ETC-HE Report 2022/10

Health Risk Assessment of Air Pollution and the Impact of the New WHO Guidelines

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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.

The health risk assessment methodology assumptions have been recently adapted to follow the recommendations by the World Health Organisation (WHO), released in 2021. The new global air quality guidelines by WHO provide up-to-date health-based guideline levels for major health-damaging air pollutants and new recommendations for assessing the risk of exposure to air pollution.

This report estimates the health risk related to air pollution in 2020 based on the latest methodology. The estimates consider 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 14 European countries (Albania, Andorra, Bosnia and Herzegovina, Iceland, Kosovo, Liechtenstein, Monaco, Montenegro, North Macedonia, Norway, San Marino, Serbia, Switzerland, and Türkiye).

A sensitivity analysis to the changes in concentration-response functions and counterfactual concentrations is performed to understand the impact of such changes on the mortality outcome estimates. The sensitivity analysis included both old and new health risk methodology assumptions but also the recommendation from the ELAPSE study on the concentration response functions. The ELAPSE project includes some of the most recent studies on the health effects at low air pollution levels by examining associations between exposures to relatively low levels of air pollution across Europe, including levels below the current EU standards.

The results for 2020 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 NO_2, and south and eastern European for O_3. The lowest impact is found for the northern and north-western parts of Europe, where the concentrations are lowest. The number of premature deaths attributed to air pollution in 2020 compared to 2019, increased for $PM_{2.5}$ and decreased for NO_2 and O_3. Apart from the changes in concentrations and demographics, the COVID-19 pandemics seems to also have an influence on these changes. For $PM_{2.5}$, the reduction in concentrations were counteracted by the excess of deaths due to the pandemics. In the case of NO_2, the reduction in concentrations was more pronounced as a result of the lockdown measures and the drastic reduction in traffic and its impact in reducing mortality was bigger than the increasing impact of excess of deaths due to COVID-19.

Changing assumptions on concentration-response functions and counterfactual concentrations have implications for estimating mortality health outcomes. The sensitivity analysis shows that it is not straightforward to assess which assumptions estimates the highest health impacts when both factors change. In this case, the final outcome will depend on the concentration at the grid-cell level. The latest assumptions are expected to reduce the health outcomes for $PM_{2.5}$ and increase for NO_2 and O_3, when compared to the previous one. When aggregated to all countries, the health outcomes are reduced by over 40 % for $PM_{2.5}$ and increased by 50 % and 30 % for NO_2 and O_3, respectively, in 2020. However, this change varies across countries depending on the concentration level the population in the individual countries is exposed to.

1 Introduction

The health risk assessments (HRAs) produced by the European Environment Agency (EEA) and the European Topic Centre (ETC) on Human Health and the Environment (HE, and its predecessors) on the risk of premature mortality due to exposure to outdoor air pollution offer an objective and comparable estimate of the impacts of air pollution since 2014. The estimations differentiate the individual impacts of fine particulate matter ($PM_{2.5}$), nitrogen dioxide (NO_2), ozone (O_3), and ambient concentration levels country-wise and at the European level, without focusing on any specific source. By identifying changes over time, the reports provide input to the development and implementation of measures to improve air quality in Europe and serve as means to communicate the impact of exposure to ambient air pollution on the population's health.

The EEA/ETC HRA focus has been on mortality-based indicators. The preference is mostly related to the better availability and quality of mortality data from death registries. It also captures an important share of the burden of disease resulting from exposure to the three main air pollutants of concern in Europe. The estimates are based on "all-cause natural mortality", which comprises all causes of death except the category of external causes of death, such as accidents, violence or self-harm. The assessments have been based on the recommendations in the HRAPIE report (WHO, 2013) to estimate the risk of exposure to pollution in Europe. However, the methodology has been recently adapted to follow the new Air Quality Guidelines (AQG) recommended by the World Health Organisation (WHO, 2021). The new AQG provide up-to-date health-based guideline levels for major health-damaging air pollutants and new recommendations of the shape of the concentration–response function (CRF) in relation to critical health outcomes for relevant averaging times.

However, studies increasingly show that ambient air pollution is not only associated with mortality but also with morbidity due to several chronic conditions inflicted by air pollution exposure. For instance, the results of the Global Burden of Disease (GBD, 2020) study clearly indicate that, for certain outcomes, the share of morbidity is not negligible. Even for diseases with high mortality burden, such as lung cancer, ischemic heart disease, and chronic obstructive pulmonary disease, the share of morbidity in Western Europe is 1.4, 5, and 36 %, respectively (IHME, 2022). This is strongly related to the increasing trend of non-communicable disease burden in countries with high socio-economic status.

It would be advantageous to assess health risk based on both mortality and morbidity indicators. ETC and EEA have started calculating the morbidity due to exposure to the same air pollutants and the results will be shown in the Eionet report ETC HE 2022/11 (ETC HE, 2022a). Combining both mortality and morbidity indicators captures a more comprehensive impact of diseases, injuries, and risk factors on population health; even if combining both health outcomes can be very demanding data-wise (Pifarré i Arolas et al., 2021; Plass et al., 2013).

This report presents the health risk assessment to estimate the mortality risk of exposure to $PM_{2.5}$, NO_2, and O_3 ambient concentration levels across 41 countries in Europe in 2020. This assessment estimates the risk based on the latest WHO CRF recommendations (WHO, 2021). To assess how much the current estimation differs from the ones presented in past HRAs, e.g., ETC/ATNI (2021), a set of calculations were undertaken to assess the sensitivity of health outcomes to changes in the baseline assumption. The report presents a recap of the HRA's methodology and describes different scenarios used in the sensitivity analysis in Section 2; Section 3 presents the results considering 2020 concentration levels across Europe, based on the latest WHO recommendations. Section 4 presents the sensitivity analysis of the mortality outcomes based on different recommendations. Section 5 discusses the possibility of combining the EEA/ETC HRA mortality indicators with the morbidity indicators presented in the Eionet report ETC HE 2022/11, and the conclusions are laid down in Section 6.

2 Estimation of the mortality outcomes

A HRA assesses a specific health outcome or a set of health outcomes in a given population. In the present HRA, the risk of mortality in a population due to exposure to air pollution is represented by the concentration-response function (CRF), which is based on Relative Risks (RR) estimates derived from epidemiological studies. Mortality due to air pollution can be quantified by combining pollutant dependent CRF with ambient air quality data (1*1 km^2 gridded data), population density data (1*1 km^2 gridded data), and the baseline frequency of the health outcome (demographic data per country, age, and sex). The mortality outcomes are estimated per grid cell, then aggregated to country-level and larger areas (e.g., EU27). ETC/ATNI (2019) and references therein thoroughly describe the steps to estimate the mortality-related outcomes. The report also covers the data requirements and data pre-processing. A short recap of the methodology and data used, including data gap-filling, is found in Annex 1.

In the EEA/ETC assessments, the health impact attributable to exposure to $PM_{2.5}$, NO_2, and O_3 in 41 European countries (the 27 EU members (EU27), Albania, Andorra, Bosnia and Herzegovina, Iceland, Kosovo, Liechtenstein, Monaco, Montenegro, North Macedonia, Norway, San Marino, Serbia, Switzerland, and Türkiye) and is quantified in terms of two mortality outcomes:

- Number of premature deaths (PD): deaths that occur before a person reaches an expected age. This expected age is the remaining life expectancy at the age of death, stratified by sex and age. Premature deaths are considered preventable if their causes can be eliminated. The baseline incidence to estimate the attributed premature deaths is the crude death rates at the national level.
- Years of life lost (YLL): the years of life lost due to premature deaths. It estimates the average number of years people would have lived if they had not died prematurely. The crude death rates and life expectancy at the national level are the baseline indicators to estimate YLL. The YLL per 100 000 inhabitants is also used in this report as an indicator to be comparable across countries.

The baseline incidence considers only natural deaths for ages above 30 years old for $PM_{2.5}$ and NO_2, and all ages for O_3. The age groups differ to represent the same ages included in the respective epidiemological studies the CFRs are based on.

The estimation targets the long-term effect of $PM_{2.5}$ and NO_2 exposure, based on annual means, and the acute effect of O_3, based on the annual sum of daily maximum running 8-h average concentrations above 35 ppb (SOMO35) divided by the number of days in a year.

Up to 2021, the estimation of mortality outcomes was based on the CRF recommendations in the HRAPIE project report (WHO, 2013). From 2022, the EEA/ETC will consider the latest WHO global AQG (WHO, 2021) instead. The latest WHO global guidelines are based on a review of the latest available epidemiological studies documenting the adverse health effects of exposure to air pollution. The descriptions of the CRFs and counterfactual concentrations are presented in Table 2.1. Note that, as in the previous 2013 report, the WHO still recommends assuming a linear increase in the risk of mortality of x % for a y µg/m^3 increase in concentration. For instance, the mortality risk due to $PM_{2.5}$ exposure increases by 8 % for a 10 µg/m^3 increase in $PM_{2.5}$ annual mean concentrations when considering WHO AQG.

Additionally, to the updated WHO Global AQG, the CRFs determined by the ELAPSE project (Brunekreft et al., 2021) were also considered. This project includes some of the most recent studies on the health effects at low air pollution levels by examining associations between exposures to relatively low levels of air pollution across Europe, including levels below the current EU standards. The findings of the project were not included in the WHO review. It focuses on several pollutants – $PM_{2.5}$ (including particle composition), black carbon, NO_2, and O_3 – and how the exposure to these pollutants relates to all-cause and cause-specific mortality and morbidity endpoints. For all-cause mortality, the ELAPSE study reports CRFs only for $PM_{2.5}$ and NO_2 since there is still a lack of new studies proving the relation between long-term exposure to O_3 and mortality in Europe.

Table 2.1 describes the CRFs recommended by WHO (2013, 2021) and ELAPSE. Note that all CRFs reflect long-term exposure to the pollutant, except for O_3 that describes the acute exposure (short-term) to O_3.

Table 2.1: Concentration-response functions (as RR) linking exposure to $PM_{2.5}$, NO_2, and O_3 and mortality, and their associated 95 % confidence interval (CI)

Pollutant	RR per 10 µg/m³ (95 % CI)			Health outcome
	WHO (2013)	WHO (2021)	ELAPSE (2021)	
$PM_{2.5}$	1.062 (1.040 – 1.083)	1.08 (1.06 - 1.09)	1.118 (1.06 – 1.179)	All-cause (natural) mortality in ages above 30 years old
NO_2	1.055 (1.031 - 1.08)	1.02 (1.01 - 1.04)	1.045 (1.026 – 1.065)	All-cause (natural) mortality in ages above 30 years old
O_3	1.0029 (1.0014 – 1.0043)	1.0043 (1.0034 - 1.0052)		All-cause (natural) mortality in all ages

We have also introduced changes in the counterfactual concentration assumed for the estimations. The counterfactual concentration is a reference exposure level against which the health impacts are calculated (C_0 in Eq. A.1, Annex 1). Currently, the EEA/ETC HRAs aligns the counterfactual concentration with the AQG levels defined by WHO (2021) for $PM_{2.5}$ and NO_2. The counterfactual concentration for O_2 is still based on 35 ppb (SOMO35). Changing counterfactual concentrations will also impact the final outcome. The rationale for the counterfactual concentrations stated in Table 2.2 is described below.

Estimates based on different combinations of CRFs and counterfactual concentrations were compared to assess the sensitivity of the mortality-related health outcomes to any of these parameters, or both. Table 2.2 describes the CRF and counterfactual combinations used for the sensitivity analysis. The baseline scenarios are the scenarios with the assumptions that have been considered for previous (WHO2013, up to 2021) and current (WHO2021, this report) assumptions for HRA estimations. For ELAPSE we assume that the scenarios follow the same counterfactual concentration assumptions as the scenarios based on the WHO (2021) CRFs.

Table 2.2: Description of the concentration-response function (RR – see Table 2.1) and counterfactual concentration combination used for the sensitivity analysis

Name	Description		Counterfactual concentration		
		RR	$PM_{2.5}$ (µg/m³)	NO_2 (µg/m³)	O_3 (ppb)
WHO2013	Baseline	WHO (2013)	0	20	35
WHO2013_sens1	Sensitivity	WHO (2013)	2.5	10	10
WHO2013_sens2	Sensitivity	WHO (2013)	5	0	-
WHO2021	Baseline	WHO (2021)	5	10	35
WHO2021_sens1	Sensitivity	WHO (2021)	2.5	20	10
WHO2021_sens2	Sensitivity	WHO (2021)	0	0	-
ELAPSE	Baseline	ELAPSE	5	10	35
ELAPSE_sens1	Sensitivity	ELAPSE	2.5	20	10
ELAPSE_sens2	Sensitivity	ELAPSE	0	0	-

For $PM_{2.5}$, the HRAPIE report (WHO, 2013) indicates that the quantification of long-term impacts "should be calculated at all levels of $PM_{2.5}$". That is why EEA has considered a counterfactual concentration of 0 µg/m³ in the past (until 2021), even if some scientists interpreted the text in WHO (2013) as "all anthropogenic levels of $PM_{2.5}$". The Global updates of the WHO AQG (WHO, 2021) refer to the new AQG

level of 5 µg/m^3 as the lowest concentration level from which a "minimal relevant amount" of a health outcome will result from long-term exposure. This threshold is so because the data supporting the analysis do not provide evidence of the risk function assuming a linear shape below 5 µg/m^3. Therefore, it has been decided to take 5 µg/m^3 as the counterfactual concentration for the new baseline scenario while maintaining 0 µg/m^3 for sensitivity analyses since there is no evidence of a minimum concentration below which no effect is expected. A third value for the counterfactual concentration (2.5 µg/m^3) was considered in prior assessments in the sensitivity analysis, e.g., ETC/ATNI (2021), because 2.5 µg/m^3 is the lowest average background concentration level in Europe (ETC/ACM, 2017) and the minimum observed exposure concentration in several epidemiolocal studies (Brauer et al., 2022;WHO, 2021). The analyses for $PM_{2.5}$ in this report will consider the three counterfactual concentrations: 5, 2.5 and 0 µg/m^3. For NO_2, the HRAPIE report (WHO, 2013) recommends quantifying the long-term exposure effects from 20 µg/m^3. Soon after the HRAPIE report was released, new epidemiological studies claimed that this threshold was considered too high, which is why EEA has also been using, for the past sensitivity analyses, a counterfactual concentration of 10 µg/m^3. The concentration level of 10 µg/m^3 is now the AQG level for NO_2 in WHO (2021). Additionally, all concentration levels were considered to be harmful to human health to be consistent with the assumptions for $PM_{2.5}$. Therefore, three counterfactual concentrations were analysed in this report: 20, 10, and 0 µg/m^3.

For O_3, we have decided to keep the counterfactual concentration of 70 µg/m^3, equivalent to SOMO35, and keep SOMO10 as a sensitivity threshold, as recommended in HRAPIE (WHO, 2013).

Note that 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, HRAPIE (WHO, 2013) suggested that adding the results for $PM_{2.5}$ and NO_2 may lead to double counting of the effects (up to 30 %).

3 Mortality due to air pollution levels in Europe in 2020

The population mortality related to exposure to $PM_{2.5}$, NO_2, and O_3 concentration levels in 2020 in Europe based on the CRFs recommended by the WHO AQG in 2021 (see Table 2.1) and the counterfactual concentrations are 5 µg/m^3, 10 µg/m^3 and 35 ppb for $PM_{2.5}$, NO_2 and O_3, respectively. The estimations are presented for individual countries and aggregated areas (EU27, EEA32 and all countries). Map 3.1, Map 3.2, and Map 3.3 show the population-weighted mean concentration, the estimated number of attributable premature deaths, and the YLL per 100 000 inhabitants distribution across Europe for $PM_{2.5}$, NO_2, and O_3, respectively. Table 3.1 shows the total population, the population-weighted mean concentrations, and the estimated number of attributable premature deaths; Table 3.2 shows the YLL and the YLL per 100 000 inhabitants.

The exposure to concentration levels in 2020 resulted in 275 000 premature deaths related to $PM_{2.5}$ exposure, 64 000 to NO_2, and 28 000 to O_3 across the 41 countries included in the assessment (40 in case of $PM_{2.5}$, since Türkiye is not included in the interpolated map used for the calculation due to a lack of enough number of background stations). For EU27, the number of premature deaths is 238 000, 49 000, and 24 000, respectively. When considering both the life expectancy and the dying age, the estimate points to 2 773 000 (583) YLL (YLL/100 000 inhabitants) due to exposure to $PM_{2.5}$, 680 000 (122) due to exposure to NO_2, and 306 000 (55) due to exposure to O_3. For the EU27, YLL (YLL/100 000 inhabitants) are 2 410 000 (544), 484 000 (109), 249 000 (56), respectively.

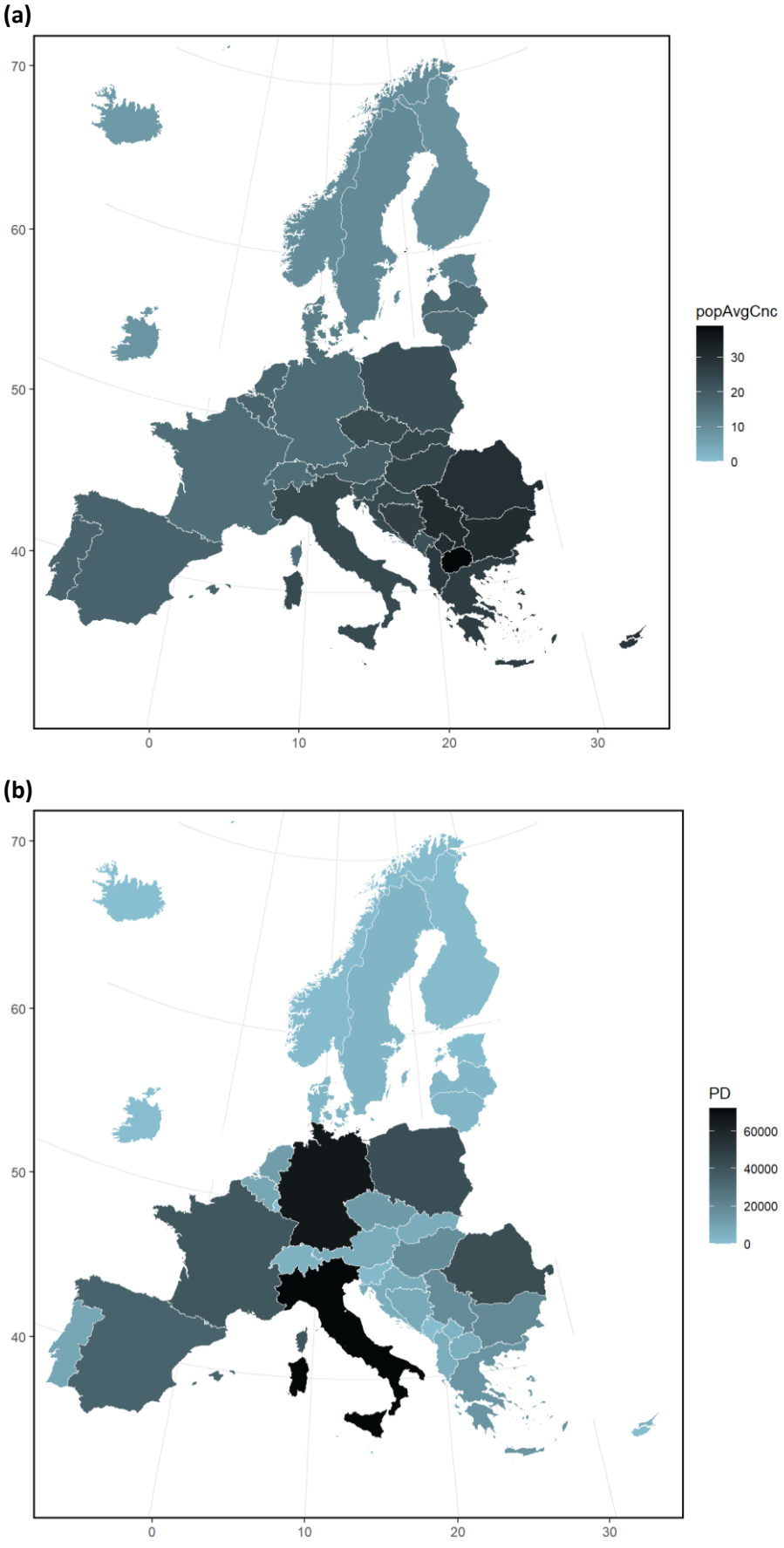
The results show that the largest absolute health impacts in terms of premature deaths and YLL attributable to air pollution are estimated for the countries with some of the largest populations. However, in relative terms, i.e., when considering YLL per 100 000 inhabitants, the outcome can be quite different and follow the population-weighted mean concentrations more closely. This difference is clearly seen in Map 3.1, Map 3.2, and Map 3.3.

For $PM_{2.5}$, the largest absolute health impacts are estimated for, in order of decreasing rank, Italy, Poland, Germany, Romania, and Spain. 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, Finland, Norway, Sweden, and Estonia.

