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Health risk assessments of air pollution

Estimations of the 2019 HRA, benefit analysis of reaching specific air quality standards and more

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Summary

Air pollution is a major cause of premature death and disease and is the single largest environmental health risk in Europe. Heart disease and stroke are the most common reasons for premature deaths attributable to air pollution, followed by lung diseases and lung cancer.

This report estimates the health risk related to air pollution in 2019 considering the number of premature deaths and years of life lost related to exposure to fine particulate matter, ozone and nitrogen dioxide, both for the 27 Member States of the European Union and for additional European countries to sum up a total of 41. Besides the sensitivity studies typically presented in the EEA's risk assessment on concentration-response functions and counterfactual concentrations the potential health benefits of attaining the EU air quality standards and the WHO guideline values for fine particulate matter in ambient air are assessed. It also assesses progress towards the health-related objective of the EU's Zero Pollution Action Plan. Finally, it presents the latest estimates of the health impacts of exposure to the following key air pollutants: fine particulate matter, nitrogen dioxide and ozone.

The results in general show that the largest health risks are estimated for the countries with the largest populations. However, in relative terms, when considering e.g., years of life lost per 100 000 inhabitants, the largest relative risks are observed in central and eastern European countries for $PM_{2.5}$, in central and southern European countries for NO2, and south and eastern European for O. The lowest impact is found for the northern and north-western parts of Europe, where the concentrations are lowest.

The analysis on the EU's progress to reach the 2030 target established in the Zero Pollution Action Plan shows a steady decrease in the number of premature deaths along the years, and if it continues to fall at a comparable rate in the future, then the target would be achieved by 2032. The assessment on the minimum gains in avoided mortality should $PM_{2.5}$ EU standards and WHO recommendations have been reached already in 2019 shows that reaching the EU limit value of 25 µg/m^3 would have left the estimated number of premature deaths unchanged in EU-27; if the 41 countries are considered, the difference in mortality would have been of only 0.3 %. On the contrary, had the new WHO air quality guideline level of 5 µg/m^3 been attained in all areas where concentrations were above it, the number of estimated premature deaths would have been at least 58 % lower in average for the 41 European countries and for the EU-27.

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1 Introduction

Air pollution is a major cause of premature death and disease and is the single largest environmental health risk in Europe. Heart disease and stroke are the most common reasons for premature deaths attributable to air pollution, followed by lung diseases and lung cancer (WHO, 2018). The International Agency for Research on Cancer has classified air pollution, in particular fine particles or particulate matter with a diameter of 2.5 µm or les ($PM_{2.5}$), as a leading cause of cancer. The World Health Organization (WHO) provides evidence of links between exposure to air pollution and type 2 diabetes, obesity, systemic inflammation, Alzheimer's disease and dementia. A recent global review found that chronic exposure can affect every organ in the body, complicating and exacerbating existing health conditions (Schraufnagel et al., 2019).

Air pollution also has considerable economic impacts. It increases medical costs and reduces economic productivity due to the ill health of workers. Particulate matter (PM), nitrogen dioxide (NO_2) and ground-level ozone (O_3) are the pollutants that cause the greatest harm to human health and the environment in Europe.

Mortality is the health outcome for which the scientific evidence is more robust. It is also the most serious effect of air pollution. In the past, the European Environment Agency (EEA) and the European Topic Centre on Air pollution, noise, transport and industrial pollution (ETC/ATNI), and its predecessors, have been estimating mortality due to long-term exposure to air pollution. The methodology used for such calculations is explained in several reports (ETC/ACM, 2017a; EEA, 2018; ETC/ATNI, 2020a) and the results have been published in the Air quality in Europe report series (EEA, 2020) and in (ETC/ATNI, 2020a).

The methodology used by EEA and ETC/ATNI to estimate mortality follows the recommendations made by the World Health Organization back in 2013 (WHO, 2013a). As explained later in the current report

- for $PM_{2.5}$, all-cause (natural) mortality is considered in people aged over 30 years for all concentrations (i.e., concentrations above 0 µg/m^3), assuming a linear increase in the risk of mortality of 6.2 % for a 10 µg/m^3 increase in $PM_{2.5}$;
- for NO_2, all-cause (natural) mortality is considered in people aged over 30 for concentrations above 20 µg/m^3, assuming a linear increase in the risk of mortality of 5.5 % for a 10 µg/m^3 increase in NO_2;
- for O_3, all-cause (natural) mortality is considered for all ages, assuming a linear increase in the risk of mortality of 0.29 % for a 10 µg/m^3 increase in O_3 values over 35 ppb.

Furthermore, the calculations have come together with a sensitivity analysis using various concentrations above which to consider the health impacts (or counterfactual values), namely the effects from 2.5 µg/m^3 for $PM_{2.5}$ (on top of 0 µg/m^3, as mentioned above), from 10 µg/m^3 for NO_2 (on top of 20 µg/m^3, as mentioned above), and from 10 ppb for O_3 (on top of 35 ppb, as mentioned above).

To protect human health against the effects of long-term exposure to air pollution, the European Union has set air quality standards in the Ambient air quality Directive (AAQD) (EU, 2008). These standards took into account the WHO recommendations and guidelines (WHO, 2006). Both, air quality standards and air quality guideline levels are maximum concentration values that should not be exceeded (see Table 1.1). In the case of the European Union, limit and target values are concentrations that must be attained and not exceeded once attained. In case of exceedances, the States must implement air quality plans in order to achieve the limit and target values. In the case of the WHO, the guidelines try to be reference tools to help policy makers in setting standards and goals for air quality management. They also include the so-called "interim targets", that are concentrations associated with a specified decrease of mortality risk proposed as incremental steps in progressive reduction of air pollution. The interim targets are intended for use in areas where pollution is high. They reflect the essence of benefit assessment based on linear concentration–response associations. The WHO has just completed and published a review of its AQ Guidelines (WHO, 2021)

The WHO, in the context of the revision of its air quality guidelines, has conducted a series of systematic reviews investigating associations between a range of air pollutants and human health outcomes. Two of these systematic reviews address long-term exposure to PM (Chen, J. and Hoek, G., 2020) and NO_2 and O_3 (Huangfu, P. and Atkinson, R., 2020). In them, new relative risks are proposed for associations for the pollutants and mortality. Nevertheless, for the calculations presented in this report, it was decided to keep the relative risks and counterfactual values used in the past. In this way, comparisons with the past values are easily performed, and no additional sources of uncertainty (apart to that inherent to the methodology itself) are introduced. For future studies, and once the new WHO air quality guidelines are published and the evidence in the systematic reviews is discussed, it is planned to incorporate the new recommendations.

Table 1.1: Some relevant air quality standards for protection of human health from exposure to PM2.5, NO2 and O3

		EU Air quality Directive 2008/50/EC		WHO air quality guidelines 2005	WHO air quality guidelines 2021
Pollutant	**Averaging period**	**Standard and concentration**	**Comments**	**Level and concentration**	
$PM_{2.5}$	Annual			IT 1, 35 µg/m^3	IT 1, 35 µg/m^3
		LV, 25 µg/m^3		IT 2, 25 µg/m^3	IT 2, 25 µg/m^3
		Indicative LV, 20 µg/m^3			
				IT 3, 15 µg/m^3	IT 3, 15 µg/m^3
				AQG, 10 µg/m^3	IT 4, 10 µg/m^3
					AQG, 5 µg/m^3
NO_2	Annual	LV, 40 µg/m^3		AQG, 40 µg/m^3	IT 1, 40 µg/m^3
					IT 2, 30 µg/m^3
					IT 3, 20 µg/m^3
					AQG, 10 µg/m^3
O_3	Maximum daily 8-hour mean			IT 1, 160 µg/m^3	IT 1, 160 µg/m^3
		TV, 120 µg/m^3	Not to be exceeded on more than 25 days per year, averaged over three years		IT 2, 120 µg/m^3
				AQG, 100 µg/m^3	AQG, 100 µg/m^3
	Peak season				IT1, 100 µg/m^3
					IT2, 70 µg/m^3
					AQG, 60 µg/m^3

Notes: LV: limit value; TV: target value; IT: interim target; AQG: air quality guideline.
Peak season means "Average of daily maximum 8-hour mean O_3 concentration in the six consecutive months with the highest six-month running-average O_3 concentration".
Sources: EU, 2008, WHO (2006, 2021).

Apart from the AQ legal standards set in the AAQDs, the European Union has established in its strategies to abate air pollution specific targets and objectives related to the impacts on human health of air pollution. In 2013, the Clean Air Policy Package, adopted after an extensive review of the EU air policy to that date, included a Clean Air Programme for Europe (EU, 2013), that set an objective of reducing by 52 % in 2030 the premature mortality due to particulate matter and ozone, relative to 2005.

The recently published Zero Pollution Action Plan (EU, 2021), in the context of the European Green Deal (EU, 2019), has slightly modified that target. The new goal is to reduce by 2030 the number of premature deaths caused by $PM_{2.5}$ by 55%, again relative to 2005. Furthermore, the Zero Pollution Action Plan has the vision for 2050 that air pollution is reduced to levels no longer considered harmful to health and natural ecosystems.

Despite applying the same methodology as in the past EEA´s *Air quality in Europe* reports, the results presented in this study are not fully comparable to those in previous studies by EEA and ETC/ATNI. This is because the calculations, previously produced under the ETC system, are now undertaken internally at the EEA. As explained in Soares *et al*., 2021, the use of different input data sources for mortality and the use of different proxy for gap filling data in the countries not reporting health data, makes the results slightly different, but does not change the results dramatically. Using different mortality input data results on minor differences for countries with low population density and gap-filling affects mostly the Western Balkan countries.

The present report presents the impact of air pollution on health in 2019 and the results of several analyses. Chapter 2 presents the data used in the different analyses of the report. Chapter 3 shows the calculations in terms of mortality (both premature deaths and years of life lost) for year 2019, following the same structure as in the previous *Air quality in Europe* reports. Chapter 4 assesses how close the EU is to reach the 2030 target as established in the Zero Pollution Action Plan, by comparing the 2019 situation with that in 2005. Chapter 5 presents a benefit analysis of the gains in avoided mortality should different EU standards and WHO recommendations have been reached already in 2019.

2 Input data used in the HRA calculations

The health risk assessment presented throughout the report for the 41 countries across Europe are based on gridded data: ambient air concentrations and population density data. Thus, the estimation is done for each grid cell and then aggregated per country (or group of countries). Please see detailed methodology at (ETC/ATNI, 2020a) and references herein.

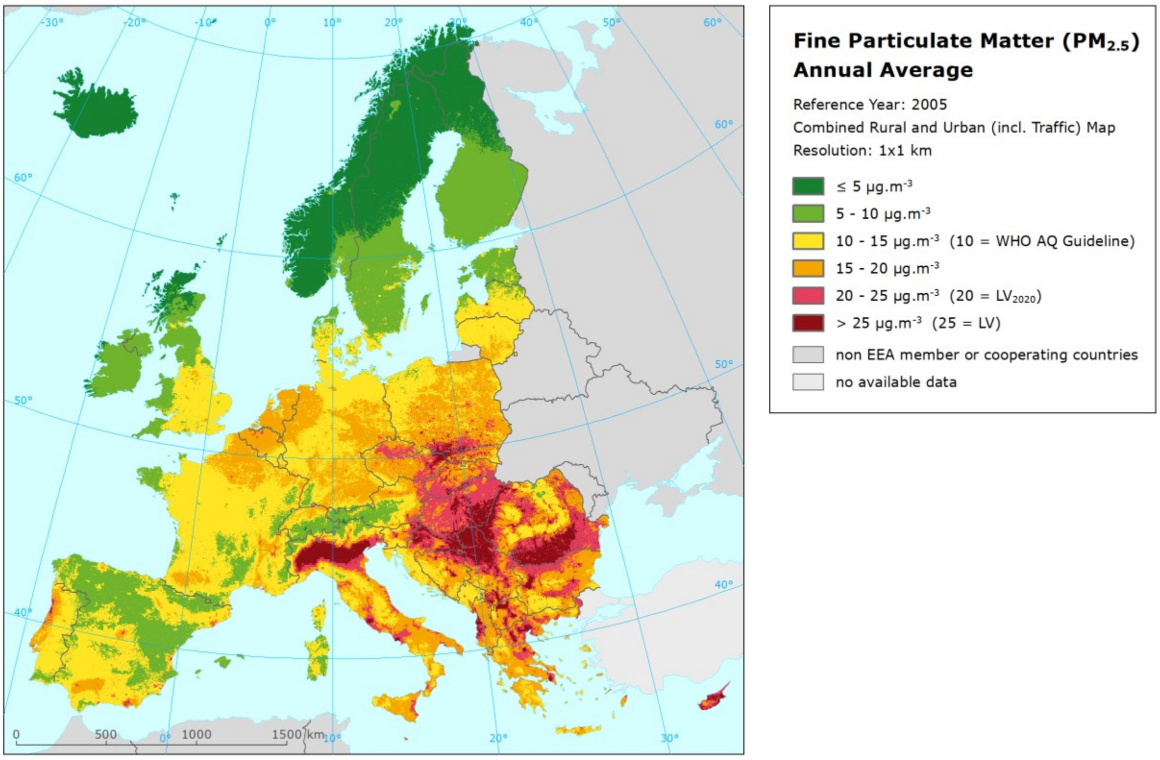
2.1 Ambient air concentrations

Concentration maps with annual statistics of the relevant pollutant metrics are produced on a 1*1 km^2 grid resolution for most of Europe (whole Europe apart from Belarus, Moldova, Ukraine and European parts of Russia and Kazakhstan). The annual statistics are estimated using a mapping method ('Regression – Interpolation – Merging Mapping') that combines the monitoring data from rural and urban background stations for $PM_{2.5}$, O_3 and NO_2 with results from the EMEP chemical transport model and other supplementary data, such as altitude, meteorology, and population density (ETC/ATNI, 2021 and references herein) using linear regression model followed by kriging of its residuals. For NO_2, and since 2017 maps also for $PM_{2.5}$, urban traffic station data was also included to take into account hotspots, since traffic is the most important source of NO_2 and an important source of PM. In this methodology, separate rural and urban background (and for NO_2 and $PM_{2.5}$ also urban traffic) map layers are created separately and subsequently merged into the final map. A caveat for the concentration maps is the exclusion of overseas territories such as Madeira, Azores, Canary Islands, French Guiana, Guadeloupe, Martinique, Mayotte and Réunion. These territories are therefore excluded of the HRA calculations. In this report, the final merged maps in 1*1 km^2 grid resolution are used as input data for the health risk assessment. Both 2005 and 2019 maps have been produced based on the most up-to-date methodology, i.e., including the urban traffic map layer for both NO_2 and $PM_{2.5}$, as described in (ETC/ATNI, 2021).

