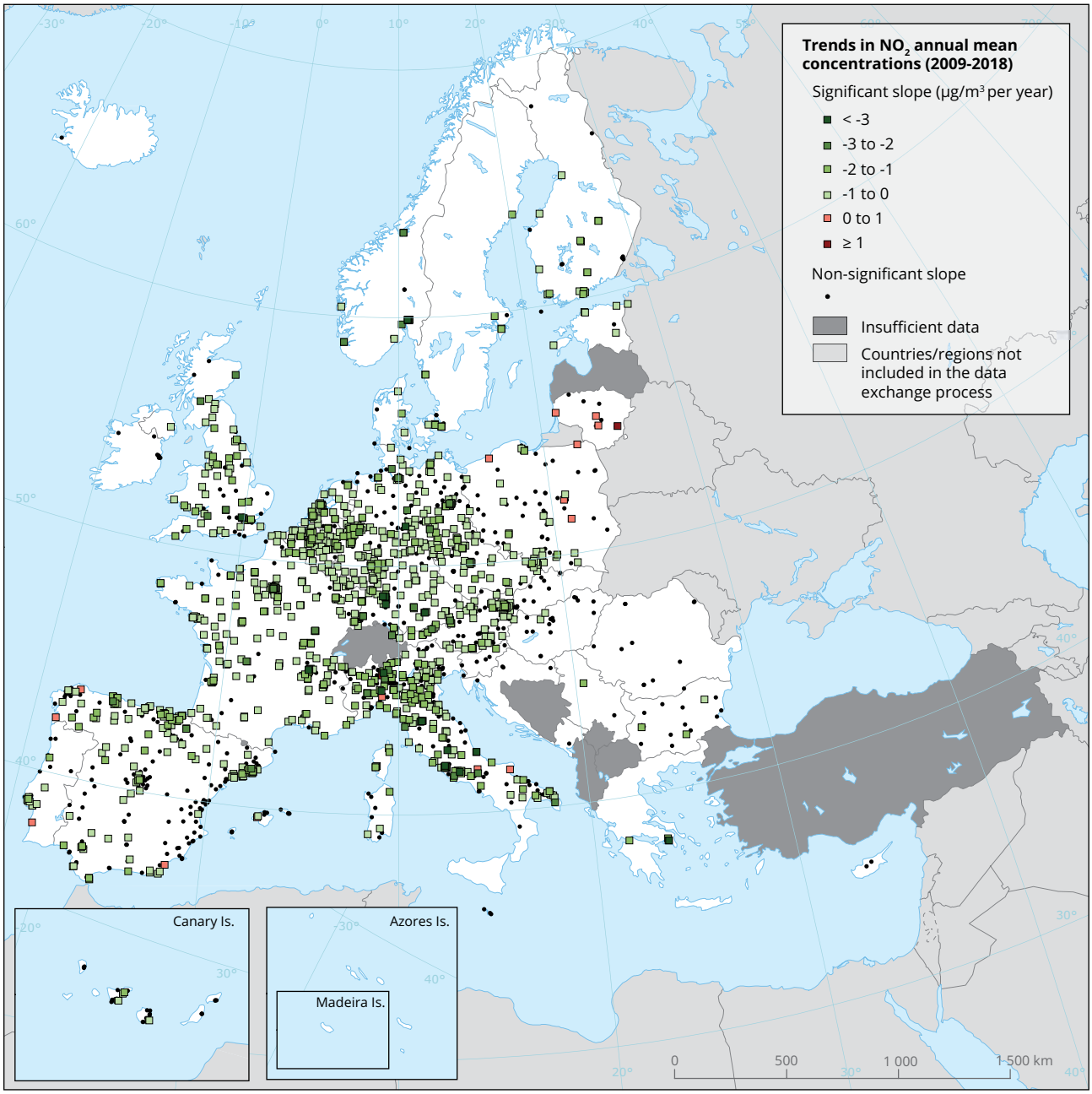
Note: The graph is based on the annual mean concentration values. For each country, the number of stations considered (in brackets) and the lowest, highest and average values (in µg/m³) recorded at its stations are given. The rectangles mark the 25th and 75th percentiles. At 25 % of the stations, levels 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



