ETC HE Report 2022/11

Estimating the morbidity related environmental burden of disease due to exposure to $PM_{2.5}$, NO_2 and O_3 in outdoor ambient air

Authors:
Sarah Kienzler (UBA), Joana Soares (NILU), Alberto González Ortiz (EEA), Dietrich Plass (UBA)

European Environment Agency
European Topic Centre
Human health and the environment

Cover design: EEA
Layout: EEA / ETC HE

Publication Date:
ISBN 978-82-93970-07-1

How to cite this report:
Kienzler, S., Soares, J., González Ortiz, & A., Plass, D. (2022). *Estimating the morbidity related environmental burden of disease due to exposure to $PM_{2.5}$, NO_2 and O_3 in outdoor ambient air.* (Eionet Report – ETC HE 2022/11). European Topic Centre on Human Health and the Environment.

The report is available from https://www.eionet.europa.eu/etcs/all-etc-reports and https://zenodo.org/communities/eea-etc/?page=1&size=20.

ETC HE coordinator: NILU - Stiftelsen Norsk institutt for luftforskning (NILU - Norwegian Institute for Air Research)

ETC HE consortium partners: German Environment Agency/Umweltbundesamt (UBA), Aether Limited, Czech Hydrometeorological Institute (CHMI), Institut National de l'Environnement Industriel et des Risques (INERIS), Swiss Tropical and Public Health Institute (Swiss TPH), Universitat Autònoma de Barcelona (UAB), Vlaamse Instelling voor Technologisch Onderzoek (VITO), 4sfera Innova S.L.U., klarFAKTe.U

European Topic Centre on
Human health and the environment (ETC HE)
https://www.eionet.europa.eu/etcs/etc-he

Contents

Acknowledgements

The ETC task manager was Cristina Guerreiro (NILU). The EEA task manager was Alberto González Ortiz.

Other contributors were Simone Schucht (INERIS), Mike Holland (Imperial College & EMRC) and Joseph V. Spadaro (SERC, WHO consultant, ECEH office Bonn).

Additionally, Jan Horálek (CHMI) provided valuable data input.

Summary

Epidemiological studies have increasingly shown that ambient air pollution is not only associated with mortality but also with the occurrence of a number of long and short-term diseases. Further, the Global Burden of Disease study clearly indicated, that e. g. particulate matter pollution is also associated with a considerable burden of disease related to morbidity effects.

In addition to the most recent EEA's health risk assessments, this report estimates the morbidity related health burden associated with exposure to the same three key air pollutants: fine particulate matter ($PM_{2.5}$), nitrogen dioxide (NO_2) and ozone (O_3). Years lived with disability (YLDs) or attributable hospitalisation cases are assessed for the year 2019 for numerous European countries, depending on the respective data availability. Besides, the methodological approach as well as reviews on evidence-based health outcomes, health data and concentration-response functions are provided.

For the ten considered risk-outcome pairs, the results showed the highest morbidity related burden of disease in Europe for $PM_{2.5}$ associated with chronic obstructive pulmonary disease (COPD) with 51.6 YLDs per 100 000 inhabitants ≥25 years. For NO_2 the highest morbidity burden resulted from diabetes mellitus (DM) with 54.6 YLDs per 100 000 inhabitants ≥35 years. For short-term O_3 exposure hospital admissions due to respiratory diseases were estimated at 18 attributable cases per 100 000 inhabitants ≥65 years.

In addition to the estimates, the report contains suggestions for further sensitivity analyses. These would allow a better assessment of the effects resulting from different input data on the results.

The estimations presented in this report are the first of its kind that are carried out for a wide range of morbidity health outcomes associated with different outdoor air pollutants in Europe, using a consistent methodology and data from European health databases.

1 Importance of the morbidity component for assessments of the environmental burden of disease due to ambient air pollution

The general advantage of burden of disease (BoD) assessments compared to the use of single epidemiological health indicators such as mortality or incidence rates is that, by using summary measures, they allow to capture a more comprehensive impact of diseases, injuries and risk factors on population health, using e.g. the Disability-Adjusted Life Year (DALY) as the core summary measure to assess the population health status (GBD 2019 Diseases and Injuries Collaborators, 2020). DALYs can be calculated from the sum of years of life lost (YLLs) due to premature death and years lived with disability (YLDs). In addition, monetization of health effects may further enhance the value of BoD estimates, which however is not the focus of this report.

To estimate the overall BoD quantified by YLLs and YLDs several epidemiological parameters and additional assumptions are needed. The YLLs are estimated by multiplying the number of age- and sex-specific deaths due to a certain cause by the remaining life expectancy at age of death. For life expectancy an aspirational global standard or an observed national standard can be used, depending on the goals of the assessment. The YLDs are estimated by multiplying age- and sex specific number of cases (prevalence) by a disability weight (DW), indicating the severity of a disease on a scale from zero (no reduction of health) to one, the worst imaginable health state sometimes set equal to death. The DALYs are the sum of the YLLs and YLDs.

Because estimating DALYs for health outcomes and DALYs attributable to risk factors especially for many countries is very data demanding, many assessments focus on single health indicators (EEA, 2020; Pifarré i Arolas et al., 2021; Plass et al., 2013; Vlajinac et al., 2008). These are for example 'attributable deaths' or the YLLs, the mortality component of the DALYs (Murray, 1994). The preference for mortality-based indicators is mostly related to the greater availability and quality of mortality data from death registries. Especially, when the aim is to estimate the BoD of risk factors for a large number of countries, mortality data is readily available from supranational organizations such as the World Health Organisation (WHO) or European institutions such as Eurostat. It can be assumed that death registries at least in European countries have a comparably good coverage close to 100 % (World Bank, 2022).

The current EEA BoD estimates focus on mortality and already capture an important share of the environmental burden of disease (EBD) resulting from exposure to the three main air pollutants of concern in Europe – fine particulate matter ($PM_{2.5}$), nitrogen dioxide (NO_2) and ozone (O_3) (EEA, 2021). The EEA 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. Studies increasingly show that ambient air pollution is not only associated with mortality but also with morbidity due to several short-term and chronic conditions.

For instance, the results of the Global Burden of Disease (GBD) 2019 study clearly indicate that, for certain outcomes, the share of morbidity is not negligible. To give an example: in Western Europe, 307 663 of the 441 346 DALYs due to type 2 diabetes mellitus attributable to ambient air $PM_{2.5}$ pollution ([1]) are related to the morbidity component measured as YLD in the year 2019. 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 not negligible with 1.4, 5 and 36 %, respectively (IHME, 2022). This is strongly related to the high rates of non-communicable disease burden in countries with a high socio-economic status.

For a more comprehensive assessment of the EBD due to selected ambient air pollutants, this Eionet report by the European Topic Centre for Human Health and the Environment (ETC HE) focuses on the identification of relevant morbidity health outcomes associated with the ambient air pollutants $PM_{2.5}$,

([1]) However, this estimate is significantly higher than the respective results of this report (compare Table 4.6). Possible explanations for the differences are discussed in section 6.

NO_2 and O_3, the selection of appropriate concentration-response functions (CRF) and the relevant health data. This report further aims to provide an adequate methodology and estimates for the morbidity related EBD for all countries (data permitting) previously considered in the mortality assessment of the EEA's annual air quality in Europe reports. All analyses were carried out for the reference year 2019.

2 Preparatory work

This section describes the processes and agreements needed as preparatory work before estimating the morbidity-EBD due to the ambient air pollutants $PM_{2.5}$, NO_2 and O_3. In section 3, the methodology, the input data and necessary adjustments as well as the model assumptions will be presented.

2.1 Prioritization of health outcomes

For the prioritization of relevant health outcomes we consulted on the one hand the previous work done in the European Topic Centre for Air pollution, Transport, Noise and Industrial pollution (ETC-ATNI), and the experts of the ETC HE, but also considered the most recent results of environmental epidemiology studies such as ELAPSE (Effects of Low-Level Air Pollution: A Study in Europe) (Wolf et al., 2021), the new WHO air quality guidelines (AQG, 2021) (WHO, 2021), the relevant work from the GBD 2019 study (GBD 2019 Risk Factors Collaborators, 2020), and also the information provided by the HRAPIE assessment (WHO, 2013a, 2013b). We focused on health outcomes that allowed estimating the YLDs based on incidence or prevalence of disease following the rational of health risk assessments based on the EBD-methodology (Prüss-Üstün et al., 2003). Incidence is defined as the number of new cases of a health condition during a time period (e.g. week, month or year). Prevalence is defined as total number of cases of a health condition at a specific point in time or as a cumulative number for a period (e.g. the percentage of the population with a health condition at the middle of a year or the total number of new and pre-existing cases in a certain year). For the morbidity related EBD calculations, we followed the prevalence approach and therefore selected prevalence-based data where possible - both for the relative risks in the calculation of the population attributable fraction (PAF) and for the health data to calculate the baseline BoD.

For the assessment of the EBD it was necessary to define risk-outcome pairs. Because the results of this report should complement the available mortality-based estimates it was decided to follow the EEA's selection of ambient air pollutants and $PM_{2.5}$, NO_2 and O_3 were prioritized. PM_{10} was not included in the assessments as most of the recent health risk assessments focused on $PM_{2.5}$. Furthermore, the underlying environmental epidemiology studies provided a clearer association for the $PM_{2.5}$ fraction.

We screened recent and historically relevant scientific papers and reports for available evidence ratings of risk-outcome pairs and extracted the information necessary to support the prioritization process. In addition to the literature-based review, we also consulted ETC HE experts. Furthermore, we also discussed our possible risk-outcome pair candidates with the responsible persons in charge of estimating the EBD for the impact assessment of the ongoing revision of the EU Air Quality Directive. To avoid overestimation of the EBD due to ambient air pollution we decided for strict inclusion criteria based on available evaluations of the evidence for causality for the respective risk-outcome pairs. We decided to split the risk-outcome pairs into three groups (see Table 2.1). For this report we did not perform any new evidence rating for the risk-outcome pairs but leaned on already available comprehensive evidence assessments published by US EPA (US EPA, 2016, 2019, 2020), WHO (WHO, 2013a, 2013b), the GBD study (GBD 2019 Risk Factors Collaborators, 2020) and a study from the Germany Environment Agency (Schneider et al., 2018). All the assessments used a different wording to describe the evidence level that indicated a causal relationship between a risk and an outcome. For our selection of risk-outcome pairs we grouped the ranking into three levels as indicated in Table 2.1.

Table 2.1: Evidence classification

Evidence		
Tier 1	**Tier 2**	**Not considered**
(convincing) causal	suggestive evidence	inadequate evidence
likely causal	moderate evidence	unlikely evidence
probably causal		limited evidence
sufficient evidence		insufficient evidence
strong evidence		weak evidence

For a first assessment of the morbidity related EBD, only outcomes with a tier 1 evidence rating were considered. Tier 2 outcomes could be considered by the ETC HE as a follow-up.

Using this prioritization process ten risk-outcome pairs were considered to have an adequate evidence level to be included in the first set of estimates (Table 2.2). However, it should be noted that the high level of evidence still may differ slightly between these risk-outcome pairs.

Table 2.2: Risk-outcome pairs considered

Risk factor	Considered outcome
$PM_{2.5}$	Asthma (children)
	Chronic Obstructive Pulmonary Disease (COPD)
	Ischemic Heart Disease (IHD)
	Lung Cancer (LC)
	Stroke
	Diabetes Mellitus (DM)
NO_2	Asthma (adults)
	Stroke
	Diabetes Mellitus (DM)
O_3	Hospital admissions for respiratory diseases

All outcomes for $PM_{2.5}$ and NO_2 were considered as associated with long-term exposures to those pollutants. Hospital admissions were considered as associated with short-term exposure to O_3. This was also in line with the mortality related EBD estimates. More details on the outcomes can be found in the Annex 1 Table A1.1. We are aware that we did not consider all health outcomes associated with the selected air pollutants. However, the evidence ratings indicated that these were the outcomes where the causal relationship is robust. It can be assumed that in future more evidence for additional health outcomes will allow for further inclusion of risk-outcome pairs as a follow-up by the ETC HE. Finally, since CRFs were based on single-pollutant models, there was a risk of double counting for asthma, DM and stroke due to exposure to $PM_{2.5}$ and NO_2. In general, the WHO warns against a possible overlap between $PM_{2.5}$ and NO_2 effects of about 30 %. The estimate on the overlap is based on data from studies focusing on mortality. The overlap for morbidity effects is not easily quantifiable, because it can vary strongly by outcome.

2.2 Concentration-response functions

For each of the ten selected risk-outcome pair CRFs were extracted from the relevant studies or reports, that were also screened for the respective evidence rating. To identify an adequate CRF, we mainly focused on effect measures that were reported per unit increase in exposure and indicating a linear relationship between exposure and outcome. The integrated CRF from the GBD 2019 study is an example where a non-linear CRF could be included in subsequent sensitivity analyses. For our purposes we only considered outcomes which showed significant or at least borderline significant statistical associations with the selected air pollutants. The final set of estimates and the related effect measures per unit of exposure increase (increment) were extracted for the ten risk-outcome pairs identified and used in the estimations of the PAF. It should be noted that CRFs are mainly derived using epidemiological studies that estimated the effect measures (hazard ratio or HR; relative risk or RR; odds ratio or OR) on incidence data. This is mainly related to the fact, that e. g. in cohort studies only incident events (new cases of a disease or deaths) and not prevalent cases are used to model the effects estimates. Due to the lack of CRFs based on prevalence data, it is common to apply the derived PAF to prevalent health data (and not exclusively to incidence cases) to calculate the EBD. This approach was also used in this report, knowing that the results are thus subject to a certain degree of uncertainty.

For several health outcomes more than one qualified CRF was identified. To reflect the variety of estimates, sensitivity analyses could be conducted using these CRFs in a follow-up study by the ETC HE (see section 5). Only single pollutant CRFs were considered, with potential risk of partial double counting as pointed out above. The only exception is the association between O_3 and hospital admissions for respiratory diseases, which was based on a two-pollutant model (adjusted for PM_{10}).

2.3 Health data

For the EBD assessment in general, incidence or prevalence data of the related diseases are needed to quantify the YLDs. Compared to mortality, data on morbidity for most diseases (except infectious diseases or cancers) and in most countries is not captured routinely in specific registries and is thus not routinely stored and not publicly available in any supranational database. We have therefore searched for the necessary health data and described the most suitable datasets in the following. We selected the data sources based on the highest coverage of European countries, timeliness, and the possibility to stratify the data by age-groups and sex. Furthermore, as we followed the prevalence approach for estimating the morbidity related EBD, we have chosen prevalence health data where possible.

In comparison to many other conditions, the incidence of cancers is increasingly captured by the cancer registries improving the monitoring of this disease group. Lung cancer is one of the outcomes considered for our health risk assessment. The European Cancer Information System (ECIS) – as one possible data source - provides data on lung cancer incidence stratified by age-groups and sex for the year 2020 (EC, 2022b). The International Agency for Research on Cancer (IARC) is another adequate source of reference for the estimation of YLDs. In contrast to the ECIS database, IARC already provides lung cancer data converted into prevalent cases, and was therefore the chosen database.