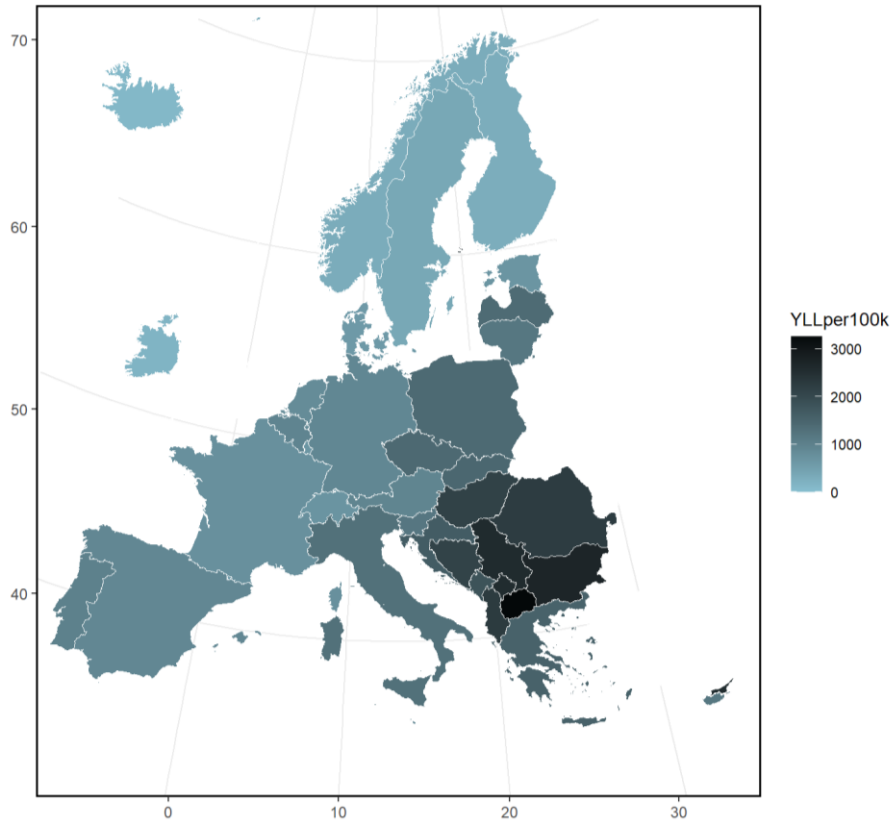
The largest absolute impacts from exposure to NO_2 are seen, in order of decreasing rank, in Türkiye, Italy, Germany, Spain, and France. When considering YLL per 100 000 inhabitants, the highest rates are found in, in order of decreasing rank, Bulgaria, Türkiye, Romania, Greece, and Serbia. The smallest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

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

Map 3.1: $PM_{2.5}$ population-weighted mean concentration (popAvgCnc, µg/m^3) (a), number of premature deaths (PD) (b) and years of life lost per 100 000 inhabitants (YLLper100k) (c), , due to exposure to $PM_{2.5}$ concentration levels in 2020 across Europe

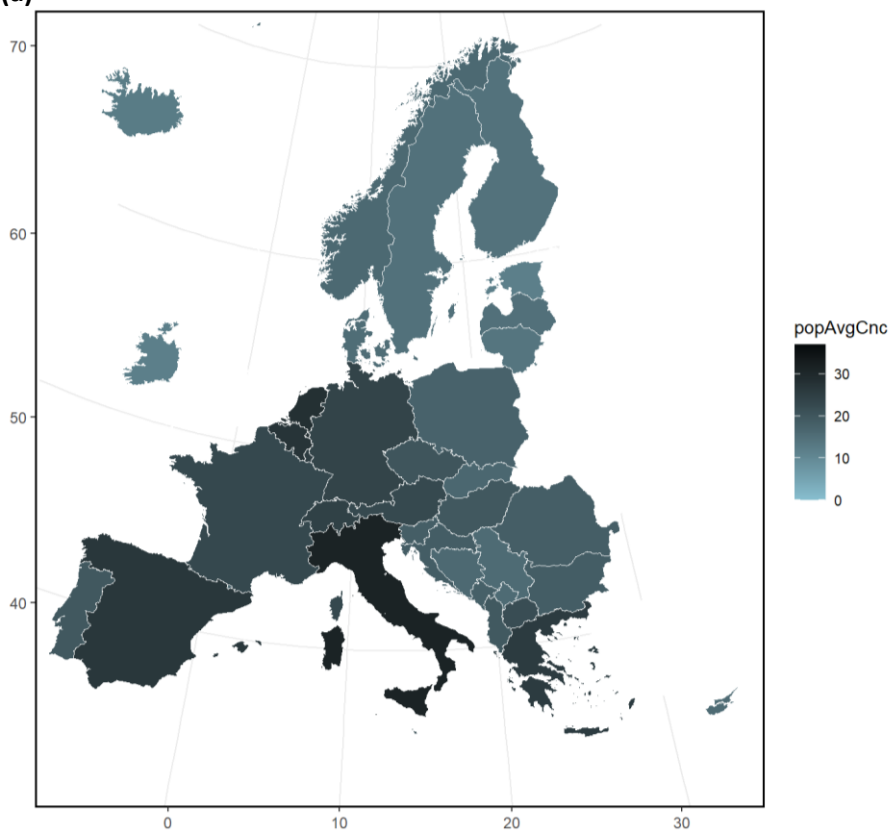


(c)

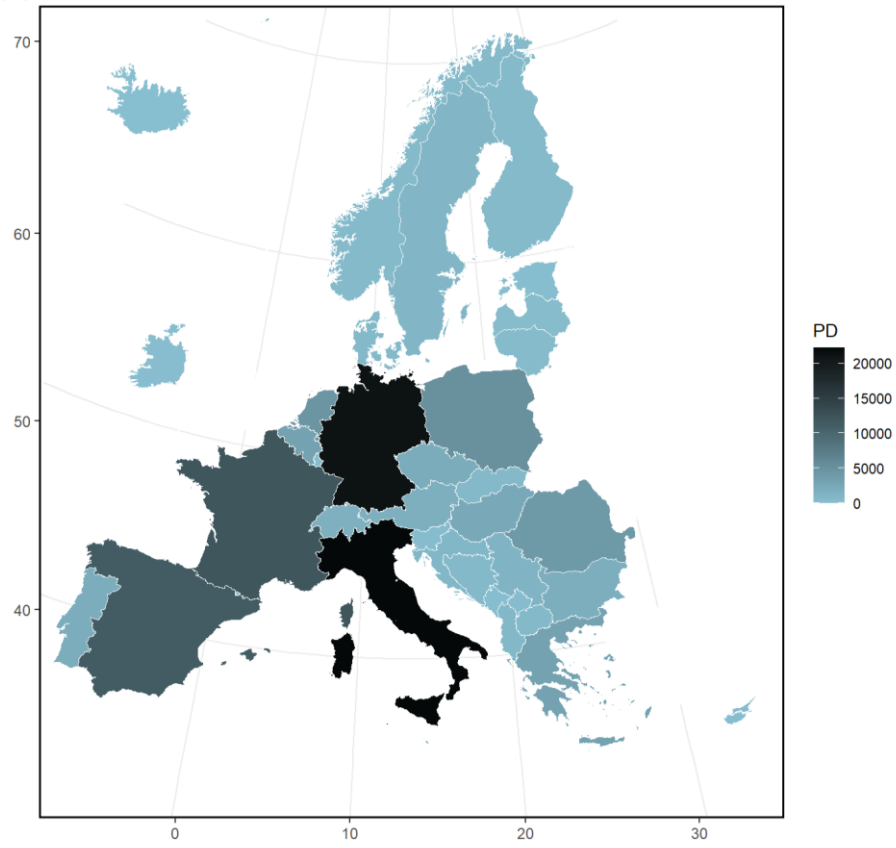


Map 3.2: **NO_2 population-weighted mean concentration (µg/m³) (a), number of premature deaths (b) and years of life lost (c), per 100 000 inhabitants, due to exposure to NO_2 concentration levels in 2020 across Europe**

(a)



(b)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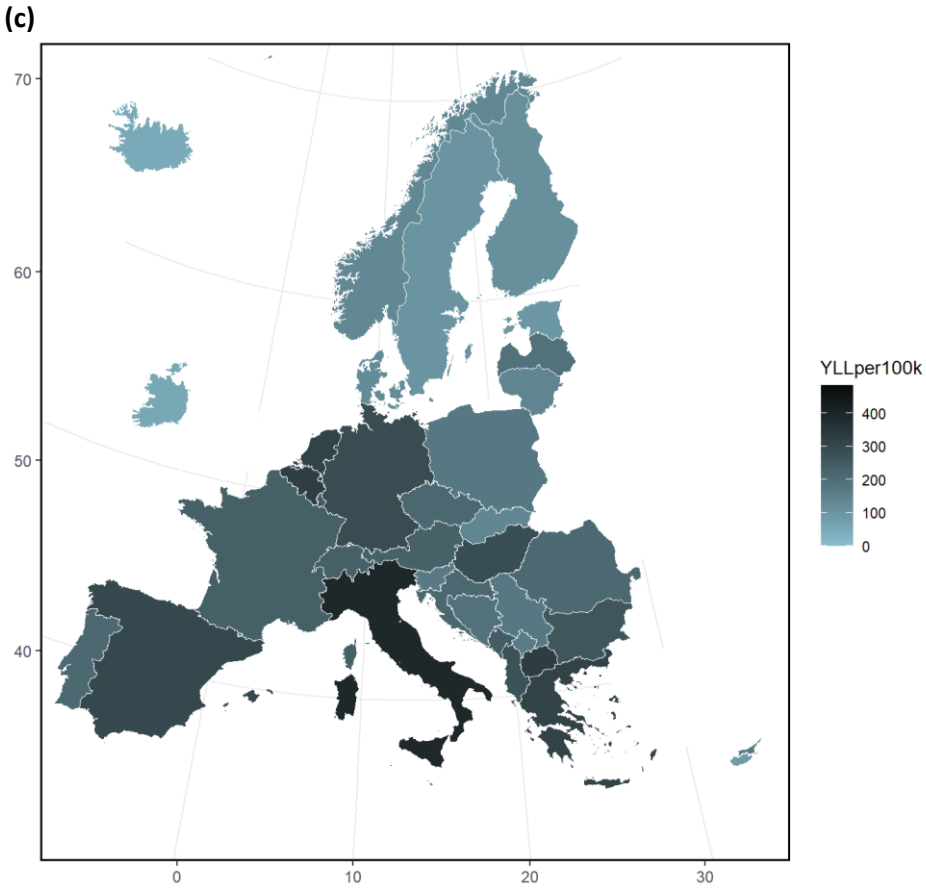
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60
50
40
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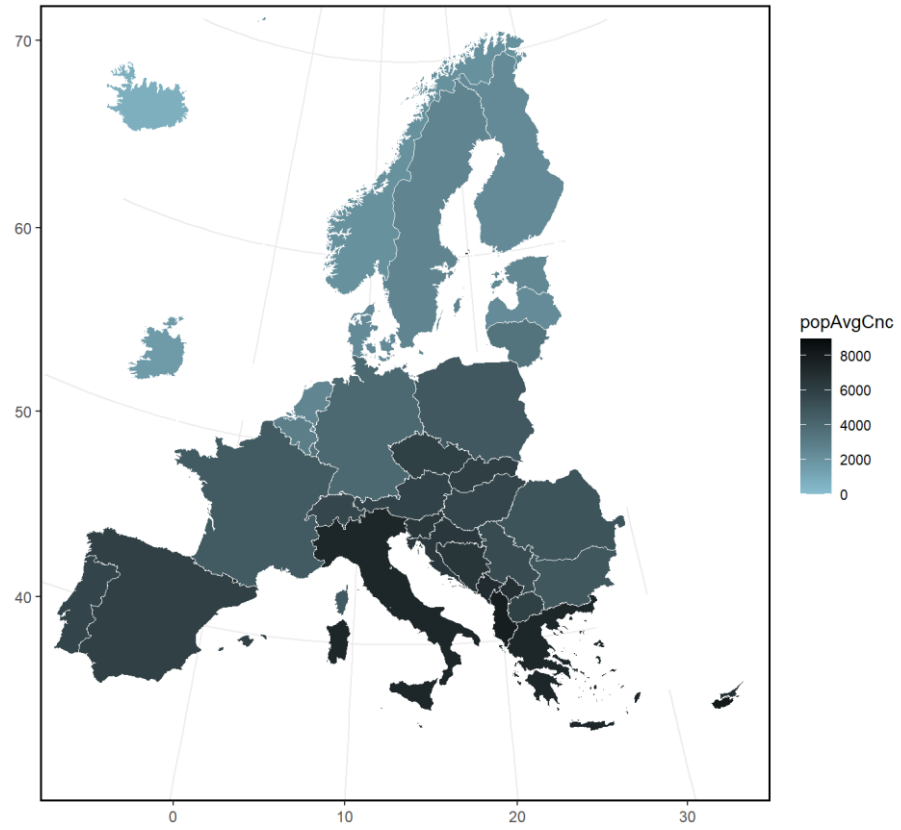
10
20
30
YLLper100k
400
300
200
100
0

Map 3.3: O_3 population-weighted mean concentration (PopAvgCNC, µg/m^3.days) (a), number of premature deaths (PD) (b) and years of life lost per 100 000 inhabitants (YLLper100k) (c),, due to exposure to O_3 concentration levels in 2020 across Europe

(a)



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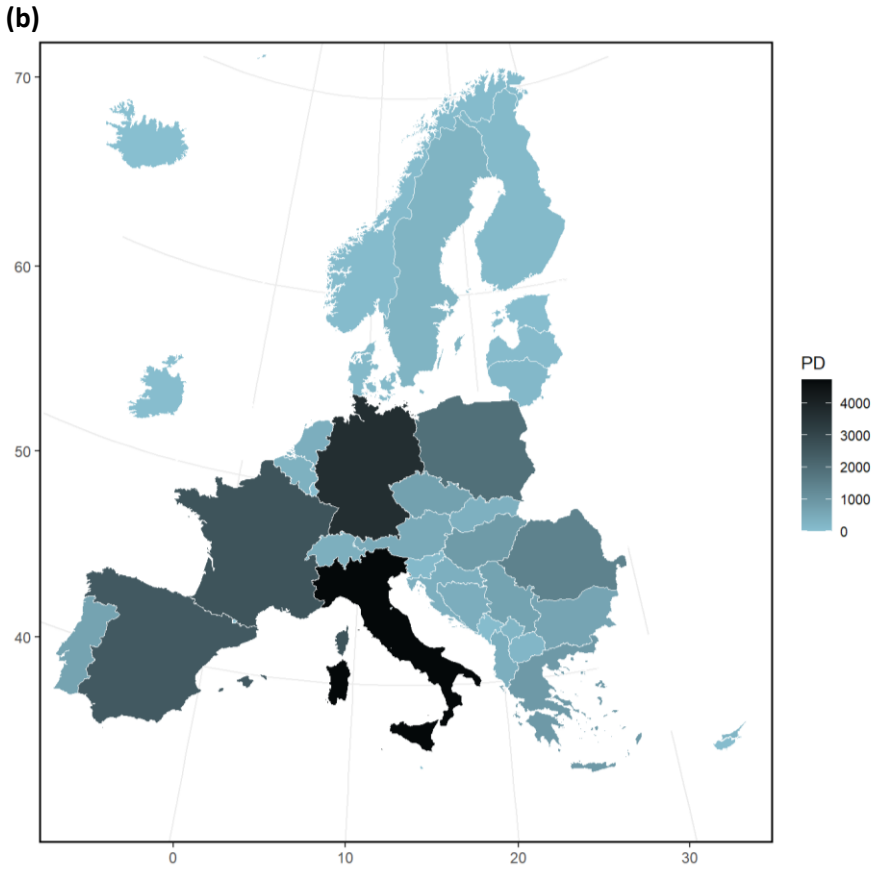


(c)

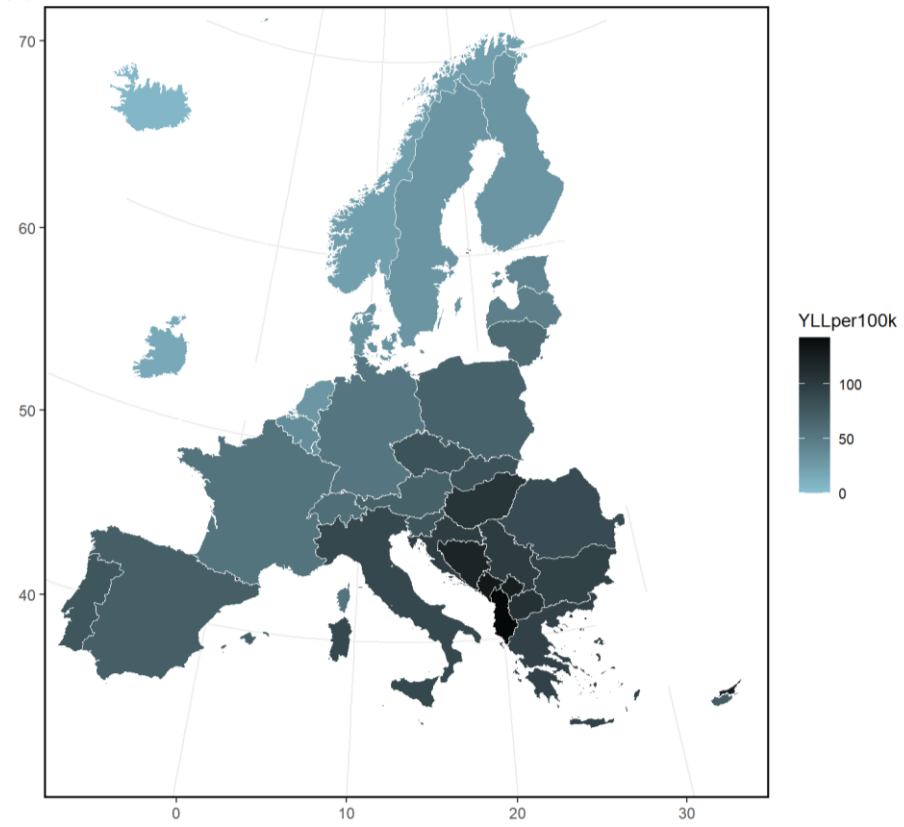


Table 3.1: Premature deaths (PD) attributable to $PM_{2.5}$, NO_2, and O_3 exposure in 41 European countries and the EU27 in 2020

		$PM_{2.5}$		NO_2		O_3	
Country	Population (1 000)	Annual mean	PD	Annual mean	PD	SOMO35	PD
Austria	8 901	9.9	3 200	14.3	810	4 584	470
Belgium	11 522	9.4	3 900	14.3	1 100	3 798	530
Bulgaria	6 951	17	10 600	16.7	1 700	2 967	430
Croatia	4 058	15.4	4 100	13.1	420	4 760	300
Cyprus	1 230	14	560	20.8	180	6 295	60
Czechia	10 694	12.5	6 900	12.5	740	4 252	620
Denmark	5 823	7.6	1 000	7.5	40	2 287	140
Estonia	1 329	5.4	60	5.8	<10	1 468	30
Finland	5 525	4.4	60	6.2	10	1 365	80
France	65 178	8.6	16 500	12.2	4 400	4 271	3 100
Germany	83 166	9.1	28 900	15.2	10 000	4 195	4 600
Greece	10 718	14.5	8 800	16.9	1 900	6 167	920
Hungary	9 770	14.5	9 500	14.9	1 400	4 044	640
Ireland	4 964	7.1	490	7.4	50	1 908	70
Italy	59 641	15	52 300	17.7	11 200	6 067	5 100
Latvia	1 908	9.1	830	9.7	100	1 699	50
Lithuania	2 794	9.8	1 500	10.1	140	2 044	100
Luxembourg	626	7.3	80	15.8	50	4 272	20
Malta	515	10.2	150	11	10	6 592	30
Netherlands	17 408	9.1	5 000	15.9	1 800	3 426	640
Poland	37 958	16	36 500	13.1	3 400	3 216	1 700
Portugal	9 795	8.1	2 600	12.5	850	3 585	470
Romania	19 329	15.2	21 600	15.1	3 100	2 955	1 000
Slovakia	5 458	14.5	3 900	11.3	210	3 867	260
Slovenia	2 096	12.5	1 300	12.8	150	5 008	130
Spain	45 166	10	17 000	14.6	4 800	4 522	2 400
Sweden	10 328	4.8	370	6.5	40	2 181	240
Albania	2 846	15.6	3 600	12.8	330	5 678	310
Andorra	78	8.5	20	17.6	10	2 812	<10
Bosnia and Herzegovina	3 825	25.8	9 200	14.1	610	4 047	300
Iceland	364	4.2	< 1	7.2	<10	1 582	<10
Kosovo	1 782	19.4	3 100	14.4	260	3 901	130
Liechtenstein	39	8.1	10	15.3	<10	4 976	<10
Monaco	38	10.5	20	18.1	10	6 445	<10
Montenegro	622	17.4	920	13.7	90	4 338	50
North Macedonia	2 076	20.3	3 800	14.2	290	4 345	180
Norway	5 368	4.6	160	8.2	90	2 042	90
San Marino	35	12.8	20	13.2	<10	5 387	<10
Serbia	6 927	22.7	14 400	14.9	1 200	3 099	420
Switzerland	8 606	8.1	1 700	14.5	660	5 387	450
Türkiye (TR)	83 155	N/A	N/A	24.9	12 300	4 561	2 300
EU27	442 851	11.2	238 000	14.1	49 000	4 182	24 000
EEA32 (no TR)	457 228	11	240 000	-	-	-	-
EEA32	540 383	-	-	15.7	62 000	4 237	27 000
All Countries (no TR)	475 456	11.4	275 000	-	-	-	-
All countries	558,612	-	-	15.7	64 000	4 228	28 000

Notes:
The annual mean (in µg/m^3) and the SOMO35 (in µg/m^3.days), expressed as population-weighted concentration, are obtained according to the methodology described by ETC HE (2022b) and references herein and not only from monitoring stations.
Rounding: population for every country and every aggregation is rounded to the nearest thousand; PDs are rounded, for every country, to the nearest hundred if the number is above 1,000 and to the nearest ten if the number is below 1,000; PDs are rounded (once the unrounded national totals have been added) to the nearest thousand for EU27, EEA32 and all countries.