2.1.1 2005 data

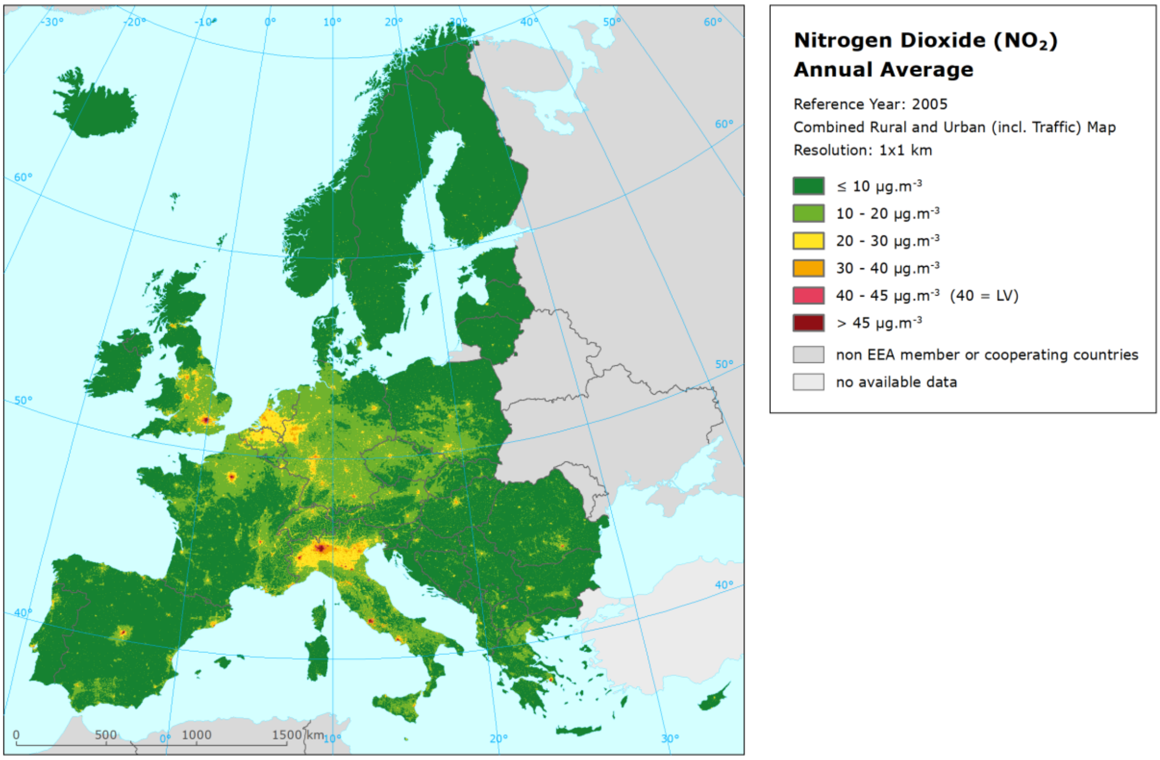
European air quality maps for 2005 for $PM_{2.5}$, O_3 and NO_2 were produced in (ETC/ATNI, 2020b) and are reproduced here for convenience.

Map 2.1: Concentration map of PM2.5 annual average, 2005

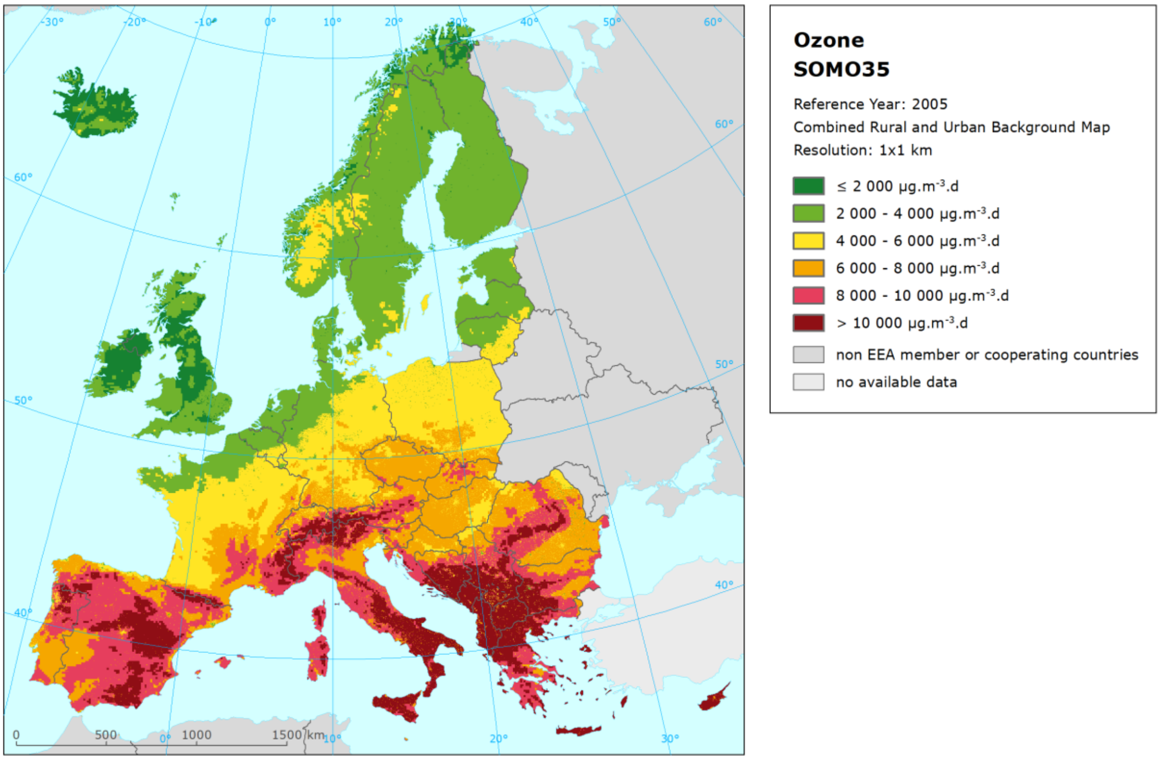


Note: Turkey is not included due to the lack of air quality data.

Map 2.2: Concentration map of NO2 annual average, 2005



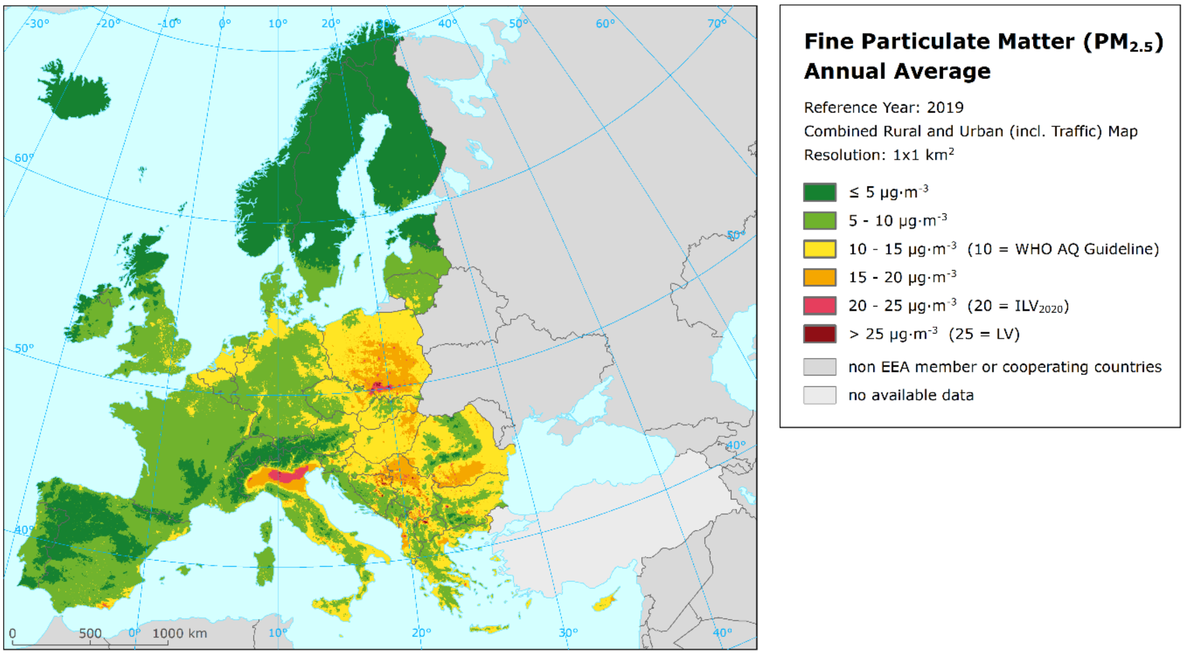
Map 2.3: Concentration map of O3 indicator SOMO35, 2005



2.1.2 2019 data

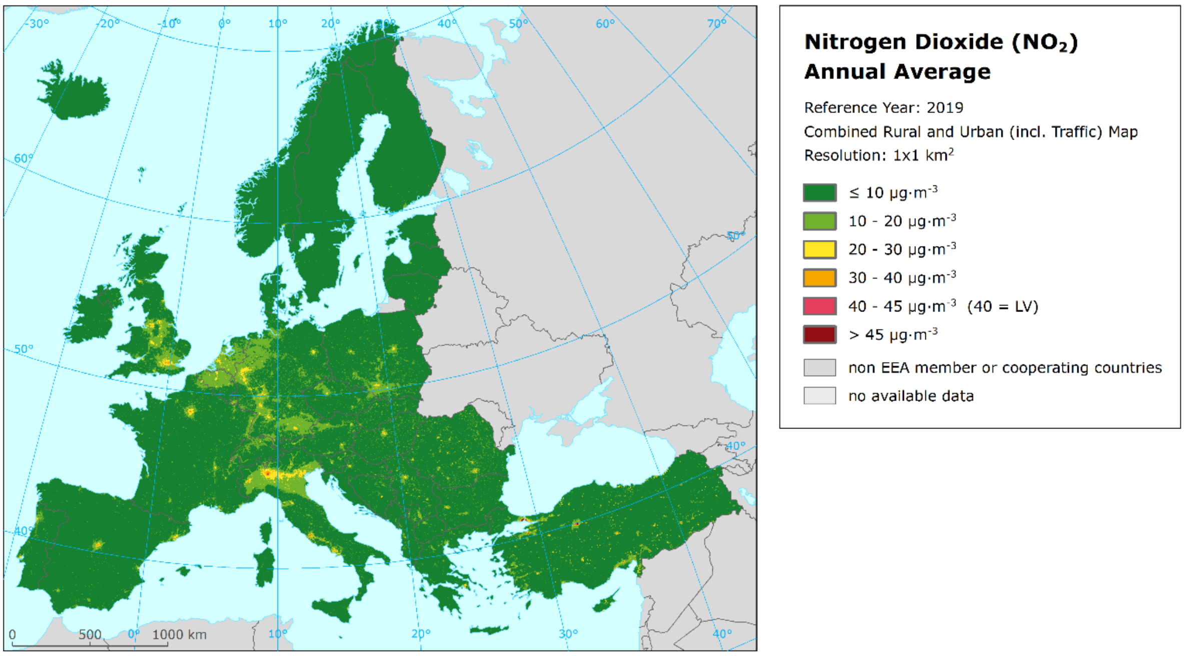
European air quality maps for 2019 for $PM_{2.5}$, O_3 and NO_2 were produced in (ETC/ATNI, 2021) and are reproduced here for convenience.

Map 2.4: Concentration map of PM2.5 annual average, 2019

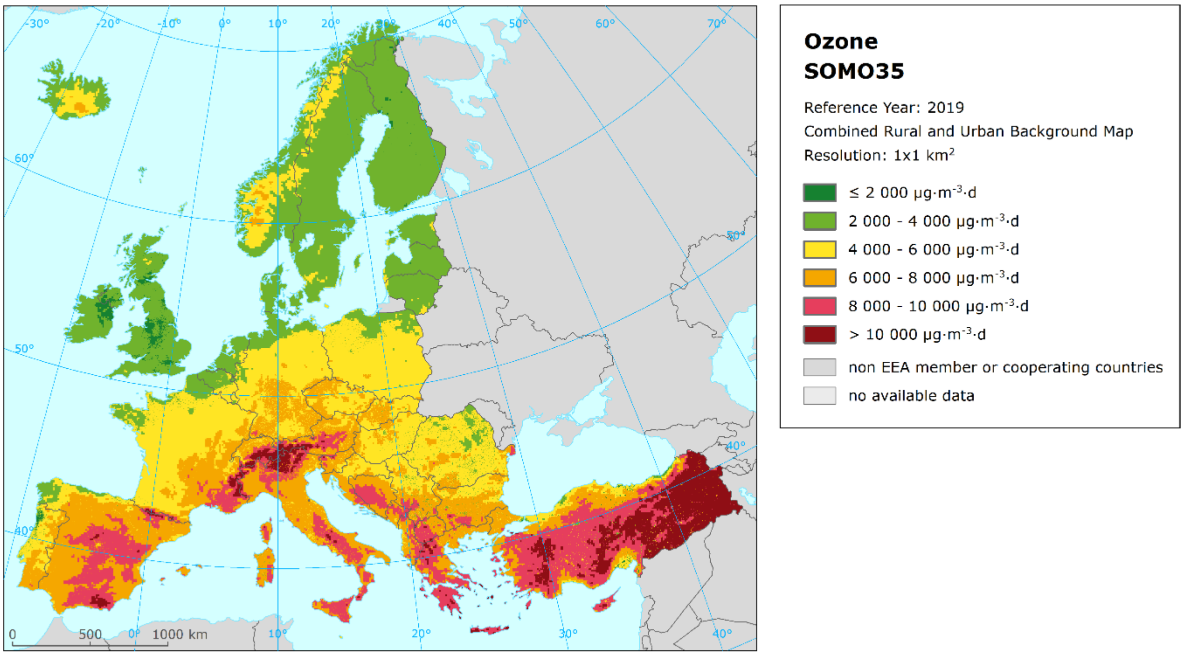


Note: Turkey is not included because, due to the lack of rural $PM_{2.5}$ stations, no proper interpolation results could be estimated for this country in a rural map.