For the remaining health outcomes, no clinical registries with doctor's diagnosed incident or prevalent cases were available. The currently best available approximation for the data on the prevalence for the selected diseases was the European Health Interview Survey (EHIS). This survey provides self-reported information on the occurrence of diseases in the last 12 months. Despite the fact that this survey collects only self-reported data, the questionnaire ensures that at least the life-time prevalence of a disease was confirmed by a doctor's diagnosis. It therefore can be assumed that the doctor's diagnosis remains valid also for the occurrence of the disease in the last twelve months. Nonetheless, self-reported data are prone to biases such as recall-bias or social desirability bias. Regarding the latter, the study participants tend to answer the questions according to social norms and thus might e. g.

underestimate their weight or not truthfully answer questions about addictive behaviours such as smoking or drinking alcohol as well as having sexual transmitted diseases. However, both biases should not strongly affect the estimates as the related outcomes are chronic conditions and people having this disease are mostly not stigmatized and would generally report the condition in a questionnaire.

Eurostat provides the most recent results of hospital discharges for respiratory diseases as well as of the EHIS for all remaining health outcomes we considered (COPD, IHD, DM, stroke, asthma (adults)), except asthma in children younger than 15 years (EC, 2022a). Here, it would be also possible to investigate the use of the most recent data from the Global Asthma Network, which continues the work of the International Study of Asthma and Allergies in Childhood (ISAAC). The screened data sources can be found in the Annex 1 Table A1.2.

2.4 Counterfactual values for the concentrations of air pollutants

For the assessment of the morbidity related EBD, the counterfactual concentrations (C_0) were aligned with the assumptions used in the current health risk assessment for mortality, i.e., 5 µg/m³ for $PM_{2.5}$, 10 µg/m³ for NO_2 and 70 µg/m³ (as the annual sum of daily maximum running 8-h average concentrations over 35 ppm, SOMO35) for O_3.

2.5 Estimating DALYs – the all-cause natural mortality vs. cause specific challenge

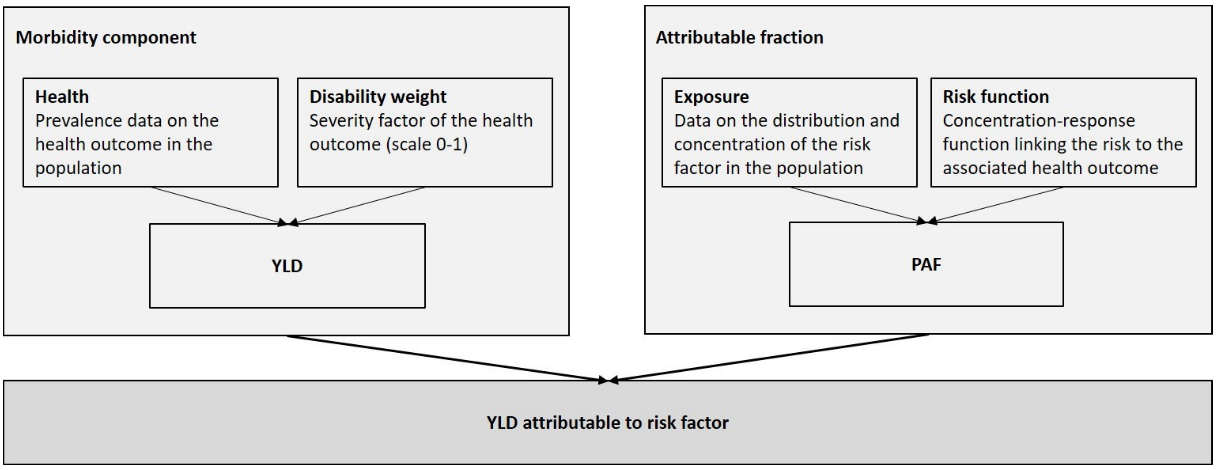
If the goal of a health risk assessment is to estimate the DALYs attributable to air pollution, both the morbidity and mortality estimates need to be calculated by the cause specific approach. This allows adding the estimates for YLLs and YLDs for each specific outcome and to present the sum as the attributable burden in a consistent approach. The summation of YLLs from the all-cause approach and YLDs from a cause-specific approach is not adequate. Further, there is also no equivalent concept of incidence or prevalence for ‘all natural causes’, and also the necessary DW for health outcomes are condition specific. The DW is a weighting factor for the severity of a disease. Thus, if a summation of mortality and morbidity burden is envisaged, it is necessary to estimate the condition specific mortality burden. Therefore, for future EEA’s analyses, we recommend estimating also the mortality attributed to the specific causes considered in the morbidity estimates.

3 Estimation of morbidity related EBD

3.1 Methodological approach

The aim was to estimate the EBD that can be attributed to a specific environmental risk factor, i. e. ambient air pollutant ($PM_{2.5}$, NO_2 or O_3). As we focus on the morbidity related EBD, information on cause specific health outcomes in the population in terms of YLDs was required first. These estimates were then multiplied by the population attributable fraction (PAF), which is used to determine the share of the EBD attributable to the respective risk factor (air pollutant). A schematic flow chart for the calculation is displayed in Figure 3.1.

Figure 3.1: Flow chart of calculation process for the morbidity related EBD of a given health outcome



Various input data are needed for the morbidity related EBD assessment: prevalence data of a disease in the population (health) and the severity of this disease (DW), data on the distribution and concentration of the risk factor in the population (exposure) as well as a risk function (CRF) representing the association of the risk-outcome pair.

For the calculation of the YLDs, the number of prevalent cases of a cause specific health outcome (P_o) were multiplied by the respective DW (Equation 1). DWs represent the severity of a health outcome on a scale ranging from zero to one. Generally, prevalence data should be used for the same population group regarding age and sex as was considered to derive the CRF. The input data used for these are listed in the sections below on health data and disability weights.

$$\mathbf{YLDs} = \mathbf{P}_{\boldsymbol{o}} * \mathbf{DW} \qquad \text{Equation 1}$$

To estimate the PAF, a CRF is required. Generally, the formula to estimate the PAF requires a relative risk (RR) as the key input parameter. For many air pollutants RRs are not available requiring hazard ratios (HR) or odds ratios (OR) to be used in the formula. HR, RR, and OR are effect measures used in epidemiologic studies and describe the associations between e.g. a risk and a health outcome in a quantitative way. This limitation is crucial as e.g. OR can only be used as approximation for the RR under the rare-disease assumption (prevalence less than 10 %). Under a continuous exposure the RR, OR or HR can e. g. be estimated for a certain increase of exposure concentrations (increment or unit increase; UC). Here, a CRF can be derived allowing to extrapolate the effect estimates to required exposures. The RR for a specific exposure concentration (RR_c) is calculated using the following Equation 2:

$$\boldsymbol{RR_c} = \mathbf{exp}\,[\,\boldsymbol{\beta}\,(\boldsymbol{C} - \boldsymbol{C_0})\,] \qquad \text{Equation 2}$$

where C is the specific exposure concentration in the population and C_0 the counterfactual concentration, which describes a reference exposure level. This can either be the theoretically lowest value, an achievable value or a politically set limit value. β is the concentration-response factor corresponding to the slope of the curve. Assuming a log-linear relationship, the β value in turn is calculated as follows (Equation 3):

$$\boldsymbol{\beta} = \frac{\mathbf{ln}\,(\boldsymbol{RR})}{\boldsymbol{UC}} \qquad \text{Equation 3}$$

By combining the two formulas described above, the PAF can be calculated (Equation 4):

$$PAF = \frac{1}{Pop_t} \sum Pop_c \cdot (\frac{RR_c - 1}{RR_c})$$ Equation 4

where Pop_c is the population exposed to a specific concentration and Pop_t the total population of the considered age group.

Lastly, to estimate the morbidity related disease burden (MB) attributable to a specific risk factor, the YLD estimates are multiplied by the PAF (Equation 5):

$$MB = YLDs * PAF$$ Equation 5

O_3-specific calculation processes:

In the case of the risk-outcome pair hospital admissions for respiratory diseases and O_3, no YLDs but attributable hospital admission cases were calculated, as no eligible CRF was identified (see also section 3.6). The calculation was based on three steps. First, since the SOMO35 concentrations represent an annual sum, daily mean values are required for the EBD calculation in this assessment, the SOMO35 concentrations were divided by 365 ($C_{daily\ mean}$) (Equation 6).

$$C_{daily\ mean} = \frac{SOMO35\ (annual\ sum)}{365}$$ Equation 6

Second, a linear function y was derived, which described the increase in hospitalisations as a function of the specific daily mean SOMO35 concentrations. For this, the increase rate in hospital admissions is divided by the unit increase of the daily mean SOMO35 concentration (UC) (see Table 3.2), multiplied by the specific daily mean SOMO35 concentration ($C_{daily\ mean}$) (Equation 7).

$$y = \frac{increase\ rate\ in\ hospital\ admissions}{UC} * C_{daily\ mean}$$ Equation 7

Third, by multiplying y with data on total hospital admissions (P_o) and the specific exposed population (Pop_c), attributable hospital admission cases could be calculated using the following formula (Equation 8):

$$\text{Attributable cases} = y * Pop_c * \sum P_o$$ Equation 8

Note: Due to methodological differences between the most recent all-cause mortality calculations in the EEA's health risk assessment and the morbidity assessments performed here, there are differences in the respective input parameters for some equations. This is particularly relevant for Equation 4 and Equation 5. One of the main reasons is that the mortality calculations are based on spatially gridded data. Accordingly, the different process steps and input data were combined differently.

3.2 Input data and preparation

The following sections describe the input data and processing steps used in the morbidity related EBD calculations for the respective health outcomes. Calculations were made for European countries for which input data were comprehensively available (population, health and exposure data). Since health data was most comprehensively available for 2019, this year was selected as the reference year for all calculations. Nevertheless, IARC's lung cancer prevalence data were only available for the year 2020. Here, it was assumed that these data were also valid for 2019.

3.3 Ambient air pollution exposure

For all three considered air pollutants, 2019 data on the European population exposure distribution per country were based on the Eionet report ETC/ATNI 2021/1 on European air quality for 2019 (Horálek et al., 2022). The exposure data correspond to the annual average concentrations of $PM_{2.5}$ and NO_2 in ambient air and the SOMO35 for O_3. In the ETC/ATNI report, the respective annual average population exposures were classified in different concentration classes (e.g. in 5 µg/m³ classes for $PM_{2.5}$). For our estimations, the respective concentrations were provided in smaller exposure class ranges: 1 µg/m³ for $PM_{2.5}$ and NO_2, and 250 µg/m³·d for O_3 (SOMO35). The finer exposure classes allow better alignment to the underlying concentration values of the CRFs. For the assignment of the population to a specific exposure concentration, the mean value of the respective exposure classes was used, which represents the concentration C in Equation 2 or $C_{daily\ mean}$ in Equation 7. As described in section 3.1, the SOMO35 exposure values (annual sum) were converted into daily mean values.

3.4 Population

For 2019, country specific population numbers stratified by age and sex in 1-year age groups were available for almost all countries from Eurostat (Eurostat, 2022). No information was available for the three countries Bosnia and Herzegovina, San Marino and Monaco. In general, population data were used to calculate absolute numbers of disease cases using the prevalence rates of the respective health outcomes. In addition, population data were also used for the calculation of the PAF or attributable cases (Equation 4 and Equation 8).

3.5 Health data

Table 3.1 lists the sources of the respective prevalence health data used for the morbidity assessments, together with the age groups for which the data are available. Because EHIS data did not include information on asthma for children or adolescents younger than 15 years and data from the Global Asthma Network were not yet comprehensively available, prevalence data from the IHME (GBD 2019 study) were used for this age group. Regarding health data on lung cancer, the age stratification of the ECIS data was very rough for the morbidity assessment (15-year age groups) and was only available as incidence. Therefore, prevalence data from the IARC with 5-year age groups were preferred, as already specified in section 2.3. However, the reporting year was 2020 and not 2019 as for the other outcomes, because no prevalence data were available for 2019. Furthermore, with regard to hospitalisations for respiratory diseases, it was assumed that hospital admissions (for which there were no available data) are equivalent to hospital discharges. In addition, health data for Serbia and Kosovo under the UN Security Council Resolution 1244/99 were not always reported for both countries separately. For example, IHME data on asthma for Serbia included data for Kosovo. This can also be assumed for the IARC data on lung cancer. On the other hand, EHIS and Eurostat reported health data for both countries, if available. Regarding the EBD assessment, calculations were made for both countries separately when possible. More information and links to the data can be found in Annex 1 Table A1.1.

Table 3.1: Health data sources for considered outcomes (prevalence)

Outcome	Data source[a]	ICD10 code	Explanation	Age groups	Remarks
Asthma (children)	IHME	J45-46		All ages (5-year age groups)	
Asthma (adults)	EHIS	J45-46	Allergic asthma included	≥15 (10-year age groups)	Self-reported
COPD	EHIS	J40-44 and J47	Chronic bronchitis, chronic obstructive pulmonary disease, emphysema	≥15 (10-year age groups)	Self-reported
IHD	EHIS	I20-25	Coronary heart disease or angina pectoris	≥15 (10-year age groups)	Self-reported
LC[b]	IARC	C33-34		All ages (5-year age groups)	
Stroke	EHIS	I60-69	Cerebral haemorrhage, cerebral ischaemia or chronic consequences of stroke	≥15 (10-year age groups)	Self-reported
DM	EHIS	E10-14	Type 1 and 2 diabetes (gestational diabetes excluded)	≥15 (10-year age groups)	Self-reported
Hospital admissions for respiratory diseases (in-patients)[c]	Eurostat	J00-99	The data describe hospital discharges per 100 000 inhabitants	All ages (5-year age groups)	

Notes: ([a]) IHME: Data for Serbia included data for Kosovo, IARC: data for Serbia presumably included data for Kosovo, EHIS: data for Serbia excluded data for Kosovo, EUROSTAT: data for Serbia excluded data for Kosovo; ([b]) lung cancer data was reported for 2020 (not 2019 as for the other outcomes); ([c]) it was assumed also that hospital admissions are equivalent to hospital discharges.

3.6 Concentration response functions

Table 3.2 lists the selected CRFs including the corresponding 95 % confidence intervals (CI) and characteristics for the respective risk-outcome pairs. Furthermore, the table lists the age groups for which we applied the single effect measures. Note that, unlike the other risk-outcome pairs, the association between O_3 or rather SOMO35 and hospital admissions for respiratory diseases is based on a two-pollutant model (adjusted for PM_{10}). Moreover, the effect measure for this association corresponds to the percentage increase in hospital admissions. This does not represent a risk estimate such as RR, OR or HR and thus, cannot be used to calculate the PAF according to Equation 4. Hence, no PAF and YLDs could be estimated for this risk-outcome pair. Alternatively, attributable hospital admission cases were calculated (see section 3.1).