Table 3.2: Years of life lost (YLL) attributable to $PM_{2.5}$, NO_2 and O_3 exposure in 41 European countries (individual and total) and the EU27 in 2020

country	$PM_{2.5}$		NO_2		O_3	
	YLL	YLL/10^5 inhab.	YLL	YLL/10^5 inhab.	YLL	YLL/10^5 inhab.
Austria	30 600	344	7 800	88	4 600	52
Belgium	36 200	314	9 800	85	5 100	44
Bulgaria	107 900	1 552	17 000	245	4 400	64
Croatia	40 000	985	4 100	102	3 000	75
Cyprus	6 000	490	2 000	160	700	57
Czechia	68 700	643	7 300	68	6 300	59
Denmark	11 200	193	440	8	1 600	27
Estonia	690	52	10	0	300	23
Finland	680	12	80	2	930	17
France	175 800	270	47 000	72	34 100	52
Germany	296 300	356	102 700	123	49 100	59
Greece	86 200	804	18 300	171	9 200	85
Hungary	102 500	1 049	15 000	154	7 200	73
Ireland	5 900	120	580	12	880	18
Italy	462 300	775	98 700	165	45 900	77
Latvia	9 000	474	1 100	59	610	32
Lithuania	15 900	571	1 500	54	1 100	39
Luxembourg	810	129	560	89	250	40
Malta	1 700	338	140	26	350	68
Netherlands	49 800	286	18 500	106	6 700	39
Poland	415 700	1 095	38 500	101	20 300	53
Portugal	25 800	264	8 300	85	4 800	49
Romania	234 100	1 211	33 800	175	11 300	58
Slovakia	45 700	838	2 400	45	3 100	57
Slovenia	11 900	569	1 500	69	1 300	61
Spain	164 700	365	46 600	103	24 100	53
Sweden	3 300	32	380	4	2 200	22
Albania	36 900	1 296	3 300	116	3 300	115
Andorra	210	267	120	150	30	35
Bosnia and Herzegovina	91 000	2 379	6 100	158	3 100	81
Iceland	< 5	1	10	1	50	13
Kosovo	30 400	1 706	2 600	147	1 400	78
Liechtenstein	70	186	30	85	20	52
Monaco	160	407	60	157	30	78
Montenegro	9 500	1 531	950	153	560	90
North Macedonia	34 600	1 668	2 700	128	1 700	80
Norway	1 600	30	970	18	990	18
San Marino	210	613	20	69	20	69
Serbia	142 900	2 063	11 500	166	4 300	62
Switzerland	16 000	186	6 200	72	4 500	52

country	$PM_{2.5}$		NO_2		O_3	
	YLL	YLL/10^5 inhab.	YLL	YLL/10^5 inhab.	YLL	YLL/10^5 inhab.
Türkiye (TR)			161 900	195	36 600	44
EU27	2 410 000	544	484 000	109	249 000	56
EEA32 (no TR)	2 427 000	531	-	-	-	-
EEA32	-	-	653 000	121	291 000	54
All Countries (no TR)	2 773 000	583	-	-	-	-
All countries	-	-	680 000	122	306 000	55

Notes:

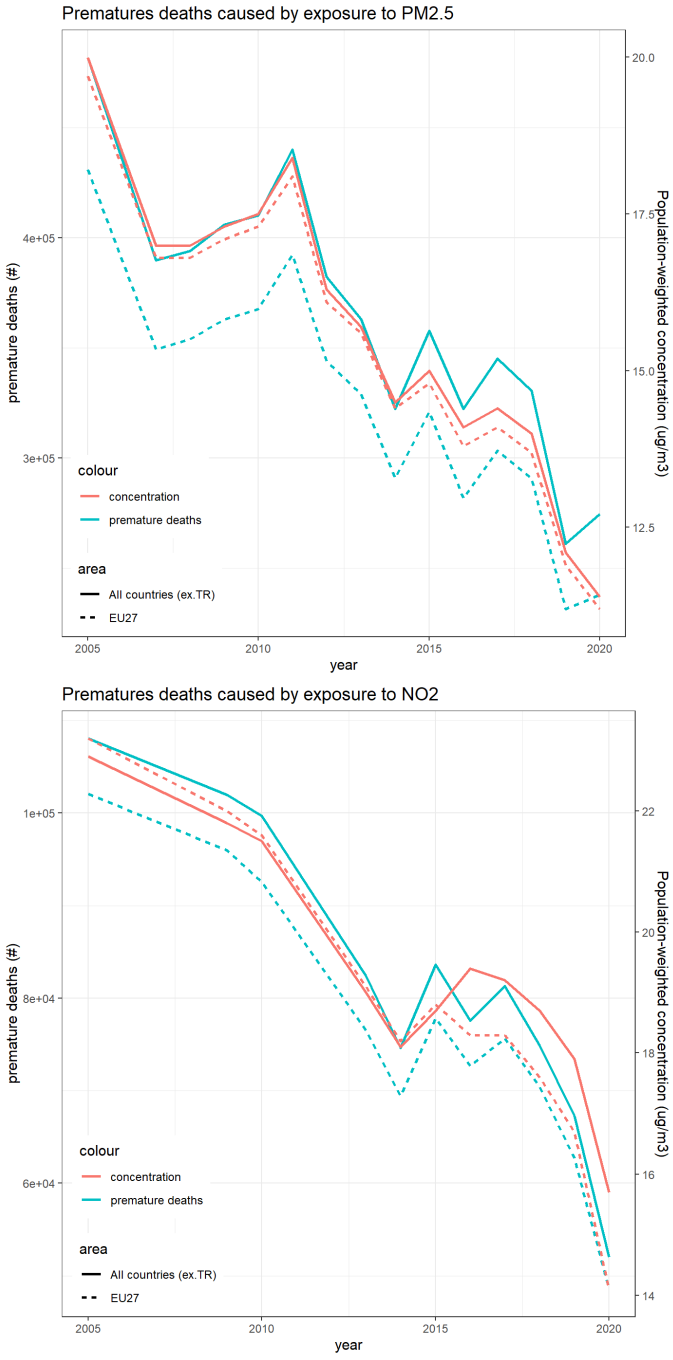
Rounding: YLLs are rounded, for every country, to the nearest hundred if the number is above 1,000 and to the nearest ten if the number is below 1,000; YLLs are rounded (once the unrounded national totals have been added) to the nearest thousand for EU27, EEA32 and all countries; YLL/100,000 inhabitants are calculated from the unrounded YLL and total population and are not rounded.

The health outcome for years before 2020 was estimated based on the updated WHO Global AQG to compare 2020 results with the risk associated with concentration levels in previous years. Figure 3.1 shows the estimation of the premature deaths related to the pollution of $PM_{2.5}$, NO_2, and O_3, respectively, between 2005 and 2020 for two aggregated areas: EU27 and all countries except Türkiye. Türkiye's NO_2 and O_3 data was excluded in this analysis for consistency across the years as data for Türkiye are only available from 2016 due to the lack of sufficient monitoring data for the interpolated concentration maps (ETC HE, 2022b). Figure 3.1 also includes the population-weighted average concentration (secondary vertical axis) to describe the average concentration levels the European population has been exposed to since 2005. The data supporting Figure 3.1 is available in Table A3.1, in Annex 3. The YLL has the same development as the number of premature deaths and is, therefore, not shown here.

The mortality associated with $PM_{2.5}$ and NO_2 concentration levels has decreased in both areas since 2005 (over 40 %). When comparing 2020 and 2019, the estimations on the number of premature deaths show a slight increase in 2020, 3 % for EU27 and 5 % for all countries (ex. Türkiye) for $PM_{2.5}$, and a sharp decrease for NO_2, 29 % and 24 %, respectively. Though the population-weighted concentration for $PM_{2.5}$ has not increased, the mortality related to its exposure has increased. The population-weighted concentration for $PM_{2.5}$ was reduced by 6 % for both EU27 and all countries (ex. Türkiye) and 18 and 14 % for NO_2, respectively. The increase in the risk related to $PM_{2.5}$ in 2020 reflects an increase in mortality due to COVID-19. The European region registered over 1.3 million excess deaths associated with the pandemic in 2020 (WHO, 2022), and these deaths are included in all natural causes in the mortality rates. On the other hand, for NO_2, the mortality rate increase did not have the same impact since the population-weighted concentration has decreased substantially due to lockdowns imposed to curb the spread of COVID-19 (EEA, 2020; Solberg et al., 2021).

The O_3 concentration is strongly dependent on meteorology and precursor emissions. This dependency reflects the variability of the mortality associated with exposure to O_3 concentration levels over the years, with the increase typically correlating with sunny and dry summers. After the 2018 peak, the concentrations have been decreasing. However, the number of premature deaths is higher in 2020. Like $PM_{2.5}$, this increase is related to the increase in mortality rates.

Figure 3.1 Development of the number of premature deaths (vertical-left axis) due to exposure to $PM_{2.5}$, NO_2, and O_3 concentration levels (vertical-right axis) from 2005 to 2020 for EU27 and all countries (except Türkiye)



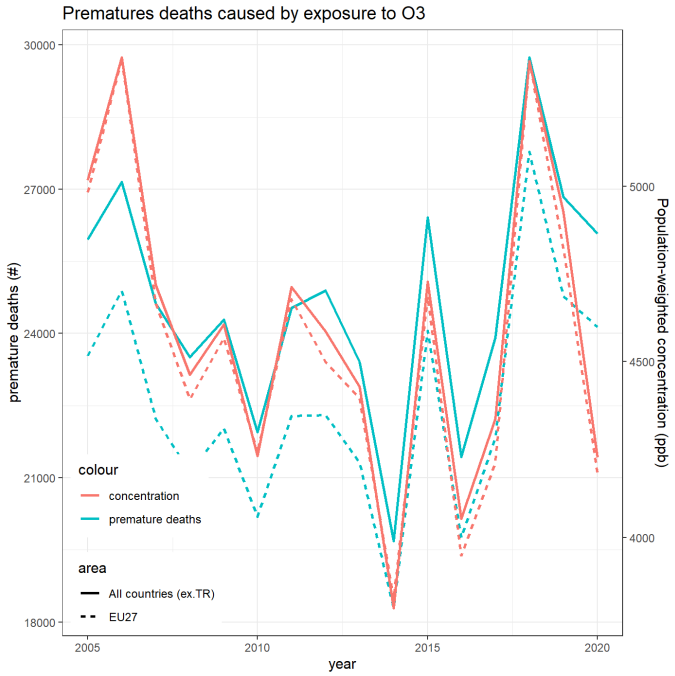


Table 3.3: The range of variability in the number of premature deaths (PD) and years of life lost (YLL) attributable to $PM_{2.5}$, NO_2, and O_3 exposure in the EU27 and 41 (40, in the case of $PM_{2.5}$) European countries (All countries) in 2020

area		$PM_{2.5}$	NO_2	O_3
EU27	PD	182 000 – 265 000	25 000 – 95 000	19 000 – 29 000
	YLL	1 840 000 – 2 687 000	245 000 – 949 000	197 000 – 301 000
All Countries	PD	210 000 – 306 000	33 000 – 126 000	22 000 – 34 000
	YLL	2 120 000 – 3 091 000	344 000 – 1 329 000	242 000 – 370 000

Other uncertainties and caveats related to the input data and methodology are described in Annex 1.

4 Sensitivity analysis of the estimation of mortality health outcomes

This section aims to indicate how sensitive the estimation of health outcomes is to changes in the CRFs, the counterfactual concentrations, or both and to indicate the change in EEA 's estimations between the HRA's new and old assumptions on CRFs and counterfactual concentrations. Figure A2.1, Figure A2.2, and Figure A2.3 in Annex 2 describe the risk and its behaviour based on the choice of CRF and counterfactual concentration for $PM_{2.5}$, NO_2, and O_3, respectively. The CRF defines the slope of a log-linear function (Eq. A1.1, Annex 1), and the counterfactual concentration defines the lowest concentration level a population is exposed to that is considered potentially harmful in the estimation (risk of mortality = 1).

The general behaviour is the following:

- **Changing CRF and assuming the same counterfactual concentration** impacts linearly on the estimations: the highest estimation will be based on the highest CRF and the difference between estimations will be higher when the concentration levels are higher.
- **Assuming a constant CRF and varying the counterfactual concentration** implies that the highest counterfactual concentration will result in a lower estimation of mortality. The risk is the same, but a lower counterfactual level implies that the risk analysis considers a larger range of concentration levels.
- **Varying both CRF and counterfactual concentration** makes the estimates dependent on three variables: the CRF, counterfactual concentration, and the concentration at the grid-cell level. The latter becomes a key factor in determining which scenario results in higher estimation since the functions tend to intersect at some point.

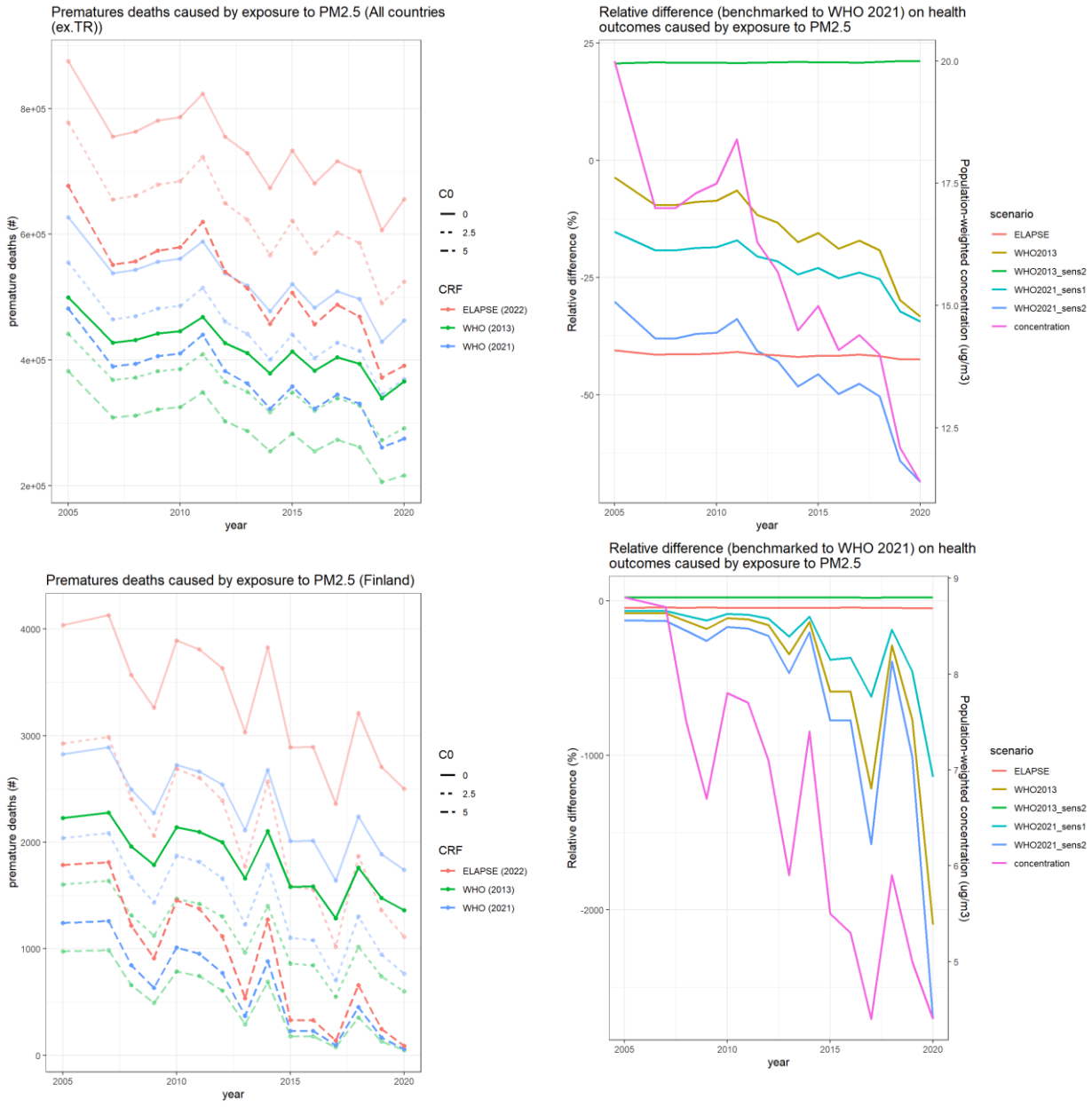
Note that the grid cells with concentration below the counterfactual level are not included in the mortality estimation.

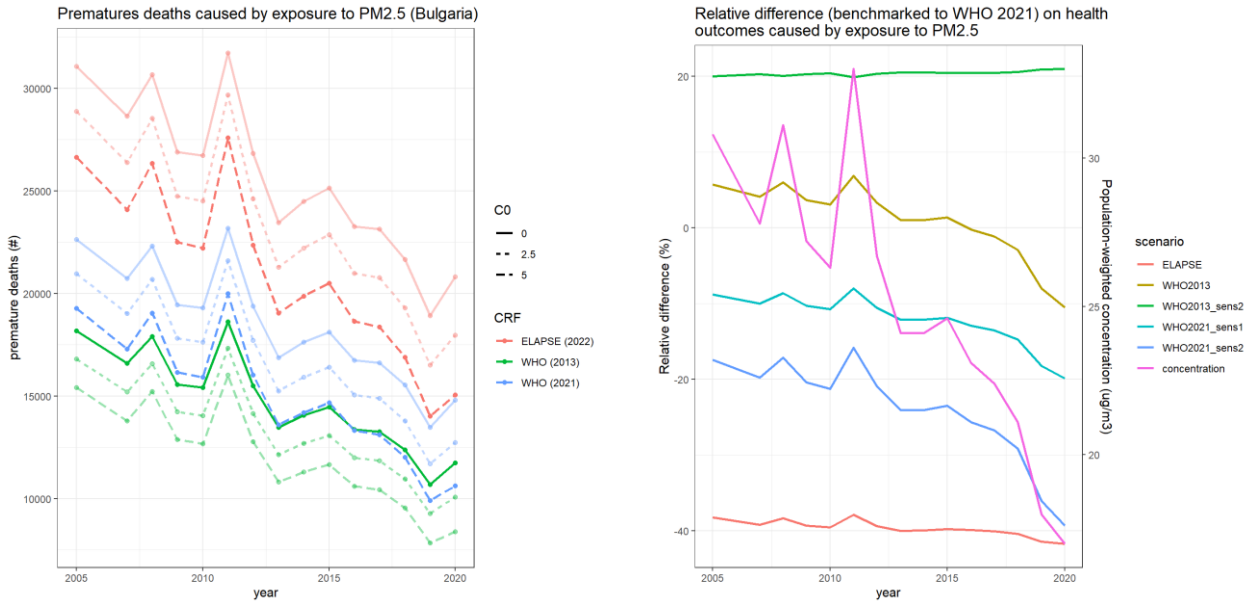
The analysis is presented in two ways: the development since 2005 to see how changes in concentration have impacted the health outcomes based on the different assumptions and comparing the three baseline scenarios for 2020.

4.1 $PM_{2.5}$

Figure 4.1 (left panels) shows the estimates of the number of premature deaths for all countries (except Türkiye), Finland, and Bulgaria, based on the scenarios described in Table 2.2 for $PM_{2.5}$. The results for two individual countries show the contrast between choosing a country with low (Finland) and mid-high (Bulgaria) concentration levels. Figure 4.1 (right panels) shows the comparison between specific scenarios and the adopted baseline scenario (WHO2021), relative to WHO2021: WHO2013_sens2 and ELAPSE to check the sensitivity to the CRF, WHO2021_sens1, WHO2021_sens2 to check the sensitivity to the counterfactual concentration, and WHO2013 to check the differences between the previous assumptions and the current ones. The data supporting these Figures is available in Table A3.1 and Table A3.2 in Annex 3.