Map 2.5: Concentration map of NO2 annual average, 2019



Map 2.6: Concentration map of O3 indicator SOMO35, 2019



2.2 Population

2.2.1 Population grid and country total population numbers

The population density map used for estimating annual statistics is based on the GEOSTAT 2011 dataset (Eurostat, 2014), and is mapped on the same grid resolution as the ambient air concentrations, facilitating the health outcomes estimation. To make use of the population density available, the GEOSTAT 2011 population data was scaled with the total population data available country-wise from Eurostat (Eurostat, 2021a), for 2005 and 2019. The data reflects the total population on the 31st of December of the indicated year reported by the National Statistical offices.

The scaling of the population (scaled pop$_i$) was done, for years 2005 and 2019, by applying the following:

$$\boldsymbol{scaled\ pop_i = pop_i \times \frac{pop_{c\_Eurostat}}{pop_c}},$$

where : pop_i is the population in the i^{th} grid cell for country *c* in the GEOSTAT 2011 population density map, pop_c is the total population for country *c* calculated based on the GEOSTAT 2011 population density map, and $pop_{c\_Eurostat}$ is the total population reported to Eurostat for country *c* for years 2005 and 2019.

Since the concentration maps do not include overseas territories, population data for those territories need to be excluded from the original Eurostat data. Moreover, the GEOSTAT 2011 Cyprus population data includes both Greek Cypriots and Turkish Cypriots. The Eurostat data includes only Greek Cypriots, requiring the addition of the Turkish Cypriot population. These above-mentioned corrections are done by applying additional scaling factor for France, Portugal, Spain and Cyprus:

$$scaled\ pop_i = pop_i \times \frac{pop_{c\_Eurostat}}{pop_c} \times \frac{pop_{c2015}}{pop_{c\_Eurostat2015}}$$

where : pop_{c2015} is the total population for country c calculated based on the GEOSTAT 2011 population density map for year 2015 (ETC/ATNI, 2018), and $pop_{c\_Eurostat2015}$ is the total population reported to Eurostat for country *c* for year 2015 (Eurostat, 2021a).

The total population for years 2005, 2019 and 2015 is available from Eurostat for all countries across Europe.

2.2.2 Population numbers distributed by age groups

Estimation of all-cause (natural) mortality due to $PM_{2.5}$ and NO_2 is considered in people aged over 30 years (see section 2.4) and requires as input age distribution of population numbers. The data for 2005 and 2019 is available from Eurostat (Eurostat, 2021b), with 1-year interval, for almost all countries. Gap filling of missing information is only necessary for Kosovo (2005), Bosnia and Herzegovina, San Marino and Monaco (both for 2005 and 2019). It is done by using relative age distribution numbers (that is, the percentage of population in each age group) from Serbia for Kosovo and Bosnia and Herzegovina, from Italy for San Marino, and from France for Monaco.

2.3 Demographic data

2.3.1 Data on cause of death, number of deaths and life expectancy

Eurostat data on cause of death (Eurostat, 2021c) is available since 2011 for 5-year interval, from less than 1 year to '95 years or over'. It is compiled based on the ICD10 Mortality Tabulation List, the latest tabulation existing for mortality data.

For the health outcomes, and according to the description of the concentration-response functions (CRFs, see section 2.4), only natural deaths should be considered. Therefore, causes of death due to injury or poisoning (V01-Y89) and unknown and unspecified causes (R00-R99) as well as total deaths due to all causes, are excluded before calculations.

Estimation of natural deaths with 1-year interval is based on interpolation using ratio between all natural deaths and all causes deaths (5-year interval) and Eurostat data on total number of deaths (Eurostat, 2021d) given with 1-year interval.

After this operation, mortality data is aligned with life expectancy data, available from Eurostat database (Eurostat, 2021e) on a 1-year interval, by age and sex, from 0 to 85+ years old, since 1960. To reflect all age groups available for mortality data (up to 95+), life expectancies are extrapolated for ages above 85, using regression on life expectancy data for age groups 79 – 85.

2.3.2 Data gap-filling

The logic of gap-filling of demographic data has been summarized in table 2.1. Data on causes of death from the first available year (2011) is used for 2005. Data on number of deaths and life expectancy are available for most of countries for 2005. For countries for which data on causes of death, number of deaths and/or life expectancy is not available for years 2005 and 2011, gap filling is performed using relative age distribution numbers of mortality (mortality ratios, or number of deaths per population in each age group) and years of life lost (YLL) (YLL ratios) from neighbouring countries with similar social-economical characteristics. Original data is used where possible, i.e., if the original life expectancy numbers exist, they are used for calculating YLL ratios, even if mortality ratios have to be gap-filled (e.g., for Montenegro and North Macedonia, 2005).

Similarly, as 2019 data on causes of deaths, death numbers and life expectancy are still not available in Eurostat, relative age distribution numbers of mortality (mortality ratios) and YLL (YLL ratios) are used from the last available year, as specified in table 2.1.

Table 2.1 Logic of gap filling of demographic data

Data set	Health risk assessment year	Country	Data used for gap filling	Year of data used for gap filling	Country of data used for gap filling
Causes of death	2005	EU27 + (IS, LI, NO, RS, CH, UK)	Causes of death	2011	EU27 + (IS, LI, NO, RS, CH,UK)
Causes of death	2005	AL, BA, ME, MK, XK,	Mortality ratios	2011	RS
Causes of death	2005	AD, MC	Mortality ratios	2011	FR
Causes of death	2005	SM	Mortality ratios	2011	IT
Number of death	2005	MC	Mortality ratios	2005	FR
Number of death	2005	SM	Mortality ratios	2005	IT
Life expectancy	2005	AL, BA, XK,	YLL ratios	2005	RS
Life expectancy	2005	AD, MC	YLL ratios	2005	FR
Life expectancy	2005	SM	YLL ratios	2005	IT
Causes of death	2019	EU26 + (IS, LI, NO, RS,UK)	Mortality ratios	2018	EU26 + (IS, LI, NO, RS, UK)
Causes of death	2019	FR	Mortality ratios	2016	FR
Causes of death	2019	CH	Mortality ratios	2017	CH
Causes of death	2019	AL, BA, ME, MK, XK,	Mortality ratios	2018	RS
Causes of death	2019	AD, MC	Mortality ratios	2016	FR
Causes of death	2019	SM	Mortality ratios	2018	IT
Number of death	2019	EU27 + (AD, AL, IS, LI, ME, MK, NO, RS, CH, UK, XK)	Mortality ratios	2018	EU27 + (AD, AL, IS, LI, ME, MK, NO, RS, CH, UK, XK)

Data set	Health risk assessment year	Country	Data used for gap filling	Year of data used for gap filling	Country of data used for gap filling
Number of death	2019	BA	Mortality ratios	2018	RS
Number of death	2019	MC	Mortality ratios	2018	FR
Number of death	2019	SM	Mortality ratios	2018	IT
Life expectancy	2019	EU27 + (AL, IS, LI, ME, MK, NO, RS, CH, UK)	YLL ratios	2018	EU27 + (AL, IS, LI, ME, MK, NO, RS, CH, UK)
Life expectancy	2019	BA, XK,	YLL ratios	2018	RS
Life expectancy	2019	AD, MC	YLL ratios	2018	FR
Life expectancy	2019	SM	YLL ratios	2018	IT

Note:
AD: Andorra; AL: Albania; BA: Bosnia and Herzegovina; CH: Switzerland; EU-26: EU-27 except France (France is treated separately for causes of death 2019, since no 2017-2018 data were available at the time of calculations); FR: France; IS: Iceland; IT: Italy; LI: Liechtenstein; MC: Monaco; ME: Montenegro; MK: North Macedonia; NO: Norway; RS: Serbia; SM: San Marino; UK: United Kingdom; XK: Kosovo, under UN Security Council Resolution 1244/99.
YLL: years of life lost.

2.4 Concentration response functions and counterfactual concentrations

The impacts on mortality attributable to exposure to $PM_{2.5}$, NO_2 and O_3 in Europe presented in this report are based on two different mortality endpoints:

- attributed premature deaths (PD): deaths that occur before a person reaches an expected age. This expected age is typically the life expectancy for a country stratified by sex and age. Premature deaths are considered preventable If their causes can be eliminated.
- years of life lost (YLL): the years of potential life lost as a result of premature deaths. It is an estimate of the average number of years that a person would have lived if they had not died prematurely (for additional information see, for instance, EEA,2020).

The concentration-response relationship and the population at risk have been selected following the recommendations from the Health Risks of Air Pollution in Europe (HRAPIE) project (WHO, 2013a). For chronic exposure to $PM_{2.5}$, all-cause (natural) mortality is considered in people aged over 30 years for all concentrations (i.e., concentrations above 0 µg/m^3), assuming a linear increase in the risk of mortality of 6.2 % for a 10 µg/m^3 increase in $PM_{2.5}$. For chronic exposure to NO_2, all-cause (natural) mortality is considered in people aged over 30 for concentrations above 20 µg/m^3, assuming a linear increase in the risk of mortality of 5.5 % for a 10 µg/m^3 increase in NO_2. For acute exposure to O_3, all-cause (natural) mortality is considered for all ages, assuming a linear increase in the risk of mortality of 0.29 % for a 10 µg/m^3 increase in O_3 values over 35 ppb. A detailed description of the methodology can be found in ETC/ATM (2017a); EEA (2018) and ETC/ATNI (2020a).

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

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

3 Health risk assessment in Europe for 2019

This chapter presents the results of the health impact calculations in 2019. The presentation follows the same format as in the previous *Air quality in Europe* reports (EEA, 2020) and the input data and methodology have been explained in the previous sections.

3.1 Health impacts, results for 2019

Tables 3.1 and 3.2 show the results of the health impact calculations for 2019 related to $PM_{2.5}$, NO_2, and O_3 exposure for 41 European countries. These tables show the total country population, the population-weighted mean concentrations and the estimated number of attributable premature deaths (Table 3.1), the number of years of life lost (YLL) and the YLL per 100 000 inhabitants (Table 3.2) attributed to exposure to $PM_{2.5}$, NO_2 and O_3 concentration levels in 2019.

In the 41 countries listed, 373 000 premature deaths are attributed to $PM_{2.5}$ exposure, 47 700 to NO_2 exposure and 19 070 to O_3 exposure. In the EU-28, the premature deaths attributed to $PM_{2.5}$, NO_2 and O_3 exposure are 340 000, 46 200 and 17 680, respectively. Finally, in the EU-27, 307 000, 40 400 and 16 800 premature deaths are attributed to $PM_{2.5}$, NO_2 and O_3 exposure.

In line with the changes in concentrations, the estimated deaths attributable to $PM_{2.5}$ and NO_2 went on decreasing in relation to previous years. Those attributed to $PM_{2.5}$ are 10-11 % lower than those estimated for 2018, while those for NO_2 decreased slightly more, by 13-16%. In contrast, for O_3 the decrease was of 7-9 % confirming, after the increase in 2018 compared to 2017, the high interannual variability and the lack of a real tendency.

In the 41 countries assessed, 4 068 000 YLL are attributed to $PM_{2.5}$ exposure, 512 800 to NO_2 exposure, and 215 100 to O_3 exposure (Table 3.2). In the EU-28, the YLL attributed to $PM_{2.5}$, NO_2 and O_3 exposure are 3 726 000, 497 500, and 200 000, respectively. Finally, in the EU-27, 3 370 000, 435 600 and 190 000 YLL are attributed to $PM_{2.5}$, NO_2 and O_3 exposure.

The largest absolute health impacts in terms of premature deaths and YLL attributable to air pollution are estimated for the countries with some of the largest populations. However, in relative terms, i.e., when considering YLL per 100 000 inhabitants, the outcome can be quite different.

For $PM_{2.5}$, largest absolute health impacts are estimated for, in order of decreasing rank, Germany, Italy, Poland, the United Kingdom and France (Table 3.1 and map 3.1). When considering YLL per 100 000 inhabitants, the largest relative impacts are observed in central and eastern European countries where the highest concentrations of $PM_{2.5}$ are also observed, namely, in order of decreasing rank, Bosnia and Herzegovina, Serbia, Kosovo, North Macedonia and Bulgaria. The smallest relative impacts are found in countries situated in the north and north-west of Europe, namely, in order of increasing rank, Iceland, Norway, Sweden, Finland and Ireland.

For NO_2, the largest absolute impacts from exposure are seen, in order of decreasing rank, in Italy, Spain, Germany, the United Kingdom and France. When considering YLL per 100 000 inhabitants, the highest rates are found in, in order of decreasing rank, Greece, Romania, Italy, Bulgaria and Spain. The smallest relative impacts are found in Denmark, Estonia, Finland, Iceland, Latvia, Lithuania, Malta and Sweden, with barely any impact.

Regarding O_3, the countries with the largest absolute impacts are, in order of decreasing rank, Germany, Italy, France, Spain and Poland. The countries with the highest rates of YLL per 100 000 inhabitants are, in order of decreasing rank, Bosnia and Herzegovina, Montenegro, Albania, Croatia and Greece. The countries with the smallest relative impacts are, in order of increasing rank, Iceland, Ireland, the United Kingdom, Norway and Finland.