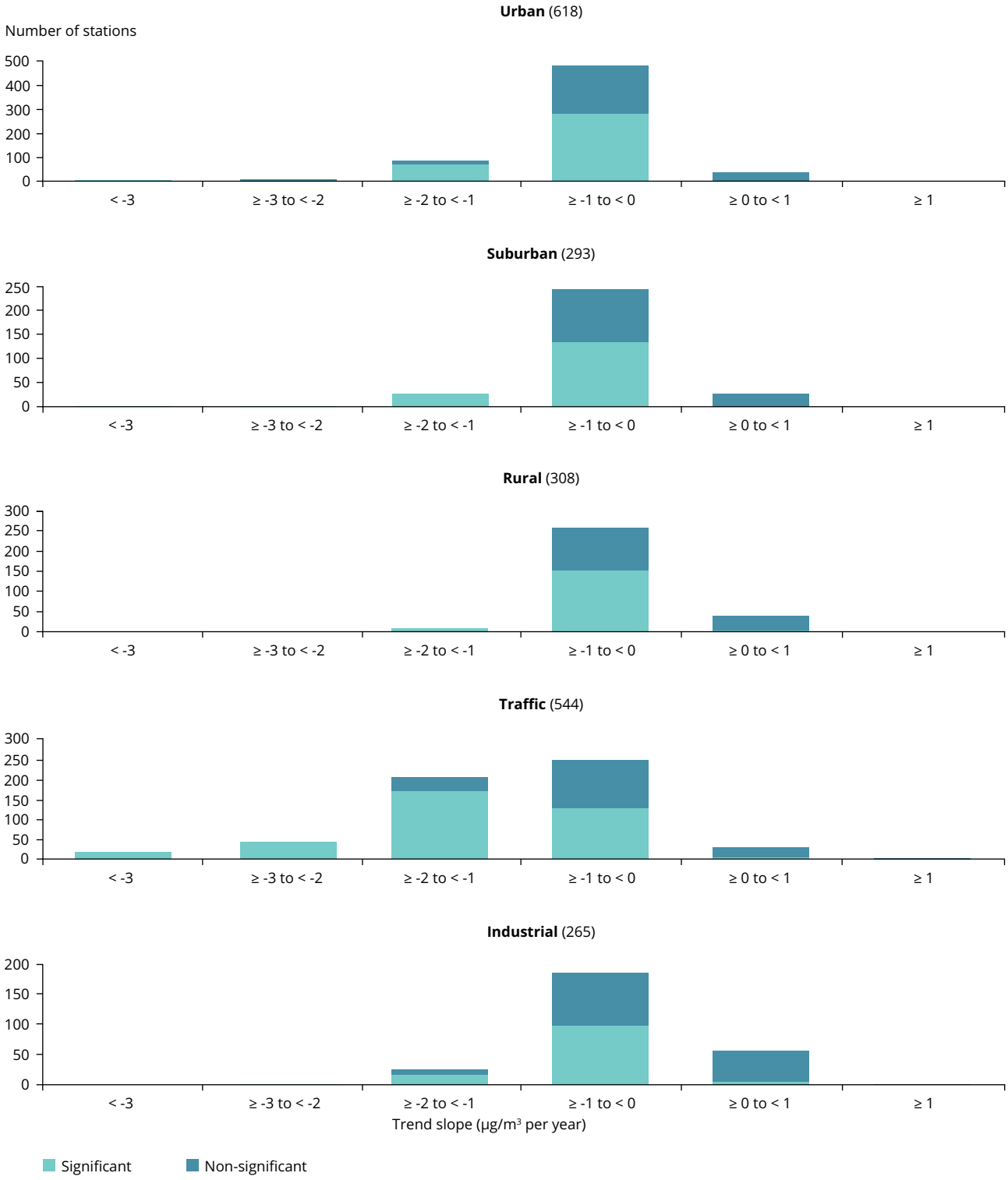
Map 6.2 Trends in NO_2 annual mean concentrations (2009-2018)



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/m³ 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/m³ per year, 10 stations, and 0.26 µg/m³ 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/m³ per year, four stations), followed by Norway (-1.60 µg/m³ per year, 18 stations), Serbia (-1.34 µg/m³ per year, two stations), Sweden (-0.88 µg/m³ per year, 18 stations) and Italy (-0.74 µg/m³ 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/m³ per year, 10 stations, and 7.03 µg/m³ per year, one station, respectively), the other countries registered an average decrease. The highest average decrease was in Slovakia (-6.34 µg/m³ per year, nine stations), followed by Greece (-3.55 µg/m³ per year, two stations) and Italy (-3.25 µg/m³ per year, 335 stations).