Figure 4.1: Development of premature deaths due to exposure to $PM_{2.5}$ concentration levels (vertical-left axis) from 2005 to 2020 for all countries (except Türkiye), Finland, and Bulgaria considering the baseline (highlighted) and sensitivity scenarios (left panel). The relative difference (vertical-left axis) between the WHO2021 baseline scenario and selected scenarios and the population-weighted mean concentration (vertical-right axis) across the same period (right panel). See Table 2.2 for the scenario description





As expected, Figure 4.1 (left panels) shows that for scenarios assuming the same CRF, the number of premature deaths will be higher for estimations with the lowest counterfactual concentration. Therefore, all estimations considering all concentration levels (C_0= 0 µg/m^3) have the highest outcome and considering counterfactual concentration level of 5 µg/m^3 results in the lowest estimates. On the other hand, when assuming the same counterfactual concentration, the estimations with the highest CRF will result in the highest number of premature deaths. Therefore, all the scenarios assuming the ELAPSE (2022) CRFs have the highest outcome and the scenarios assuming the WHO (2013) CRFs have the lowest (if cross-compared with scenarios with the same counterfactual concentration). This behaviour is seen by the constant relative difference between scenarios with the same counterfactual concentration and varying relative difference for scenarios with the same CRF (Figure 4.1, right panels). The relative difference between scenarios with the same CRF depends of the level of concentrations at the grid-cells. The relative difference is increasing as the concentrations are decreasing across the years and getting closer to the counterfactual level assumed in the WHO2021 (a smaller population is impacted if concentration levels are close to or below the counterfactual concentration).

As mentioned in the introduction of this Section, when varying both CRF and counterfactual concentration it is not straightforward to say which assumption (scenario) will produce the highest number of premature deaths. The outcome depends on the concentration level the population is exposed to. For example, when the population is exposed to concentrations much higher than the counterfactual level (e.g., Bulgaria), clustering between scenarios assuming the same CRF is clear. Suppose the difference between the concentration the population is exposed to and the counterfactual concentration is small (low impact), or the concentration is lower than the counterfactual concentration (no impact) (e.g., Finland), the clustering is between scenarios with the same counterfactual concentration. For averaged concentrations across the 40 countries, the scenario analysis shows the scenarios combining ELAPSE (2022) CRFs with counterfactual concentration of 0 (ELAPSE_sens2) and 2.5 µg/m^3 (ELAPSE_sens1) resulting in the highest outcome, and WHO2013 CRFs with counterfactual concentration of 5 µg/m^3 (WHO2013_sens2) with the lowest. The remaining scenarios cluster in pairs, where one scenario has an higher CRF but lower counterfactual concentration and the other the opposite: (1) ELAPSE CRF and C_0=5 (ELAPSE) clusters with WHO2021 CRF and C_0=0 µg/m^3 (WHO2021_sens2); (2) WHO2021 CRF and C_0=2.5 (WHO2021_sens1) clusters with WHO2013 CRF and C_0=0 µg/m^3 (WHO2013); and (3) WHO2021 CRF and C_0=5 clusters with WHO2013 CRF and C_0=2.5 µg/m^3 (WHO2013_sens1). Within these clusters, the scenarios with the highest CRF are typically showing higher outcomes. However, with the decrease of concentration levels the population is exposed to since 2005, this may change, e.g., 2012 for cluster (1) for all countries where the counterfactual concentration level becomes the constraining factor. For more details on the behaviour of the risk functions the reader is referred to Annex 2.

Thus, when comparing the three baseline scenarios assuming the average concentrations across the 40 countries, ELAPSE baseline scenario will result in the highest estimates and the new WHO2021 baseline scenario the lowest. For countries with concentrations typically closer to levels in Bulgaria (i.e., 3 to 4 times higher the counterfactual level of 5 μg/m^3), ELAPSE baseline scenario will result in the highest estimates and both old and new assumptions (WHO2013 and WHO2021 baseline scenario, respectively) will result in similar estimates. For countries with concentrations typically closer to levels in Finland (close to the counterfactual level or lower), the old assumptions (WHO2013) will result in higher estimations, followed by ELAPSE and WHO2021 (new assumptions).

The mortality risk for a population exposed to $PM_{2.5}$ based on the current HRA methodology (WHO2021 baseline scenario) is typically lower than the previous one (WHO2013 baseline scenario). The mortality risk associated with exposure to $PM_{2.5}$ concentration is higher in the current methodology. However, assuming the counterfactual concentration at the same level as the WHO AQG level (5 μg/m^3) instead of 0 μg/m^3 implies that areas with populations exposed to very low concentrations (those below 5 μg/m^3) are not considered to be at risk: 2.5 % of the population in Europe, in 2020, was exposed to $PM_{2.5}$ concentration of 5 μg/m^3 and below, 1.1 % in 2005 (ETC HE (2022a), Figure A1.1. Annex 1). Only at levels above 22 μg/m^3 do the estimations based on WHO2021 surpass WHO2013 (97 % of the population considered in the analysis is exposed to concentrations of 22 μg/m^3 or below in 2020).

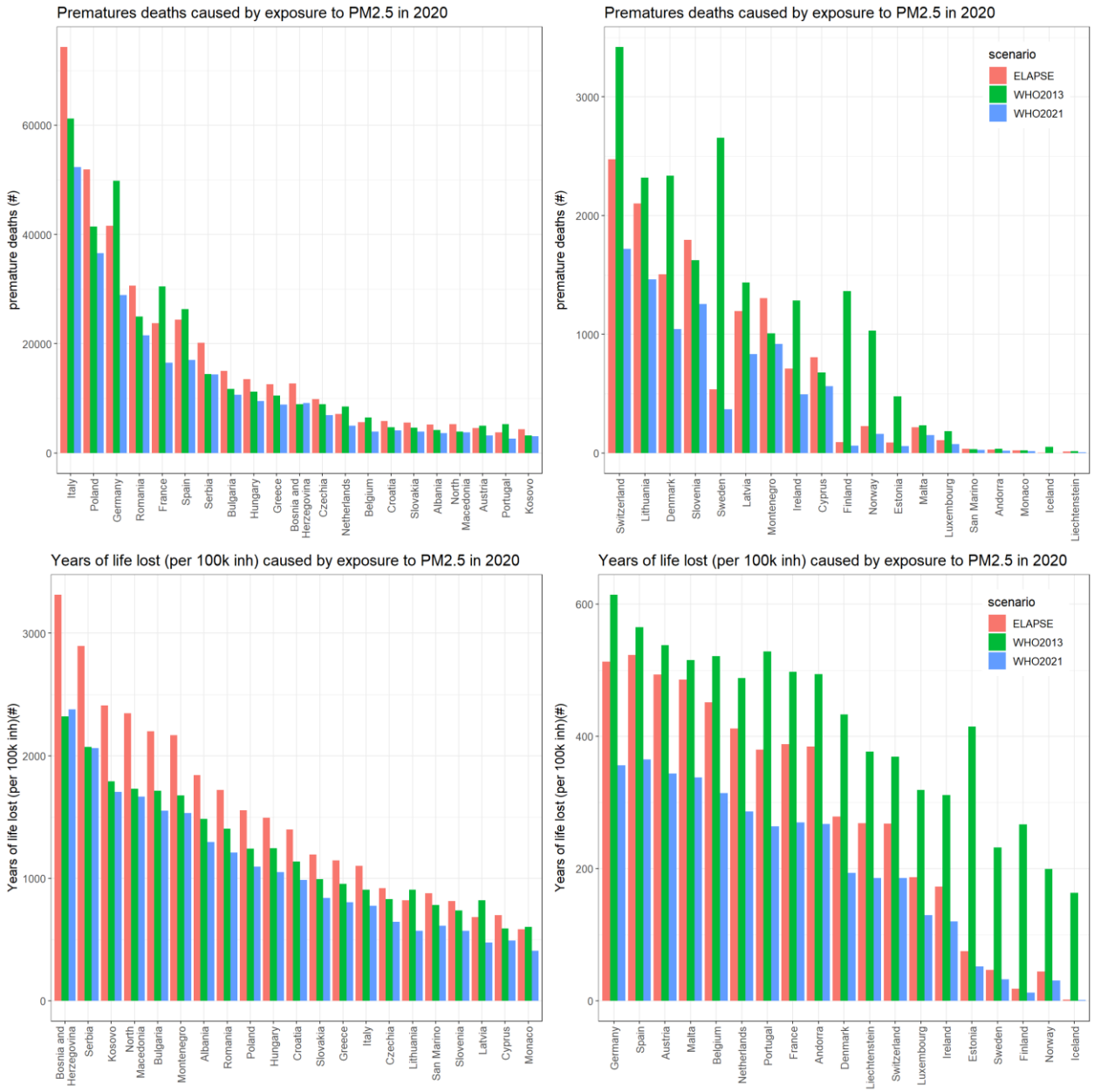
Other considerations are:

- sharper reduction in the number of premature deaths since 2005 when considering the ELAPSE's CRF recommendations, followed by WHO (2021) and least pronounced for scenarios considering WHO (2013)'s CRF recommendations (see Figure A2.1 in Annex 2). This will impact the estimations on reaching the Zero Pollution Action Plan (ZPAP) target set by the European Commission. The ZPAP sets the goal of reducing the number of premature deaths caused by $PM_{2.5}$ in 2030 by at least 55 % compared with 2005 levels.
- the scenario closer to the baseline scenario simulating the old HRA assumptions (WHO2013) is WHO2021_sens1 (C_0=2.5) scenario.

The following Figures indicate how the mortality outcomes due to $PM_{2.5}$ levels in Europe in 2020 change across the countries depending on the baseline assumptions. Figure 4.2 shows the number of premature deaths and years of life lost per 100 000 inhabitants estimated based on the assumptions of the three baseline scenarios. The data supporting these Figures are available in Table A3.7 in Annex 3.

As expected from the analysis above, the estimation based on the WHO2021 baseline scenario translates into the lowest health outcome country-wise, except for Bosnia and Herzegovina. Nevertheless, the difference between the estimations varies depending on the level of concentrations in the individual countries.

Figure 4.2: Number of premature deaths (top) and years of life lost per 100 000 inhabitants (per 100k inh) (bottom) due to exposure to $PM_{2.5}$ concentration levels in 2020 for individual countries based on the baseline estimations (see Table 2.2 for the scenario description)

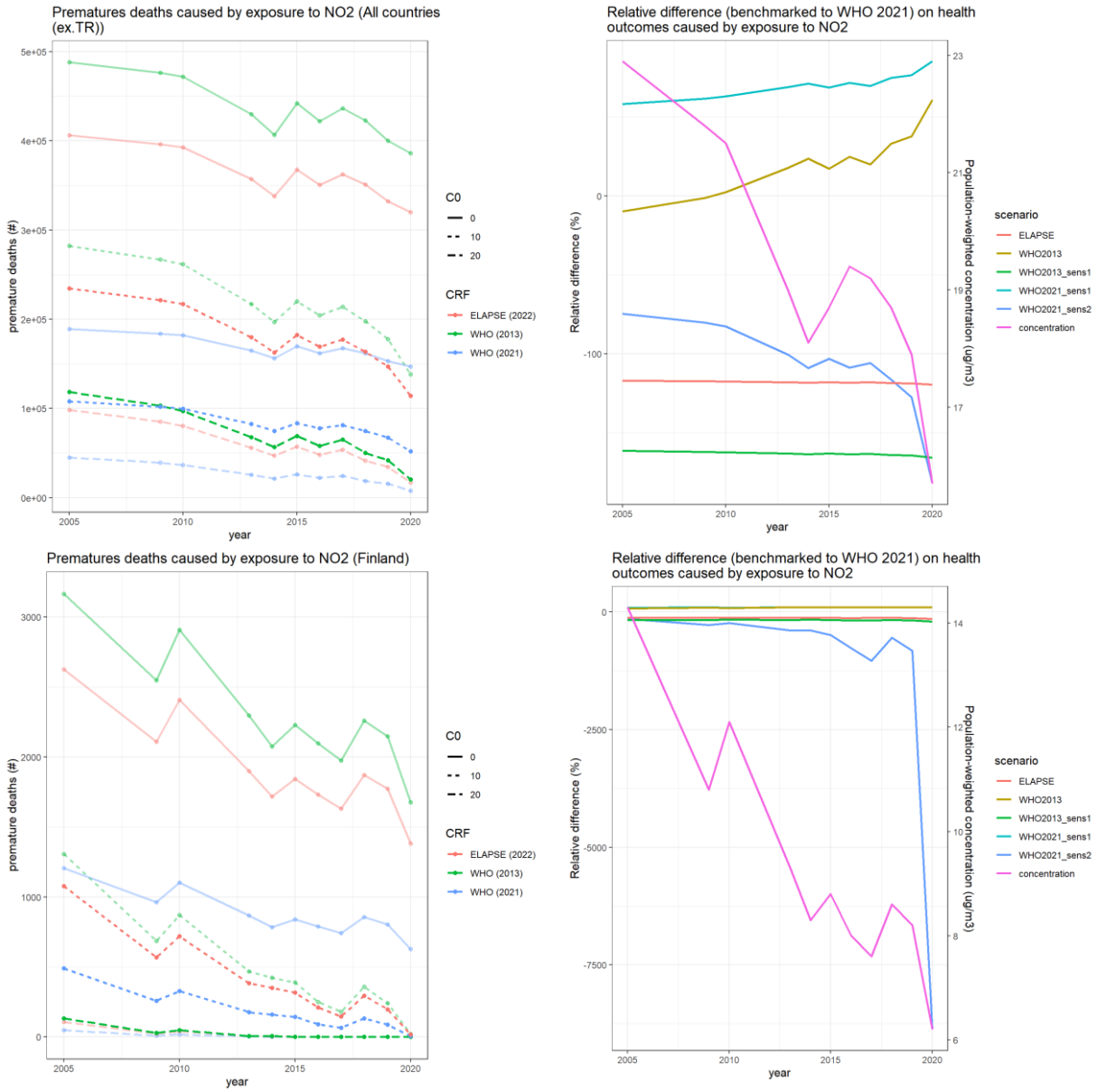


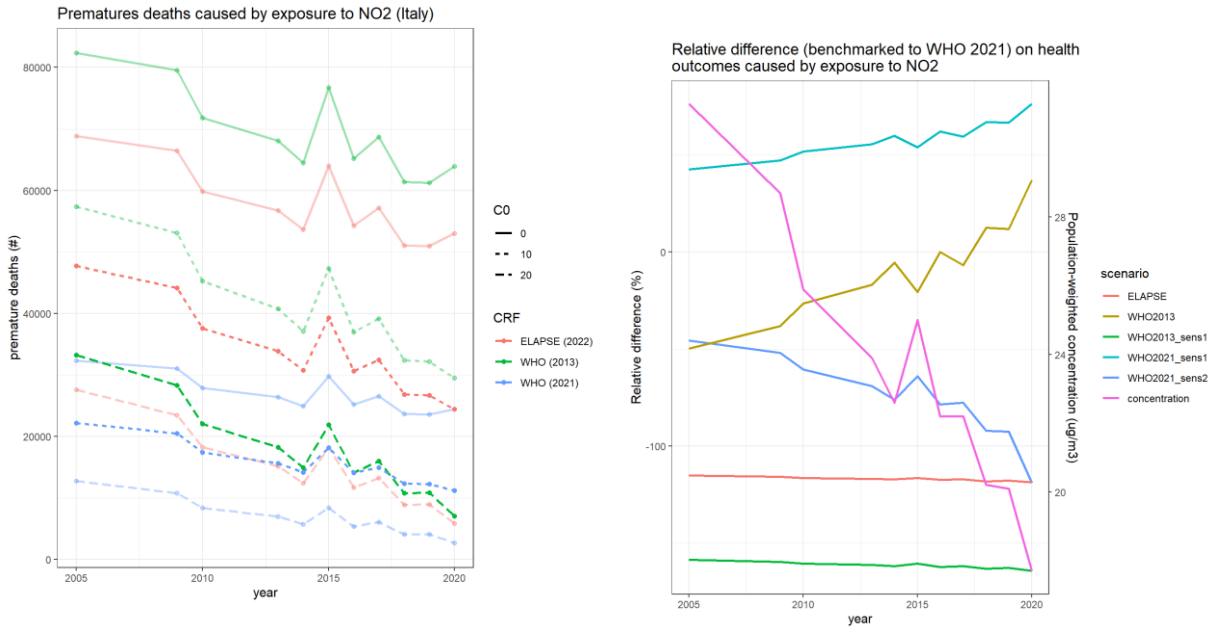
Notes: please be aware of the different units in the Y-axes.

4.2 NO_2

Figure 4.3 (left panels) shows the estimates for the number of premature deaths for all countries (except Türkiye), Finland, and Italy, based on the scenarios described in Table 2.2 for NO_2 The results for two individual countries show the contrast between choosing a country with low (Finland) and mid-high (Italy) concentration levels. Figure 4.3 (right panels) shows the comparison between specific scenarios and the adopted baseline scenario (WHO2021), relative to WHO2021: WHO2013_sens1 and ELAPSE to check the sensitivity to the CRF, WHO2021_sens1, WHO2021_sens2 to check the sensitivity to the counterfactual concentration, and WHO2013 to check the differences between the previous assumptions and the current ones. The data supporting these Figures are available in Table A3.3 and Table A3.4 in Annex 3.

Figure 4.3 **Development of premature deaths due to exposure to NO_2 concentration levels (vertical-left axis) from 2005 to 2020 for all countries (except Türkiye), Finland, and Italy considering the baseline (highlighted) and sensitivity scenarios (left panel). The relative difference (vertical-left axis) between the WHO2021 baseline scenario and selected scenarios and the population-weighted mean concentration (vertical-right axis) across the same period (right panel). See Table 2.2 for the scenario description**





As expected, Figure 4.3 (left panels) show that for scenarios assuming the same CRF, the number of premature deaths will be higher for estimations assuming the lowest counterfactual concentration. Therefore, all scenarios considering all concentration levels (C_0= 0 µg/m^3) have the highest outcome and those considering counterfactual concentration level of 20 µg/m^3 result on the lowest estimates (if cross-compared with scenarios with the same CRF). On the other hand, when assuming the same counterfactual concentration, the scenarios with the highest CRF will result in higher number of premature deaths. This is why all the scenarios assuming WHO (2013)'s CRF have the highest outcome and the scenarios assuming WHO (2021)'s CRF have the lowest (if cross-compared with scenarios with the same counterfactual concentration). On the right panels, these behaviours are seen by the constant relative difference between scenarios with the same counterfactual concentration and varying relative difference for scenarios with the same CRF. The latter depends on the level of concentrations the population is exposed to. In the case of NO_2, the scenario benchmarked (WHO2021) has the counterfactual value of 10 µg/m^3. When compared with the scenario with the same CRF but higher counterfactual concentration (WHO2021_sens1), the difference increases (negative) with the decreasing concentrations because more concentration levels are included in the mortality risk estimations with the WHO2021. On the contrary, there is an increase on the relative difference (positive), when compared with the scenario with the same CRF but lower counterfactual concentration (WHO2021_sens2), as less levels of concentration are included in the estimation of WHO2021 and the concentrations are decreasing, on average.

For NO_2, when assessing the results across the scenarios (varying both CRF and counterfactual concentrations), the highest estimates are for WHO2013_sens2 and ELAPSE_sen2, the scenarios assuming the highest CRFs and the lowest counterfactual concentration (C_0= 0 µg/m^3). The lowest estimate is for WHO2021_sens1, with the lowest CRF and the highest counterfactual concentration (C_0= 20 µg/m^3). If we compare average (All countries) and mid-high (Italy) concentration levels, the results are very similar, especially for the last decade. Two cluster of scenarios emerge (apart from the two scenarios with the highest estimates): one comprised of WHO2021 baseline, ELAPSE baseline, and WHO2021_sens2 and the other of the three scenarios with counterfactual concentration of 20 µg/m^3, and the remaining one with 10 µg/m^3, WHO2021 baseline. Within these clusters, the scenarios with the highest CRF are typically showing higher outcomes. However, with the decreasing of the concentration level the population is exposed to since 2005, this may change, e.g., in 2019 for the first cluster. If the population is exposed to concentration levels close to or below the counterfactual level, like in Finland, the WHO2021_sens2 (C_0= 0 µg/m^3) is singled out as the 3rd highest estimate. This is because all levels are considered when estimating the mortality risk. For the remaining scenarios, the two clusters are based on the counterfactual concentrations (10 vs 20 µg/m^3) since most of the population in Finland is expose to levels below these two counterfactual levels. When comparing the three baseline scenarios only, ELAPSE baseline scenario

will result in the highest estimates. For more details on the behaviour of the risk functions the reader is referred to Annex 2.