Map 3.1: Absolute premature deaths attributable to PM2.5, at country level, 2019

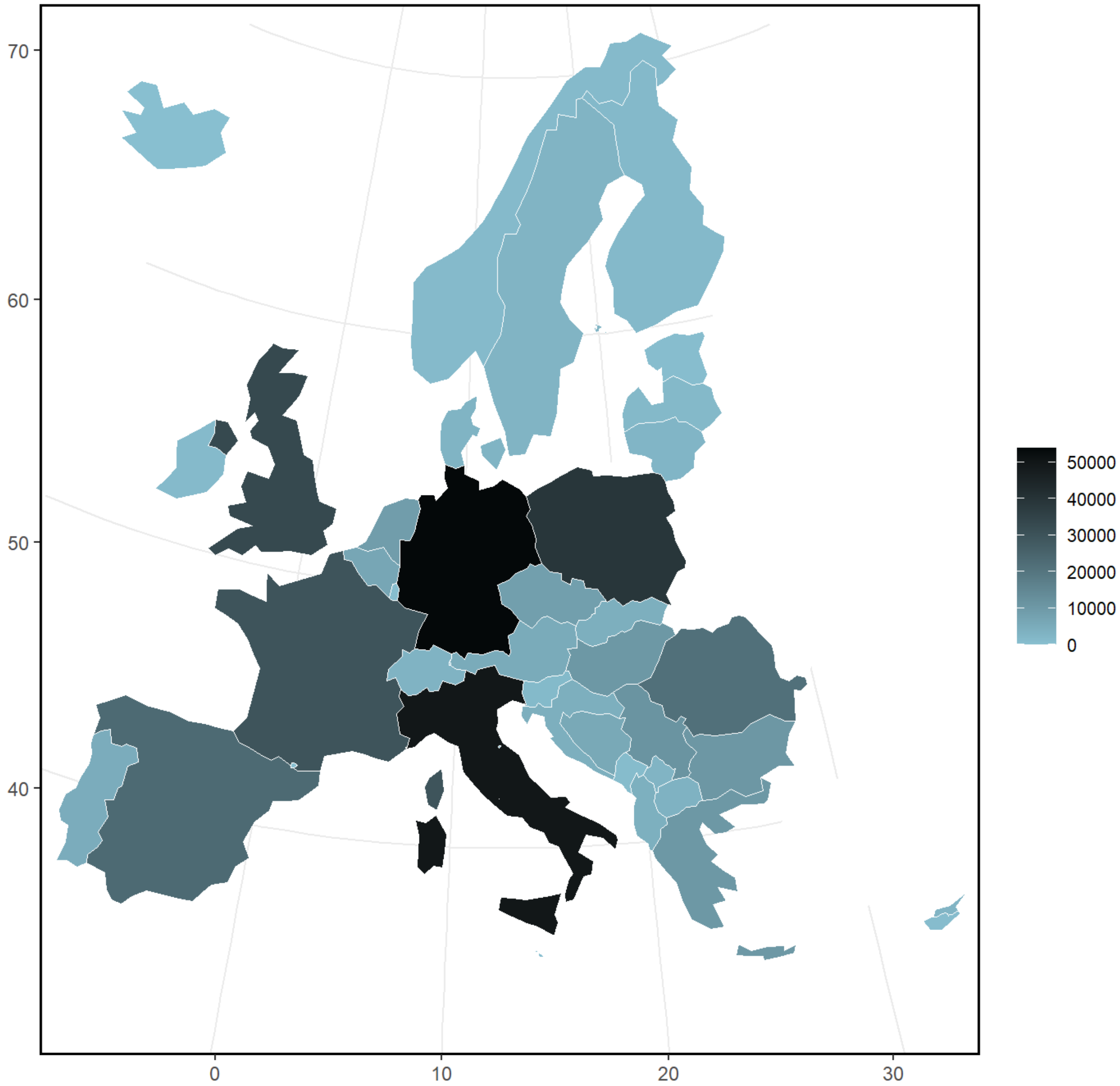


Table 3.1: Premature deaths attributable to PM2.5, NO2 and O3 exposure in the EU-27 (current membership), the EU-28 (until 31 January 2020) and 41 European countries, 2019

		$PM_{2.5}$		NO_2		O_3	
Country	**Population (1 000)**	**Annual mean ([a])**	**Premature deaths ([b])**	**Annual mean ([a])**	**Premature deaths ([b])**	**SOMO35 ([a])**	**Premature deaths ([b])**
Austria	8 859	11.3	5 200	16.4	550	5 802	360
Belgium	11 456	11	6 500	18.5	750	3 337	270
Bulgaria	7 000	18	10 600	18.6	1 120	3 513	290

		$PM_{2.5}$		NO_2		O_3	
Country	Population (1 000)	Annual mean ([a])	Premature deaths ([b])	Annual mean ([a])	Premature deaths ([b])	SOMO35 ([a])	Premature deaths ([b])
Croatia	4 076	14.7	4 200	14.3	170	6 155	240
Cyprus	1 213	14.7	700	20.9	130	5 645	40
Czechia	10 650	13.8	8 500	14.2	190	5 400	460
Denmark	5 806	9.4	2 900	9.1	< 1	3 472	150
Estonia	1 325	5.5	500	7.5	< 1	2 736	30
Finland	5 518	5	1 500	8.2	< 1	2 292	90
France	65 041	9.5	29 800	15.2	4 970	4 788	2 050
Germany	83 019	10.1	53 800	17.5	6 000	4 612	3 350
Greece	10 725	15.8	10 400	19.2	2 310	7 054	650
Hungary	9 773	14.5	10 400	16.6	880	4 473	440
Ireland	4 904	7.7	1 300	10.5	30	2 119	50
Italy	59 817	14.5	49 900	20	10 640	6 657	3 170
Latvia	1 920	10.1	1 600	10.4	< 1	2 547	50
Lithuania	2 794	12.1	2 500	11	< 1	3 220	90
Luxembourg	614	8.1	200	18.4	20	3 807	10
Malta	494	12.2	300	11.5	< 1	5 878	20
Netherlands	17 282	10.7	8 900	19.1	1 000	3 331	380
Poland	37 973	17.6	39 300	14.2	1 190	4 390	1 370
Portugal	9 776	8.3	4 900	14.9	540	3 327	270
Romania	19 414	15.1	21 500	19.5	3 660	3 221	640
Slovakia	5 450	14.5	4 200	13.5	10	4 778	190
Slovenia	2 081	13.2	1 400	14.3	40	5 754	90
Spain	44 789	10.2	23 300	18.6	6 250	5 818	1 820
Sweden	10 230	5.4	2 800	8	< 1	3 143	220
Albania	2 862	17.5	4 000	15.2	160	5 727	180
Andorra	76	10.8	40	20	< 1	7 535	< 1
Bosnia and Herzegovina	3 492	21.6	5 900	14.3	140	7 068	280
Iceland	357	4	50	11.2	< 1	1 620	< 1
Kosovo	1 796	20.1	2 800	17.5	180	4 378	90
Liechtenstein	38	8.1	10	16.5	< 1	5 727	< 1
Monaco	38	12.9	20	24.1	10	6 930	< 1
Montenegro	622	18.5	900	14.9	10	6 009	40
North Macedonia	2 077	20.6	3 400	18	120	4 038	90

		PM$_{2.5}$		NO$_2$		O$_3$	
Country	**Population (1 000)**	**Annual mean ([a])**	**Premature deaths ([b])**	**Annual mean ([a])**	**Premature deaths ([b])**	**SOMO35 ([a])**	**Premature deaths ([b])**
Norway	5 328	5.5	1 200	9.8	30	2 696	80
San Marino	35	13	30	15.8	< 1	5 956	< 1
Serbia	6 964	20.8	11 400	17.9	660	4 089	320
Switzerland	8 545	8.7	3 200	16.7	170	5 847	300
United Kingdom	66 671	9.7	33 100	18.7	5 750	1 886	880
EU-27	**441 998**	**11.9**	**307 000**	**16.7**	**40 400**	4 827	**16 800**
EU-28	*508 668*	*11.7*	*340 000*	*16.9*	*46 200*	*4 454*	*17 680*
Total	**540 899**	***11.8***	**373 000**	***16.8***	**47 700**	***4 478***	**19 070**

Notes:

([a]) The annual mean (in µg/m^3) and the SOMO35 (in µg/m^3·days), expressed as population-weighted mean concentration, are obtained according to the methodology described by ETC/ATNI (2021) and references therein and not only from monitoring stations.

([b]) EU-27, EU-28 and Total values are rounded, after addition, to the nearest thousand for population and premature deaths due to PM$_{2.5}$; to the nearest hundred for NO$_2$; and to the nearest ten for O$_3$.

The national totals are rounded to the nearest hundred or ten for PM$_{2.5}$; and to the nearest ten for NO$_2$ and O$_3$.

Table 3.2: Years of life lost (YLL) attributable to PM2.5, NO2 and O3 exposure in the EU-27 (current membership), the EU-28 (until 31 January 2020) and 41 European countries, 2019

	PM$_{2.5}$		NO$_2$		O$_3$	
Country	**YLL ([a])**	**YLL/10^5 inhabitants([b])**	**YLL ([a])**	**YLL/10^5 inhabitants ([b])**	**YLL ([a])**	**YLL/10^5 inhabitants ([b])**
Austria	53 700	606	5 700	65	3 900	44
Belgium	69 300	605	7 900	69	3 000	26
Bulgaria	112 400	1 606	11 900	170	3 200	46
Croatia	43 400	1 064	1 700	42	2 600	64
Cyprus	7 200	595	1 400	119	400	33
Czechia	95 000	892	2 100	19	5 300	50
Denmark	30 700	530	10	< 1	1 600	28
Estonia	5 600	423	< 5	< 1	400	29
Finland	15 900	288	< 5	< 1	1 000	18
France	354 100	544	59 100	91	25 800	40
Germany	560 800	676	62 500	75	36 200	44
Greece	107 300	1 001	23 900	223	6 900	64
Hungary	117 800	1 205	10 000	102	5 200	53
Ireland	15 800	322	400	8	600	13

	$PM_{2.5}$		NO_2		O_3	
Country	**YLL** [(a)]	**YLL/10⁵ inhabitants**([b])	**YLL** ([a])	**YLL/10⁵ inhabitants** ([b])	**YLL** [(a)]	**YLL/10⁵ inhabitants** ([b])
Italy	504 500	843	107 600	180	33 200	55
Latvia	17 700	924	10	< 1	600	33
Lithuania	27 900	998	< 5	< 1	1 100	38
Luxembourg	2 100	346	300	44	100	22
Malta	3 200	641	< 5	< 1	200	43
Netherlands	95 200	551	10 700	62	4 300	25
Poland	490 300	1 291	14 900	39	17 800	47
Portugal	51 100	523	5 600	57	2 900	30
Romania	244 800	1 261	41 800	215	7 600	39
Slovakia	50 900	934	100	2	2 500	45
Slovenia	15 500	744	400	19	1 000	46
Spain	251 300	561	67 500	151	20 400	45
Sweden	26 400	258	< 5	< 1	2 200	21
Albania	42 500	1 486	1 700	60	2 000	71
Andorra	500	617	40	58	50	62
Bosnia and Herzegovina	60 800	1 742	1 400	41	2 900	84
Iceland	500	147	< 5	< 1	30	8
Kosovo	29 400	1 640	1 800	103	900	52
Liechtenstein	100	258	< 5	< 1	10	26
Monaco	300	731	80	214	20	57
Montenegro	9 700	1 566	140	23	500	74
North Macedonia	33 900	1 632	1200	56	1 000	47
Norway	12 300	232	300	5	900	16
San Marino	300	757	< 5	< 1	20	49
Serbia	117 600	1 689	6 800	98	3 400	49
Switzerland	34 400	403	1 800	21	3 300	39
United Kingdom	355 900	534	61 900	93	10 000	15
EU-27	3 370 000	762	435 600	99	190 000	**43**
EU-28	*3 726 000*	*732*	*497 500*	*98*	*200 000*	*39*
Total	4 068 000	752	512 800	95	215 100	**40**

Notes:

(a) EU-27, EU-28 and Total figures of YLL are rounded, after addition, to the nearest thousand for $PM_{2.5}$; and to the nearest hundred for NO_2 and O_3. National data are rounded to the nearest hundred for $PM_{2.5}$; and to the nearest hundred or ten for NO_2 and O_3.

(b) Values of YLL per 100 000 inhabitants are not rounded.

The largest contribution to the uncertainties in the estimates of premature deaths and YLLs is related to the choice of the relative risk coefficients. In the results presented for 2019, the uncertainties in health outcomes (expressed as 95 % CIs) are estimated as follows:

- for the EU-27 estimates of attributable premature deaths, 203 000-401 000 for $PM_{2.5}$, 23 300-57 400 for NO_2 and 8 130-24 870 for O_3; and for the YLL: 2 228 000-4 409 000 for $PM_{2.5}$, 251 500-618 400 for NO_2, and 91 900-281 300 for O_3.
- for the EU-28 estimates of attributable premature deaths, 225 000-445 000 for $PM_{2.5}$, 26 700-65 600 for NO_2 and 8 550-26 170 for O_3; and for the YLL: 2 463 000-4 877 000 for $PM_{2.5}$, 287 100-706 500 for NO_2, and 96 700-296 100 for O_3.
- for the 41 European countries estimates of attributable premature deaths, 247 000-488 000 for $PM_{2.5}$, 27 500-67 700 for NO_2 and 9 220-28 220 for O_3; and for the YLL: 2 691 000-5 322 000 for $PM_{2.5}$, 295 900-728 500 for NO_2, and 104 000-318 400 for O_3.

3.2 Sensitivity analysis of the health impact estimates in 2019

The recommendations from the *Health risks of air pollution in Europe* (HRAPIE) report (WHO, 2013a) indicate that the quantification of long-term effects of $PM_{2.5}$, NO_2 and O_3 should be estimated for all concentration levels, annual levels above 20 µg/m^3 and concentrations above 35 parts per billion (ppb), respectively. The results in the previous section followed those recommendations.