Table 3.2: Selected CRFs and the according reference studies

Pollutant	Outcome	Effect measure OR/RR/HR (95 % CI)	Increment per unit	Prevalence/ Incidence	Effect measure applied to age groups [years]	Remarks	Reference
$PM_{2.5}$	Asthma (children)	1.03 (1.01-1.05)	1 µg·m^{-3}	Incidence	<15		(Khreis et al., 2017)
	COPD	1.17 (1.06-1.29)	5 µg·m^{-3}	Incidence	≥25		(Liu et al., 2021)(ELAPSE project)

Pollutant	Outcome	Effect measure OR/RR/HR (95 % CI)	Increment per unit	Prevalence/ Incidence	Effect measure applied to age groups [years]	Remarks	Reference
	IHD	1.02 (0.95-1.10)	5 µg·m^{-3}	Incidence	≥25		(Wolf et al., 2021)(ELAPSE project)
	LC	1.13 (1.05-1.23)	5 µg·m^{-3}	Incidence	≥25	Considered ICD10 code C34 differs from health data as these also include C33.	(Hvidtfeldt et al., 2021) (ELAPSE project)
	Stroke	1.10 (1.01-1.21)	5 µg·m^{-3}	Incidence	≥25		(Wolf et al., 2021)(ELAPSE project)
	T2DM	1.09 (1.05-1.13)	10 µg·m^{-3}	Prevalence	≥25		(Zang et al., 2022)
NO_2	Asthma (adults)	1.17 (1.10-1.25)	10 µg·m^{-3}	Incidence	≥15		(Liu et al., 2021)(ELAPSE Project)
	Stroke	1.08 (1.04-1.12)	10 µg·m^{-3}	Incidence	≥25		(Wolf et al., 2021)(ELAPSE project)
	DM	1.08 (1.00-1.17)	10 µg·m^{-3}	Incidence/ prevalence	≥35		(Eze et al., 2015)
O_3 (SOMO35)	Hospital admissions for respiratory diseases	1.0044 (1.0007-1.0083)	10 µg·m^{-3}	Cases	≥65	The effect measure is defined as percental increase in hospitalisations and the coefficient is adjusted for PM_{10} in two-pollutant model	(WHO, 2013a) (HRAPIE project)

3.7 Disability weights

DWs were obtained from the GBD 2019 study (GBD 2019 Risk Factors Collaborators, 2020). The respective DWs were calculated dividing the annual YLDs by the prevalence data for the considered diseases for the WHO European Region (Equation 9).

$$DW = \frac{YLD_o}{P_o} \qquad \textbf{Equation 9}$$

These were available in 5-year age groups stratified by sex and were applied to all individual countries. Estimating the DWs from YLD and prevalence data allows to use a weight that is adjusted for the severity distributions and co-morbidity.

It should be noted that the DW calculated for DM is a combined DW for both type 1 and type 2 DM. Furthermore, no DW is available for hospital admissions due to respiratory diseases. Since no YLDs but attributable cases were estimated for hospital admissions related to O_3 (SOMO35), this information was not needed.

4 Results

The following section provides an overview of EBD indicators (PAFs; YLDs, or attributable cases for hospital admissions; and YLDs per 100 000 inhabitants, or attributable cases per 100 000 inhabitants) for the selected risk-outcome pairs. In addition to the central estimate we also provide a 95 % CI, which represent the uncertainty in the effect measures (RR, HR or OR). Using the CI allows to present a most likely lowest and highest estimates of the disease burden resulting from the exposure to the selected air pollutants. For some countries, no EBD indicators were modelled due to missing input data, e.g. on population, health or exposure data. In the result tables, these missing values are indicated as no data (ND). Gap filling methods have not yet been included but can be added in a subsequent report. All reported results refer to the respective age groups of the total population.

4.1 $PM_{2.5}$ (long-term effects)

Asthma (children <15 years)

The overall burden due to morbidity effects of asthma in children resulting from the exposure to $PM_{2.5}$ pollution in the selected European countries was estimated at 27 133 YLDs (Table 4.1). According to the absolute numbers, the highest disease burden was estimated for Poland with 4 757 YLDs and the lowest for Iceland with <1 YLD. Adjusted for the size of the population <15 years the highest rates per 100 000 inhabitants were observed for Poland, North Macedonia and Cyprus, with 81.5, 70.3 and 64.8 YLDs per 100 000 inhabitants. The lowest rates were estimated for Iceland, Estonia and Finland with 1.2, 3.1 and 3.5 YLDs per 100 000 inhabitants (Figure 4.1). Figure 4.1 only shows the countries for which YLDs per 100 000 inhabitants <15 years could be estimated.

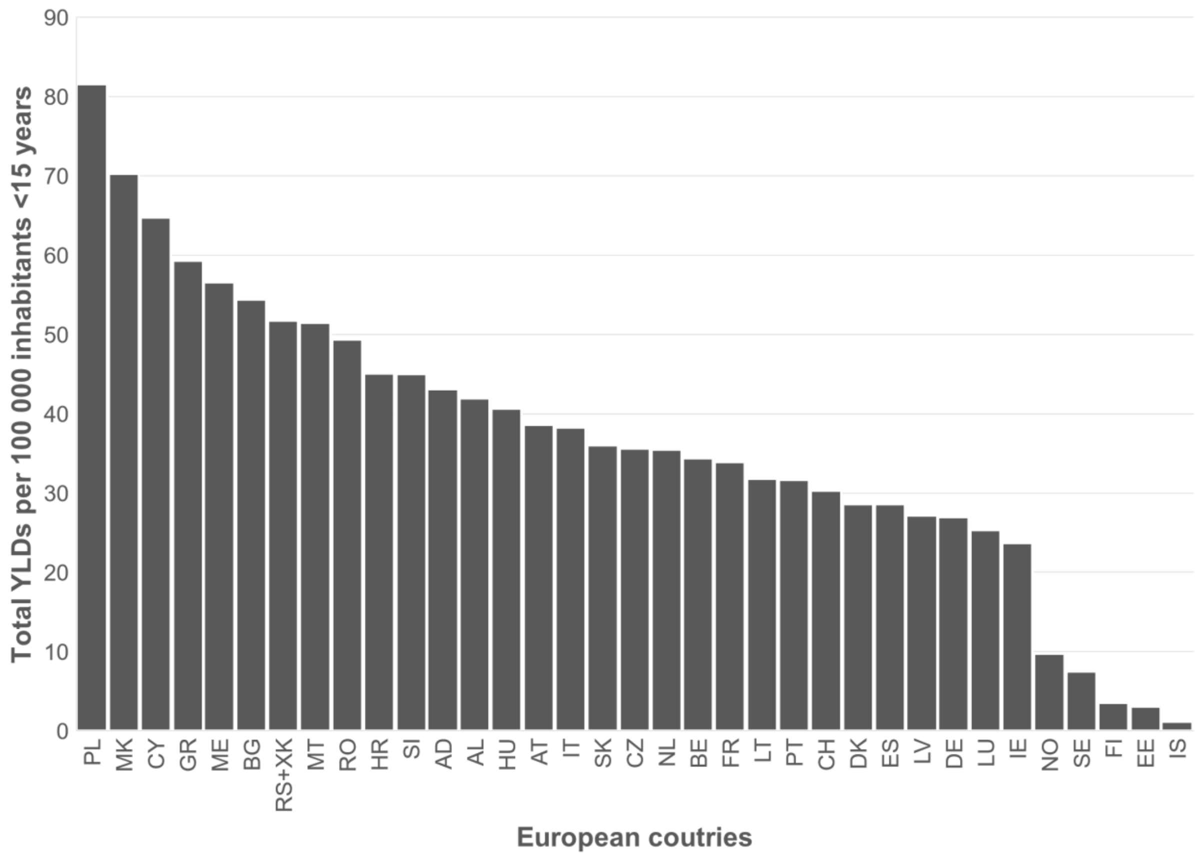
Table 4.1: Asthma disease burden (morbidity) attributable to $PM_{2.5}$ for children <15 years for different European countries 2019

	PAF (95 % CI: low, high)			YLDs[(a)] (95 % CI: low, high)			YLDs/10^5 inhabitants <15 years (95 % CI: low, high)		
Country	mean	low	high	mean	low	high	mean	low	high
Andorra	0.157	0.056	0.245	<10	<10	<10	43.1	15.4	67.3
Albania	0.303	0.116	0.445	207	79	304	41.9	16.0	61.6
Austria	0.169	0.061	0.260	494	178	762	38.6	13.9	59.6
Bosnia & Herzegovina	0.371	0.149	0.521	ND	ND	ND	ND	ND	ND
Belgium	0.161	0.058	0.251	668	239	1 039	34.4	12.3	53.6
Bulgaria	0.314	0.121	0.458	546	210	798	54.4	20.9	79.4
Switzerland	0.103	0.036	0.164	389	136	617	30.3	10.6	48.0
Cyprus	0.250	0.093	0.377	91	34	138	64.8	24.0	97.6
Czechia	0.227	0.084	0.344	603	222	915	35.6	13.1	54.0
Germany	0.140	0.050	0.220	3 045	1 080	4 783	27.0	9.6	42.4
Denmark	0.121	0.043	0.192	274	97	433	28.6	10.1	45.2
Estonia	0.022	0.008	0.036	<10	<10	11	3.1	1.1	5.0
Spain	0.139	0.050	0.217	1 981	710	3 083	28.6	10.2	44.5
Finland	0.015	0.005	0.024	31	11	51	3.5	1.2	5.8
France	0.124	0.044	0.194	4 108	1 455	6 458	33.9	12.0	53.3
Greece	0.269	0.101	0.401	912	342	1 359	59.3	22.3	88.4

Country	PAF (95 % CI: low, high) mean	low	high	YLDs[a] (95 % CI: low, high) mean	low	high	YLDs/10^5 inhabitants <15 years (95 % CI: low, high) mean	low	high
Croatia	0.242	0.091	0.363	265	99	397	45.1	16.8	67.6
Hungary	0.243	0.090	0.368	578	213	874	40.6	15.0	61.5
Ireland	0.075	0.026	0.119	239	83	381	23.7	8.3	37.8
Iceland	0.004	0.001	0.006	<1	<1	<10	1.2	<1.0	2.0
Italy	0.239	0.089	0.358	3 014	1 125	4 518	38.3	14.3	57.4
Liechtenstein	0.085	0.030	0.137	ND	ND	ND	ND	ND	ND
Lithuania	0.186	0.068	0.287	134	49	207	31.8	11.5	49.0
Luxembourg	0.087	0.030	0.140	25	<10	40	25.3	8.8	40.5
Latvia	0.138	0.049	0.213	83	30	129	27.2	9.8	42.2
Monaco	0.204	0.074	0.313	ND	ND	ND	ND	ND	ND
Montenegro	0.320	0.124	0.463	63	25	92	56.6	21.9	82.0
North Macedonia	0.359	0.142	0.512	239	95	341	70.3	27.8	100.2
Malta	0.190	0.068	0.293	35	13	54	51.5	18.6	79.5
Netherlands	0.154	0.055	0.241	972	346	1 521	35.5	12.6	55.5
Norway	0.031	0.011	0.050	91	32	148	9.8	3.4	15.8
Poland	0.307	0.118	0.450	4 757	1 820	6 977	81.5	31.2	119.6
Portugal	0.091	0.032	0.144	445	157	705	31.6	11.1	50.1
Romania	0.255	0.095	0.382	1 502	562	2 249	49.4	18.5	73.9
Serbia[b]	0.365	0.143	0.523	743	291	1 065	51.8	20.3	74.2
Sweden	0.025	0.009	0.041	136	47	220	7.5	2.6	12.1
Slovenia	0.211	0.078	0.321	141	52	215	45.0	16.5	68.4
Slovakia	0.242	0.089	0.366	309	114	467	36.0	13.3	54.4
San Marino	0.214	0.078	0.327	ND	ND	ND	ND	ND	ND
Türkiye	ND	ND	ND	ND	ND	ND	ND	ND	ND
All countries				**27 133**	**9 957**	**41 355**	**37.4**	**13.7**	**57.1**

Notes: ([a]) Total and national data are rounded; ([b]) Serbia including Kosovo; ND = No data.

Figure 4.1: Asthma disease burden attributable to $PM_{2.5}$ for children <15 years for different European countries 2019 (in descending order)



Notes: Serbia including Kosovo (RS+XK).

Chronic Obstructive Pulmonary Disease (adults ≥25 years)

The overall burden due to morbidity effects of COPD resulting from exposure to $PM_{2.5}$ pollution in the selected European countries was estimated at 175 731 YLDs (Table 4.2). The absolute numbers indicate the highest burden in Germany with 38 460 YLDs and the lowest in Iceland with <10 YLDs. Countries presenting the highest rates were Serbia, Lithuania, and Croatia with 90.0, 84.6 and 80.9 YLDs per 100 000 inhabitants ≥25 years, respectively. The lowest rates were estimates for Estonia, Finland each with 4.0, Sweden with 3.0 and Iceland with 1.2 YLDs per 100 000 inhabitants ≥25 years (Figure 4.2). Figure 4.2 only shows the countries for which YLDs per 100 000 inhabitants ≥25 years could be estimated.