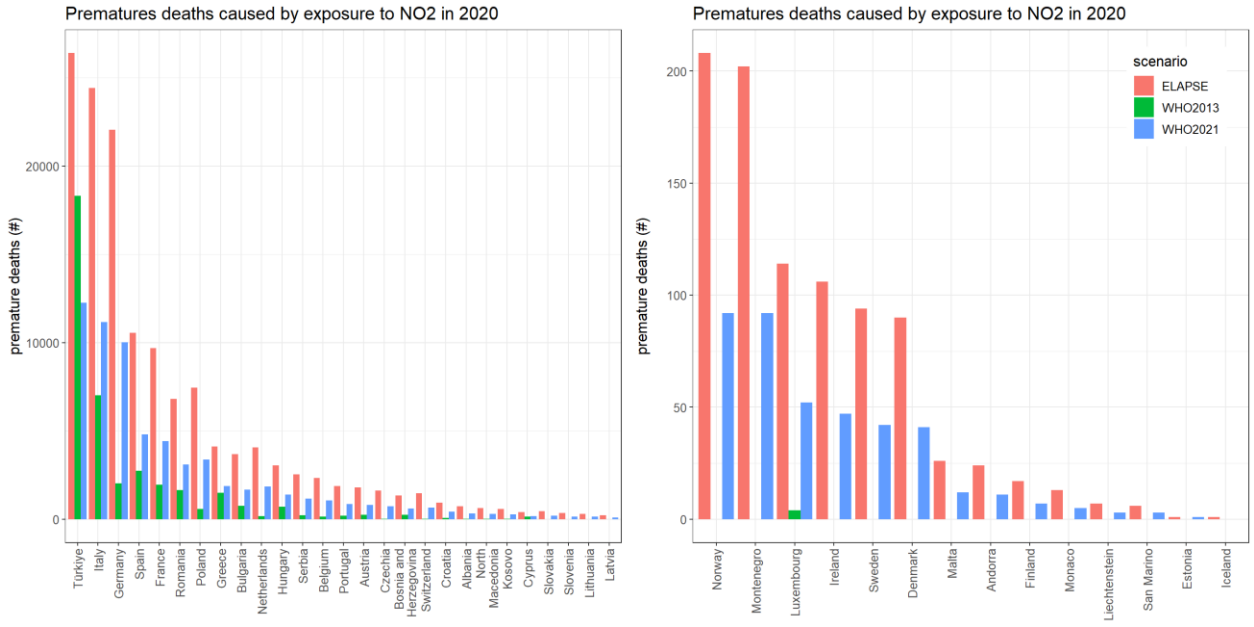
The relative risk for a population exposed to NO_2 based on the current HRA methodology (WHO2021 baseline scenario) is lower than the previous one (WHO2013 baseline scenario). However, assuming the counterfactual concentration at the same level as the WHO AQG level (10 µg/m^3) instead of at 20 µg/m^3 implies that more population is considered to be at risk. In 2020, the percentage of the European population exposed to levels of 10 µg/m^3 and below was 27.2 % (6.4 % in 2005). 78.6 % (39.8 % in 2005) was exposed to concentrations levels of 20 µg/m^3 and below (ETC HE (2022a), Figure A2.2 in Annex 2).

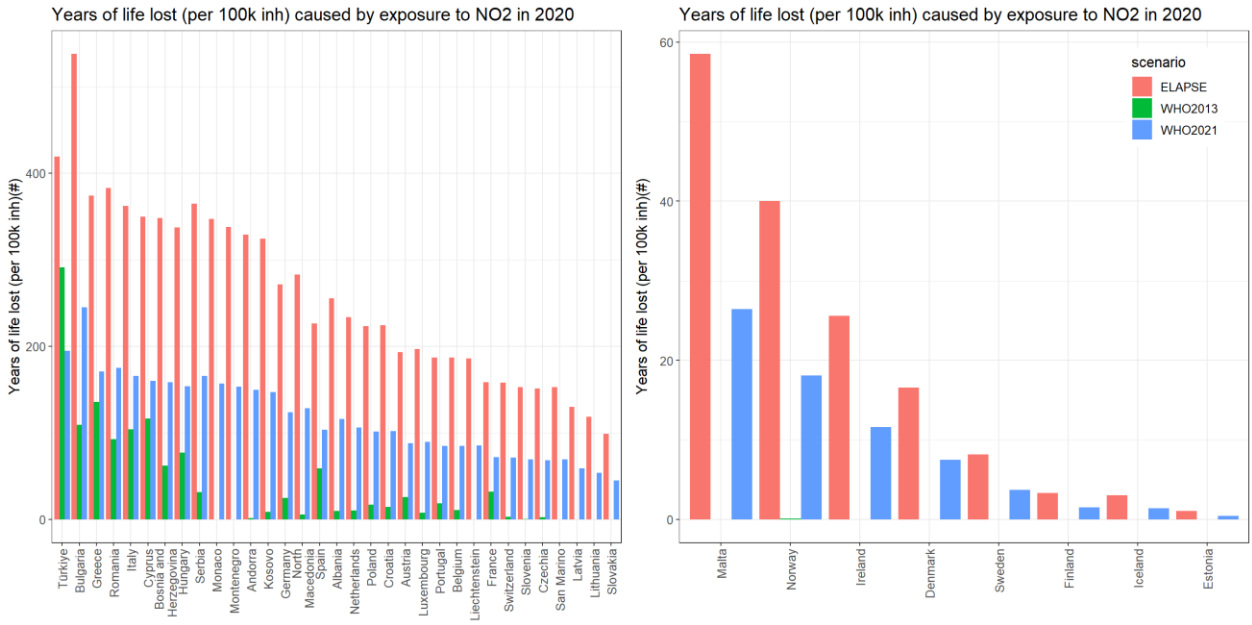
Other considerations are:

- sharper reduction in the number of premature deaths since 2005 when considering the scenarios based on the WHO (2013) and ELAPSE (2021) CRF recommendations, and least pronounced for scenarios considering WHO (2021) CRF recommendations (see Figure A2.1 in Annex 2).
- the scenario closer to the baseline scenario simulating the old HRA assumptions (WHO2013) is WHO2021 (C_0=10) scenario.

The following Figures indicate how the mortality outcomes due to NO_2 levels in Europe in 2020 change across the countries depending on the baseline assumptions. Figure 4.4 shows the number of premature deaths and years of life lost per 100 000 inhabitants estimated based on the assumptions of the three baseline scenarios. The data supporting these Figures are available in Table A3.3 in Annex 2.

Figure 4.4: Number of premature deaths (top) and years of life lost per 100 000 inhabitants (per 100k inh) (bottom) due to exposure to NO_2 concentration levels in 2020 for individual countries on the baseline estimations (see Table 2.2 for the scenario description)





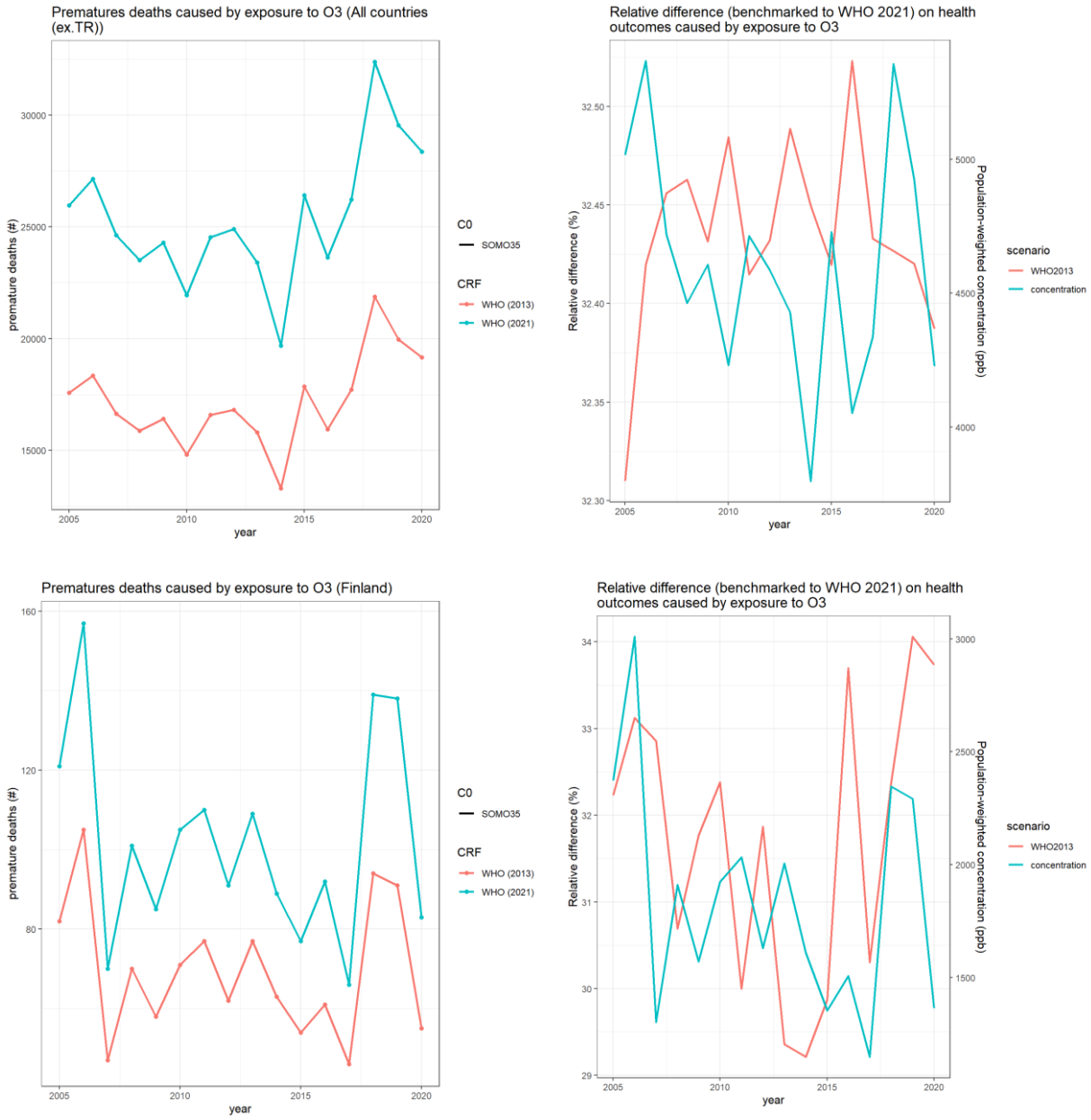
Notes: please be aware of the different units on the Y-axes.

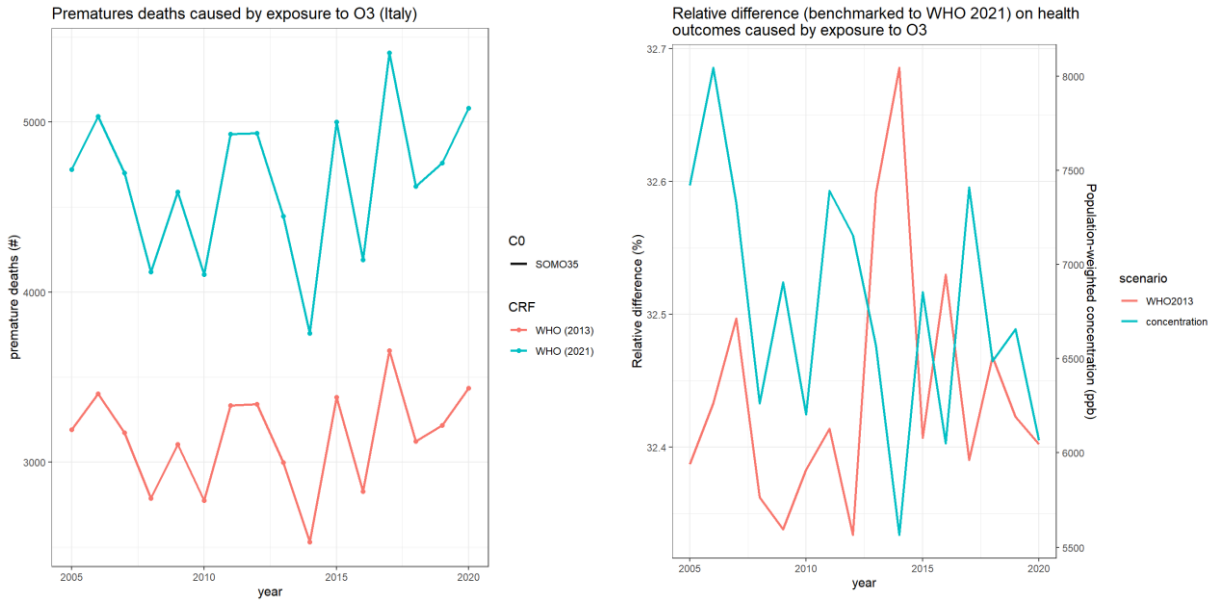
As expected from the analysis above, all the countries have the highest numbers with the estimation based on the ELAPSE scenario, followed by WHO2021. Only Türkiye shows estimates higher for WHO2013, since much of the population is exposed to levels above 20 µg/m^3. However, the difference between the estimations varies depending on the level of concentration the population in the individual countries is exposed to.

4.3 O_3

Figure 4.5 (left panels) shows the estimates for the number of premature deaths for all countries (except Türkiye), Finland, and Italy, based on the scenarios described in Table 2.2 for O_3 The results for two individual countries show the contrast between choosing a country with low (Finland) and mid-high (Italy) concentration levels. Figure 4.5 (right panels) shows the comparison between the old baseline scenario (WHO2013) against the adopted baseline scenario (WHO2021). Note that SOMO10 is not available for the whole extent of the period analysed and, therefore, not included. The data supporting these Figures are available in Table A3.5 and Table A3.6 in Annex 3.

Figure 4.5: Development of premature deaths due to exposure to O_3 concentration levels (vertical-left axis) from 2005 to 2020 for all countries (except Türkiye), Finland, and Italy considering the baseline (highlighted) scenarios (left panel). The relative difference (vertical-left axis) between the WHO2021 baseline scenario and WHO2013 baseline scenario and the population-weighted mean concentration (vertical-right axis) across the same period (right panel). See Table 2.2 for the scenario description

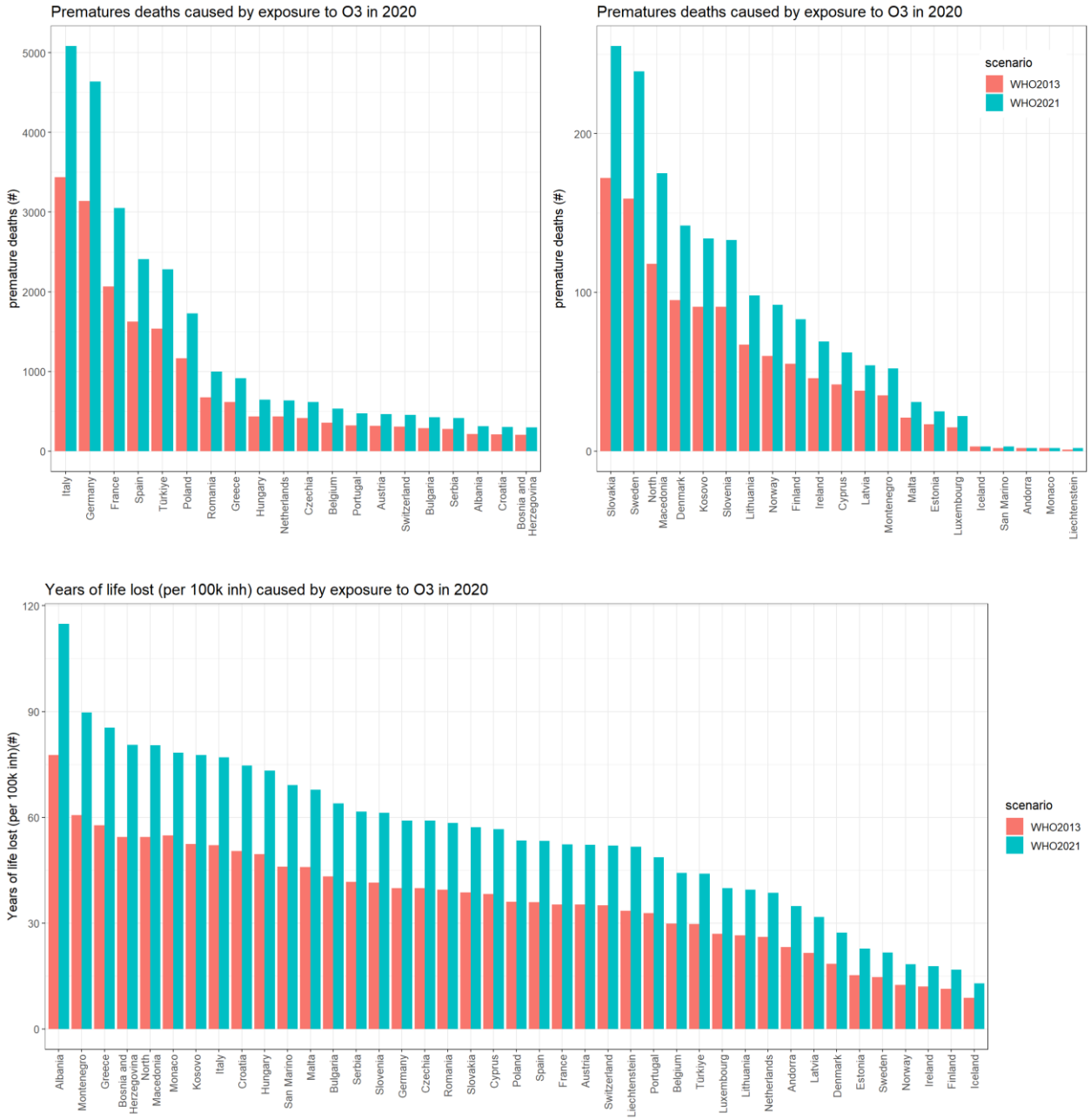




The analysis for O_3 is only based on the changes to the CRF. Since the risk is considered higher in WHO (2021), the WHO2021 scenario increases the magnitude of the health outcomes (over 30 %). If the counterfactual concentration were also changed, e.g., for SOMO10, the numbers would increase substantially (see Figure A2.3, Annex 2). Contrary to the other two pollutants, there is no clear decreasing trend in the population-weighted mean concentration. The exposure to O_3 varies substantially across the years since the O_3 concentrations are highly dependent on meteorology.

The following Figures indicate how the mortality outcomes due to O_3 levels in Europe in 2020 change across the countries depending on the baseline assumptions. Figure 4.6 shows the number of premature deaths and years of life lost per 100 000 inhabitants estimated based on the two baseline scenarios. The data supporting these Figures are available in Table A3.7 in Annex 2.

Figure 4.6: Number of premature deaths (top) and years of life lost per 100 000 inhabitants (per 100k inh) (bottom) due to exposure to O_3 concentration levels in 2020 for individual countries on the baseline estimations (see Table 2.2 for the scenario description)



Notes: please be aware of the different units in the Y-axes.

As expected, the new scenario (WHO2021) results in the highest estimations, albeit different from country to country, as it only depends on the ozone metric.

5 Combining both mortality and morbidity outcomes

Burden of disease is the impact of a health outcome (e.g., a disease) measured by different indicators, e.g. mortality, morbidity and costs. It is often quantified in terms of Disability-Adjusted Life Years (DALY). DALY is a core summary measure to assess the population's health status (GBD, 2019) based on both mortality and morbidity indicators.

DALYs can be calculated from the sum of YLL and years lived with disability (YLD). YLD measures years lost due to disability and it is estimated by combining the number of prevalent cases of a particular health outcome (P_o) and the disability weight factor (DW), according to Eq.5.1. DW reflects the severity of the disease on a scale from 0 (perfect health) to 1 (dead) (WHO, 2014). One DALY is one lost year of healthy life.

$$\mathrm{YLDs} = \mathrm{P}_o * \mathrm{DW} \quad (5.1)$$

An Eionet report on identifying relevant morbidity health outcomes is available (ETC HE, 2022a). This report focuses on the same ambient air pollutants and geographical coverage as the EEA/ETC HRA. It includes a selection of appropriate CRFs and underlying health data, and provides an adequate methodology for the morbidity-related burden of disease and estimates for 2019 for the following outcomes:

- $PM_{2.5}$: Chronic Obstructive Pulmonary Disease, Ischemic Heart Disease, Lung Cancer, Diabetes Mellitus, Stroke, and Asthma (children).
- NO_2: Asthma (adults), Diabetes Mellitus, Stroke.
- O_3: Hospital admissions for respiratory diseases.

To estimate the DALYs attributable to air pollution, estimates on both cause-specific morbidity and mortality health outcomes are necessary. Therefore, the summation of YLLs from the all-cause approach and YLDs from a cause-specific approach is inadequate. A consistent approach would be adding the estimates for YLLs and YLDs for each specific cause and presenting the sum as the attributable burden. The next step would be to explore cause-specific mortality health outcomes aligned with the morbidity outcomes presented in (ETC HE, 2022a).

6 Conclusions

In 2020, the mortality associated with exposure to air pollution across Europe remained high, especially in central and south-eastern European countries. The largest mortality is attributable to $PM_{2.5}$, followed by NO_2 and O_3. The exposure to concentrations levels above the 2021 WHO AQ guideline levels in 2020 resulted in 275 000 premature deaths related to $PM_{2.5}$ exposure, and 64 000 to NO_2, across the 41 countries included in the assessment (40 in the case of $PM_{2.5}$). The short-term exposure to O_3 implied 28 000 premature deaths. For EU27, the attributed number of premature deaths for 2020 is 238 000, 49 000, and 24 000, respectively. When considering both the number of deaths and the age at which it occurs, the number of years of life lost for the 41 European countries is 2 773 000, 680 000, and 306 000 due to exposure to $PM_{2.5}$, NO_2, and O_3, respectively. For EU27, years of life lost (YLL per 100 000 inhabitants) are 2 410 000 (544), 484 000 (109), 249 000 (56), respectively.