To assess how sensitive the estimations are, additional calculations were undertaken following the same methodology as described in previous sections but with different starting thresholds (or counterfactual concentrations). Table 3.3 summarises the estimated health impacts in 2019 of concentrations equal to or above 2.5 and 10 µg/m^3 for $PM_{2.5}$ and NO_2, respectively, and of SOMO10 (the annual average of daily maximum running 8-hour average O_3 concentrations above 10 ppb) for O_3. These values should be compared with the values in Tables 3.1 and 3.2. The rationale for choosing 2.5 µg/m^3 for $PM_{2.5}$ is that the European $PM_{2.5}$ background concentration level is estimated to be, on average, 2.5 µg/m^3 (ETC/ACM, 2017b). For NO_2, Raaschou-Nielsen et al. (2012) showed an increase in all-cause mortality when NO_2 concentrations were lower than 20 µg/m^3, with 10 µg/m^3 being the lowest value observed affecting their study participants. Finally, for O_3, the HRAPIE project (WHO, 2013a) recommends using SOMO10 as an alternative to the assessment of only SOMO35. The *Review of evidence on health aspects of air pollution* (REVIHAAP) (WHO, 2013b) also suggests that there is no specific threshold for effects and that small O_3 concentrations might affect human health.

The number of premature deaths and YLL attributable to $PM_{2.5}$ exposure when including the full range of concentration for $PM_{2.5}$ (Tables 3.1 and 3.2) is around 25 % higher than the estimations based on concentrations equal to or above 2.5 µg/m^3 (Table 3.3). For NO_2, the estimations considering only concentrations above 20 µg/m^3 (Tables 3.1 and 3.2) are more than four times lower than when assuming a threshold of 10 µg/m^3 (Table 3.3). The results in Tables 3.1 and 3.2 indicate that in many countries concentrations do not exceed 20 µg/m^3 and, therefore, the estimations of premature deaths and YLL attributable to NO_2 above that concentration are zero. Finally, for O_3, estimating health effects based on SOMO10 provides a number of premature deaths and YLL that are about four times higher than an estimation based on SOMO35

Table 3.3: Estimated number of premature deaths and years of life lost attributable to PM2.5 (from a concentration of 2.5 µg/m3), NO2 (from a concentration of 10 µg/m3) and O3 (for SOMO10), reference year 2019

	Pollutant and concentration threshold		
	$PM_{2.5}$ 2.5 µg/m^3	NO_2 10 µg/m^3	O_3 SOMO10
EU-27			
Premature deaths	245 000	166 300	67 930
Years of life lost	2 695 000	1 800 700	771 900
YLL/100 000 inh.	610	407	175
EU-28			
Premature deaths	270 000	193 200	75 180
Years of life lost	2 962 000	2 090 700	854 200
YLL/100 000 inh.	582	411	168
Total			
Premature deaths	298 000	205 300	80 640
Years of life lost	3 254 000	2 216 600	913 400
YLL/100 000 inh.	602	410	169

Note*: Totals for the EU-27 Member States ('EU-27'), EU-27 Member States and the United Kingdom ('EU-28'), and 41 European countries ('Total').*

4 Distance to the health-related objective of the Zero Pollution Action Plan

The Zero Pollution Action Plan (EU, 2021), published in June 2021 as a part of the European Green Deal (EU, 2019), has the vision for 2050 that air, water and soil pollution is reduced to levels no longer considered harmful to health and natural ecosystems and that respect the boundaries our planet can cope with, thus creating a toxic-free environment. It has set, *inter alia*, the target to reduce by 2030 the number of premature deaths caused by $PM_{2.5}$ by 55%, relative to 2005.

In this section we will analyse the EU progress towards that target. For that, we will first present the health impact calculations in 2005, similarly as the analysis presented for 2019 in Section 3.1. The 2019 results will be then compared with those in 2005.

4.1 Health impacts, results for 2005

Similarly to tables 3.1 and 3.2 for 2019, tables 4.1 and 4.2 show the results of the health impact calculations for 2005 related to $PM_{2.5}$, NO_2, and O_3 exposure for 41 European countries. These tables show the total country population, the population-weighted mean concentrations, and the estimated number of attributable premature deaths (Table 4.1), the number of years of life lost (YLL) and the YLL per 100 000 inhabitants (Table 4.2) attributed to exposure to $PM_{2.5}$, NO_2 and O_3 concentration levels in 2005.

Table 4.1: Premature deaths attributable to PM2.5, NO2 and O3 exposure in the EU-27 (current membership), the EU-28 (until 31 January 2020) and 41 European countries, 2005

		$PM_{2.5}$		NO_2		O_3	
Country	**Population (1 000)**	**Annual mean (a)**	**Premature deaths (b)**	**Annual mean (a)**	**Premature deaths (b)**	**SOMO35 (a)**	**Premature deaths (b)**
Austria	8 201	19.1	7 700	22.9	1 890	5 858	330
Belgium	10 446	18.4	10 100	27.4	3 880	2 916	230
Bulgaria	7 689	30.8	17 400	18.6	1 290	4 803	400
Croatia	4 311	24	6 500	18.6	650	6 394	250
Cyprus	1 015	28.6	1 100	15.8	30	8 218	50
Czechia	10 199	23.3	13 100	20.2	1 290	5 926	470
Denmark	5 411	12.7	3 700	15.4	340	2 383	100
Estonia	1 359	11.7	900	11.9	< 1	2 439	30
Finland	5 237	8.8	2 400	14.3	140	2 374	90
France	60 776	16	44 700	22.9	14 620	4 619	1 800
Germany	82 501	16.5	76 800	23.8	22 090	3 947	2 560
Greece	10 970	26.7	15 800	25.8	4 880	7 410	630
Hungary	10 098	25	16 900	19.6	1 700	5 666	550
Ireland	4 112	8.3	1 300	11.8	80	1 575	30
Italy	57 875	23.8	75 100	31.3	34 890	7 421	3 350
Latvia	2 250	17.2	2 600	14.7	230	2 301	50

		$PM_{2.5}$		NO_2		O_3	
Country	Population (1 000)	Annual mean ([a])	Premature deaths ([b])	Annual mean ([a])	Premature deaths ([b])	SOMO35 ([a])	Premature deaths ([b])
Lithuania	3 355	16.4	3 400	13.8	110	3 414	100
Luxembourg	461	15.7	300	25.3	110	3 459	10
Malta	403	21.2	400	20.8	50	7 177	20
Netherlands	16 306	17.7	12 900	28.3	5 740	2 540	260
Poland	38 174	22.5	43 800	17.5	3 480	4 734	1 320
Portugal	9 984	18	9 600	19.6	1 680	5 732	430
Romania	21 382	29.9	38 900	18.3	3 300	4 978	950
Slovakia	5 373	24.5	6 400	16.6	180	6 025	230
Slovenia	1 998	21.8	2 100	18.4	200	6 417	90
Spain	41 315	18.4	37 000	26.7	14 980	5 988	1 690
Sweden	9 011	10.3	5 000	14.5	200	2 585	170
Albania	3 020	27.5	6 100	19.5	530	7 870	250
Andorra	77	13.5	50	17.6	< 1	7 669	< 1
Bosnia and Herzegovina	3 843	25.9	7 300	16.1	240	6 588	270
Iceland	294	7.2	100	12.5	< 1	699	< 1
Kosovo	2 041	30.6	4 500	15.7	50	6 877	150
Liechtenstein	35	17.9	20	23.4	< 1	5 230	< 1
Monaco	33	18.9	30	36.9	20	8 949	< 1
Montenegro	613	22.2	1 000	18	60	7 043	50
North Macedonia	2 035	38.9	5 600	21.8	440	5 956	130
Norway	4 606	9.5	2 100	16.2	440	2 048	60
San Marino	30	18.3	30	23.6	10	7 579	< 1
Serbia	7 456	30.9	16 700	15.9	260	5 436	430
Switzerland	7 415	16.3	5 400	24.5	1 640	5 609	260
United Kingdom	60 203	13.1	39 700	26.1	20 390	1 658	700
EU-27	**430 209**	**19.6**	**456 000**		**118 000**		**16 170**
EU-28	490 412	*18.8*	*495 000*	*23.6*	*138 400*	*4 573*	*16 870*
Total	**521 909**	**19**	**544 000**	**23.3**	**142 100**	**4 622**	**18 470**

Notes:

(a) The annual mean (in µg/m^3) and the SOMO35 (in µg/m^3·days), expressed as population-weighted mean concentration, are obtained according to the methodology described by ETC/ATNI (2020b) and references therein and not only from monitoring stations.

(b) EU-27, EU-28 and Total values are rounded, after addition, to the nearest thousand for population and premature deaths due to $PM_{2.5}$; to the nearest hundred for NO_2; and to the nearest ten for O_3.

The national totals are rounded to the nearest hundred or ten for $PM_{2.5}$; and to the nearest ten for NO_2 and O_3.

Table 4.2: Years of life lost (YLL) attributable to PM2.5, NO2 and O3 exposure in the EU-27 (current membership), the EU-28 (until 31 January 2020) and 41 European countries, 2005

	$PM_{2.5}$		NO_2		O_3	
Country	**YLL (a)**	**YLL/10^5 inhabitants(b)**	**YLL (a)**	**YLL/10^5 inhabitants (b)**	**YLL (a)**	**YLL/10^5 inhabitants (b)**
Austria	80 400	981	19 800	241	3 700	45
Belgium	104 200	997	40 000	383	2 400	23
Bulgaria	175 700	2 285	13 000	169	4 300	56
Croatia	66 000	1 531	6 600	153	2 600	61
Cyprus	10 700	1 056	200	24	500	45
Czechia	137 900	1 352	13 600	134	5 200	51
Denmark	39 200	725	3 600	66	1 100	20
Estonia	10 100	743	40	3	300	22
Finland	26 200	501	1 600	30	1 000	19
France	508 400	836	166 300	274	21 800	36
Germany	820 700	995	236 000	286	28 400	34
Greece	165 800	1 512	51 200	467	6 900	63
Hungary	190 300	1 885	19 100	189	6 400	63
Ireland	14 200	345	900	22	400	10
Italy	733 200	1 267	340 400	588	34 100	59
Latvia	27 900	1 241	2 500	112	600	25
Lithuania	38 500	1 148	1 200	36	1 200	35
Luxembourg	3 500	755	1 200	263	100	23
Malta	4 000	996	500	119	200	49
Netherlands	139 000	852	61 700	379	2 900	18
Poland	532 000	1 394	42 200	111	16 900	44
Portugal	99 700	999	17 500	175	4 700	47
Romania	412 100	1 927	34 900	163	10 800	51
Slovakia	71 600	1 333	2 000	37	2 700	50

	$PM_{2.5}$		NO_2		O_3	
Country	**YLL** [(a)]	**YLL/10^5 inhabitants**([b])	**YLL** ([a])	**YLL/10^5 inhabitants** ([b])	**YLL** [(a)]	**YLL/10^5 inhabitants** ([b])
Slovenia	22 300	1 117	2 200	109	1 000	48
Spain	383 900	929	155 500	376	18 500	45
Sweden	47 000	522	1 900	21	1 700	19
Albania	59 900	1 982	5 200	172	2 600	86
Andorra	500	710	10	7	50	60
Bosnia and Herzegovina	71 800	1 868	2 400	62	2 800	72
Iceland	900	290	< 5	< 1	10	4
Kosovo	44 700	2 192	400	22	1 500	75
Liechtenstein	200	500	30	98	10	20
Monaco	300	976	300	789	20	70
Montenegro	10 200	1 657	600	92	500	78
North Macedonia	54 200	2 665	4 300	210	1 300	64
Norway	21 400	464	4 400	96	700	15
San Marino	300	994	60	202	20	61
Serbia	164 700	2 210	2 600	34	4 400	59
Switzerland	57 100	770	17 200	232	2 900	39
United Kingdom	416 600	692	214 100	356	7 800	13
EU-27	**4 864 000**	**1 131**	**1 235 700**	**287**	**180 400**	**42**
EU-28	*5 281 000*	*1 077*	*1 449 900*	*296*	*188 200*	*38*
Total	**5 767 000**	**1 105**	**1 487 300**	**285**	**205 000**	**39**

Notes:

(a) EU-27, EU-28 and Total figures of YLL are rounded, after addition, to the nearest thousand for $PM_{2.5}$; and to the nearest hundred for NO_2 and O_3. National data are rounded to the nearest hundred for $PM_{2.5}$; and to the nearest hundred or ten for NO_2 and O_3.

(b) Values of YLL per 100 000 inhabitants are not rounded.

4.2 Sensitivity analysis of the health impact estimates in 2005

Similarly to table 3.3 for 2019, table 4.3 summarises the estimated health impacts in 2005 of concentrations equal to or above 2.5 and 10 µg/m^3 for $PM_{2.5}$ and NO_2, respectively. The same could not be done for SOMO10 (the annual average of daily maximum running 8-hour average O_3 concentrations above 10 ppb) for O_3, since there were no data of SOMO10 for 2005. The rationale for these alternative counterfactual concentrations can be found in section 3.2

Table 4.3: Estimated number of premature deaths and years of life lost attributable to $PM_{2.5}$ (from a concentration of 2.5 µg/m^3), NO_2 (from a concentration of 10 µg/m^3), reference year 2005

	Pollutant and concentration threshold	
	$PM_{2.5}$ 2.5 µg/m^3	NO_2 10 µg/m^3
EU-27		
Premature deaths	402 000	272 400
Years of life lost	4 285 000	2 879 100
YLL/100 000 inh.	996	669
EU-28		
Premature deaths	434 444	315 600
Years of life lost	4 624 000	3 332 600
YLL/100 000 inh.	943	680
Total		
Premature deaths	478 000	331 400
Years of life lost	5 065 000	3 491 300
YLL/100 000 inh.	970	669

***Note**: Totals for the current EU-27 Member States ('EU-27'), current EU-27 Member States and the United Kingdom ('EU-28') and 41 European countries ('Total').*

4.3 Comparison of premature deaths attributed to air pollution in 2019 and 2005

Table 4.4 presents the number of premature deaths in 2019 and compares them with those in 2005. The numbers for 2005 and 2019 are taken from tables 4.1 and 3.1, respectively. The change in 2019 is given as a percentage of the original value in 2005.