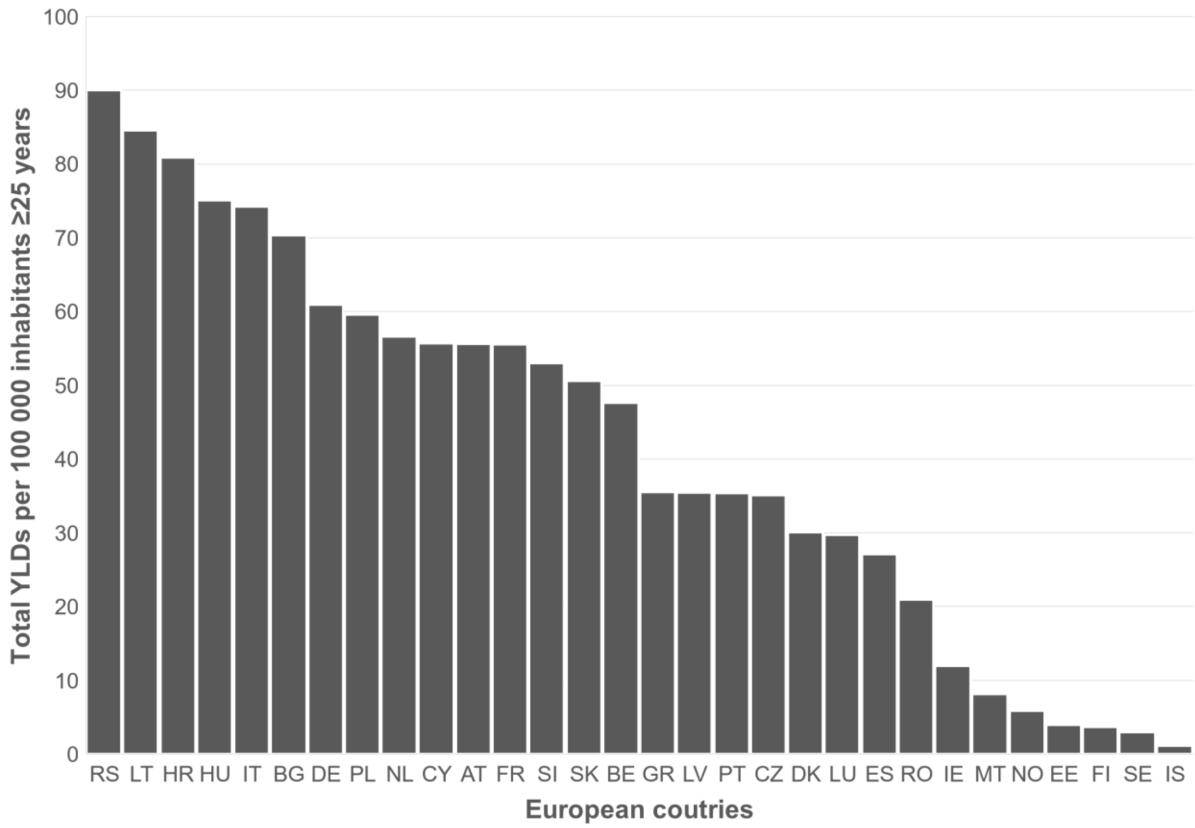
Table 4.2: COPD disease burden (morbidity) attributable to $PM_{2.5}$ for adults ≥25 years for different European countries 2019

	PAF (95 % CI: low, high)			YLDs[(a)] (95 % CI: low, high)			YLDs/10^5 inhabitants ≥25 years (95 % CI: low, high)		
Country	**mean**	**low**	**high**	**mean**	**low**	**high**	**mean**	**low**	**high**
Andorra	0.166	0.065	0.254	ND	ND	ND	ND	ND	ND
Albania	0.319	0.134	0.459	ND	ND	ND	ND	ND	ND
Austria	0.178	0.071	0.270	3 676	1 464	5 574	55.6	22.1	84.3

Country	PAF (95 % CI: low, high)			YLDs[(a)] (95 % CI: low, high)			YLDs/10^5 inhabitants ≥25 years (95 % CI: low, high)		
	mean	low	high	mean	low	high	mean	low	high
Bosnia & Herzegovina	0.387	0.172	0.535	ND	ND	ND	ND	ND	ND
Belgium	0.171	0.067	0.261	3 915	1 545	5 984	47.7	18.8	72.8
Bulgaria	0.329	0.140	0.472	3 780	1 603	5 418	70.4	29.8	100.9
Switzerland	0.109	0.042	0.170	ND	ND	ND	ND	ND	ND
Cyprus	0.263	0.108	0.390	347	142	513	55.7	22.8	82.4
Czechia	0.239	0.097	0.356	2 806	1 141	4 174	35.1	14.3	52.2
Germany	0.148	0.058	0.228	38 460	15 035	59 316	60.9	23.8	94.0
Denmark	0.129	0.050	0.199	1 237	481	1 920	30.1	11.7	46.7
Estonia	0.024	0.009	0.038	39	15	63	4.0	1.5	6.4
Spain	0.147	0.058	0.225	9 602	3 794	14 670	27.1	10.7	41.5
Finland	0.015	0.006	0.025	148	56	238	3.7	1.4	5.9
France	0.131	0.051	0.202	26 216	10 241	40 471	55.6	21.7	85.8
Greece	0.283	0.117	0.414	2 876	1 190	4 209	35.5	14.7	52.0
Croatia	0.255	0.105	0.375	2 462	1 014	3 622	80.9	33.3	119.0
Hungary	0.256	0.104	0.381	5 484	2 232	8 144	75.1	30.6	111.5
Ireland	0.079	0.031	0.124	392	151	614	12.0	4.6	18.7
Iceland	0.004	0.002	0.007	<10	<10	<10	1.2	<1.0	1.9
Italy	0.251	0.103	0.370	34 236	140 96	50 391	74.3	30.6	109.3
Liechtenstein	0.090	0.035	0.142	ND	ND	ND	ND	ND	ND
Lithuania	0.197	0.079	0.297	1 758	703	2 656	84.6	33.8	127.8
Luxembourg	0.093	0.036	0.145	132	51	207	29.7	11.4	46.7
Latvia	0.145	0.058	0.221	510	202	778	35.5	14.0	54.1
Monaco	0.215	0.086	0.325	ND	ND	ND	ND	ND	ND
Montenegro	0.335	0.143	0.477	ND	ND	ND	ND	ND	ND
North Macedonia	0.376	0.164	0.526	ND	ND	ND	ND	ND	ND
Malta	0.200	0.080	0.303	30	12	46	8.2	3.2	12.4
Netherlands	0.163	0.064	0.250	7 026	2 757	10 798	56.6	22.2	87.0
Norway	0.033	0.013	0.052	219	83	348	5.9	2.2	9.3
Poland	0.323	0.136	0.464	16 826	7 100	24 221	59.6	25.2	85.8
Portugal	0.097	0.037	0.150	2 752	1 067	42 79	35.4	13.7	55.0
Romania	0.268	0.111	0.394	3 000	1 237	44 07	20.9	8.6	30.8
Serbia	0.384	0.167	0.540	4 711	2 042	6 622	90.0	39.0	126.5
Sweden	0.027	0.010	0.043	217	82	343	3.0	1.1	4.7
Slovenia	0.222	0.090	0.332	834	338	1 244	53.0	21.5	79.1
Slovakia	0.255	0.104	0.378	2 036	830	3 020	50.6	20.6	75.0
San Marino	0.225	0.090	0.339	ND	ND	ND	ND	ND	ND
Türkiye	ND	ND	ND	ND	ND	ND	ND	ND	ND
Kosovo	0.373	0.160	0.527	ND	ND	ND	ND	ND	ND
All countries				**175 731**	**70 702**	**264 297**	**51.6**	**20.8**	**77.6**

Notes: ([a]) Total and national data are rounded; ND = No data.

Figure 4.2: COPD disease burden attributable to $PM_{2.5}$ for adults ≥25 years for different European countries 2019 (in descending order)



Ischemic Heart Disease (adults ≥25 years)

The overall burden due to morbidity effects of IHD resulting from exposure to fine particulate matter pollution in the selected European countries was estimated at 10 120 YLDs (Table 4.3). The highest burden according to the absolute numbers was estimated for Poland with 3 044 YLDs and the lowest for Iceland with <1 YLDs. The highest rates were observed for Serbia, Poland and Bulgaria with 15.7, 10.8 and 10.2 YLDs per 100 000 inhabitants ≥25 years, respectively. For many countries rates lower than 5 YLDs per 100 000 ≥25 years were detected (Figure 4.3). Figure 4.3 only shows the countries for which YLDs per 100 000 inhabitants ≥25 years could be estimated.

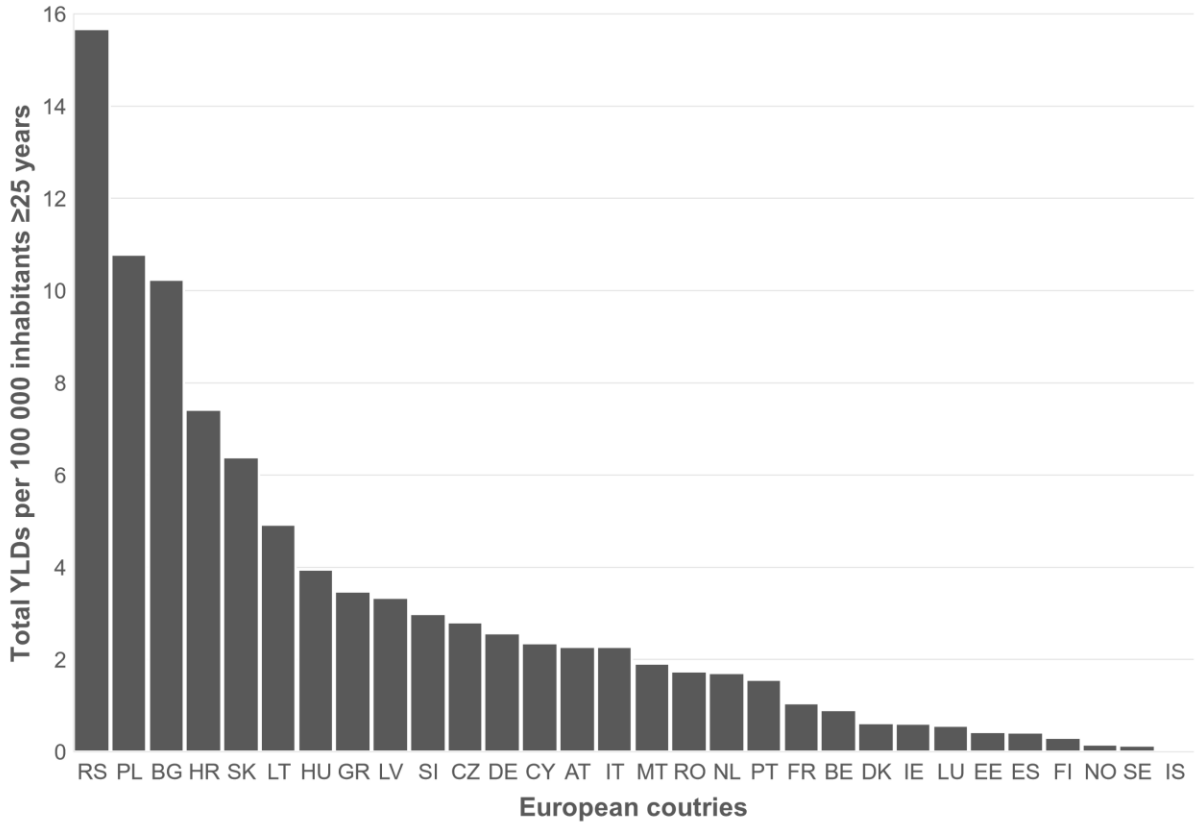
Table 4.3: IHD disease burden (morbidity) attributable to $PM_{2.5}$ for adults ≥25 years for different European countries 2019

	PAF (95 % CI: low, high)			YLDs[(a)] (95 % CI: low, high)			YLDs/10^5 inhabitants ≥25 years (95 % CI: low, high)		
Country	mean	low	high	mean	low	high	mean	low	high
Andorra	0.023	0.000	0.104	ND	ND	ND	ND	ND	ND
Albania	0.048	0.000	0.209	ND	ND	ND	ND	ND	ND
Austria	0.025	0.000	0.113	150	<1	685	2.3	<1.0	10.4
Bosnia & Herzegovina	0.063	0.000	0.263	ND	ND	ND	ND	ND	ND
Belgium	0.023	0.000	0.108	74	<1	341	<1.0	<1.0	4.1
Bulgaria	0.050	0.000	0.217	550	<1	2 381	10.2	<1.0	44.3
Switzerland	0.015	0.000	0.068	ND	ND	ND	ND	ND	ND
Cyprus	0.038	0.000	0.170	15	<1	65	2.4	<1.0	10.5

Country	PAF (95 % CI: low, high) mean	low	high	YLDs[(a)] (95 % CI: low, high) mean	low	high	YLDs/10^5 inhabitants ≥25 years (95 % CI: low, high) mean	low	high
Czechia	0.034	0.000	0.154	225	<1	1 007	2.8	<1.0	12.6
Germany	0.020	0.000	0.093	1 623	<1	7 504	2.6	<1.0	11.9
Denmark	0.017	0.000	0.080	26	<1	120	<1.0	<1.0	2.9
Estonia	0.003	0.000	0.014	4	<1	20	<1.0	<1.0	2.0
Spain	0.020	0.000	0.093	147	<1	673	<1.0	<1.0	1.9
Finland	0.002	0.000	0.009	12	<1	58	<1.0	<1.0	1.5
France	0.018	0.000	0.082	500	<1	2 312	1.1	<1.0	4.9
Greece	0.042	0.000	0.183	281	<1	1 243	3.5	<1.0	15.4
Croatia	0.037	0.000	0.165	226	<1	1 002	7.4	<1.0	32.9
Hungary	0.037	0.000	0.165	289	<1	1 293	4.0	<1.0	17.7
Ireland	0.011	0.000	0.049	20	<1	95	<1.0	<1.0	2.9
Iceland	0.001	0.000	0.002	<1	<1	<10	<1.0	<1.0	<1.0
Italy	0.037	0.000	0.163	1 048	<1	4 651	2.3	<1.0	10.1
Liechtenstein	0.012	0.000	0.056	ND	ND	ND	ND	ND	ND
Lithuania	0.028	0.000	0.125	102	<1	465	4.9	<1.0	22.4
Luxembourg	0.012	0.000	0.057	<10	<1	12	<1.0	<1.0	2.7
Latvia	0.020	0.000	0.092	48	<1	220	3.3	<1.0	15.3
Monaco	0.030	0.000	0.137	ND	ND	ND	ND	ND	ND
Montenegro	0.052	0.000	0.222	ND	ND	ND	ND	ND	ND
North Macedonia	0.060	0.000	0.252	ND	ND	ND	ND	ND	ND
Malta	0.028	0.000	0.127	<10	<1	32	1.9	<1.0	8.7
Netherlands	0.022	0.000	0.102	213	<1	982	1.7	<1.0	7.9
Norway	0.004	0.000	0.020	<10	<1	29	<1.0	<1.0	0.8
Poland	0.049	0.000	0.212	3 044	<1	13 240	10.8	<1.0	46.9
Portugal	0.013	0.000	0.060	121	<1	565	1.6	<1.0	7.3
Romania	0.039	0.000	0.174	251	<1	1 111	1.8	<1.0	7.8
Serbia	0.060	0.000	0.257	820	<1	3 492	15.7	<1.0	66.7
Sweden	0.004	0.000	0.017	10	<1	46	<1.0	<1.0	<1.0
Slovenia	0.032	0.000	0.143	47	<1	211	3.0	<1.0	13.4
Slovakia	0.037	0.000	0.164	257	<1	1 151	6.4	<1.0	28.6
San Marino	0.032	0.000	0.144	ND	ND	ND	ND	ND	ND
Türkiye	ND	ND	ND	ND	ND	ND	ND	ND	ND
Kosovo	0.058	0.000	0.248	ND	ND	ND	ND	ND	ND
All countries				**10 120**	**<1**	**45 006**	**3.0**	**<1.0**	**13.2**

Notes: ([a]) Total and national data are rounded; ND = No data.

Figure 4.3: IHD disease burden attributable to $PM_{2.5}$ for adults ≥25 years for different European countries 2019 (in descending order)



Lung Cancer (adults ≥25 years)

The overall burden due to morbidity effects of LC resulting from exposure to fine particulate matter pollution in the selected European countries was estimated at 5 136 YLDs (Table 4.4). According to the absolute numbers the highest burden was estimated for Italy with 814 YLDs and the lowest for Estonia with <10 YLD. Very low YLD rates under 5 YLDs per 100 000 inhabitants ≥25 years were observed for all countries (Figure 4.4).Figure 4.4 only shows the countries for which YLDs per 100 000 inhabitants ≥25 years could be estimated.