The mortality related to air pollution is typically higher for countries with a larger population and lowest for countries with either small populations or low average population-weighted concentrations or a combination of both. When considering years of life lost per 100 000 inhabitants, the situation might change dramatically, with the largest mortality being observed in central and south-eastern European countries due to exposure to $PM_{2.5}$.

The number of premature deaths attributed to air pollution in 2020 compared to 2019, increased for $PM_{2.5}$ and decreased for NO_2 and O_3. Apart from the changes in concentrations and demographics, the COVID-19 pandemics seems to also have an influence on these changes. For $PM_{2.5}$, the reduction in concentrations were counteracted by the excess of deaths due to the pandemics. In the case of NO_2, the reduction in concentrations was more pronounced as a result of the lockdown measures and the drastic reduction in traffic and its impact in reducing mortality was bigger than the increasing impact of excess of deaths due to COVID-19.

Changing assumptions on CRFs and counterfactual concentrations have implications for estimating mortality health outcomes. The sensitivity analysis shows that it is not straightforward to assess which baseline scenario estimates the highest concentrations when both CRF and counterfactual concentration change. In this case, the final outcome will depend on the concentration at the grid-cell level. The EEA/ETC HRA methodology has been adapted based on the latest WHO recommendations (WHO, 2021) – both CRFs and AQG levels (counterfactual concentrations for $PM_{2.5}$, NO_2). Compared to the previous assumptions on CRF and counterfactial concentrations, these changes are expected to reduce the health outcomes for $PM_{2.5}$ and increase for NO_2 and O_3. When aggregated to all countries, the health outcomes in 2020 are reduced by over 40 % for $PM_{2.5}$ and increased by 50 % and 30 % for NO_2 and O_3, respectively. This change varies across countries depending on the concentration level the population of the individual country is exposed to.

To estimate the DALYs attributable to air pollution, estimates on both cause-specific morbidity and mortality health outcomes are necessary. For the future, a consistent approach would be adding the estimates for YLLs and YLDs for each specific outcome and presenting the sum as the attributable burden. A report on identifying relevant morbidity health outcomes is available (ETC HE, 2022a). The next step would be to explore cause-specific mortality health outcomes aligned with the morbidity outcomes presented in that report.

7 References

Brunekreef, B., et al., 2021, *Mortality and Morbidity Effects of Long-Term Exposure to Low-Level PM2.5, BC, NO2, and O3: An Analysis of European Cohorts in the ELAPSE Project*, Health Effects Institute, Boston, ISSN 1041-5505.

Brauer, M., et al., 2022, *Mortality–Air Pollution Associations in Low Exposure Environments (MAPLE): Phase 2*, Research Report 212, Health Effects Institute, Boston.

EEA, 2020, *Air quality in Europe 2020, EEA Report No 9/2020*, European Environment Agency, (https://www.eea.europa.eu//publications/air-quality-in-europe-2019) accessed 14 July 2022.

IHME, 2022, *GBD Compare, Institute for Health Metrics and Evaluation* (https://vizhub.healthdata.org/gbd-compare/) accessed 30/08/2022.

Eurostat, 2014, *GEOSTAT 2011 grid dataset, Population distribution dataset*, (http://ec.europa.eu/eurostat/web/gisco/geodata/reference-data/population-distribution-demography) accessed October 10, 2019,

Eurostat, 2022a, *Population change - Demographic balance and crude rates at national level, Eurostat,* (http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=demo_gind&lang=en accessed 26/07/2022.

Eurostat, 2022b, *Population on 1 January by age and sex, Eurostat,* (http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=demo_pjan&lang=en) accessed 26/07/2022.

Eurostat, 2022c*, Causes of death - deaths by country of residence and occurrence, Eurostat,* (http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=hlth_cd_aro&lang=en) accessed 26/07/2022.

Eurostat, 2022d, *Deaths by age and sex,* Eurostat, (http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=demo_magec&lang=en) accessed 26/07/2022

Eurostat, 2022e, Life expectancy by age and sex, Eurostat, (http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=demo_mlexpec&lang=en) accessed 26/07/2022.

ETC/ACM, 2017, *European air quality maps for 2014 — PM_{10}, $PM_{2.5}$, ozone, NO_2 and NO_x spatial estimates and their uncertainties*, ETC/ACM Technical Paper 2016/6, European Topic Centre on Air Pollution and Climate Change Mitigation.

WHO, 2019, *Metrics: Population Attributable Fraction (PAF)*, https://www.who.int/data/gho/indicator-metadata-registry/imr-details/1287 access 25 November 2022.

ETC/ATNI, 2021, *Health risk assessments of air pollution. Estimations of the 2019 HRA, benefit analysis of reaching specific air quality standards and more*, ETC/ATNI Report 10/2021, European Topic Centre on Air Pollution, Transport, Noise and Industrial Pollution (ETC/ATNI), ISBN 978-82-93752-34-9, Kjeller.

ETC/ATNI, 2019, *Health risk assessments of air pollution in Europe. Methodology description and 2017 results,* ETC/ATNI Report 2019/13, European Topic Centre on Air Pollution, Transport, Noise and Industrial Pollution (ETC/ATNI), ISBN 978-82-93752-11-0, Kjeller.

ETC HE, 2022a, *Estimating the morbidity related disease burden due to selected ambient air pollutants*, ETC HE Report 2022/11, European Topic Centre on Human Health and the Environment (ETC HE), ISBN 978-82-93970-07-1, Kjeller.

ETC HE, 2022b, *European air quality maps for 2020 — PM_{10}, $PM_{2.5}$, ozone, NO_2, NO_x and benzo(a)pyrene spatial estimates and their uncertainties*, ETC HE Report 2022/12, European Topic Centre on Human Health and the Environment (ETC HE), ISBN 978-82-93970-07-1.

Global Burden of Disease (GBD), 2020, Global burden of 369 diseases and injuries in 204 countries and territories, 1990-2019: a systematic analysis for the Global Burden of Disease Study 2019, *The Lancet*, 396: 1204-22.

Ostro, B., 2004, *Outdoor air pollution: Assessing the environmental burden of disease at national and local levels*, WHO Environmental Burden of Disease Series no. 5, Geneva, World Health Organization.

Pifarré i Arolas, H., et al., 2021, *Years of life lost to COVID-19 in 81 countries*, Scientific Reports 11:3504, doi:10.1038/s41598-021-83040-3.

Plass, D., et al., 2013, *Quantifying the burden of disease due to premature mortality in Hong Kong using standard expected years of life lost*, BMC Public Health, 13:863

Solberg, S., et. al., 2021, Quantifying the Impact of the Covid-19 Lockdown Measures on Nitrogen Dioxide Levels throughout Europe. *Atmosphere*, 12(131), 20. https://doi.org/10.3390/atmos12020131

WHO, 2013, *Health risks of air pollution in Europe – HRAPIE project Recommendations for concentration–response functions for cost–benefit analysis of particulate matter, ozone and nitrogen dioxide Recommendations for concentration–response functions for cost–benefit analysis of particulate matter, ozone and nitrogen dioxide*, World Health Organization, Regional Office for Europe, Copenhagen.

WHO, 2021, *WHO global air quality guidelines: particulate matter ($PM_{2.5}$ and PM_{10}), ozone, nitrogen dioxide, sulphur dioxide and carbon monoxide: executive summary.* World Health Organisation, Geneva

WHO, 2022, *Estimates of Excess Mortality Associated With COVID-19 Pandemic* (as of 25 March 2022), World Health Organization, Geneva (dataset: https://cdn.who.int/media/docs/default-source/world-health-data-platform/covid-19-excessmortality/2022-03-25_covid-19_gem.zip?sfvrsn=2d5835e0_2)

8 List of abbreviations

Abbreviation	Name	Reference
AQG	Air quality guidelines	
CI	Confidence interval	
CRF	Concentration response function	
DALY	Disability-adjusted life year	
DW	Disability weight	
EEA	European Environment Agency	www.eea.europa.eu
ELAPSE	Effects of low-level air pollution: a study in Europe	www.elapseproject.eu
ETC/ATNI	European Topic Centre on Air pollution, Transport, Noise and Industrial pollution	
ETC HE	European Topic Centre on Human Health and the Environment	
EU	European Union	www.european-union.europa.eu
DALY	Disability-adjusted life year	
HRAPIE	Health risks of air pollution in Europe	
m^3	Cubic meter	
MI	Myocardial infarction	
N/A	Not Available	
NO_2	Nitrogen dioxide	
O_3	Ozone	
PAF	Population attributable fraction	
PD	Premature deaths	
$PM_{2.5}$	Fine particulate matter (diameter below 2.5 µm)	
ppb	Parts per billion	
RR	Relative risk	
SOMO35	Annual sum of daily maximum running 8-h average concentrations above 35 ppb	
SOMO10	Annual sum of daily maximum running 8-h average concentrations above 10 ppb	
TR	Türkiye	
WHO	World Health Organization	www.who.int
YLL	Year of life lost due to death	
YLD	Year lived with disability	
µg	Microgram	

Annex 1 Methodology

Estimation of health outcomes related to air pollution

For European ambient air pollution levels, the relative risk in a population whose exposure is estimated by an average concentration (RR_C) can be described as a log-linear function relating concentrations and mortality (Ostro, 2004; WHO, 2013), as specified below:

$$RR_C = \exp\left[\beta\ (C - C_0)\right] \qquad \text{(A1.1)}$$

where, *C* is the concentration level the population is exposed to, C_0 is the baseline concentration, and β is based on the concentration-response factor (CRF) estimated by epidemiological studies *(CRF* depends on the pollutant and health outcome one wants to estimate, see Section 2 for more details on the concentration-response functions applied). C_0 can either be the background concentration (i.e., the level that would exist without any human-made pollution), a concentration below which no health effects are expected, or a counterfactual concentration level. β can be estimated as follows:

$$\beta = \frac{\ln(CRF)}{UC} \qquad \text{(A1.2)}$$

where *UC* is the unit of concentration.

According to WHO (2019), the population attributable fraction (PAF) can be used as a metric to assess the contribution of a risk factor to a disease or a death. PAF can be defined as the 'proportional reduction in population disease or mortality that would occur if exposure to a risk factor were reduced to an alternative ideal exposure scenario'. Assuming that the population is exposed to a single concentration level over the assessed period, PAF can be calculated based on the relative risk as follows:

$$PAF = \frac{RR_C - 1}{RR_C} \qquad \text{(A1.3)}$$

Finally, a health outcome attributable to air pollution is estimated by:

$$health\ outcome = PAF \cdot MR \cdot Pop \qquad \text{(A1.4)}$$

Where *MR* is the baseline incidence of the health effect expected for the population amount *Pop.* Since we are dealing with mortality, the term PAF indicates the proportional reduction in population death that would occur if exposure to a risk factor were reduced to an alternative ideal exposure scenario.

The HRA presented in this report focuses on estimating mortality-related health outcomes: the number of premature deaths and YLL. Mortality measures the number of deaths in a particular population due to a specific or non-discriminated cause. Premature deaths occur before a person reaches an expected age, thus considered preventable if their cause is eliminated. The so-called expected age is usually the life expectancy for a country, typically stratified by sex and age. This health outcome is estimated as follows:

$$PD = PAF\ \sum_{a,s} CDR_{a,s} * Pop_{a,s} \qquad \text{(A1.5)}$$

where PD is the number of premature deaths, $CDR_{a,s}$ is the crude death rate by sex (s) and age (a) in a particular population due to a specific cause, and $Pop_{a,s}$ is the population fraction stratified by age and sex.

YLL is defined as the years of potential life lost in the population due to premature mortality. It is an estimate of the average number of years that a person would have lived if the person had not died prematurely. YLL takes into account the life expectancy at the moment of death and is greater for deaths at a younger age and lower for deaths at an older age (Murray and Lopez, 1996). It gives, therefore, more nuanced information than the number of premature deaths alone. YLL is determined by relating CDR with life expectancy:

$$YLL = PAF \sum_{a,s} CDR_{a,s} * Pop_{a,s} * LE_{a,s} \qquad \text{(A1.6)}$$

where $LE_{a,s}$ is the average time a person is expected to live, based on the year of birth, sex (s) and age (a).

For this HRA, Equations (A.1.1) to (A.1.6) are applied to every single grid cell of the concentration maps (*C* in A1.1). Table 2.1 and Table 2.2 describe the CRFs and C_0's used in this report. The health outcomes are then aggregated to country-level or larger areas, e.g., EU27.

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 (the whole Europe apart from Belarus, Moldova, Ukraine, and European parts of Russia and Kazakhstan; in the case of $PM_{2.5}$ Türkiye is also excluded due to lack of enough background stations to produce the maps). The annual statistics are estimated using a mapping method, 'Regression – Interpolation – Merging Mapping' (RIMM) using a linear regression model followed by kriging of its residuals (ETC HE, 2022b and references herein). The mapping method 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 or CAMS Ensemble and other supplementary data, such as altitude, meteorology, and population density. Urban traffic station data was also included for NO_2 and $PM_{2.5}$, to account for hotspots, since traffic is the most important source of NO_2 and an important source of PM. Lastly, the rural and urban background (and for NO_2 and $PM_{2.5}$ also urban traffic) map layers are merged into the final map and used as input data for the health risk assessment. Note that all the data supporting the RIMM refers to the year estimated.

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 from the HRA calculations.

The ETC HE Report (ETC HE, 2022b) includes the analysis of the latest maps available, including the associated uncertainties.

Population

The population data is used for estimating the health outcomes, as the health outcomes result from collocating concentration levels and populating density. Thus, the higher the population density, the higher the population risk will be if concentrations are above the counterfactual concentrations. We use population density maps (gridded) based on the GEOSTAT 2011 dataset (Eurostat, 2014), the European population distribution in 2011. It is mapped on the same grid resolution as the ambient air concentrations presented above facilitating the health outcomes estimation per grid-cell. The GEOSTAT 2011 population data was scaled with the total population data available country-wise from Eurostat (Eurostat, 2022a) to make it consistent with the estimated year. The data reflects the total population on the 31st of December of the indicated year reported by the National Statistical Offices. This data has been available yearly since 1960 for all countries across Europe. The scaling of the population (scaled pop_i) was done by applying the following:

$$scaled\ pop_i = pop_i \times \frac{pop_{c\_Eurstat}}{pop_c} \qquad \text{(A1.3)}$$

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 the estimated year.

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 Greek and Turkish Cypriots. The Eurostat data includes only Greek Cypriots, requiring the addition of the Turkish Cypriot population. These corrections mentioned above are done by applying additional scaling factors for France, Portugal, Spain, and Cyprus:

$$scaled\ pop_i = pop_i \times \frac{pop_{c\_Eurostat}}{pop_c} \times \frac{pop_{c2015}}{pop_{c\_Eurostat2015}} \quad \text{(A1.3)}$$

where pop_{c2015} is the total population for country *c* calculated based on the GEOSTAT 2011 population density map scaled for year 2015 (ETC/ATNI, 2018), and $pop_{c\_Eurostat2015}$ is the total population reported to Eurostat for country *c* for the year 2015 (Eurostat, 2022a). Year 2015 was arbitrary selected as reference for performing the spatial scaling of population numbers due to computationally demanding task of re-scaling the whole population density map for every single year. Plus, the ratios should remain fairly similar over the time.

The population distribution by age groups is required to estimate how many people have died per age group. Eurostat (2022b) provides data with a 1-year age interval, from 'less than a year' to 99 years old, for almost all countries assessed. Gap filling of missing information was necessary for several countries, years and age groups. It was done by using relative age distribution numbers (that is, the percentage of the population in each age group) from Serbia for other West Balkan countries, from Italy for San Marino, from France for Andorra and Monaco, and by applying average relative age distribution numbers from data available in 2005 – 2019 period for all other countries.

The population data have uncertainties inherent to statistical products and processes, and data completeness depends on the availability of raw data transmitted by the National Statistical Offices (ESS, 2012). Typically the data is available with two or more years of delay.

Demographic data

Data on the cause of death, number of natural deaths, and life expectancy are needed to calculate the health outcomes. The latter is needed only for estimating the years of life lost.

Eurostat data on causes of death (Eurostat, 2022c) is available since 2011 for 5-year interval, from less 'than 1 year' to '80 years or over'. It is compiled based on the ICD10 Mortality Tabulation List, the latest tabulation existing for mortality data. According to the description of the concentration-response functions (see Table 2.1), only natural deaths should be considered. Therefore, causes of death due to injury or poisoning (V01-Y89), unknown and unspecified causes (R00-R99), and total deaths due to all causes are excluded before calculations.

Estimating the number of natural deaths with a 1-year interval is based on interpolation using the ratio between all-natural deaths and all (natural + external) causes of death (5-year interval) and Eurostat data on the total number of deaths (Eurostat, 2022d) given with a 1-year interval.

After this operation, mortality data is aligned with life expectancy data, available from the Eurostat database (Eurostat, 2022e) on a 1-year interval, by age and sex, from 0 to 85+ years old, since 1960. Life expectancies are extrapolated for ages above 85, using regression on life expectancy data for age groups 79 – 85, to reflect all age groups available for mortality data (up to 95+).

Gap-filling was done for countries where the data described above is unavailable in the Eurostat datasets. Data on causes of death are available from 2011 onwards and that year is used as proxy for years 2005 - 2010. Afterwards, gap filling is performed for missing data on external causes of deaths using average of number of deaths due to external causes from previous 5 years. Then, missing numbers of deaths due to natural causes are gap-filled by subtracting the number of deaths due to external causes from the totals.

Data on the number of deaths and life expectancy are available for most countries since 2005. Nevertheless, for cases where data is unavailable, gap filling is performed using relative age distribution numbers of mortality (mortality ratios, or the number of deaths per population in each age group) and YLL ratios, following similar methodology as described for population numbers. 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.

Similarly, as 2020 data on causes of death, death numbers and life expectancy are still unavailable in Eurostat for some countries, relative age distribution numbers of mortality (mortality ratios) and YLL (YLL ratios) are used from the last available year. Tables with the logic of gap filling of demographic data (Data set vs Health risk assessment year vs proxy country) is available upon request.

The demographic data have uncertainties inherent to statistical products and processes, and data completeness depends on the availability of raw data transmitted by the National Statistical Offices (ESS, 2012). Typically the data is available with two or more years of delay. The data may also be available in different age aggregations (single-year *vs.* 5-year age intervals).

Annex 2 Estimating risk: a general understanding

To better understand the impact of changing the CRFs and counterfactual concentrations, the risk of exposure to a certain concentration level (1 µg/m^3 increment) is plotted against the population exposed to the same concentration levels in 41 (40 for $PM_{2.5}$) European countries in 2005 and 2020. Figure A2.1, Figure A2.2 and Figure A2.3 show the risk estimation (see Eq. A1.1) based on the baseline and sensitivity scenarios (specific for each pollutant). The CRFs and counterfactual concentrations are described in Table 2.1 and Table 2.2. The Figures also show the cumulative distribution of the European population exposed to the same levels of concentration for the analysis carried on in Section 4.

The CRF defines the slope of the risk function (assuming it has a linear shape) and the counterfactual concentration defines the lowest concentration level a population is exposed to that is considered in the estimation (risk of mortality = 1). Changing the CRF and assuming the same counterfactual concentration will impact the estimations linearly: the highest estimation will be based on the highest CRF and the difference between estimations will be higher when the concentration levels are higher.

Assuming a constant CRF and varying the counterfactual concentration implies that the higher the counterfactual concentrations, the lower the estimates will be. A lower counterfactual level implies that the risk analysis considers a larger range of concentration levels. When both CRF and counterfactual concentration vary, the concentration at the grid-cell level becomes a key factor in determining which scenario results in higher estimation since the functions tend to intersect at some point. For example, Figure A2.1 show the $PM_{2.5}$ baseline scenarios (see Table 2.2 for the description of the scenarios) intersect between 10 and 11 µg/m^3 for WHO2013 and ELAPSE and between 22 and 23 µg/m^3 for WHO2013 and WHO2021; Figure A2.2 show the NO_2 baseline scenarios intersect at between 25 and 26 µg/m^3 for WHO2013 and WHO2021 and between 66 and 67 µg/m^3 for WHO2013 and ELAPSE; and Figure A2.3 show no intersection for O_3 because the baseline scenarios assume the same counterfactual concentrations.