([31]) The rest of reported modelled exceedances correspond to Leicester Urban Area (43 µg/m³), South West (44 µg/m³), North East Scotland (44 µg/m³), Kingston upon Hull (45 µg/m³), Nottingham Urban Area (46 µg/m³), Bournemouth Urban Area (46 µg/m³), Reading/Wokingham Urban Area (46 µg/m³), Cardiff Urban Area (46 µg/m³), Liverpool Urban Area (48 µg/m³), Southend Urban Area (48 µg/m³), East Midlands (48 µg/m³), North Wales (49 µg/m³), Greater Manchester Urban Area (50 µg/m³), Portsmouth Urban Area (50 µg/m³), Coventry/Bedworth (50 µg/m³), North West Merseyside (50 µg/m³), South East (51 µg/m³), Central Scotland (51 µg/m³), Sheffield Urban Area (53 µg/m³), Yorkshire Humberside (53 µg/m³), Tyneside (54 µg/m³), West Midlands (54 µg/m³), North East (54 µg/m³), Teesside Urban Area (55 µg/m³) and Southampton Urban Area (55 µg/m³).

([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).

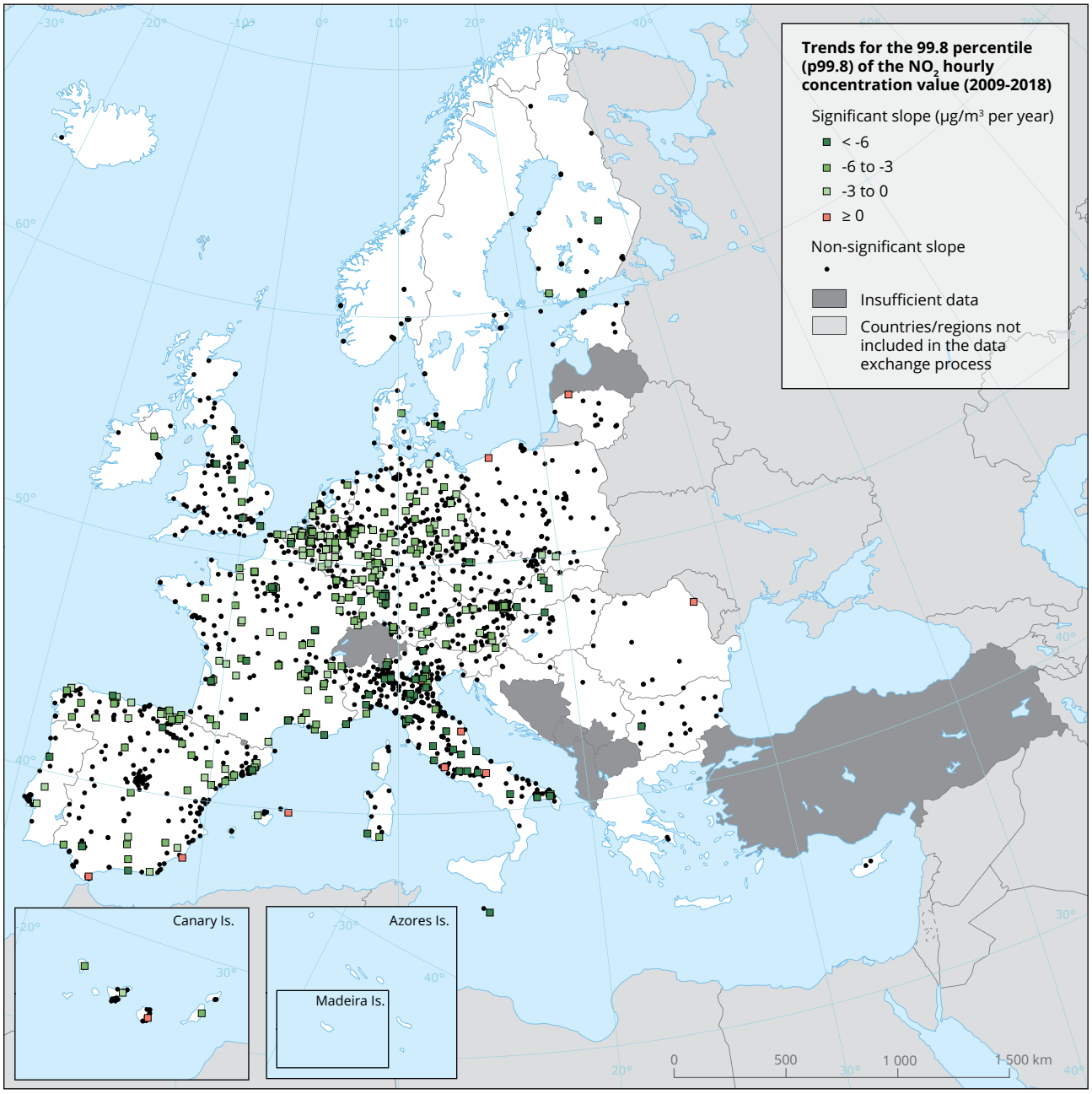
6.5 Contribution of emissions of nitrogen oxides and meteorology to ambient nitrogen dioxide concentrations

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.