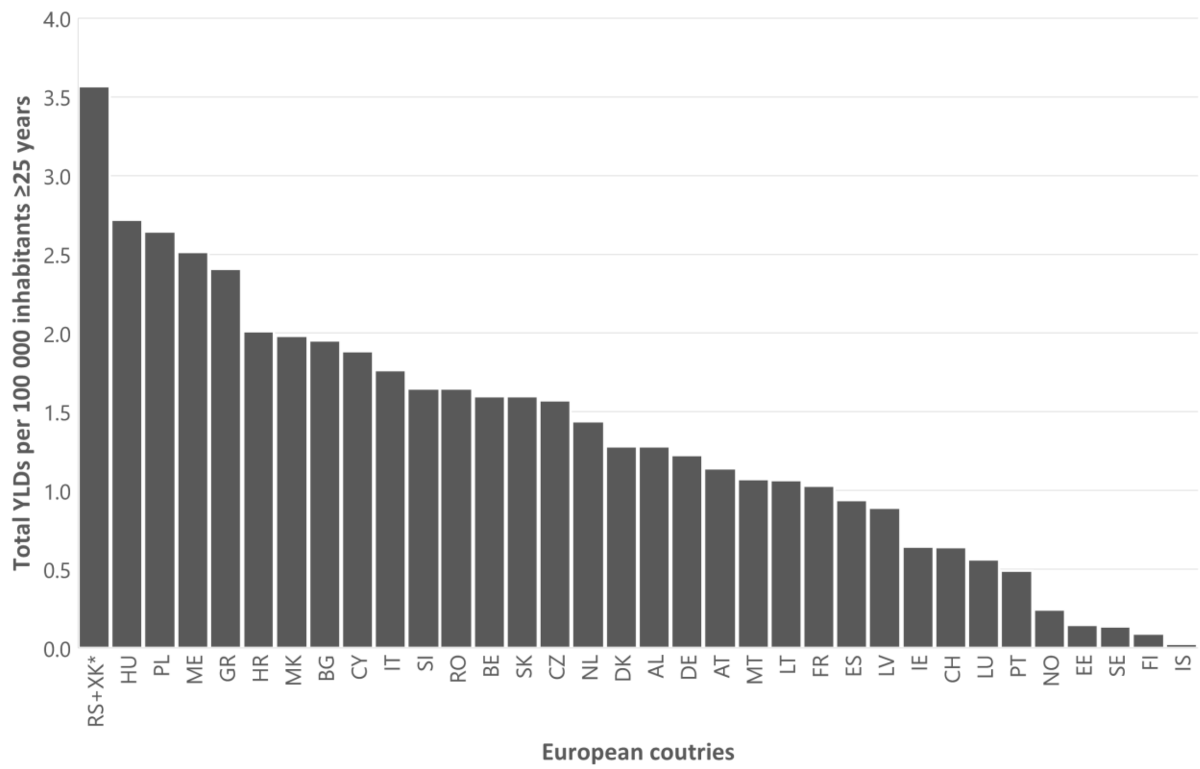
Table 4.4: LC disease burden (morbidity) attributable to $PM_{2.5}$ for adults ≥25 years for different European countries 2019

	PAF (95 % CI: low, high)			YLDs[a] (95 % CI: low, high)			YLDs/10^5 inhabitants ≥25 years (95 % CI: low, high)		
Country	**mean**	**low**	**high**	**mean**	**low**	**high**	**mean**	**low**	**high**
Andorra	0.131	0.055	0.212	ND	ND	ND	ND	ND	ND
Albania	0.259	0.114	0.395	25	11	38	1.3	<1.0	2.0
Austria	0.142	0.060	0.227	75	32	120	1.1	<1.0	1.8
Bosnia & Herzegovina[b]	0.321	0.147	0.469	68	31	100	ND	ND	ND
Belgium	0.136	0.057	0.218	131	55	211	1.6	<1.0	2.6
Bulgaria	0.268	0.118	0.407	105	46	159	2.0	<1.0	3.0
Switzerland	0.086	0.036	0.141	41	17	67	<1.0	<1.0	1.0

Country	PAF (95 % CI: low, high) mean	low	high	YLDs[a] (95 % CI: low, high) mean	low	high	YLDs/10^5 inhabitants ≥25 years (95 % CI: low, high) mean	low	high
Cyprus	0.212	0.091	0.331	12	<10	18	1.9	<1.0	2.9
Czechia	0.192	0.082	0.302	126	54	197	1.6	<1.0	2.5
Germany	0.117	0.049	0.190	774	321	1 255	1.2	<1.0	2.0
Denmark	0.102	0.042	0.166	53	22	86	1.3	<1.0	2.1
Estonia	0.018	0.007	0.031	<10	<10	<10	<1.0	<1.0	<1.0
Spain	0.117	0.049	0.188	332	139	534	<1.0	<1.0	1.5
Finland	0.012	0.005	0.020	<10	<10	<10	<1.0	<1.0	<1.0
France	0.104	0.043	0.168	486	202	788	1.0	0.4	1.7
Greece	0.228	0.099	0.353	195	84	301	2.4	1.0	3.7
Croatia	0.206	0.089	0.320	61	26	95	2.0	<1.0	3.1
Hungary	0.206	0.088	0.323	199	85	311	2.7	1.2	4.3
Ireland	0.063	0.026	0.103	21	9	35	<1.0	<1.0	1.1
Iceland	0.003	0.001	0.005	<1	<1	<1	<1.0	<1.0	<1.0
Italy	0.203	0.088	0.315	814	351	1 265	1.8	<1.0	2.7
Liechtenstein	0.071	0.029	0.117	ND	ND	ND	ND	ND	ND
Lithuania	0.157	0.066	0.250	22	9	35	1.1	<1.0	1.7
Luxembourg	0.073	0.030	0.120	<10	<10	<10	<1.0	<1.0	<1.0
Latvia	0.116	0.048	0.185	13	<10	21	0.9	0.4	1.4
Monaco	0.172	0.072	0.273	ND	ND	ND	ND	ND	ND
Montenegro	0.274	0.122	0.413	11	<10	16	2.5	1.1	3.8
North Macedonia	0.309	0.140	0.459	29	13	43	2.0	<1.0	2.9
Malta	0.160	0.067	0.255	<10	<10	<10	1.1	<1.0	1.7
Netherlands	0.129	0.054	0.209	179	74	289	1.4	0.6	2.3
Norway	0.026	0.011	0.043	<10	<10	15	<1.0	<1.0	<1.0
Poland	0.262	0.115	0.400	746	328	1 137	2.6	1.2	4.0
Portugal	0.076	0.031	0.124	38	16	62	<1.0	<1.0	<1.0
Romania	0.217	0.094	0.336	236	102	366	1.6	0.7	2.6
Serbia[c]	0.314	0.141	0.468	224	100	334	3.6	1.6	5.3
Sweden	0.021	0.009	0.035	10	<10	17	<1.0	<1.0	<1.0
Slovenia	0.178	0.076	0.281	26	11	41	1.6	<1.0	2.6
Slovakia	0.205	0.088	0.321	64	28	101	1.6	<1.0	2.5
San Marino	0.180	0.076	0.286	ND	ND	ND	ND	ND	ND
Türkiye	ND	ND	ND	ND	ND	ND	ND	ND	ND
All countries[b]				**5 136**	**2 194**	**8 075**	**1.5**	**<1.0**	**2.3**

Notes: ([a]) Total and national data are rounded; ([b]) Rates per 100 000 inhabitants ≥25 years do not include figures for Bosnia & Herzegovina due to missing age-stratified population data; ([c]) Presumably Serbia including Kosovo; ND = No data.

Figure 4.4: LC disease burden attributable to $PM_{2.5}$ for adults ≥25 years for different European countries 2019 (in descending order)



Notes**:** * Presumably Serbia including Kosovo (RS+XK).

Stroke (adults ≥25 years)

The overall burden due to morbidity effects of stroke resulting from exposure to fine particulate matter pollution in the selected European countries was estimated at 128 796 YLDs (Table 4.5). According to the absolute numbers the highest EBD was observed for Germany with 25 236 YLDs and the lowest for Iceland with <10 YLDs. The highest rates were estimated for Bulgaria, Croatia and Poland with 107.8, 82.9 and 73.2 YLDs per 100 000 inhabitants ≥25 years, respectively. The lowest were observed for Sweden, Estonia and Iceland with 3.3, 2.9 and <1.0 YLDs per 100 000 inhabitants ≥25 years, respectively (Figure 4.5).Figure 4.5 only shows the countries for which YLDs per 100 000 inhabitants ≥25 years could be estimated.

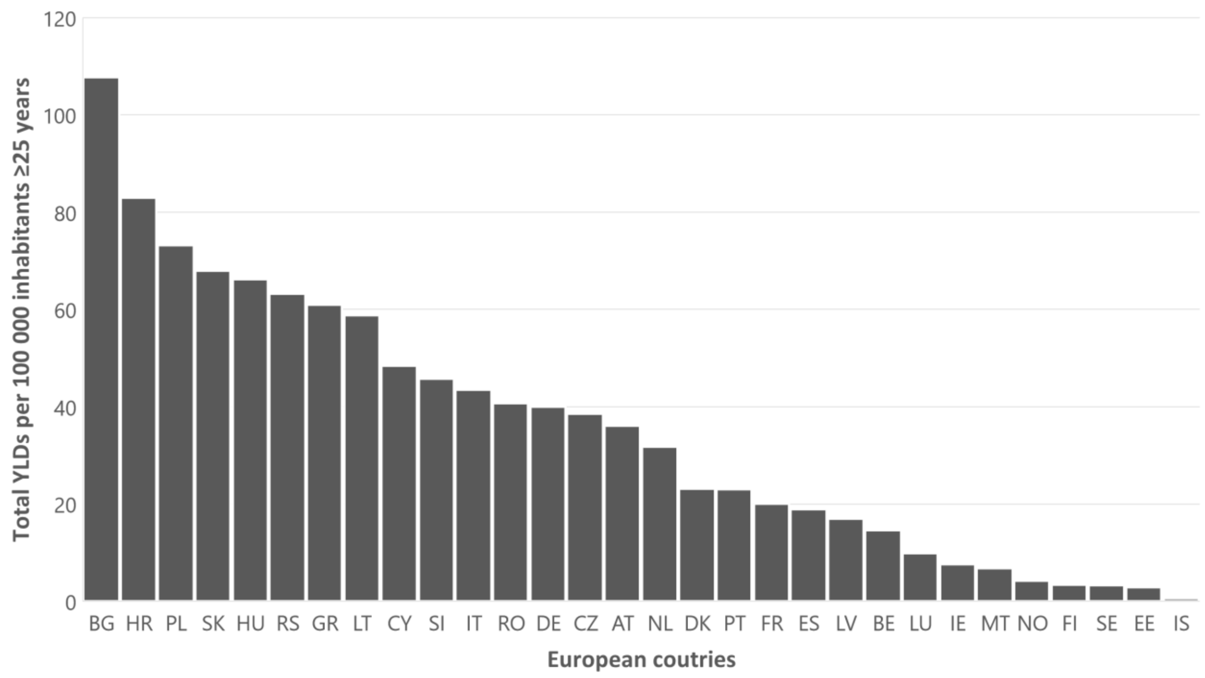
Table 4.5: Stroke disease burden (morbidity) attributable to $PM_{2.5}$ for adults ≥25 years for different European countries 2019

	PAF (95 % CI: low, high)			YLDs[(a)] (95 % CI: low, high)			YLDs/10^5 inhabitants ≥25 years (95 % CI: low, high)		
Country	**mean**	**low**	**high**	**mean**	**low**	**high**	**mean**	**low**	**high**
Andorra	0.104	0.011	0.197	ND	ND	ND	ND	ND	ND
Albania	0.209	0.024	0.371	ND	ND	ND	ND	ND	ND
Austria	0.113	0.013	0.211	2 384	265	4 458	36.1	4.0	67.4
Bosnia & Herzegovina	0.263	0.032	0.444	ND	ND	ND	ND	ND	ND
Belgium	0.108	0.012	0.203	1 197	132	2 257	14.6	1.6	27.5
Bulgaria	0.217	0.026	0.383	5 790	681	10 213	107.8	12.7	190.1

Country	PAF (95 % CI: low, high) mean	low	high	YLDs[a] (95 % CI: low, high) mean	low	high	YLDs/10^5 inhabitants ≥25 years (95 % CI: low, high) mean	low	high
Switzerland	0.068	0.007	0.131	ND	ND	ND	ND	ND	ND
Cyprus	0.170	0.019	0.310	301	34	550	48.4	5.5	88.3
Czechia	0.154	0.017	0.282	3 081	349	5 651	38.6	4.4	70.7
Germany	0.093	0.010	0.176	25 236	2 757	48 019	40.0	4.4	76.1
Denmark	0.080	0.009	0.154	951	103	1 822	23.1	2.5	44.3
Estonia	0.014	0.002	0.028	29	<10	56	2.9	<1.0	5.8
Spain	0.093	0.010	0.175	6 710	740	12 643	19.0	2.1	35.7
Finland	0.009	0.001	0.019	138	15	273	3.4	<1.0	6.8
France	0.082	0.009	0.156	9 469	1 034	18 032	20.1	2.2	38.2
Greece	0.183	0.021	0.331	4 936	568	8 902	61.0	7.0	110.0
Croatia	0.165	0.019	0.299	2 524	289	4 575	82.9	9.5	150.3
Hungary	0.165	0.019	0.302	4 836	548	8 859	66.2	7.5	121.3
Ireland	0.049	0.005	0.095	249	27	481	7.6	0.8	14.7
Iceland	0.002	0.000	0.005	<10	<1	<10	<1.0	<1.0	1.2
Italy	0.163	0.019	0.295	20 039	2 295	36 330	43.5	5.0	78.8
Liechtenstein	0.056	0.006	0.109	ND	ND	ND	ND	ND	ND
Lithuania	0.125	0.014	0.233	1 222	136	2 276	58.8	6.6	109.5
Luxembourg	0.057	0.006	0.111	44	<10	85	9.9	1.1	19.1
Latvia	0.092	0.010	0.173	244	27	459	17.0	1.9	31.9
Monaco	0.137	0.015	0.255	ND	ND	ND	ND	ND	ND
Montenegro	0.222	0.026	0.389	ND	ND	ND	ND	ND	ND
North Macedonia	0.252	0.030	0.433	ND	ND	ND	ND	ND	ND
Malta	0.127	0.014	0.237	25	<10	48	6.8	<1.0	12.8
Netherlands	0.102	0.011	0.194	3 946	432	7 482	31.8	3.5	60.3
Norway	0.020	0.002	0.040	158	17	310	4.2	<1.0	8.3
Poland	0.212	0.025	0.375	20 655	2 419	36 597	73.2	8.6	129.7
Portugal	0.060	0.007	0.115	1 792	194	3 436	23.0	2.5	44.2
Romania	0.174	0.020	0.315	5 831	668	10 555	40.7	4.7	73.7
Serbia	0.257	0.031	0.444	3 310	397	5 720	63.2	7.6	109.3
Sweden	0.017	0.002	0.032	243	26	474	3.3	<1.0	6.5
Slovenia	0.143	0.016	0.262	719	81	1 322	45.7	5.2	84.1
Slovakia	0.164	0.019	0.300	2 737	310	5 007	68.0	7.7	124.4
San Marino	0.144	0.016	0.266	ND	ND	ND	ND	ND	ND
Türkiye	ND	ND	ND	ND	ND	ND	ND	ND	ND
Kosovo	0.248	0.030	0.431	ND	ND	ND	ND	ND	ND
All countries				**128 796**	**14 556**	**236 894**	**37.8**	**4.3**	**69.6**

Notes: ([a]) Total and national data are rounded; ND = No data.