Figure A2.1 Mortality risk associated to exposure to $PM_{2.5}$ concentration levels estimated based on the baseline scenarios (solid lines) and specific sensitivity scenarios (dashed lines) (see Table 2.2) and the percentage of the European population exposed above the same concentration levels in 2005 and 2020

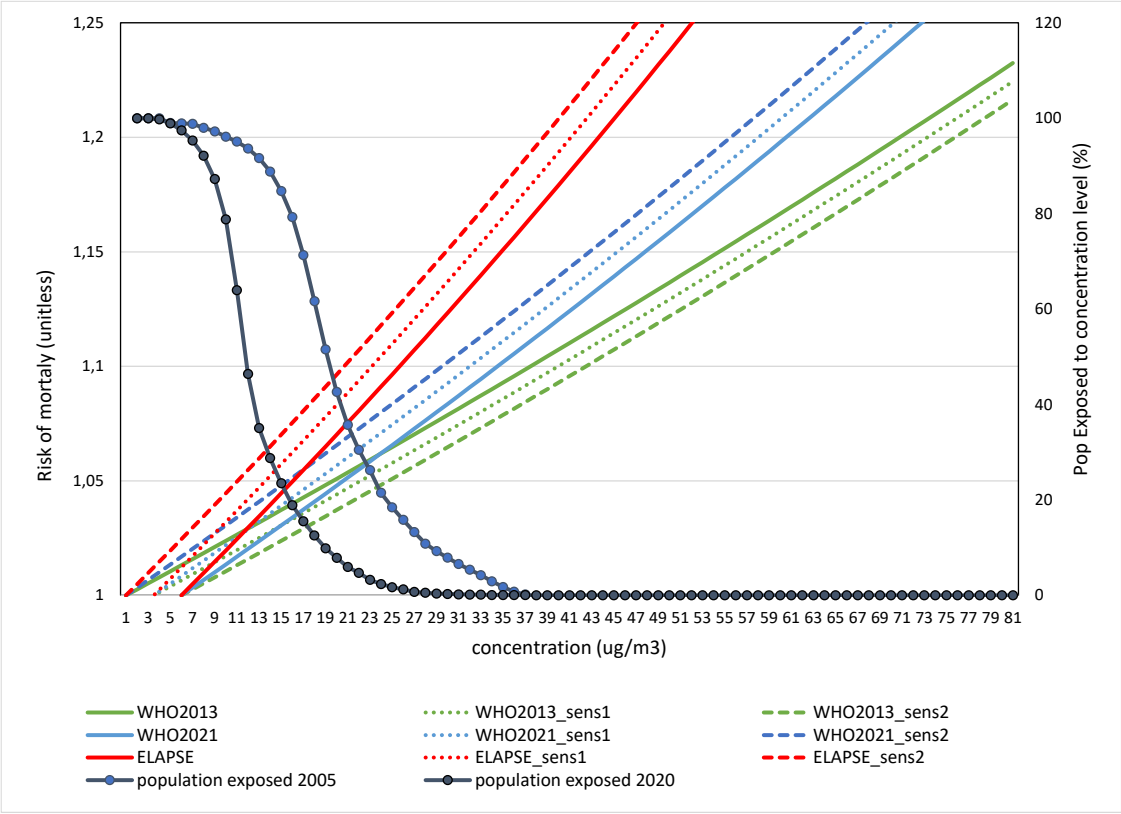


Figure A2.2 Mortality risk associated to exposure to NO_2 concentration levels estimated based on the baseline scenarios (solid lines) and specific sensitivity scenarios (dashed lines) (see Table 2.2) and the percentage of the European population exposed above the same concentration levels in 2005 and 2020.

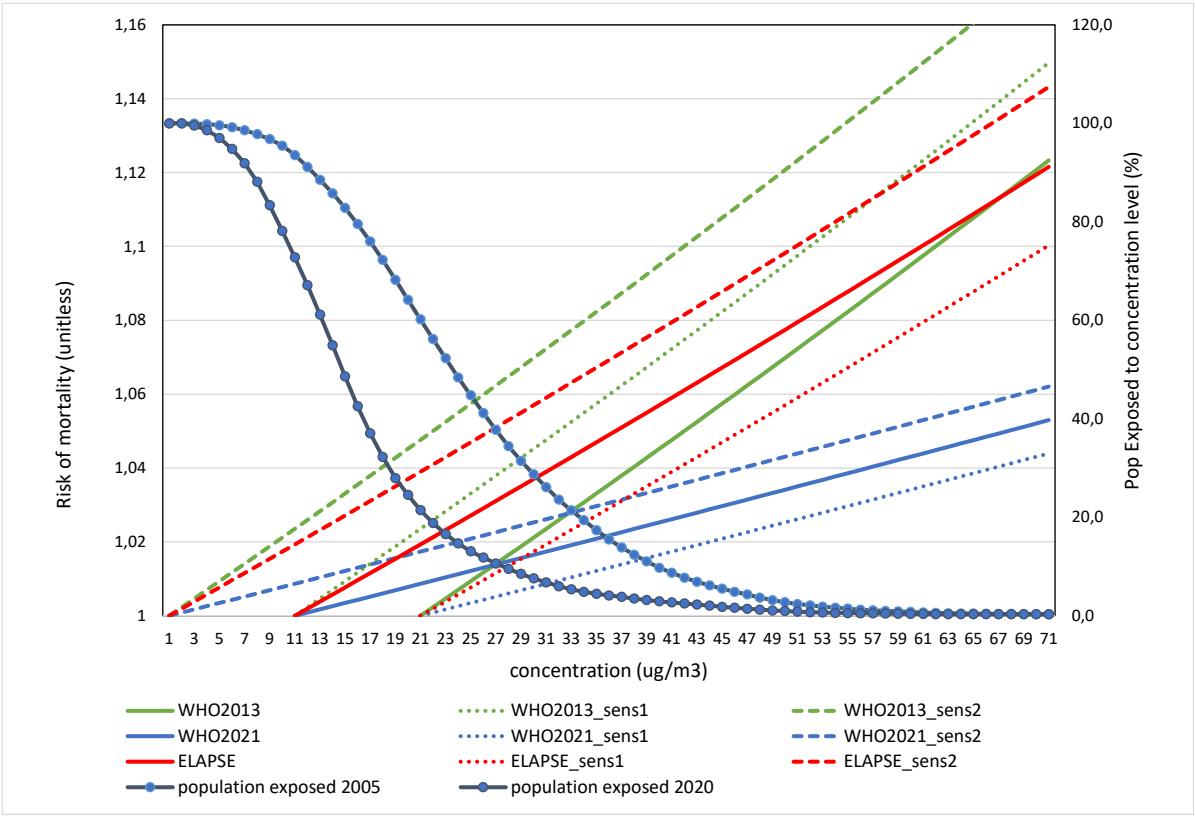
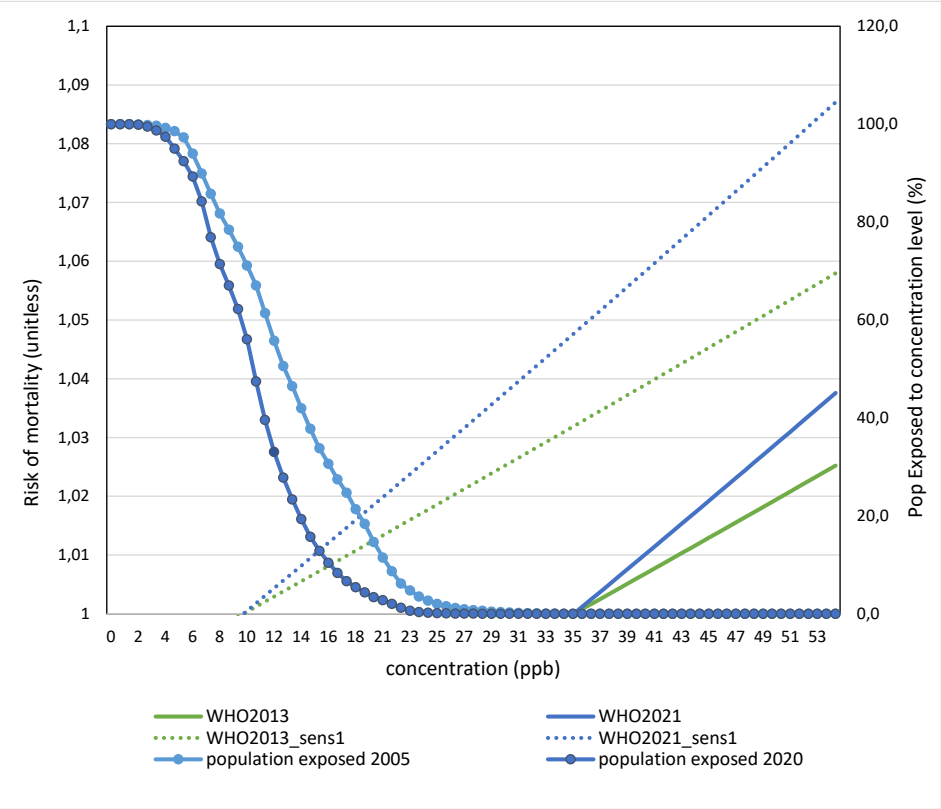


Figure A2.3 Mortality risk associated to exposure to O_3 concentration levels estimated based on the baseline scenarios (solid lines) and specific sensitivity scenarios (dashed lines) (see Table 2.2) and the percentage of the European population exposed above the same concentration levels in 2005 and 2020



Annex 3 Tables with the data supporting the Figures

Table A3.1 Number of premature deaths due to exposure to $PM_{2.5}$ concentration levels between 2005 and 2020 for all countries (except Türkiye) based on the baseline and sensitivity scenarios (see Table 2.2 for scenario description)

scenario	year	All countries (ex.TR)	Finland	Bulgaria
WHO2013	2005	499471	2228	18175
WHO2013_sens1	2005	441405	1604	16803
WHO2013_sens2	2005	382518	975	15419
WHO2021	2005	482037	1242	19274
WHO2021_sens1	2005	555345	2041	20969
WHO2021_sens2	2005	627330	2827	22636
ELAPSE	2005	677517	1787	26640
ELAPSE_sens2	2005	875666	4035	31073
ELAPSE_sens1	2005	777933	2925	28885
WHO2013	2007	427212	2279	16588
WHO2013_sens1	2007	368269	1639	15202
WHO2013_sens2	2007	308472	988	13794
WHO2021	2007	389939	1262	17304
WHO2021_sens1	2007	464733	2085	19032
WHO2021_sens2	2007	538141	2892	20730
ELAPSE	2007	551482	1814	24086
ELAPSE_sens2	2007	755666	4132	28639
ELAPSE_sens1	2007	654982	2987	26395
WHO2013	2008	431617	1962	17912
WHO2013_sens1	2008	372106	1316	16585
WHO2013_sens2	2008	311763	661	15232
WHO2021	2008	394002	845	19051
WHO2021_sens1	2008	469487	1677	20700
WHO2021_sens2	2008	543592	2495	22316
ELAPSE	2008	556973	1219	26354
ELAPSE_sens2	2008	763091	3569	30659
ELAPSE_sens1	2008	661423	2408	28537
WHO2013	2009	442005	1788	15565
WHO2013_sens1	2009	382054	1124	14234
WHO2013_sens2	2009	321368	493	12882
WHO2021	2009	406132	633	16160
WHO2021_sens1	2009	481983	1434	17825
WHO2021_sens2	2009	556612	2274	19455
ELAPSE	2009	573970	910	22512
ELAPSE_sens2	2009	781106	3260	26900
ELAPSE_sens1	2009	678821	2063	24735
WHO2013	2010	445577	2141	15426
WHO2013_sens1	2010	385551	1469	14055
WHO2013_sens2	2010	324692	790	12668
WHO2021	2010	410170	1012	15914
WHO2021_sens1	2010	486250	1873	17624
WHO2021_sens2	2010	560943	2726	19300
ELAPSE	2010	579268	1456	22211

scenario	year	All countries (ex.TR)	Finland	Bulgaria
ELAPSE_sens2	2010	786770	3892	26734
ELAPSE_sens1	2010	684406	2687	24507
WHO2013	2011	468245	2097	18629
WHO2013_sens1	2011	408977	1423	17335
WHO2013_sens2	2011	348825	746	16022
WHO2021	2011	440056	955	20002
WHO2021_sens1	2011	515085	1818	21600
WHO2021_sens2	2011	588757	2665	23174
ELAPSE	2011	619807	1376	27583
ELAPSE_sens2	2011	823738	3811	31733
ELAPSE_sens1	2011	723133	2607	29686
WHO2013	2012	426967	1999	15505
WHO2013_sens1	2012	365169	1305	14148
WHO2013_sens2	2012	302538	608	12774
WHO2021	2012	382397	775	16032
WHO2021_sens1	2012	460819	1662	17725
WHO2021_sens2	2012	537918	2540	19390
ELAPSE	2012	540633	1117	22348
ELAPSE_sens2	2012	755509	3633	26827
ELAPSE_sens1	2012	649446	2393	24621
WHO2013	2013	411160	1661	13469
WHO2013_sens1	2013	349432	966	12151
WHO2013_sens2	2013	286974	290	10815
WHO2021	2013	363050	372	13606
WHO2021_sens1	2013	441331	1230	15257
WHO2021_sens2	2013	518397	2113	16879
ELAPSE	2013	514204	536	19049
ELAPSE_sens2	2013	729237	3031	23459
ELAPSE_sens1	2013	623012	1774	21284
WHO2013	2014	378612	2104	14060
WHO2013_sens1	2014	317012	1401	12687
WHO2013_sens2	2014	254575	691	11292
WHO2021	2014	322326	883	14202
WHO2021_sens1	2014	400788	1787	15926
WHO2021_sens2	2014	477825	2677	17621
ELAPSE	2014	457420	1275	19878
ELAPSE_sens2	2014	673529	3827	24489
ELAPSE_sens1	2014	566915	2568	22213
WHO2013	2015	413149	1583	14469
WHO2013_sens1	2015	348294	862	13081
WHO2013_sens2	2015	282783	181	11670
WHO2021	2015	357799	230	14670
WHO2021_sens1	2015	440024	1104	16414
WHO2021_sens2	2015	521085	2012	18118
ELAPSE	2015	507032	331	20504
ELAPSE_sens2	2015	733553	2891	25143
ELAPSE_sens1	2015	621568	1588	22856
WHO2013	2016	382988	1584	13361
WHO2013_sens1	2016	319173	845	11994
WHO2013_sens2	2016	254736	179	10602

scenario	year	All countries (ex.TR)	Finland	Bulgaria
WHO2021	2016	322320	230	13327
WHO2021_sens1	2016	403289	1080	15051
WHO2021_sens2	2016	483163	2013	16744
ELAPSE	2016	456734	330	18643
ELAPSE_sens2	2016	680592	2894	23263
ELAPSE_sens1	2016	569908	1556	20988
WHO2013	2017	404170	1288	13265
WHO2013_sens1	2017	338664	551	11859
WHO2013_sens2	2017	273034	78	10433
WHO2021	2017	345093	98	13118
WHO2021_sens1	2017	427551	705	14892
WHO2021_sens2	2017	509443	1641	16627
ELAPSE	2017	487960	141	18376
ELAPSE_sens2	2017	716389	2360	23133
ELAPSE_sens1	2017	602993	1019	20785
WHO2013	2018	394015	1762	12376
WHO2013_sens1	2018	327963	1019	10970
WHO2013_sens2	2018	261293	356	9550
WHO2021	2018	330676	454	12025
WHO2021_sens1	2018	414489	1303	13795
WHO2021_sens2	2018	497166	2242	15533
ELAPSE	2018	468816	658	16883
ELAPSE_sens2	2018	700561	3213	21663
ELAPSE_sens1	2018	585983	1872	19306
WHO2013	2019	338808	1478	10700
WHO2013_sens1	2019	272483	742	9282
WHO2013_sens2	2019	205775	134	7835
WHO2021	2019	261047	170	9908
WHO2021_sens1	2019	345171	947	11713
WHO2021_sens2	2019	428477	1889	13483
ELAPSE	2019	371875	249	14015
ELAPSE_sens2	2019	606421	2706	18928
ELAPSE_sens1	2019	490232	1362	16504
WHO2013	2020	366113	1363	11735
WHO2013_sens1	2020	291439	603	10077
WHO2013_sens2	2020	216505	49	8391
WHO2021	2020	274623	62	10618
WHO2021_sens1	2020	369189	769	12729
WHO2021_sens2	2020	463063	1741	14795
ELAPSE	2020	391149	91	15049
ELAPSE_sens2	2020	655578	2501	20816
ELAPSE_sens1	2020	524406	1112	17971

Table A3.2: Number of premature deaths related to exposure to $PM_{2.5}$: comparing between specific scenarios and the adopted baseline scenario (WHO2021), relative to WHO2021 (see Table 2.2 for scenario description)

scenario	year	All countries (ex.TR)	Finland	Bulgaria
WHO2021_sens1	2005	-15.21	-64.33	-8.79
WHO2021_sens1	2007	-19.18	-65.21	-9.99
WHO2021_sens1	2008	-19.16	-98.46	-8.66
WHO2021_sens1	2009	-18.68	-126.54	-10.30
WHO2021_sens1	2010	-18.55	-85.08	-10.75
WHO2021_sens1	2011	-17.05	-90.37	-7.99
WHO2021_sens1	2012	-20.51	-114.45	-10.56
WHO2021_sens1	2013	-21.56	-230.65	-12.13
WHO2021_sens1	2014	-24.34	-102.38	-12.14
WHO2021_sens1	2015	-22.98	-380.00	-11.89
WHO2021_sens1	2016	-25.12	-369.57	-12.94
WHO2021_sens1	2017	-23.89	-619.39	-13.52
WHO2021_sens1	2018	-25.35	-187.00	-14.72
WHO2021_sens1	2019	-32.23	-457.06	-18.22
WHO2021_sens1	2020	-34.43	-1140.32	-19.88
WHO2021_sens2	2005	-30.14	-127.62	-17.44
WHO2021_sens2	2007	-38.01	-129.16	-19.80
WHO2021_sens2	2008	-37.97	-195.27	-17.14
WHO2021_sens2	2009	-37.05	-259.24	-20.39
WHO2021_sens2	2010	-36.76	-169.37	-21.28
WHO2021_sens2	2011	-33.79	-179.06	-15.86
WHO2021_sens2	2012	-40.67	-227.74	-20.95
WHO2021_sens2	2013	-42.79	-468.01	-24.06
WHO2021_sens2	2014	-48.24	-203.17	-24.07
WHO2021_sens2	2015	-45.64	-774.78	-23.50
WHO2021_sens2	2016	-49.90	-775.22	-25.64
WHO2021_sens2	2017	-47.62	-1574.49	-26.75
WHO2021_sens2	2018	-50.35	-393.83	-29.17
WHO2021_sens2	2019	-64.14	-1011.18	-36.08
WHO2021_sens2	2020	-68.62	-2708.06	-39.34
WHO2013	2005	-3.62	-79.39	5.70
WHO2013	2007	-9.56	-80.59	4.14
WHO2013	2008	-9.55	-132.19	5.98
WHO2013	2009	-8.83	-182.46	3.68
WHO2013	2010	-8.63	-111.56	3.07
WHO2013	2011	-6.41	-119.58	6.86
WHO2013	2012	-11.66	-157.94	3.29
WHO2013	2013	-13.25	-346.51	1.01
WHO2013	2014	-17.46	-138.28	1.00
WHO2013	2015	-15.47	-588.26	1.37
WHO2013	2016	-18.82	-588.70	-0.26
WHO2013	2017	-17.12	-1214.29	-1.12
WHO2013	2018	-19.15	-288.11	-2.92
WHO2013	2019	-29.79	-769.41	-7.99
WHO2013	2020	-33.31	-2098.39	-10.52
WHO2013_sens2	2005	20.65	21.50	20.00

scenario	year	All countries (ex.TR)	Finland	Bulgaria
WHO2013_sens2	2007	20.89	21.71	20.28
WHO2013_sens2	2008	20.87	21.78	20.05
WHO2013_sens2	2009	20.87	22.12	20.28
WHO2013_sens2	2010	20.84	21.94	20.40
WHO2013_sens2	2011	20.73	21.88	19.90
WHO2013_sens2	2012	20.88	21.55	20.32
WHO2013_sens2	2013	20.95	22.04	20.51
WHO2013_sens2	2014	21.02	21.74	20.49
WHO2013_sens2	2015	20.97	21.30	20.45
WHO2013_sens2	2016	20.97	22.17	20.45
WHO2013_sens2	2017	20.88	20.41	20.47
WHO2013_sens2	2018	20.98	21.59	20.58
WHO2013_sens2	2019	21.17	21.18	20.92
WHO2013_sens2	2020	21.16	20.97	20.97
ELAPSE	2005	-40.55	-43.88	-38.22
ELAPSE	2007	-41.43	-43.74	-39.19
ELAPSE	2008	-41.36	-44.26	-38.33
ELAPSE	2009	-41.33	-43.76	-39.31
ELAPSE	2010	-41.23	-43.87	-39.57
ELAPSE	2011	-40.85	-44.08	-37.90
ELAPSE	2012	-41.38	-44.13	-39.40
ELAPSE	2013	-41.63	-44.09	-40.00
ELAPSE	2014	-41.91	-44.39	-39.97
ELAPSE	2015	-41.71	-43.91	-39.77
ELAPSE	2016	-41.70	-43.48	-39.89
ELAPSE	2017	-41.40	-43.88	-40.08
ELAPSE	2018	-41.78	-44.93	-40.40
ELAPSE	2019	-42.46	-46.47	-41.45
ELAPSE	2020	-42.43	-46.77	-41.73