As shown in Table 4.4, the number of premature deaths attributed to exposure to $PM_{2.5}$ in the EU-27 has decreased from 2005 to 2019 by 33 %, and in all countries, by 31 %. Although it is still far from the 55 % set as objective in the ZPAP, the progression seems in good track, as explained in section 4.4. All countries have seen a decrease in the number of deaths attributed to exposure to $PM_{2.5}$, with the only exceptions of Ireland and San Marino, that registered the same number in both years. The highest decreases, above 40 %, are found, in order of decreasing rank, in Iceland, Liechtenstein, Portugal, Romania, Estonia, Sweden, Norway and Switzerland. The smallest ones, below 20 % but in all cases above 10 %, in, in order of increasing rank, Montenegro, Poland, the United Kingdom and Bosnia and Herzegovina.

In the case of NO_2, premature deaths have decreased by two thirds in both the EU-27 and all the countries. Some countries have totally reduced the number of premature deaths attributed to exposure to NO_2, as is the case of Denmark, Finland, Latvia, Lithuania, Malta, San Marino and Sweden. Some other countries, where the PD were negligible already in 2005, have continued the same, as Andorra, Estonia, Iceland and Liechtenstein. Finally, some countries have increased the number of PD attributed to exposure to NO_2, such as Cyprus, Kosovo, Serbia and Romania; but in most of these cases the total number of PD is still low and could be due to the uncertainties of the calculations.

Finally, for O_3, the picture is quite mixed, and it reflects the high interannual variability of O_3 concentrations. Considering EU-27 and all countries, the number of premature deaths in 2019 have slightly increased by 4 % and 3 %, respectively. When looking at individual countries, increases of 50 % or more can be seen in, in order of decreasing rank, Ireland and Denmark (but with very low number of deaths, so the increase can be attributed to the uncertainties of the calculations) and decreases among 30 % and 40 % in, in order of decreasing rank, Kosovo, Portugal, Romania and North Macedonia. Furthermore, six countries (Estonia, Finland, Latvia, Luxembourg, Malta and Slovenia) have experienced no changes; together with five more where the numbers have continued to be negligible (Andorra, Iceland, Liechtenstein, Monaco and San Marino).

Table 4.4: Premature deaths attributed to exposure to PM2.5, NO2 and O3 in years 2005 and 2019 and relative change between both years

	$PM_{2.5}$			NO_2			O_3		
Country	**2005**	**2019**	**% change**	**2005**	**2019**	**% change**	**2005**	**2019**	**% change**
Austria	7 700	5 200	-32.5	1 890	550	-70.9	330	360	9.1
Belgium	10 100	6 500	-35.6	3 880	750	-80.7	230	270	17.4
Bulgaria	17 400	10 600	-39.1	1 290	1 120	-13.2	400	290	-27.5
Croatia	6 500	4 200	-35.4	650	170	-73.8	250	240	-4.0
Cyprus	1 100	700	-36.4	30	130	333.3	50	40	-20.0
Czechia	13 100	8 500	-35.1	1 290	190	-85.3	470	460	-2.1
Denmark	3 700	2 900	-21.6	340	< 1	-100	100	150	50.0
Estonia	900	500	-44.4	< 1	< 1	NA	30	30	0
Finland	2 400	1 500	-37.5	140	< 1	-100	90	90	0
France	44 700	29 800	-33.3	14 620	4 970	-66.0	1 800	2 050	13.9
Germany	76 800	53 800	-29.9	22 090	6 000	-72.8	2 560	3 350	30.9
Greece	15 800	10 400	-34.2	4 880	2 310	-52.7	630	650	3.2
Hungary	16 900	10 400	-38.5	1 700	880	-48.2	550	440	-20.0
Ireland	1 300	1 300	0	80	30	-62.5	30	50	66.7
Italy	75 100	49 900	-33.6	34 890	10 640	-69.5	3 350	3 170	-5.4
Latvia	2 600	1 600	-38.5	230	< 1	-100	50	50	0
Lithuania	3 400	2 500	-26.5	110	< 1	-100	100	90	-10.0
Luxembourg	300	200	-33.3	110	20	-81.8	10	10	0
Malta	400	300	-25.0	50	< 1	-100	20	20	0
Netherlands	12 900	8 900	-31.0	5 740	1 000	-82.6	260	380	46.2
Poland	43 800	39 300	-10.3	3 480	1 190	-65.8	1 320	1 370	3.8
Portugal	9 600	4 900	-49.0	1 680	540	-67.9	430	270	-37.2
Romania	38 900	21 500	-44.7	3 300	3 660	10.9	950	640	-32.6
Slovakia	6 400	4 200	-34.4	180	10	-94.4	230	190	-17.4
Slovenia	2 100	1 400	-33.3	200	40	-80.0	90	90	0
Spain	37 000	23 300	-37.0	14 980	6 250	-58.3	1 690	1 820	7.7
Sweden	5 000	2 800	-44.0	200	< 1	-100	170	220	29.4
Albania	6 100	4 000	-34.4	530	160	-69.8	250	180	-28.0
Andorra	50	40	-20.0	< 1	< 1	NA	< 1	< 1	NA
Bosnia and Herzegovina	7 300	5 900	-19.2	240	140	-41.7	270	280	3.7
Iceland	100	50	-50.0	< 1	< 1	NA	< 1	< 1	NA
Kosovo	4 500	2 800	-37.8	50	180	260.0	150	90	-40.0
Liechtenstein	20	10	-50.0	< 1	< 1	NA	< 1	< 1	NA
Monaco	30	20	-33.3	20	10	-50.0	< 1	< 1	NA
Montenegro	1 000	900	-10.0	60	10	-83.3	50	40	-20.0
North Macedonia	5 600	3 400	-39.3	440	120	-72.7	130	90	-30.8
Norway	2 100	1 200	-42.9	440	30	-93.2	60	80	33.3
San Marino	30	30	0	10	< 1	-100	< 1	< 1	NA
Serbia	16 700	11 400	-31.7	260	660	153.8	430	320	-25.6
Switzerland	5 400	3 200	-40.7	1 640	170	-89.6	260	300	15.4
United Kingdom	39 700	33 100	-16.6	20 390	5 750	-71.8	700	880	25.7
EU-27	456 000	307 000	-33	118 000	40 400	-66	16 170	16 800	4
EU-28	495 000	340 000	*-31*	138 400	46 200	*-67*	16 870	17 680	*5*
Total	544 000	373 000	-31	142 100	47 700	-66	18 470	19 070	3

Notes: the change is expressed as percentage of the original numbers in 2005, according to the formula: Change $_{2019\ vs\ 2005}$ = 100 * (PD_{2019} – PD_{2005}) / PD_{2005}, where "PD" are premature deaths.

Changes at country level are rounded to one decimal. Changes for the groupings of countries are rounded to integer.

Cells in green show relative decrease; cells in red, relative increases; cells in grey, no change. NA: not applicable, since the number of deaths in both years is negligible.

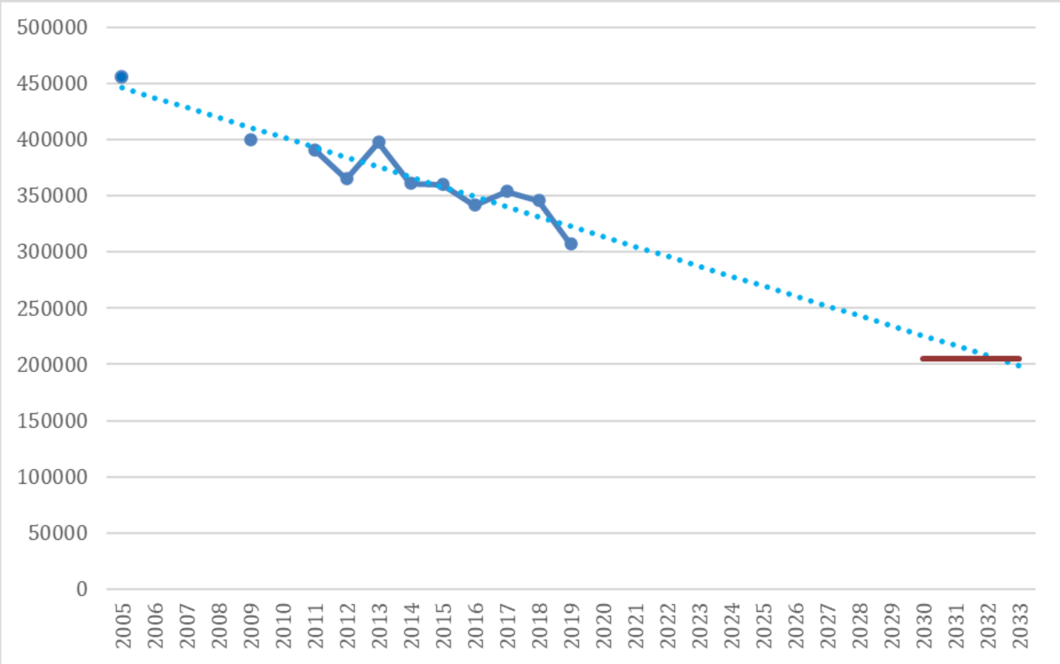
4.4 Time evolution of the premature deaths attributed to air pollution

The previous section has shown the change in mortality attributed to air pollution for the specific year of 2019 related to 2005. What we present in the current section is the time evolution, for EU-27, of the premature deaths for all years from 2005 on for which either the ETC/ATNI (and its predecessors) or the EEA have made calculations.

Figure 4.1 shows the time evolution in the number of premature deaths in EU-27 attributed to exposure to $PM_{2.5}$ and the distance to the 2030 target set in the ZPAP. The number of premature deaths shows a steady decrease along the years, with a punctual increase in 2013. Should air quality continue to improve, and the number of premature deaths per year continue to fall at a comparable rate in the future, then the target would be achieved by 2032, as shown by the dashed line in figure 4.1

Figures 4.2 and 4.3 show the time evolution of the premature deaths in EU-27 for the exposure to NO_2 and O_3, respectively. For NO_2 the decrease is steady although not constant along the years. For O_3, the time series shows constants up and downs as a reflection of the high interannual variation of the O_3 concentrations and no tendency can be inferred.

Figure 4.1: Premature deaths attributable to PM2.5, EU-27, 2005-2019 and distance to the ZPAP target



Notes:

Blue continuous line: premature deaths attributed to $PM_{2.5}$. All-cause (natural) mortality is considered in people aged over 30 years for all concentrations, assuming a linear increase in the risk of mortality of 6.2 % for a 10 µg/m^3 increase in $PM_{2.5}$.

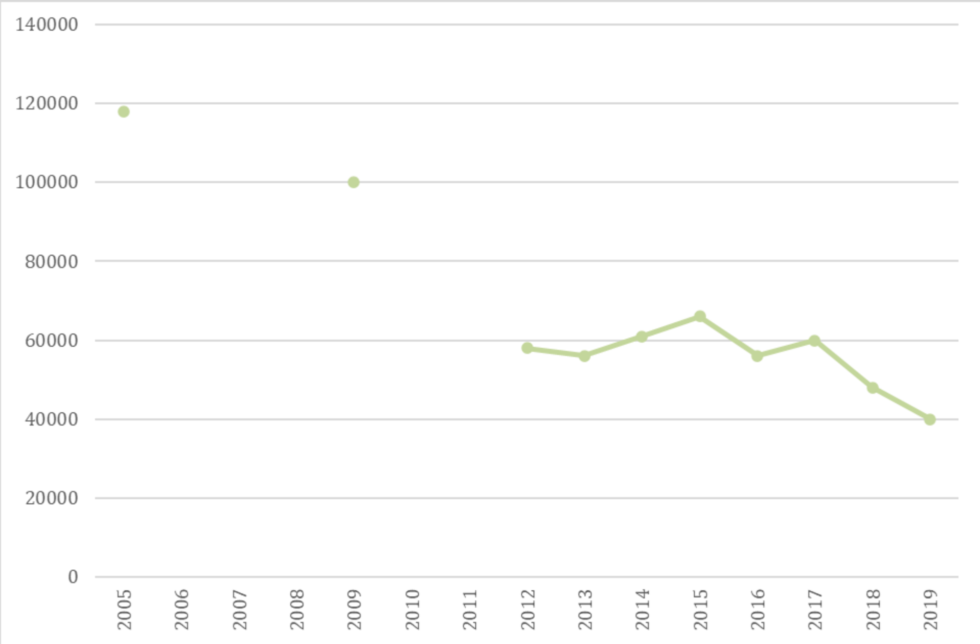
Only the concentration maps for 2005, 2009, 2017, 2018 and 2019 were produced with the current methodology, that is, including the traffic layer (see Section 2.1).

Light blue dashed line: Estimation of the evolution in the number of premature deaths attributed to $PM_{2.5}$ assuming the same linear trend in the future than in the time series 2005-2019. The 2030 ZPAP target would be attained in 2032.

Red horizontal continuous line: 2030 ZPAP target (45 % of the PD estimated in 2005, that equals 205 200).

Sources: EEA, 2020: *Air quality in Europe*, 2014, 2015, 2016, 2017, 2018, 2019, 2020 and 2021 reports; ETC/ATNI, 2020a; and ETC/ATNI, 2020b.