Figure 4.5: Stroke disease burden attributable to $PM_{2.5}$ for adults ≥25 years for different European countries 2019 (in descending order)



Diabetes Mellitus (adults ≥25 years)

The overall burden due to morbidity effects of DM resulting from exposure to fine particulate matter pollution in the selected European countries was estimated at 134 073 YLDs (Table 4.6). According to the absolute number the highest burden was estimated for Poland with 21 681 YLDs and the lowest for Iceland with <10 YLDs. The highest rates were observed for Serbia (excluding Kosovo), Poland and Croatia with 90.8, 76.8 and 69.9 YLDs per 100 000 inhabitants ≥25 years (Figure 4.6). Figure 4.6 only shows the countries for which YLDs per 100 000 inhabitants ≥25 years could be estimated.

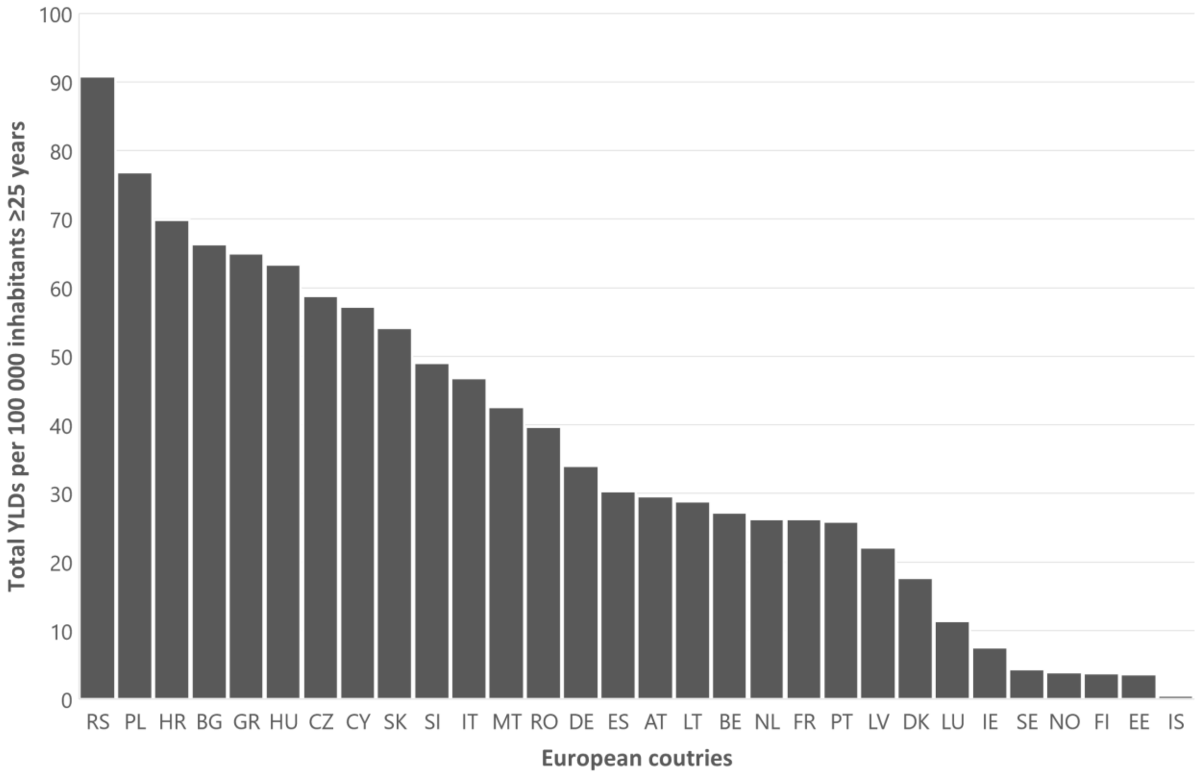
Table 4.6: DM disease burden (morbidity) attributable to $PM_{2.5}$ for adults ≥25 years for different European countries 2019

	PAF (95 % CI: low, high)			YLDs[(a)] (95 % CI: low, high)			YLDs/10^5 inhabitants ≥25 years (95 % CI: low, high)		
Country	mean	low	high	mean	low	high	mean	low	high
Andorra	0.049	0.028	0.068	ND	ND	ND	ND	ND	ND
Albania	0.101	0.059	0.140	ND	ND	ND	ND	ND	ND
Austria	0.053	0.030	0.074	1 955	1 122	2 737	29.6	17.0	41.4
Bosnia & Herzegovina	0.131	0.077	0.180	ND	ND	ND	ND	ND	ND
Belgium	0.050	0.029	0.070	2 235	1 281	3134	27.2	15.6	38.2
Bulgaria	0.105	0.061	0.146	3 563	2 071	4 927	66.3	38.6	91.7
Switzerland	0.032	0.018	0.044	ND	ND	ND	ND	ND	ND
Cyprus	0.081	0.047	0.113	356	206	496	57.2	33.0	79.7
Czechia	0.073	0.042	0.102	4 699	2 708	6 551	58.8	33.9	82.0
Germany	0.043	0.025	0.060	21 449	12 266	30 129	34.0	19.4	47.7
Denmark	0.037	0.021	0.052	727	415	1 022	17.7	10.1	24.8

Country	PAF (95 % CI: low, high) mean	low	high	YLDs[a] (95 % CI: low, high) mean	low	high	YLDs/10^5 inhabitants ≥25 years (95 % CI: low, high) mean	low	high
Estonia	0.007	0.004	0.009	36	20	51	3.7	2.1	5.2
Spain	0.043	0.025	0.061	10 735	6 152	15 048	30.3	17.4	42.5
Finland	0.004	0.002	0.006	151	86	214	3.8	2.1	5.3
France	0.038	0.022	0.053	12 378	7 078	17 389	26.2	15.0	36.9
Greece	0.088	0.051	0.122	5 258	3 041	7 306	65.0	37.6	90.3
Croatia	0.079	0.046	0.110	2 126	1 229	2 957	69.9	40.4	97.2
Hungary	0.078	0.045	0.109	4 626	2 666	6 449	63.4	36.5	88.3
Ireland	0.023	0.013	0.032	247	141	348	7.5	4.3	10.6
Iceland	0.001	0.001	0.002	<10	<10	<10	<1.0	<1.0	<1.0
Italy	0.078	0.045	0.108	21 593	12 479	30 031	46.8	27.1	65.1
Liechtenstein	0.026	0.015	0.036	ND	ND	ND	ND	ND	ND
Lithuania	0.059	0.034	0.082	600	344	839	28.9	16.6	40.4
Luxembourg	0.026	0.015	0.037	50	29	71	11.4	6.5	16.0
Latvia	0.043	0.025	0.060	318	182	445	22.1	12.7	30.9
Monaco	0.064	0.037	0.090	ND	ND	ND	ND	ND	ND
Montenegro	0.108	0.063	0.150	ND	ND	ND	ND	ND	ND
North Macedonia	0.125	0.073	0.171	ND	ND	ND	ND	ND	ND
Malta	0.060	0.034	0.083	158	91	221	42.6	24.4	59.6
Netherlands	0.048	0.027	0.067	3 262	1 867	4 579	26.3	15.0	36.9
Norway	0.009	0.005	0.013	146	83	207	3.9	2.2	5.5
Poland	0.103	0.060	0.142	21 681	12 591	30 011	76.8	44.6	106.3
Portugal	0.028	0.016	0.039	2 013	1 150	2 832	25.9	14.8	36.4
Romania	0.083	0.048	0.116	5 688	3 287	7 909	39.7	23.0	55.2
Serbia	0.126	0.074	0.174	4 754	2 776	6 547	90.8	53.0	125.1
Sweden	0.008	0.004	0.011	318	181	449	4.4	2.5	6.2
Slovenia	0.068	0.039	0.094	770	444	1 075	49.0	28.2	68.3
Slovakia	0.078	0.045	0.109	2 178	1 256	3 036	54.1	31.2	75.4
San Marino	0.068	0.039	0.095	ND	ND	ND	ND	ND	ND
Türkiye	ND	ND	ND	ND	ND	ND	ND	ND	ND
Kosovo	0.121	0.071	0.167	ND	ND	ND	ND	ND	ND
All countries				**134 073**	**77 241**	**187 011**	**39.4**	**22.7**	**54.9**

Notes: ([a]) Total and national data are rounded; ND = No data.

Figure 4.6: DM disease burden attributable to $PM_{2.5}$ for adults ≥25 years for different European countries 2019 (in descending order)



4.2 NO_2 (long-term effects)

Asthma (adults ≥15 years)

The overall burden due to morbidity effects of asthma resulting from exposure to NO_2 in the selected European countries was estimated at 126 797 YLDs (Table 4.7). According to the absolute numbers the highest disease burden was estimated for Türkiye with 43 705 YLDs and the lowest for Estonia with 19 YLDs. The highest rates were observed for Türkiye, Germany and the Netherlands with 69.6, 33.4 and 32.1 YLDs per 100 000 inhabitants ≥15 years. Countries with the lowest disease burden were Estonia, Sweden and Lithuania with 1.7, 3.5 and 4.0 YLDs per 100 000 inhabitants ≥15 years (Figure 4.7). Figure 4.7 only shows the countries for which YLDs per 100 000 inhabitants ≥15 years could be estimated.

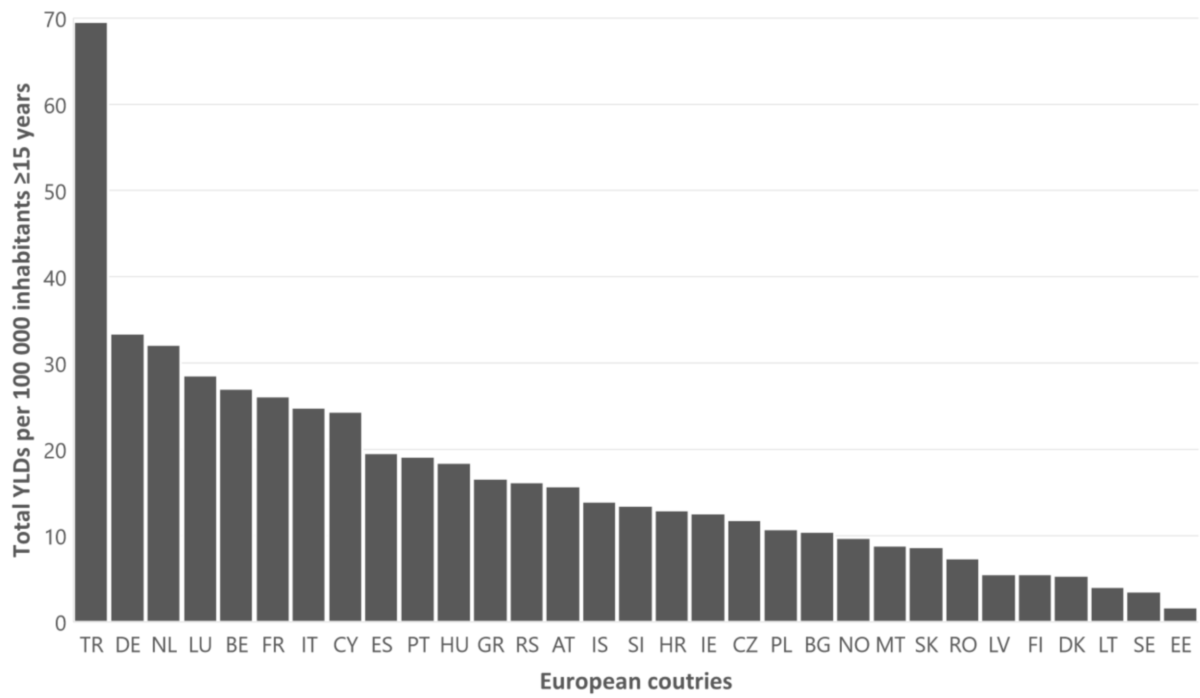
Table 4.7: Asthma disease burden (morbidity) attributable to NO_2 for adults ≥15 years for different European countries 2019

	PAF (95 % CI: low, high)			YLDs[a] (95 % CI: low, high)			YLDs/10^5 inhabitants ≥15 years (95 % CI: low, high)		
Country	**mean**	**low**	**high**	**mean**	**low**	**high**	**mean**	**low**	**high**
Andorra	0.145	0.091	0.199	ND	ND	ND	ND	ND	ND
Albania	0.087	0.055	0.120	ND	ND	ND	ND	ND	ND
Austria	0.098	0.061	0.133	1 194	752	1 632	15.8	9.9	21.5
Bosnia & Herzegovina	0.077	0.048	0.106	ND	ND	ND	ND	ND	ND
Belgium	0.123	0.077	0.169	2 576	1 621	3 528	27.1	17.0	37.1

Country	PAF (95 % CI: low, high) mean	low	high	YLDs[a] (95 % CI: low, high) mean	low	high	YLDs/10^5 inhabitants ≥15 years (95 % CI: low, high) mean	low	high
Bulgaria	0.126	0.079	0.171	627	396	853	10.5	6.6	14.2
Switzerland	0.099	0.062	0.136	ND	ND	ND	ND	ND	ND
Cyprus	0.158	0.100	0.214	179	114	243	24.4	15.5	33.0
Czechia	0.068	0.042	0.094	1 060	662	1 464	11.8	7.4	16.3
Germany	0.110	0.069	0.150	23 970	15 106	32 765	33.4	21.1	45.7
Denmark	0.019	0.012	0.027	260	161	362	5.4	3.3	7.5
Estonia	0.011	0.007	0.016	19	12	27	1.7	1.1	2.4
Spain	0.124	0.079	0.168	7 830	4 994	10 575	19.6	12.5	26.4
Finland	0.015	0.010	0.022	257	159	359	5.5	3.4	7.7
France	0.088	0.056	0.119	14 416	9 190	19 486	26.2	16.7	35.4
Greece	0.134	0.086	0.180	1 529	980	2 055	16.6	10.7	22.4
Croatia	0.075	0.047	0.104	451	283	621	12.9	8.1	17.8
Hungary	0.098	0.062	0.135	1 540	970	2 107	18.4	11.6	25.2
Ireland	0.044	0.028	0.061	490	307	674	12.6	7.9	17.3
Iceland	0.036	0.022	0.051	40	25	56	13.9	8.6	19.4
Italy	0.142	0.091	0.192	12 919	8 241	17 443	24.9	15.9	33.6
Liechtenstein	0.098	0.061	0.136	ND	ND	ND	ND	ND	ND
Lithuania	0.038	0.023	0.052	96	60	133	4.0	2.5	5.6
Luxembourg	0.123	0.078	0.168	147	93	201	28.6	18.0	39.1
Latvia	0.039	0.024	0.054	90	56	125	5.6	3.5	7.7
Monaco	0.195	0.124	0.265	ND	ND	ND	ND	ND	ND
Montenegro	0.087	0.054	0.120	ND	ND	ND	ND	ND	ND
North Macedonia	0.118	0.074	0.163	ND	ND	ND	ND	ND	ND
Malta	0.039	0.024	0.053	38	24	52	8.9	5.6	12.2
Netherlands	0.131	0.082	0.180	4 673	2 936	6 406	32.1	20.2	44.1
Norway	0.032	0.020	0.044	427	267	589	9.7	6.1	13.4
Poland	0.069	0.043	0.095	3 464	2 171	4 761	10.8	6.8	14.8
Portugal	0.082	0.052	0.113	1 698	1 068	2 327	19.1	12.0	26.2
Romania	0.136	0.086	0.184	1 204	766	1 630	7.4	4.7	10.0
Serbia	0.119	0.075	0.164	966	607	1 323	16.2	10.2	22.2
Sweden	0.012	0.008	0.017	295	183	410	3.5	2.2	4.9
Slovenia	0.073	0.046	0.101	239	149	329	13.5	8.4	18.6
Slovakia	0.057	0.035	0.079	398	247	552	8.7	5.4	12.0
San Marino	0.086	0.054	0.120	ND	ND	ND	ND	ND	ND
Türkiye	0.209	0.138	0.274	43 705	28 767	57 197	69.6	45.8	91.0
Kosovo	0.113	0.071	0.154	ND	ND	ND	ND	ND	ND
All countries				**126 797**	**81 365**	**170 284**	**28.0**	**18.0**	**37.7**

Notes: ([a]) Total and national data are rounded; ND = No data.