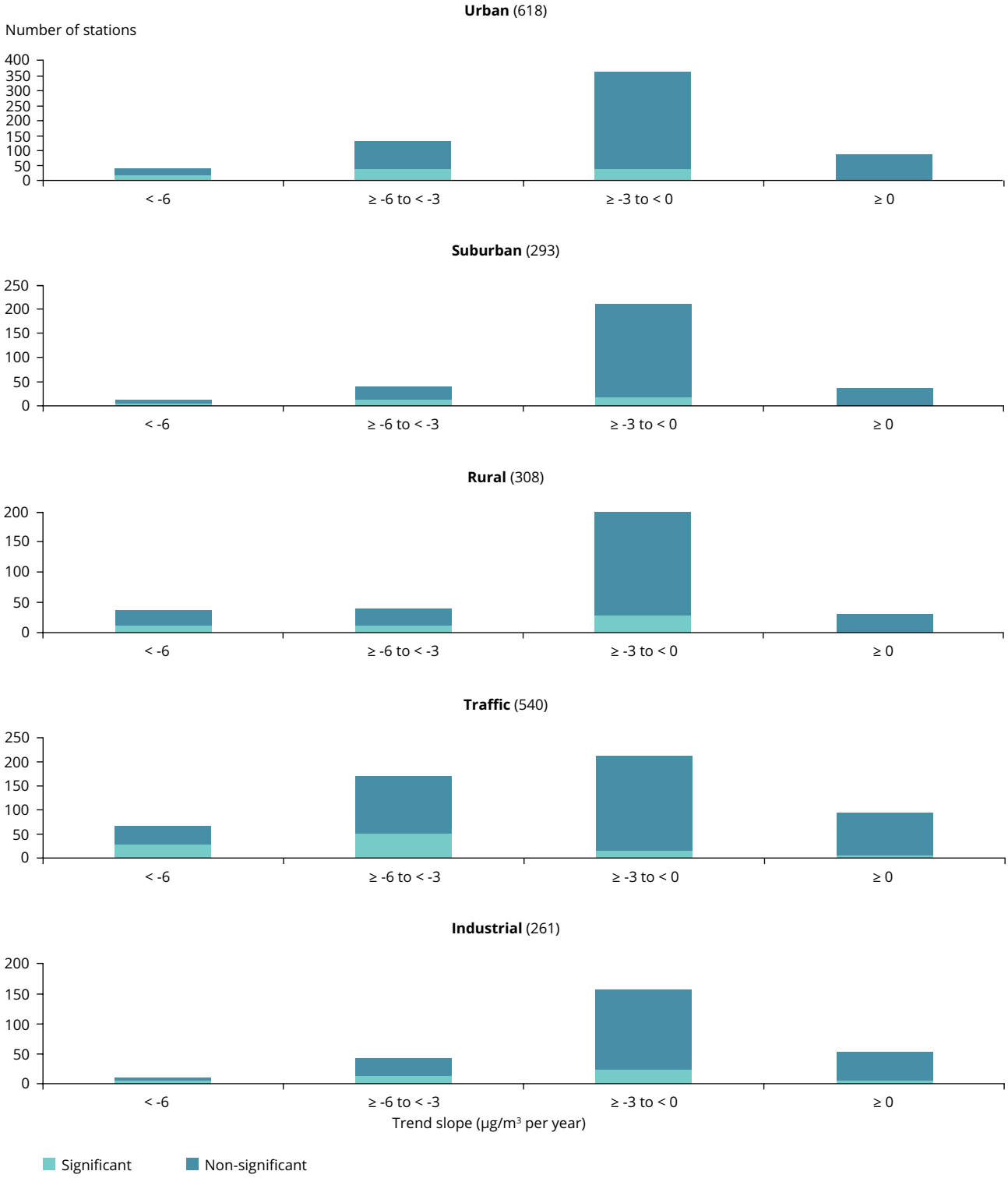
Map 6.3 Trends in the 99.8 percentile of the NO_2 hourly concentration value (2009-2018)