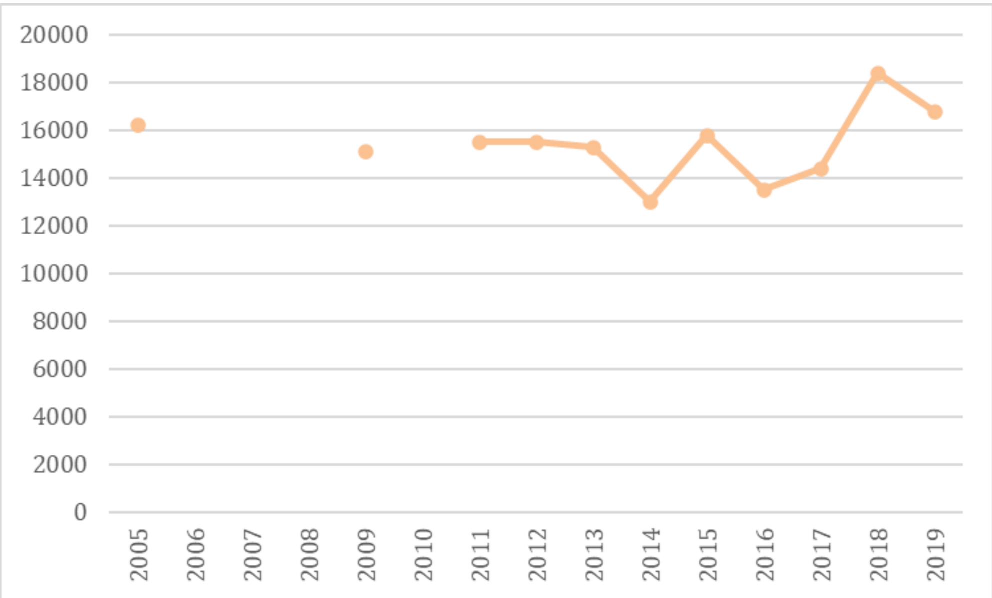
Figure 4.2: Premature deaths attributable to NO2, EU-27, 2005-2019



Notes:
Premature deaths attributed to NO_2. All-cause (natural) mortality in people aged over 30 for concentrations above 20 µg/m^3, assuming a linear increase in the risk of mortality of 5.5 % for a 10 µg/m^3 increase in NO_2.
Only the concentration maps for 2005, 2009, 2015, 2016, 2017, 2018 and 2019 were produced with the current methodology, that is, including the traffic layer (see Section 2.1).

Sources: EEA, 2020: *Air quality in Europe*, 2015, 2016, 2017, 2018, 2019, 2020 and 2021 reports; ETC/ATNI, 2020a; and ETC/ATNI, 2020b.

Figure 4.3: Premature deaths attributable to O3, EU-27, 2005-2019



Notes:
Premature deaths attributed to O_3. All-cause (natural) mortality for all ages, assuming a linear increase in the risk of mortality of 0.29 % for a 10 µg/m^3 increase in O_3 values over 35 ppb.

Sources: EEA, 2020: *Air quality in Europe*, 2014, 2015, 2016, 2017, 2018, 2019, 2020 and 2021 reports; ETC/ATNI, 2020a; and ETC/ATNI, 2020b.

4.5 Sensitivity analysis of the changes in the number of premature deaths attributed to air pollution in 2019 and 2005

The comparison made in section 4.3 shows the changes in the number of premature deaths comparing the "real" situation in 2019 with the "real" situation in 2005. The changes found can therefore be attributed to changes in the concentrations but also to changes in the demographic data, such as population amount, distribution of this population in the country and mortality data. To consider the change attributed exclusively to changes in the concentrations of the air pollutants, the "real" situation in 2005 should be compared with another situation where all the input variables remain the same (those in 2005) and the only variation occurs for the concentration, for which the 2019 values are considered.

Table 4.5 shows the hypothetical mortality attributed to the population in 2005 due to exposure to air pollution if the levels in 2005 had been those of 2019.

Table 4.5: Premature deaths attributable to PM2.5, NO2 and O3 exposure in the EU-27 (current membership), the EU-28 (until 31 January 2020) and 41 European countries, using population and other demographic data for 2005 and the 2019 concentrations

		$PM_{2.5}$		NO_2		O_3	
Country	**Population (1 000)**	**Annual mean ([a])**	**Premature deaths ([b])**	**Annual mean ([a])**	**Premature deaths ([b])**	**SOMO35 ([a])**	**Premature deaths ([b])**
Austria	8 201	11.3	4 700	16.4	500	5 802	330
Belgium	10 446	11	6 200	18.5	700	3 337	260
Bulgaria	7 689	18	10 600	18.6	1 120	3 513	290
Croatia	4 311	14.7	4 100	14.3	160	6 155	240
Cyprus	1 015	14.7	600	20.9	120	5 645	30
Czechia	10 199	13.8	8 000	14.2	170	5 400	430
Denmark	5 411	9.4	2 700	9.1	< 1	3 472	140
Estonia	1 359	5.5	500	7.5	< 1	2 736	30
Finland	5 237	5	1 400	8.2	< 1	2 292	90
France	60 776	9.5	27 000	15.2	4 520	4 788	1 870
Germany	82 501	10.1	48 000	17.5	5 350	4 612	3 000
Greece	10 970	15.8	9 600	19.2	2 150	7 054	600
Hungary	10 098	14.5	10 100	16.6	860	4 473	430
Ireland	4 112	7.7	1 200	10.5	30	2 119	50
Italy	57 875	14.5	47 200	20	10 070	6 657	3 010
Latvia	2 250	10.1	1 600	10.4	< 1	2 547	50
Lithuania	3 355	12.1	2 600	11	< 1	3 220	90
Luxembourg	461	8.1	200	18.4	20	3 807	10
Malta	403	12.2	200	11.5	< 1	5 878	20
Netherlands	16 306	10.7	7 900	19.1	890	3 331	340
Poland	38 174	17.6	34 900	14.2	1 060	4 390	1 230
Portugal	9 984	8.3	4 500	14.9	490	3 327	250
Romania	21 382	15.1	20 600	19.5	3 510	3 221	610
Slovakia	5 373	14.5	3 900	13.5	10	4 778	180
Slovenia	1 998	13.2	1 300	14.3	30	5 754	80
Spain	41 315	10.2	20 900	18.6	5 620	5 818	1 640
Sweden	9 011	5.4	2 700	8	< 1	3 143	210
Albania	3 020	17.5	4 000	15.2	160	5 727	180
Andorra	77	10.8	40	20	< 5	7 535	<.51
Bosnia and Herzegovina	3 843	21.6	6 100	14.3	150	7 068	290

		$PM_{2.5}$		NO_2		O_3	
Country	**Population (1 000)**	**Annual mean ([a])**	**Premature deaths ([b])**	**Annual mean ([a])**	**Premature deaths ([b])**	**SOMO35 ([a])**	**Premature deaths ([b])**
Iceland	294	4	40	11.2	< 1	1 620	< 1
Kosovo	2 041	20.1	3 100	17.5	190	4 378	90
Liechtenstein	35	8.1	10	16.5	<	5 727	< 1
Monaco	33	12.9	20	24.1	10	6 930	< 1
Montenegro	613	18.5	900	14.9	10	6 009	40
North Macedonia	2 035	20.6	3 100	18	110	4 038	90
Norway	4 606	5.5	1 200	9.8	30	2 696	80
San Marino	30	13	20	15.8	< 1	5 956	< 1
Serbia	7 456	20.8	11 500	17.9	670	4 089	320
Switzerland	7 415	8.7	3 000	16.7	160	5 847	270
United Kingdom	60 203	9.7	29 800	18.7	5 180	1 886	790
EU-27	430 209	11.9	283 000	16.7	**37 400**	4 827	**15 490**
EU-28	*490 412*	*11.7*	*313 000*	*16.9*	*42 600*	*4 454*	*16 280*
Total	521 909	*11.8*	346 000	*16.8*	**44 000**	*4 478*	**17 660**

Notes:

([a]) The annual mean (in µg/m^3) and the SOMO35 (in µg/m^3·days), expressed as population-weighted mean concentration in 2019, are obtained according to the methodology described by ETC/ATNI (2021) and references therein and not only from monitoring stations.

([b]) EU-27, EU-28 and Total values are rounded, after addition, to the nearest thousand for population and premature deaths due to $PM_{2.5}$; to the nearest hundred for NO_2; and to the nearest ten for O_3.

The national totals are rounded to the nearest hundred or ten for $PM_{2.5}$; and to the nearest ten for NO_2 and O_3.

Comparing the values in table 4.5 (2005 population data and 2019 concentrations) with those in table 4.1 (2005 population and concentrations data) we see that, for EU-27, 283 000 premature deaths would have been attributed to exposure to the 2019 pollution levels, instead of the 456 000 attributed to the 2005 pollution levels. This means a decrease of 38 % (173 000 premature deaths). For NO_2, a decrease of 68 % is estimated (80 600 total PD, from 118 000 to 37 400). Finally, for O_3, a decrease would also be seen, of 4 % (680, from 16 170 to 15 490). These numbers indicate that the impact of the improvement of the concentrations have been compensated by the changes in the population structure (for instance, aging population, or migration to urban areas where concentrations tend to be higher).

5 Benefit analysis of having reached different air quality standards in 2019

This chapter presents a hypothetical assessment of the potential minimum health benefits of meeting already in 2019 and across all Europe the current EU limit values and the World Health Organization (WHO) air quality guideline levels and some interim targets (those in place until now and the new ones), for $PM_{2.5}$ ([1]). It provides an updated and extended estimate of a similar exercise that was performed in EEA (2019).

For this exercise, calculations of premature deaths were made based on the assumption that all $PM_{2.5}$ concentrations for 2019 over the standard at consideration are set at that standard, while the concentrations below it remain unchanged ([2]). The rest of the methodology is applied as explained in the previous chapters of this report. It is important to note that the estimated benefits present a minimum expected benefit and are likely to be underestimated. This is because measures required to bring down concentrations above a certain value would also further reduce concentrations elsewhere that are currently below that value. With the methodology applied, these additional benefits are not captured and as such, the exercise underestimates the actual expected benefits of reaching the considered standards or recommendations. However, the measures needed to attain those standards are not considered or analysed. This is then a theoretical exercise trying to find out the health benefits of reaching the standards, without any consideration on the technical, social and/or economic impacts of reaching them.

The results are presented in table 5.1. In it, the first column shows the name of the country or group of countries, and the second one the number of premature deaths estimated with the actual 2019 concentrations (as shown also in table 3.1). The rest of pairs of columns show the number of premature deaths estimated should the specific standard or recommendation have been reached and the relative change compared to the actual 2019 situation.

Table 5.1: Estimated number of premature deaths attributable to PM2.5 in 2019 with the actual 2019 concentrations and in the cases where different air quality standards and recommendations had been attained also in the areas currently above those levels, and relative changes in the number of premature deaths

Country	PD actual	PD LV 25	% to actual	PD LV 20	% to actual	PD IT 15	% to actual	PD AQG10	% to actual	PD AQG 5	% to actual
Austria	5 200	5 200	0	5 200	0	5 100	2	4 300	17	2 300	56
Belgium	6 500	6 500	0	6 500	0	6 500	0	5 800	11	3 000	54
Bulgaria	10 600	10 500	1	10 000	6	8 600	19	6 000	43	3 100	71
Croatia	4 200	4 200	0	4 100	2	3 800	10	2 900	31	1 500	64
Cyprus	700	700	0	700	0	600	14	500	29	200	71
Czechia	8 500	8 500	0	8 500	0	8 200	4	6 200	27	3 200	62
Denmark	2 900	2 900	0	2 900	0	2 900	0	2 900	0	1 600	45
Estonia	500	500	0	500	0	500	0	500	0	400	20
Finland	1 500	1 500	0	1 500	0	1 500	0	1 500	0	1 400	7
France	29 800	29 800	0	29 800	0	29 800	0	28 100	6	15 900	47
Germany	53 800	53 800	0	53 800	0	53 800	0	51 400	4	27 000	50
Greece	10 400	10 400	0	10 300	1	9 300	11	6 700	36	3 400	67
Hungary	10 400	10 400	0	10 400	0	10 200	2	7 300	30	3 700	64
Ireland	1 300	1 300	0	1 300	0	1 300	0	1 300	0	900	31
Italy	49 900	49 900	0	49 100	2	45 200	9	34 500	31	17 700	65
Latvia	1 600	1 600	0	1 600	0	1 600	0	1 400	13	800	50

([1]) Those standards can be found in table 1.1

([2]) So, for instance, when analysing the impact of reaching in 2019 the 2005 WHO AQG for $PM_{2.5}$, all the grid concentrations above 10 µg/m^3 were set to 10 µg/m^3, while all grid concentrations below 10 µg/m^3 were remained unchanged.