Figure 4.7: Asthma disease burden attributable to NO_2 for adults ≥15 years for different European countries 2019 (in descending order)



Stroke (adults ≥25 years)

The overall burden due to morbidity effects of stroke resulting from exposure to NO_2 in the selected European countries was estimated at 63 884 YLDs (Table 4.8). According to the absolute numbers the highest burden was estimated for Germany with 15 365 YLDs and the lowest for Malta with <10 YLDs. The highest rates were observed for Bulgaria, Germany, and Greece with 32.3, 24.3 and 23.5 YLDs per 100 000 inhabitants ≥25 years, respectively. The lowest rates were found for Estonia and Malta each presenting with 1.1, and Sweden with 1.2 YLDs per 100 000 inhabitants ≥25 years (Figure 4.8). Figure 4.8 only shows the countries for which YLDs per 100 000 inhabitants ≥25 years could be estimated.

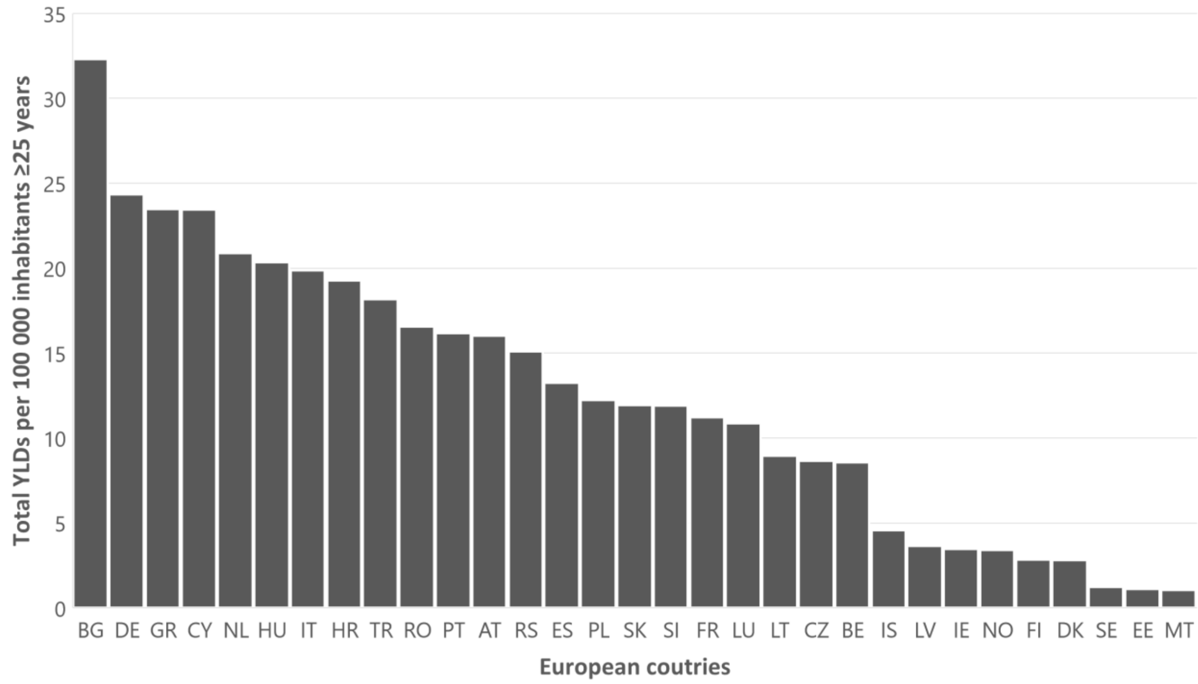
Table 4.8: Stroke disease burden (morbidity) attributable to NO_2 for adults ≥25 years for different European countries 2019

	PAF (95 % CI: low, high)			YLDs[a] (95 % CI: low, high)			YLDs/10^5 inhabitants ≥25 years (95 % CI: low, high)		
Country	mean	low	high	mean	low	high	mean	low	high
Andorra	0.074	0.039	0.107	ND	ND	ND	ND	ND	ND
Albania	0.045	0.023	0.064	ND	ND	ND	ND	ND	ND
Austria	0.050	0.026	0.072	1 060	553	1 526	16.0	8.4	23.1
Bosnia & Herzegovina	0.039	0.020	0.056	ND	ND	ND	ND	ND	ND
Belgium	0.063	0.033	0.091	704	367	1 014	8.6	4.5	12.3
Bulgaria	0.065	0.034	0.093	1 735	907	2 493	32.3	16.9	46.4
Switzerland	0.050	0.026	0.073	ND	ND	ND	ND	ND	ND
Cyprus	0.082	0.043	0.118	146	77	209	23.4	12.3	33.6
Czechia	0.035	0.018	0.050	691	359	1 001	8.7	4.5	12.5
Germany	0.056	0.029	0.081	15 365	8 018	22 124	24.3	12.7	35.1

Country	PAF (95 % CI: low, high) mean	low	high	YLDs[a] (95 % CI: low, high) mean	low	high	YLDs/10^5 inhabitants ≥25 years (95 % CI: low, high) mean	low	high
Denmark	0.010	0.005	0.014	116	60	168	2.8	1.4	4.1
Estonia	0.006	0.003	0.008	11	<10	16	1.1	<1.0	1.6
Spain	0.065	0.034	0.093	4 695	2 469	6 711	13.3	7.0	19.0
Finland	0.008	0.004	0.011	114	59	166	2.8	1.5	4.1
France	0.046	0.024	0.066	5 296	2 785	7 572	11.2	5.9	16.1
Greece	0.071	0.037	0.101	1 900	1 002	2 707	23.5	12.4	33.5
Croatia	0.038	0.020	0.056	587	305	848	19.3	10.0	27.9
Hungary	0.051	0.026	0.073	1 485	774	2 139	20.3	10.6	29.3
Ireland	0.023	0.012	0.033	114	59	165	3.5	1.8	5.0
Iceland	0.018	0.009	0.027	11	<10	16	4.6	2.4	6.6
Italy	0.074	0.039	0.106	9 157	4 816	13 088	19.9	10.4	28.4
Liechtenstein	0.049	0.026	0.072	ND	ND	ND	ND	ND	ND
Lithuania	0.019	0.010	0.028	186	96	270	8.9	4.6	13.0
Luxembourg	0.063	0.033	0.091	48	25	69	10.9	5.7	15.6
Latvia	0.020	0.010	0.029	53	27	77	3.7	1.9	5.3
Monaco	0.101	0.053	0.145	ND	ND	ND	ND	ND	ND
Montenegro	0.044	0.023	0.064	ND	ND	ND	ND	ND	ND
North Macedonia	0.060	0.031	0.087	ND	ND	ND	ND	ND	ND
Malta	0.020	0.010	0.029	<10	<10	<10	1.1	<1.0	1.5
Netherlands	0.067	0.035	0.097	2 592	1 349	3 739	20.9	10.9	30.1
Norway	0.016	0.008	0.024	127	66	184	3.4	1.8	4.9
Poland	0.035	0.018	0.051	3 453	1 795	4 988	12.2	6.4	17.7
Portugal	0.042	0.022	0.061	1 259	656	1 816	16.2	8.4	23.3
Romania	0.071	0.037	0.101	2 373	1 246	3 398	16.6	8.7	23.7
Serbia	0.061	0.032	0.088	790	412	1 139	15.1	7.9	21.8
Sweden	0.006	0.003	0.009	90	47	131	1.2	<1.0	1.8
Slovenia	0.037	0.019	0.054	187	97	271	11.9	6.2	17.2
Slovakia	0.029	0.015	0.042	481	249	698	11.9	6.2	17.3
San Marino	0.044	0.023	0.063	ND	ND	ND	ND	ND	ND
Türkiye	0.114	0.061	0.160	9 056	4 862	12 699	18.2	9.8	25.5
Kosovo	0.058	0.030	0.083	ND	ND	ND	ND	ND	ND
All countries				**63 884**	**33 550**	**91 453**	**16.4**	**8.6**	**23.4**

Notes: ([a]) Total and national data are rounded; ND = No data.

Figure 4.8: Stroke disease burden attributable to NO_2 for adults ≥25 years for different European countries 2019 (in descending order)



Diabetes Mellitus (adults ≥35 years)

The overall burden due to morbidity effects of DM resulting from exposure to NO_2 in the selected European countries was estimated at 175 095 YLDs (Table 4.9). According to the absolute numbers the highest burden was estimated for Türkiye with 54 186 YLDs and the lowest for Iceland with 18 YLDs. The highest rates were observed for Türkiye, Cyprus and Greece with 145.5, 75.7 and 60.7 YLDs per 100 000 inhabitants ≥35 years. The lowest rates were found for Estonia, Sweden and Denmark with 3.7, 4.3 and 5.5 YLDs per 100 000 inhabitants ≥35 years, respectively (Figure 4.9). Figure 4.9 only shows the countries for which YLDs per 100 000 inhabitants ≥35 years could be estimated.

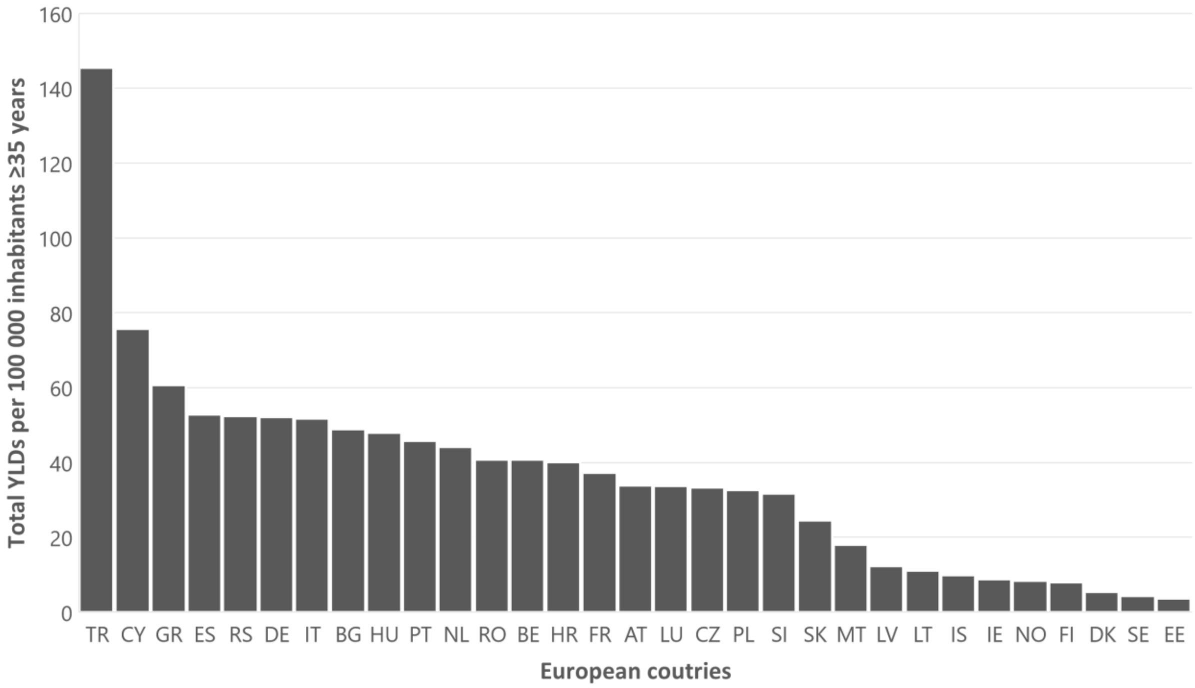
Table 4.9: DM disease burden (morbidity) attributable to NO_2 for adults ≥35 years for different European countries 2019

	PAF (95 % CI: low, high)			YLDs[(a)] (95 % CI: low, high)			YLDs/10^5 inhabitants ≥35 years (95 % CI: low, high)		
Country	**mean**	**low**	**high**	**mean**	**low**	**high**	**mean**	**low**	**high**
Andorra	0.074	0.000	0.145	ND	ND	ND	ND	ND	ND
Albania	0.045	0.000	0.087	ND	ND	ND	ND	ND	ND
Austria	0.050	0.000	0.098	1 831	<1	3 559	33.9	<1.0	65.9
Bosnia & Herzegovina	0.039	0.000	0.077	ND	ND	ND	ND	ND	ND
Belgium	0.063	0.000	0.123	2 743	<1	5 343	40.8	<1.0	79.4
Bulgaria	0.065	0.000	0.126	2 190	<1	4 236	49.0	<1.0	94.7
Switzerland	0.050	0.000	0.099	ND	ND	ND	ND	ND	ND
Cyprus	0.082	0.000	0.158	359	<1	691	75.7	<1.0	145.6
Czechia	0.035	0.000	0.068	2 198	<1	4 324	33.3	<1.0	65.5