Reference data: ©ESRI

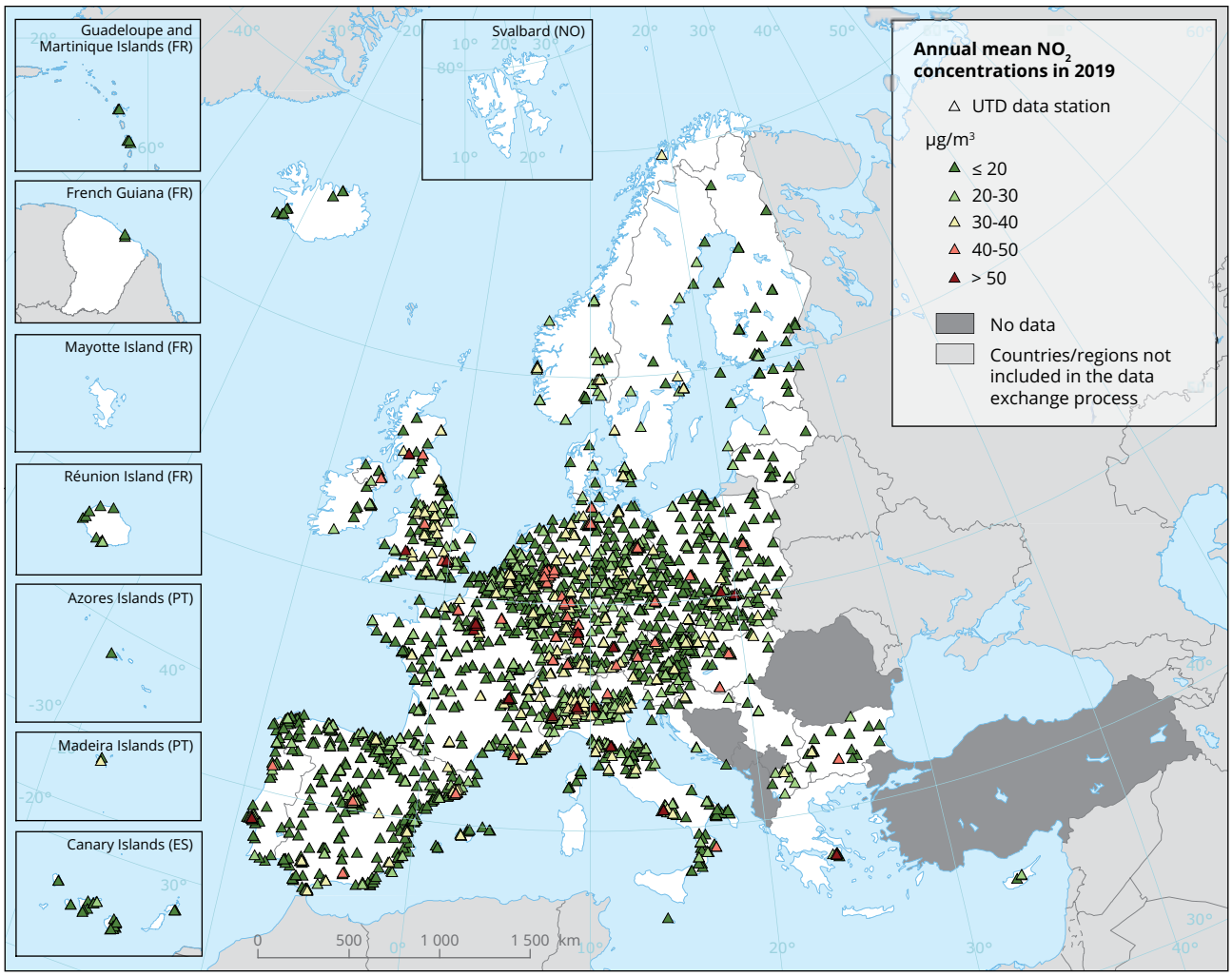
Note: The 99.8 percentile of the NO_2 hourly concentrations represents the 19th highest value in a complete series and is related to the NO_2 hourly limit value. For further information, please see Annex 2.

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/m³ in 2018 (Figure 7.1). As in previous years, values above 1.0 ng/m³ 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/m³.

Concentrations above 1.0 ng/m³ 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/m³) and suburban (16%) stations.