Country	PD actual	PD LV 25	% to actual	PD LV 20	% to actual	PD IT 15	% to actual	PD AQG10	% to actual	PD AQG 5	% to actual
Lithuania	2 500	2 500	0	2 500	0	2 500	0	2 100	16	1 100	56
Luxembourg	200	200	0	200	0	200	0	200	0	100	50
Malta	300	300	0	300	0	300	0	200	33	100	67
Netherlands	8 900	8 900	0	8 900	0	8 900	0	8 300	7	4 200	53
Poland	39 300	39 100	1	37 600	4	32 700	17	22 800	42	11 600	70
Portugal	4 900	4 900	0	4 900	0	4 900	0	4 800	2	3 000	39
Romania	21 500	21 500	0	21 300	1	19 600	9	14 300	33	7 300	66
Slovakia	4 200	4 200	0	4 200	0	4 000	5	2 900	31	1 500	64
Slovenia	1 400	1 400	0	1 400	0	1 400	0	1 100	21	600	57
Spain	23 300	23 300	0	23 200	0	23 100	1	20 800	11	11 600	50
Sweden	2 800	2 800	0	2 800	0	2 800	0	2 800	0	2 300	18
Albania	4 000	4 000	0	3 800	5	3 300	18	2 300	43	1 200	70
Andorra	40	40	0	40	0	40	0	40	0	20	50
Bosnia and Herzegovina	5 900	5 400	8	4 800	19	4 000	32	2 800	53	1 400	76
Iceland	50	50	0	50	0	50	0	50	0	50	0
Kosovo	2 800	2 800	0	2 600	7	2 100	25	1 500	46	700	75
Liechtenstein	10	10	0	10	0	10	0	10	0	10	0
Monaco	20	20	0	20	0	20	0	20	0	10	50
Montenegro	900	900	0	800	11	700	22	500	44	300	67
North Macedonia	3 400	3 200	6	2 900	15	2 500	26	1 700	50	900	74
Norway	1 200	1 200	0	1 200	0	1 200	0	1 200	0	1 000	17
San Marino	30	30	0	30	0	30	0	20	33	10	67
Serbia	11 400	11 200	2	10 300	10	8 300	27	5 700	50	2 900	75
Switzerland	3 200	3 200	0	3 200	0	3 200	0	3 200	0	1 900	41
United Kingdom	33 100	33 100	0	33 100	0	33 100	0	31 800	4	17 200	48
EU27	306 700	306 500	0	303 500	1	289 200	6	241 400	21	129 400	58
EU28	339 800	339 600	0	336 600	1	322 200	5	273 200	20	146 600	57
Total	372 800	371 700	0	366 600	2	347 700	7	292 200	22	156 900	58

Note:

- *PD actual*: number of premature deaths with the actual 2019 concentrations;
- *PD LV 25* and *% to actual*: number of premature deaths under attainment of the EU annual LV of 25 µg/m^3 and relative change compared to the actual 2019 situation;
- *PD LV 20* and *% to actual*: number of premature deaths under attainment of the EU annual indicative LV of 20 µg/m^3 and relative change compared to the actual 2019 situation;
- *PD IT 15* and *% to actual*: number of premature deaths under attainment of the 2021 WHO interim target 1 of 15 µg/m^3 and relative change compared to the actual 2019 situation;
- *PD AQG10* and *% to actual*: number of premature deaths under attainment of the 2005 WHO AQG level of 10 µg/m^3 and relative change compared to the actual 2019 situation;
- *PD AQG 5* and *% to actual*: number of premature deaths under attainment of the 2021 WHO AQG level of 5 µg/m^3 and relative change compared to the actual 2019 situation.
- The numbers of PD are presented rounded to the next hundred. This rounding could affect slightly the calculated differences.

5.1 Attainment of EU LV

Having reached in 2019 the current EU limit values for $PM_{2.5}$ in the EU-27 would have not brought any significant benefit in terms of health for the Member States. With the current LV only 200 premature deaths would have been avoided.

If we consider the rest of the countries, Bosnia and Herzegovina, North Macedonia and Serbia would have avoided among 500 and 200 premature deaths

When it comes to the EU indicative LV of 20 µg/m^3, the gain is just a bit higher. Bulgaria, Poland, Croatia, Italy, Greece and Romania, in order of decreasing rank, would have registered some gains to sum up a total 1 % avoided premature deaths in the EU. For the rest of countries, apart for the ones mentioned above, Montenegro, Kosovo and Albania would have avoided some deaths to sum up a total of 1.7 % of the estimated deaths in 2019.

This is the case because, as can be seen in Map 2.4, there are very few areas with concentrations above 20 µg/m^3 located int the countries mentioned above.

5.2 Attainment of WHO standards

In an exercise in which all concentrations were equal to or below the 2005 WHO AQG level for $PM_{2.5}$ (10 µg/m^3), premature deaths in the EU-27 would decrease by 21 %, while premature deaths in the 41 European countries would decrease by 22 % when compared with the actual results for 2019. Consequently, it is estimated that the EU-27 and all the 41 European countries would have benefits of 65 300 and 80 600 fewer premature deaths, respectively, when compared with the status in 2019.

The benefits would be higher in those countries where concentrations are well above the 2005 WHO AQG level for $PM_{2.5}$ compared to countries where concentrations are below or slightly above the WHO AQG level for $PM_{2.5}$. Specifically out of the EU-27, Bulgaria, Poland, Greece, Romania, Malta, Croatia, Slovakia, Italy and Hungary, in order of decreasing rank, would see reductions of more than or around 30%. And in the case of the other countries, in order of decreasing rank, Bosnia and Herzegovina, North Macedonia and Serbia would, at least, have halved their number of premature deaths, while Kosovo, Montenegro, Albania and San Marino would have reduced them more than 30 %.

On the contrary the MS of Denmark, Estonia, Finland, Ireland, Luxembourg, Sweden and the countries of Andorra Iceland, Liechtenstein, Monaco, Norway and Switzerland would barely get any benefit, since practically all their territory shows concentrations below 10 µg/m^3.

Nevertheless, the 241 400 premature deaths estimated in case of having reached the 2005 WHO AQG level are higher than 205 200, which is the target set in the ZPAP (figure 4.1) for 2030 and therefore it might have not been enough to reach that target already in 2019 (see 4.4).

When considering the new proposed AQG level of 5 µg/m^3, the benefits would be higher. For the EU-27, the number of premature deaths would more than halve (a decrease of 58 %), decreasing from the actual 306 700 to the new estimated 129 400 (a total 177 300 avoided premature deaths, reaching in this case by far already in 2019, the target of a maximum of 205 200 premature deaths as set in the ZPAP target for 2030).

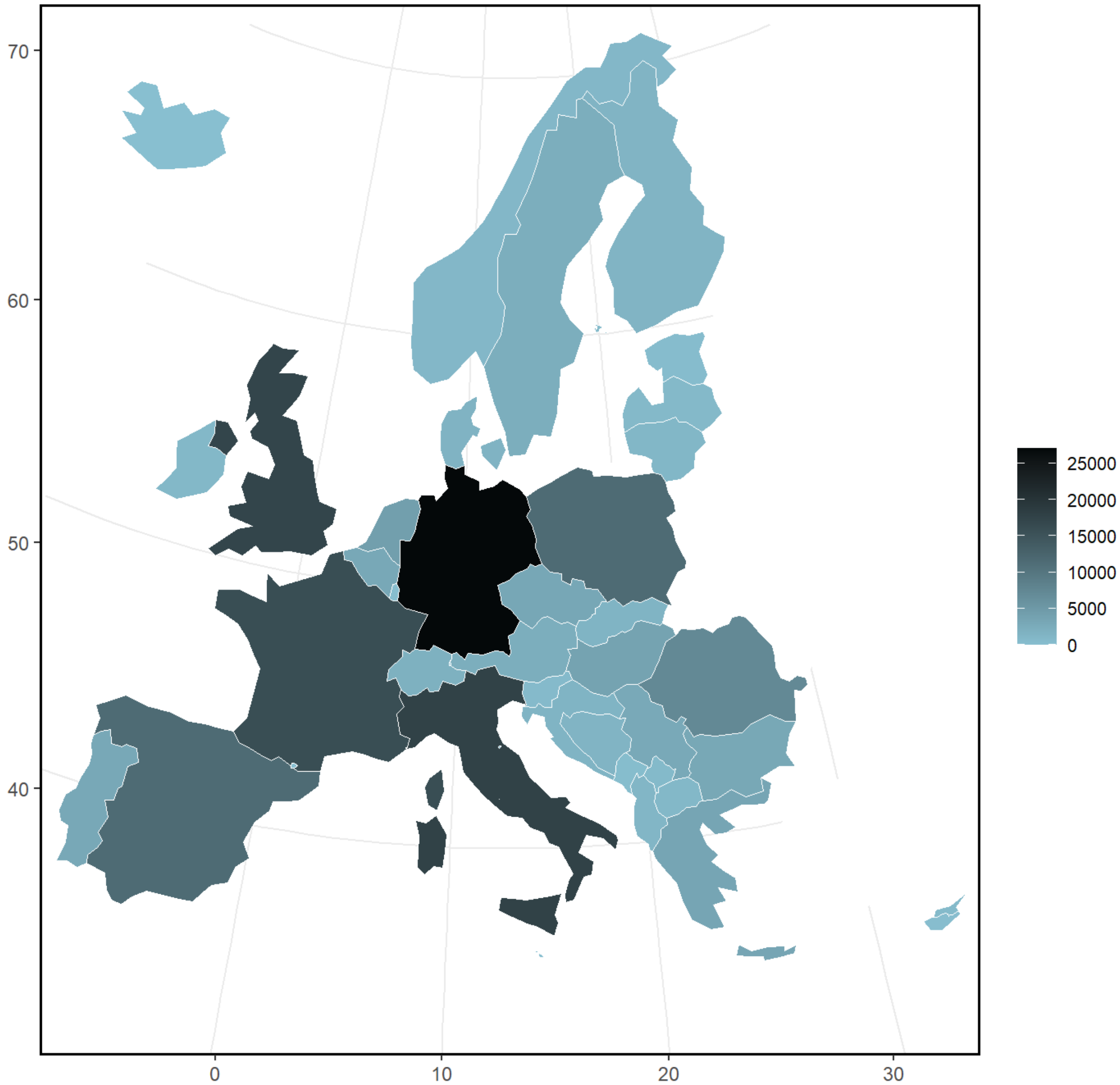
The relative figures are similar considering all the 41 countries. For the total, having achieved the new AQG level would have implied the same reduction of 58 % in the premature deaths, with a total number of 215 900 avoided premature deaths (from 372 800 to 156 900).

In this case, for the EU-27 the highest decreases (more than 60 %) would have been observed, in order of decreasing rank, in Cyprus, Bulgaria, Poland, Greece, Malta, Romania, Italy, Hungary, Croatia, Slovakia and Czechia. Considering all countries in order of decreasing rank, the numbers in Bosnia and Herzegovina, Kosovo and Serbia would be as low as, at least, one quarter of the premature deaths in 2019, and decreases would also be above 60 % in North Macedonia, Albania, Montenegro and San Marino.

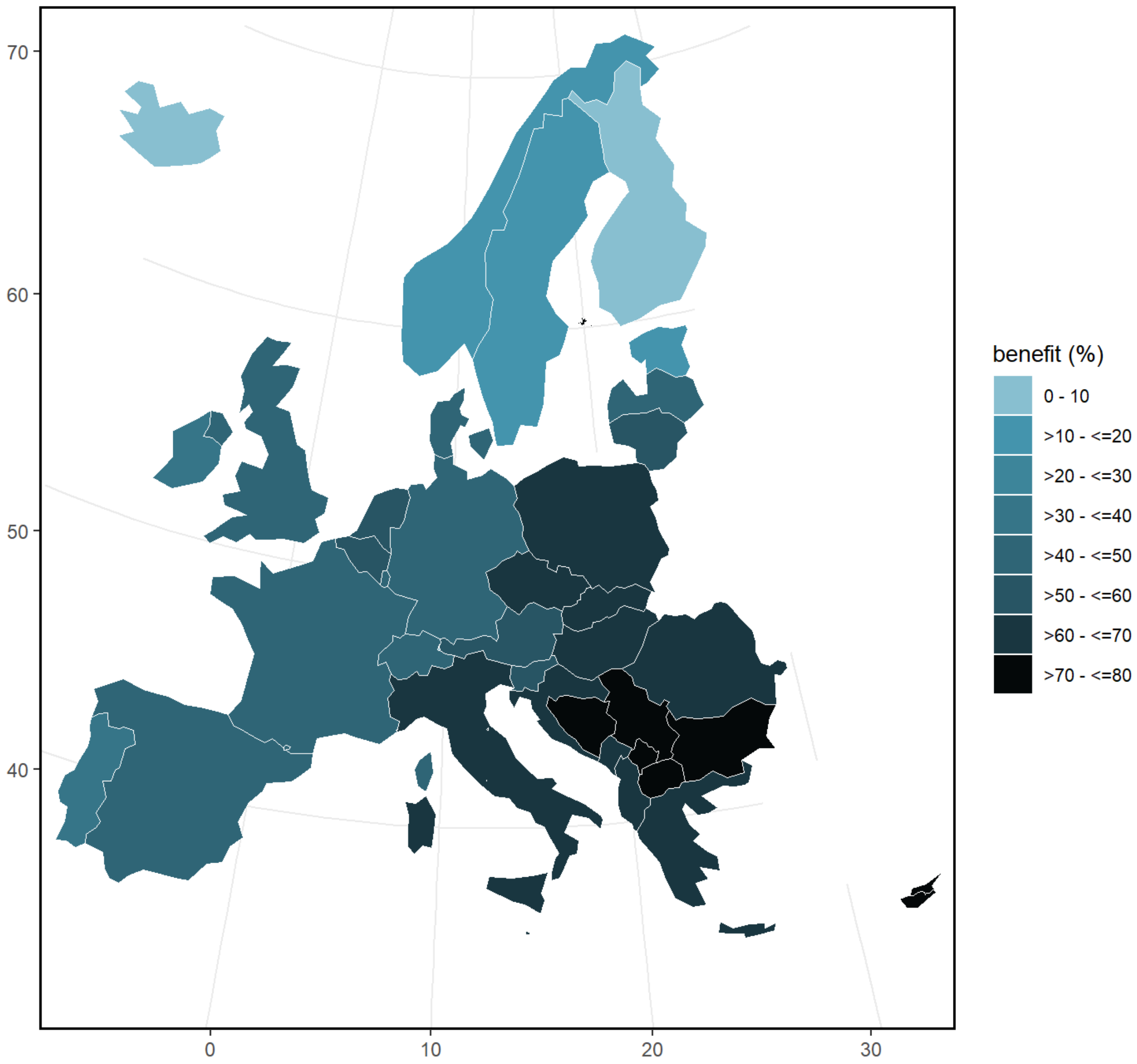
Furthermore, almost every country would gain avoided premature deaths, with the only exception of Iceland and Liechtenstein, with very favourable concentrations and exposure already below 5 µg/m^3.

Map 5.1 shows the premature deaths by country, should the 2021 WHO AQG level of 5 µg/m^3 be attained in all areas with current concentrations above that level. Map 5.2 shows the decrease in the number of premature deaths compared with the current 2019 situation.

Map 5.1: Absolute premature deaths attributable to PM2.5, at country level, in 2019, should the 2021 WHO AQG level of 5 µg/m3 be attained in all areas with current concentrations above that level



Map 5.2: Health benefit, in terms of percentage of premature deaths avoided, at country level, in 2019, should the 2021 WHO PM2.5 AQG level of 5 µg/m3 be attained in all areas with current concentrations above that level



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