Table A3.3: Number of premature deaths due to exposure to NO_2 concentration levels between 2005 and 2020 for all countries based on the baseline and sensitivity scenarios (see Table 2.2 for scenario description)

scenario	year	All countries (ex.TR)	Finland	Italy
WHO2013	2005	118550	133	33204
WHO2013_sens1	2005	282532	1307	57334
WHO2013_sens2	2005	488225	3166	82385
WHO2021	2005	108083	491	22185
WHO2021_sens2	2005	188855	1205	32299
WHO2021_sens1	2005	45047	48	12715
ELAPSE	2005	234474	1078	47732
ELAPSE_sens2	2005	406425	2625	68845
ELAPSE_sens1	2005	98204	108	27557
WHO2013	2009	103143	28	28261
WHO2013_sens1	2009	267216	686	53082
WHO2013_sens2	2009	476357	2546	79573
WHO2021	2009	101956	257	20447
WHO2021_sens2	2009	183814	963	31052
WHO2021_sens1	2009	39066	10	10778
ELAPSE	2009	221625	567	44135
ELAPSE_sens2	2009	396301	2108	66411
ELAPSE_sens1	2009	85366	23	23430
WHO2013	2010	97243	49	21998
WHO2013_sens1	2010	261666	870	45247
WHO2013_sens2	2010	472171	2907	71793
WHO2021	2010	99706	328	17375
WHO2021_sens2	2010	182022	1102	27900
WHO2021_sens1	2010	36755	18	8365
ELAPSE	2010	216946	719	37596
ELAPSE_sens2	2010	392700	2406	59844
ELAPSE_sens1	2010	80446	41	18230
WHO2013	2013	67686	7	18227
WHO2013_sens1	2013	216903	468	40735
WHO2013_sens2	2013	429950	2295	68082
WHO2021	2013	82399	176	15600
WHO2021_sens2	2013	165133	868	26377
WHO2021_sens1	2013	25537	3	6922
ELAPSE	2013	179678	385	33815
ELAPSE_sens2	2013	357215	1898	56698
ELAPSE_sens1	2013	55960	6	15098
WHO2013	2014	56934	6	14934
WHO2013_sens1	2014	196712	423	37065
WHO2013_sens2	2014	406955	2075	64480
WHO2021	2014	74633	160	14155
WHO2021_sens2	2014	156053	783	24918
WHO2021_sens1	2014	21449	2	5663
ELAPSE	2014	162870	350	30744
ELAPSE_sens2	2014	337963	1716	53659
ELAPSE_sens1	2014	47064	5	12364
WHO2013	2015	69134	2	21880

scenario	year	All countries (ex.TR)	Finland	Italy
WHO2013_sens1	2015	220055	389	47308
WHO2013_sens2	2015	442444	2228	76741
WHO2021	2015	83611	143	18161
WHO2021_sens2	2015	169925	840	29800
WHO2021_sens1	2015	26146	1	8342
ELAPSE	2015	182281	318	39301
ELAPSE_sens2	2015	367598	1842	63955
ELAPSE_sens1	2015	57200	1	18142
WHO2013	2016	79055	0	14079
WHO2013_sens1	2016	238112	251	36957
WHO2013_sens2	2016	471389	2096	65182
WHO2021	2016	90631	91	14095
WHO2021_sens2	2016	181216	789	25160
WHO2021_sens1	2016	29949	0	5334
ELAPSE	2016	197334	210	30643
ELAPSE_sens2	2016	391747	1730	54232
ELAPSE_sens1	2016	65430	0	11649
WHO2013	2017	83557	0	15952
WHO2013_sens1	2017	245228	180	39103
WHO2013_sens2	2017	483748	1973	68708
WHO2021	2017	93388	65	14938
WHO2021_sens2	2017	186037	741	26542
WHO2021_sens1	2017	31657	0	6044
ELAPSE	2017	203269	146	32443
ELAPSE_sens2	2017	402075	1630	57176
ELAPSE_sens1	2017	69167	0	13204
WHO2013	2018	69221	0	10759
WHO2013_sens1	2018	230166	358	32370
WHO2013_sens2	2018	471820	2260	61390
WHO2021	2018	87420	133	12298
WHO2021_sens2	2018	181078	855	23610
WHO2021_sens1	2018	26176	0	4061
ELAPSE	2018	190650	295	26820
ELAPSE_sens2	2018	391917	1870	51026
ELAPSE_sens1	2018	57272	0	8892
WHO2013	2019	61224	0	10796
WHO2013_sens1	2019	210476	240	32171
WHO2013_sens2	2019	450233	2147	61269
WHO2021	2019	79921	87	12242
WHO2021_sens2	2019	172605	804	23567
WHO2021_sens1	2019	23188	0	4079
ELAPSE	2019	174322	197	26664
ELAPSE_sens2	2019	373857	1772	50926
ELAPSE_sens1	2019	50654	0	8927
WHO2013	2020	38699	0	7023
WHO2013_sens1	2020	170044	21	29506
WHO2013_sens2	2020	435689	1675	63884
WHO2021	2020	64320	7	11165
WHO2021_sens2	2020	166248	628	24443
WHO2021_sens1	2020	14641	0	2639

scenario	year	All countries (ex.TR)	Finland	Italy
ELAPSE	2020	140709	17	24414
ELAPSE_sens2	2020	361318	1383	53025
ELAPSE_sens1	2020	32016	0	5802

Table A3.4 Number of premature deaths related to exposure to NO_2: comparison between specific scenarios and the adopted baseline scenario (WHO2021), relative to WHO2021 (see Table 2.2 for scenario description)

scenario	year	All countries (ex.TR)	Finland	Italy
WHO2021_sens1	2005	58.32	90.22	42.69
WHO2021_sens1	2007	61.68	96.11	47.29
WHO2021_sens1	2008	63.14	94.51	51.86
WHO2021_sens1	2009	69.01	98.30	55.63
WHO2021_sens1	2010	71.26	98.75	59.99
WHO2021_sens1	2011	68.73	99.30	54.07
WHO2021_sens1	2012	66.96	100.00	62.16
WHO2021_sens1	2013	66.10	100.00	59.54
WHO2021_sens1	2014	70.06	100.00	66.98
WHO2021_sens1	2015	70.99	100.00	66.68
WHO2021_sens1	2016	77.24	100.00	76.36
WHO2021_sens1	2017	-74.73	-145.42	-45.59
WHO2021_sens1	2018	-80.29	-274.71	-51.87
WHO2021_sens1	2019	-82.56	-235.98	-60.58
WHO2021_sens1	2020	-100.41	-393.18	-69.08
WHO2021_sens2	2005	-109.09	-389.38	-76.04
WHO2021_sens2	2007	-103.23	-487.41	-64.09
WHO2021_sens2	2008	-99.95	-767.03	-78.50
WHO2021_sens2	2009	-99.21	-1040.00	-77.68
WHO2021_sens2	2010	-107.14	-542.86	-91.98
WHO2021_sens2	2011	-115.97	-824.14	-92.51
WHO2021_sens2	2012	-158.47	-8871.43	-118.93
WHO2021_sens2	2013	-9.68	72.91	-49.67
WHO2021_sens2	2014	-1.16	89.11	-38.22
WHO2021_sens2	2015	2.47	85.06	-26.61
WHO2021_sens2	2016	17.86	96.02	-16.84
WHO2021_sens2	2017	23.71	96.25	-5.50
WHO2021_sens2	2018	17.31	98.60	-20.48
WHO2021_sens2	2019	12.77	100.00	0.11
WHO2021_sens2	2020	10.53	100.00	-6.79
WHO2013	2005	20.82	100.00	12.51
WHO2013	2007	23.39	100.00	11.81
WHO2013	2008	39.83	100.00	37.10
WHO2013	2009	-161.40	-166.19	-158.44
WHO2013	2010	-162.09	-166.93	-159.61
WHO2013	2011	-162.44	-165.24	-160.41
WHO2013	2012	-163.23	-165.91	-161.12
WHO2013	2013	-163.57	-164.38	-161.85
WHO2013	2014	-163.19	-172.03	-160.49
WHO2013	2015	-162.73	-175.82	-162.20
WHO2013	2016	-162.59	-176.92	-161.77
WHO2013	2017	-163.29	-169.17	-163.21
WHO2013	2018	-163.36	-175.86	-162.79
WHO2013	2019	-164.37	-200.00	-164.27
WHO2013	2020	-116.94	-119.55	-115.15

scenario	year	All countries (ex.TR)	Finland	Italy
WHO2013_sens2	2005	-117.37	-120.62	-115.85
WHO2013_sens2	2007	-117.59	-119.21	-116.38
WHO2013_sens2	2008	-118.06	-118.75	-116.76
WHO2013_sens2	2009	-118.23	-118.75	-117.20
WHO2013_sens2	2010	-118.01	-122.38	-116.40
WHO2013_sens2	2011	-117.73	-130.77	-117.40
WHO2013_sens2	2012	-117.66	-124.62	-117.18
WHO2013_sens2	2013	-118.09	-121.80	-118.08
WHO2013_sens2	2014	-118.12	-126.44	-117.81
WHO2013_sens2	2015	-118.76	-142.86	-118.67
WHO2013_sens2	2016	20.97	22.17	20.45
WHO2013_sens2	2017	20.88	20.41	20.47
WHO2013_sens2	2018	20.98	21.59	20.58
WHO2013_sens2	2019	21.17	21.18	20.92
WHO2013_sens2	2020	21.16	20.97	20.97
ELAPSE	2005	-40.55	-43.88	-38.22
ELAPSE	2007	-41.43	-43.74	-39.19
ELAPSE	2008	-41.36	-44.26	-38.33
ELAPSE	2009	-41.33	-43.76	-39.31
ELAPSE	2010	-41.23	-43.87	-39.57
ELAPSE	2011	-40.85	-44.08	-37.90
ELAPSE	2012	-41.38	-44.13	-39.40
ELAPSE	2013	-41.63	-44.09	-40.00
ELAPSE	2014	-41.91	-44.39	-39.97
ELAPSE	2015	-41.71	-43.91	-39.77
ELAPSE	2016	-41.70	-43.48	-39.89
ELAPSE	2017	-41.40	-43.88	-40.08
ELAPSE	2018	-41.78	-44.93	-40.40
ELAPSE	2019	-42.46	-46.47	-41.45
ELAPSE	2020	-42.43	-46.77	-41.73

Table A3.5: Number of premature deaths due to exposure to O_3 concentration levels between 2005 and 2020 for all countries based on the baseline scenarios (see Table 2.2 for scenario description)

scenario	year	All countries	Finland	Italy
WHO2013	2005	17571	82	3192
WHO2021	2005	25958	121	4721
WHO2013	2006	18346	105	3402
WHO2021	2006	27147	157	5035
WHO2013	2007	16632	47	3174
WHO2021	2007	24624	70	4702
WHO2013	2008	15880	70	2786
WHO2021	2008	23513	101	4119
WHO2013	2009	16409	58	3105
WHO2021	2009	24285	85	4589
WHO2013	2010	14819	71	2775
WHO2021	2010	21949	105	4104
WHO2013	2011	16580	77	3332
WHO2021	2011	24532	110	4930
WHO2013	2012	16821	62	3340
WHO2021	2012	24895	91	4936
WHO2013	2013	15801	77	2997
WHO2021	2013	23405	109	4446
WHO2013	2014	13300	63	2529
WHO2021	2014	19689	89	3757
WHO2013	2015	17850	54	3381
WHO2021	2015	26413	77	5002
WHO2013	2016	15943	61	2827
WHO2021	2016	23629	92	4190
WHO2013	2017	17724	46	3657
WHO2021	2017	26227	66	5409
WHO2013	2018	21876	94	3122
WHO2021	2018	32375	139	4623
WHO2013	2019	19964	91	3216
WHO2021	2019	29541	138	4759
WHO2013	2020	19166	55	3436
WHO2021	2020	28355	83	5083

Table A3.6: Number of premature deaths related to exposure to O_3: comparison between specific scenarios to baseline scenario WHO2021 (see Table 2.2 for scenario description)

scenario	year	All countries (ex.TR)	Finland	Italy
WHO2013	2005	32.31	32.23	32.39
WHO2013	2006	32.42	33.12	32.43
WHO2013	2007	32.46	32.86	32.50
WHO2013	2008	32.46	30.69	32.36
WHO2013	2009	32.43	31.76	32.34
WHO2013	2010	32.48	32.38	32.38
WHO2013	2011	32.41	30.00	32.41
WHO2013	2012	32.43	31.87	32.33
WHO2013	2013	32.49	29.36	32.59
WHO2013	2014	32.45	29.21	32.69
WHO2013	2015	32.42	29.87	32.41
WHO2013	2016	32.53	33.70	32.53
WHO2013	2017	32.42	30.30	32.39
WHO2013	2018	32.43	32.37	32.47
WHO2013	2019	32.42	34.06	32.42
WHO2013	2020	32.41	33.73	32.40

Table A3.7: Number of premature deaths (PD) and years of life lost per 100 000 inhabitants (YLL_per105) due to exposure to $PM_{2.5}$, NO_2, and O_3 concentration levels in 2020 for individual countries for the baseline estimations (see Table 2.2 for scenario description)

		$PM_{2.5}$		NO_2		O_3	
area	scenario	PD	YLL_per105	PD	YLL_per105	PD	YLL_per105
Andorra	WHO2013	36	494	0	1	2	23
Andorra	WHO2021	19	267	11	150	2	35
Andorra	ELAPSE	28	384	24	329	2	35
Albania	WHO2013	4173	1483	27	10	212	78
Albania	WHO2021	3648	1296	325	116	311	115
Albania	ELAPSE	5184	1842	720	256	311	115
Austria	WHO2013	4980	537	236	26	315	35
Austria	WHO2021	3184	344	814	88	466	52
Austria	ELAPSE	4571	493	1794	193	466	52
Bosnia and Herzegovina	WHO2013	8937	2322	239	62	202	54
Bosnia and Herzegovina	WHO2021	9155	2379	610	158	299	81
Bosnia and Herzegovina	ELAPSE	12751	3313	1339	348	299	81
Belgium	WHO2013	6523	521	134	11	358	30
Belgium	WHO2021	3931	314	1064	85	532	44
Belgium	ELAPSE	5657	451	2338	187	532	44
Bulgaria	WHO2013	11735	1715	749	109	289	43
Bulgaria	WHO2021	10618	1552	1676	245	426	64
Bulgaria	ELAPSE	15049	2199	3677	537	426	64
Switzerland	WHO2013	3419	369	26	3	309	35
Switzerland	WHO2021	1719	186	663	72	454	52
Switzerland	ELAPSE	2475	268	1461	158	454	52
Cyprus	WHO2013	679	591	133	116	42	38
Cyprus	WHO2021	564	490	183	160	62	57
Cyprus	ELAPSE	805	700	402	350	62	57
Czechia	WHO2013	8913	830	28	3	417	40
Czechia	WHO2021	6900	643	736	68	617	59
Czechia	ELAPSE	9863	919	1622	151	617	59
Germany	WHO2013	49818	614	2022	25	3141	40
Germany	WHO2021	28909	356	10015	123	4637	59
Germany	ELAPSE	41606	513	22042	272	4637	59
Denmark	WHO2013	2336	433	0	0	95	18
Denmark	WHO2021	1043	193	41	8	142	27
Denmark	ELAPSE	1504	279	90	17	142	27
Estonia	WHO2013	478	414	0	0	17	15
Estonia	WHO2021	59	52	1	0	25	23
Estonia	ELAPSE	88	75	1	1	25	23
Spain	WHO2013	26334	565	2743	59	1623	36
Spain	WHO2021	16990	365	4809	103	2410	53
Spain	ELAPSE	24380	523	10542	226	2410	53
Finland	WHO2013	1363	267	0	0	55	11
Finland	WHO2021	62	12	7	2	83	17
Finland	ELAPSE	91	18	17	3	83	17
France	WHO2013	30466	497	1945	32	2064	35
France	WHO2021	16531	270	4416	72	3051	52

area	scenario	$PM_{2.5}$		NO_2		O_3	
		PD	YLL_per105	PD	YLL_per105	PD	YLL_per105
France	ELAPSE	23786	388	9690	158	3051	52
Greece	WHO2013	10497	955	1493	136	616	58
Greece	WHO2021	8842	804	1881	171	915	85
Greece	ELAPSE	12589	1145	4106	374	915	85
Croatia	WHO2013	4741	1137	61	15	207	50
Croatia	WHO2021	4106	985	423	102	303	75
Croatia	ELAPSE	5830	1399	936	224	303	75
Hungary	WHO2013	11235	1245	696	77	436	50
Hungary	WHO2021	9470	1049	1388	154	644	73
Hungary	ELAPSE	13501	1495	3043	337	644	73
Ireland	WHO2013	1283	311	0	0	46	12
Ireland	WHO2021	494	120	47	12	69	18
Ireland	ELAPSE	711	173	106	26	69	18
Iceland	WHO2013	52	163	0	0	3	9
Iceland	WHO2021	0	1	0	1	3	13
Iceland	ELAPSE	1	2	1	3	3	13
Italy	WHO2013	61214	907	7023	104	3436	52
Italy	WHO2021	52310	775	11165	165	5083	77
Italy	ELAPSE	74279	1101	24414	362	5083	77
Liechtenstein	WHO2013	15	377	0	0	1	34
Liechtenstein	WHO2021	7	186	3	85	2	52
Liechtenstein	ELAPSE	11	268	7	186	2	52
Lithuania	WHO2013	2320	905	0	0	67	27
Lithuania	WHO2021	1462	571	137	54	98	39
Lithuania	ELAPSE	2102	820	303	119	98	39
Luxembourg	WHO2013	185	319	4	8	15	27
Luxembourg	WHO2021	75	129	52	89	22	40
Luxembourg	ELAPSE	108	187	114	197	22	40
Latvia	WHO2013	1435	819	0	0	38	21
Latvia	WHO2021	832	474	102	59	54	32
Latvia	ELAPSE	1195	681	227	130	54	32
Monaco	WHO2013	22	603	0	0	2	55
Monaco	WHO2021	15	407	5	157	2	78
Monaco	ELAPSE	21	582	13	347	2	78
Montenegro	WHO2013	1007	1677	0	0	35	61
Montenegro	WHO2021	920	1531	92	153	52	90
Montenegro	ELAPSE	1303	2168	202	338	52	90
North Macedonia	WHO2013	3900	1730	12	5	118	54
North Macedonia	WHO2021	3757	1668	289	128	175	80
North Macedonia	ELAPSE	5289	2348	638	283	175	80
Malta	WHO2013	232	515	0	0	21	46
Malta	WHO2021	152	338	12	26	31	68
Malta	ELAPSE	218	485	26	58	31	68
Netherlands	WHO2013	8475	488	181	10	433	26
Netherlands	WHO2021	4974	286	1841	106	638	39
Netherlands	ELAPSE	7156	412	4056	233	638	39
Norway	WHO2013	1031	199	0	0	60	12

		$PM_{2.5}$		NO_2		O_3	
area	**scenario**	**PD**	**YLL_per105**	**PD**	**YLL_per105**	**PD**	**YLL_per105**
Norway	WHO2021	159	30	92	18	92	18
Norway	ELAPSE	228	44	208	40	92	18
Poland	WHO2013	41429	1242	566	17	1164	36
Poland	WHO2021	36538	1095	3383	101	1727	53
Poland	ELAPSE	51888	1555	7453	223	1727	53
Portugal	WHO2013	5296	528	186	19	320	33
Portugal	WHO2021	2645	264	849	85	472	49
Portugal	ELAPSE	3804	379	1871	187	472	49
Romania	WHO2013	24980	1403	1644	92	676	39
Romania	WHO2021	21558	1211	3108	175	997	58
Romania	ELAPSE	30658	1722	6813	383	997	58
Serbia	WHO2013	14433	2071	220	32	280	42
Serbia	WHO2021	14374	2063	1154	166	415	62
Serbia	ELAPSE	20181	2896	2542	365	415	62
Sweden	WHO2013	2655	232	0	0	159	15
Sweden	WHO2021	369	32	42	4	239	22
Sweden	ELAPSE	535	47	94	8	239	22
Slovenia	WHO2013	1624	737	1	1	91	41
Slovenia	WHO2021	1256	569	152	69	133	61
Slovenia	ELAPSE	1794	813	338	153	133	61
Slovakia	WHO2013	4618	993	0	0	172	39
Slovakia	WHO2021	3894	838	207	45	255	57
Slovakia	ELAPSE	5552	1194	460	99	255	57
San Marino	WHO2013	31	783	0	0	2	46
San Marino	WHO2021	24	613	3	69	3	69
San Marino	ELAPSE	35	878	6	153	3	69
Kosovo	WHO2013	3213	1792	15	8	91	52
Kosovo	WHO2021	3058	1706	264	147	134	78
Kosovo	ELAPSE	4322	2411	581	324	134	78
Türkiye	WHO2013	N/A	N/A	18315	291	1536	30
Türkiye	WHO2021	N/A	N/A	12258	195	2280	44
Türkiye	ELAPSE	N/A	N/A	26392	419	2280	44

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