Regarding the RL, all reporting countries, except Cyprus, have at least one station with concentrations above 0.12 ng/m³. 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/m³	Measured as content in PM_{10}
		RL: 0.12 ng/m³	

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

([34]) The estimated RL (0.12 ng/m³) 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).

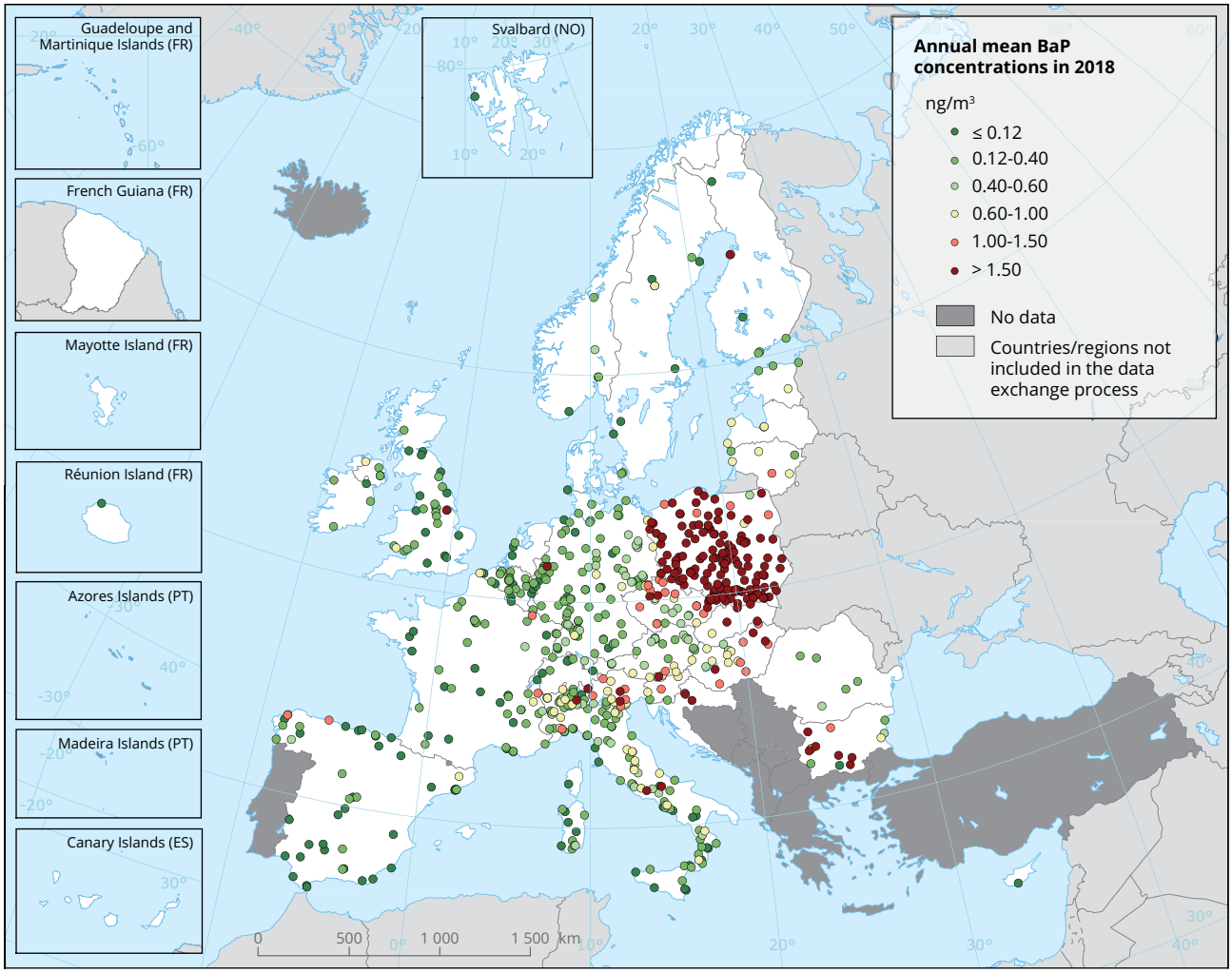
([35]) BaP is a PAH found mainly in fine particulate matter (PM). The Ambient Air Quality Directive (EU, 2004) prescribes that BaP concentration measurements should be made in the PM_{10} (particulate matter with a diameter of 10 µm or less) fraction. Going beyond this requirement, data available for 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).