Country	PAF (95 % CI: low, high) mean	low	high	YLDs[a] (95 % CI: low, high) mean	low	high	YLDs/10^5 inhabitants ≥35 years (95 % CI: low, high) mean	low	high
Germany	0.056	0.000	0.110	27 420	<1	53 274	52.2	<1.0	101.4
Denmark	0.010	0.000	0.019	184	<1	366	5.5	<1.0	10.9
Estonia	0.006	0.000	0.011	30	<1	59	3.7	<1.0	7.5
Spain	0.065	0.000	0.124	15 898	<1	30 411	52.9	<1.0	101.2
Finland	0.008	0.000	0.015	267	<1	532	8.1	<1.0	16.1
France	0.046	0.000	0.088	14 653	<1	28 041	37.3	<1.0	71.4
Greece	0.071	0.000	0.134	4 192	<1	7 966	60.7	<1.0	115.3
Croatia	0.038	0.000	0.075	1 019	<1	1 997	40.1	<1.0	78.5
Hungary	0.051	0.000	0.098	2 903	<1	5 647	47.9	<1.0	93.2
Ireland	0.023	0.000	0.044	235	<1	460	8.8	<1.0	17.3
Iceland	0.018	0.000	0.036	18	<1	37	9.9	<1.0	19.7
Italy	0.074	0.000	0.142	20 497	<1	39 197	51.7	<1.0	99.0
Liechtenstein	0.049	0.000	0.098	ND	ND	ND	ND	ND	ND
Lithuania	0.019	0.000	0.038	190	<1	377	11.1	<1.0	22.1
Luxembourg	0.063	0.000	0.123	118	<1	229	33.7	<1.0	65.4
Latvia	0.020	0.000	0.039	145	<1	287	12.3	<1.0	24.4
Monaco	0.101	0.000	0.195	ND	ND	ND	ND	ND	ND
Montenegro	0.044	0.000	0.087	ND	ND	ND	ND	ND	ND
North Macedonia	0.060	0.000	0.118	ND	ND	ND	ND	ND	ND
Malta	0.020	0.000	0.039	52	<1	101	18.0	<1.0	35.3
Netherlands	0.067	0.000	0.131	4 509	<1	8 798	44.2	<1.0	86.2
Norway	0.016	0.000	0.032	251	<1	492	8.4	<1.0	16.4
Poland	0.035	0.000	0.069	7 394	<1	14 470	32.6	<1.0	63.8
Portugal	0.042	0.000	0.082	3 044	<1	5 934	45.7	<1.0	89.2
Romania	0.071	0.000	0.136	4 829	<1	9 267	40.8	<1.0	78.3
Serbia	0.061	0.000	0.119	2 275	<1	4 433	52.4	<1.0	102.1
Sweden	0.006	0.000	0.012	253	<1	502	4.3	<1.0	8.6
Slovenia	0.037	0.000	0.073	418	<1	823	31.7	<1.0	62.4
Slovakia	0.029	0.000	0.057	793	<1	1 569	24.6	<1.0	48.7
San Marino	0.044	0.000	0.086	ND	ND	ND	ND	ND	ND
Türkiye	0.114	0.000	0.209	54 186	<1	99 450	145.5	<1.0	267.1
Kosovo	0.058	0.000	0.113	ND	ND	ND	ND	ND	ND
All countries				**175 095**	**<1**	**332 871**	**54.6**	**<1.0**	**103.8**

Notes: ([a]) Total and national data are rounded; ND = No data.

Figure 4.9: DM disease burden attributable to NO_2 for adults ≥35 years for different European countries 2019 (in descending order)



4.3 O_3 (short-term effects)

Hospital admissions for respiratory diseases (adults ≥65 years)

For O_3 no study was identified linking the incidence or prevalence of diseases with the exposure to O_3. Thus, the number of hospital admissions due to respiratory disease was used as a proxy for the morbidity burden resulting from exposure to O_3. According to the recommendations of the HRAPIE project, impact estimates were calculated for the SOMO35 (WHO, 2013a).

The estimates show that with 3 059 hospital admissions attributable to exposure to O_3 the highest burden was estimated for Italy and the lowest was found for Iceland with <10 hospital admissions (Table 4.10). The highest rates were observed for Austria, Spain and Italy with 29, 28 and 22 hospital admissions attributable to exposure to O_3 per 100 000 inhabitants ≥65 years. The lowest rates were observed for Iceland, Latvia and The Netherlands with 4, 7 and 8 hospital admissions per 100 000 inhabitants ≥65 years (Figure 4.10). Figure 4.10 only shows the countries for which hospital admissions per 100 000 inhabitants ≥65 years could be estimated.

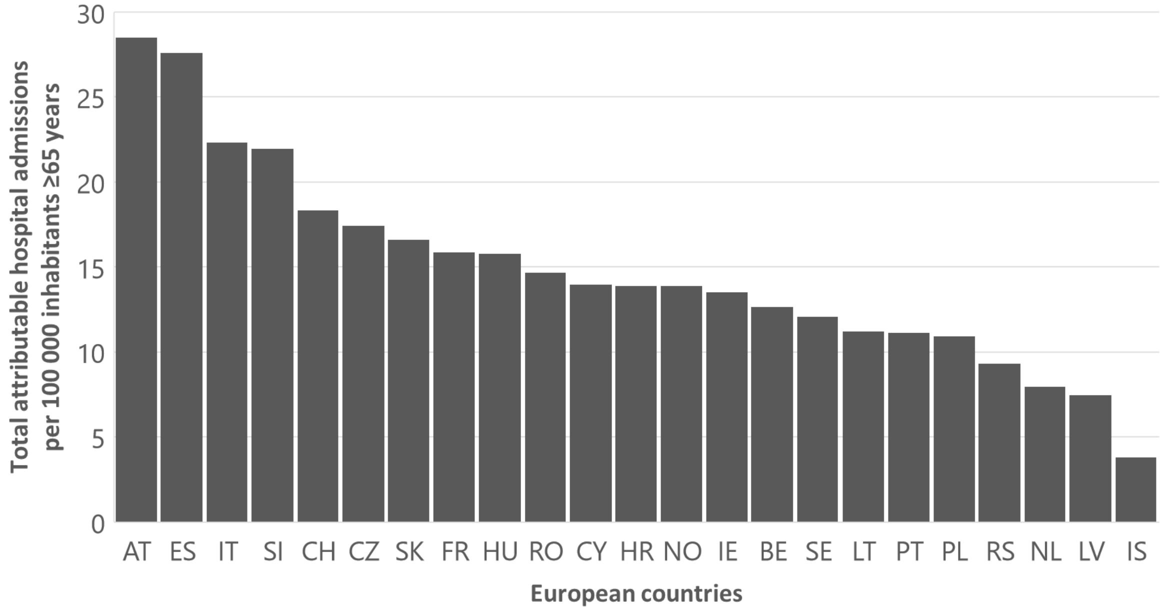
Table 4.10: Hospital admissions for respiratory disease burden (morbidity) attributable to O_3 for adults ≥65 years for different European countries 2019

	Attributable cases[(a)] (95 % CI: low, high)			Attributable cases/10^5 inhabitants ≥65 years (95 % CI: low, high)		
Country	**mean**	**low**	**high**	**mean**	**low**	**high**
Andorra	ND	ND	ND	ND	ND	ND
Albania	ND	ND	ND	ND	ND	ND
Austria	476	76	898	29	<10	54
Bosnia & Herzegovina	ND	ND	ND	ND	ND	ND
Belgium	274	44	517	13	<10	24

Country	Attributable cases[a] (95 % CI: low, high) mean	low	high	Attributable cases/10^5 inhabitants ≥65 years (95 % CI: low, high) mean	low	high
Bulgaria	ND	ND	ND	ND	ND	ND
Switzerland	289	46	546	18	<10	35
Cyprus	20	<10	37	14	<10	26
Czechia	364	58	687	17	<10	33
Germany	ND	ND	ND	ND	ND	ND
Denmark	ND	ND	ND	ND	ND	ND
Estonia	ND	ND	ND	ND	ND	ND
Spain	2 515	400	4 745	28	4	52
Finland	ND	ND	ND	ND	ND	ND
France	2 135	340	4 027	16	3	30
Greece	ND	ND	ND	ND	ND	ND
Croatia	117	19	220	14	2	26
Hungary	298	47	563	16	3	30
Ireland	93	15	176	14	2	25
Iceland	<10	<1	<10	4	1	7
Italy	3 059	487	5 771	22	4	42
Liechtenstein	ND	ND	ND	ND	ND	ND
Lithuania	62	10	117	11	2	21
Luxembourg	ND	ND	ND	ND	ND	ND
Latvia	29	<10	55	7	1	14
Monaco	ND	ND	ND	ND	ND	ND
Montenegro	ND	ND	ND	ND	ND	ND
North Macedonia	ND	ND	ND	ND	ND	ND
Malta	ND	ND	ND	ND	ND	ND
Netherlands	264	42	497	8	1	15
Norway	128	20	241	14	2	26
Poland	733	117	1 383	11	2	21
Portugal	250	40	472	11	2	21
Romania	527	84	995	15	2	28
Serbia	133	21	250	9	1	18
Sweden	246	39	464	12	2	23
Slovenia	91	14	171	22	3	41
Slovakia	145	23	274	17	3	31
San Marino	ND	ND	ND	ND	ND	ND
Türkiye	ND	ND	ND	ND	ND	ND
Kosovo	ND	ND	ND	ND	ND	ND
All countries	**12 251**	**1 949**	**23 110**	**18**	**3**	**33**

Notes: ([a]) Total and national data are rounded; ND = No data.

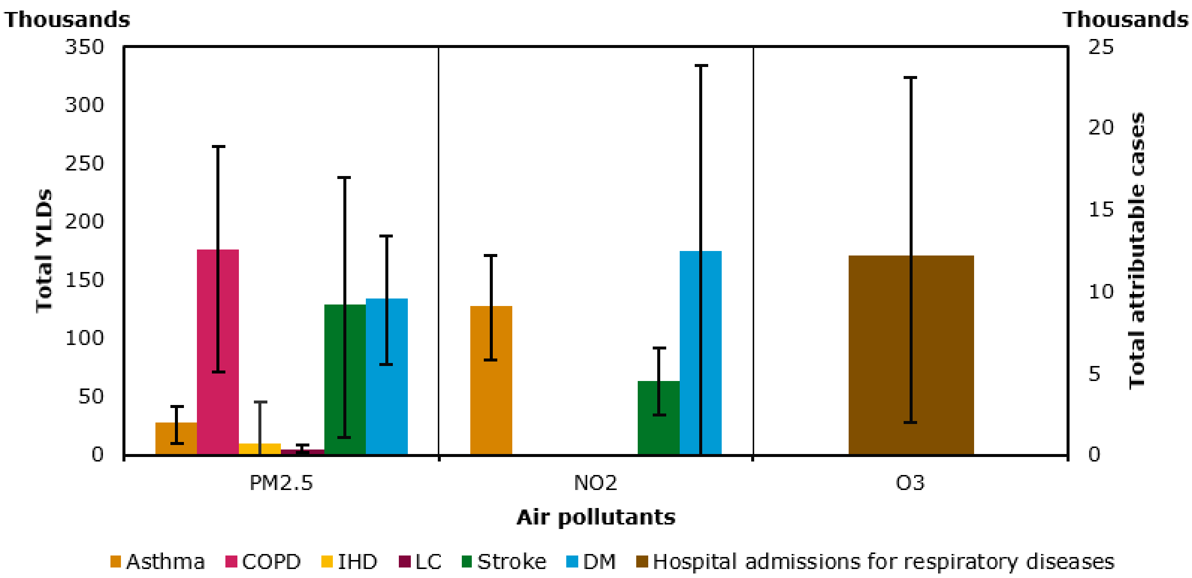
Figure 4.10: Hospital admissions for respiratory disease burden attributable to O_3 for adults ≥65 years for different European countries 2019 (in descending order)



4.4 Summary of results

The results indicate that in 2019 the highest morbidity burden in Europe resulting from $PM_{2.5}$ pollution is due to COPD with 51.6 YLDs per 100 000 inhabitants ≥25 years (95 % CI: 20.8-77.6) or rather 175 731 YLDs (95 % CI: 70 702-264 297) (Figure 4.11). For NO_2 the highest morbidity burden results from DM with 54.6 YLDs per 100 000 inhabitants ≥35 years (95 % CI: <1.0-103.8) or rather 175 095 YLDs (95 % CI: <1-332 871). Hospital admissions of persons with lower respiratory infections due to O_3 are 18 admissions per 100 000 inhabitants ≥65 years (95 % CI: 3-33) or rather 12 251 admissions (95 % CI: 1 949-23 110). When comparing the results, it is important to note that different age groups were considered in some of the estimates.

Figure 4.11: Total YLDs or attributable cases for all considered risk-outcome pairs



Notes: Total attributable cases only refer to estimates for O_3.

5 Sensitivity analyses

Sensitivity analyses can help to better assess the robustness of the results. In this sense, several further analyses could be considered as a follow-up study by the ETC HE. In the following we describe potential sensitivity analyses, which are also listed in Table 5.1.

Regarding CRFs, effect estimates from other major studies, e. g. the GBD 2019 study, could be used. Likewise, a comparison with the functions used in other European morbidity assessments (VITO/DG Env calculations as part of the revision of the Ambient Air Quality Directives) would be possible. Finally, a targeted search for effect estimates based on multi-pollutant models could be conducted in order to reduce the effect of double-counting.

With regards to health data, it would be worthwhile to compare the EHIS data used with modelled data from the GBD 2019 study. For example, Asher et al. (2020) pointed to ambiguities in the origin of the GBD asthma data and great temporal variability in the modelled data. Alternative health data, i.e. from the ECIS database, could be used in the calculations for lung cancer. For a necessary conversion of these national incidence data into prevalent cases, a conversion factor could be derived from the corresponding GBD 2019 data for individual countries.

Furthermore, the counterfactual concentration C_0 selected for each risk factor could be varied. For example, SOMO10 could be used for O_3 instead of SOMO35.

Table 5.1: Overview of possible EBD sensitivity/scenario analyses and differences in input data to the performed analyses

Pollutant	Outcome	Performed analyses		Sensitivity analyses		
		CRF	Health data source	CRF (95 % CI)	CRF source	Health data source
$PM_{2.5}$	Asthma (children)		EHIS			IHME
	COPD	ELAPSE project			IHME	
	LC	ELAPSE project	IARC	1.09 (1.04-1.14); 1.08 (1.03-1.12)	(Hamra et al., 2014); (Huang et al., 2017)	IHME; ECIS incidence multiplied by IHME factor (incidence/prevalence)
	Stroke	ELAPSE project		1.13 (1.11-1.15)	(Alexeeff et al., 2021)	
	DM	(Zang et al., 2022)		1.10 (1.04-1.17)	IHME; (Yang et al., 2020)	
NO_2	Asthma (adults)		EHIS			IHME
	Stroke	ELAPSE project		1.003 (0.964-1.043)	(Schneider et al., 2018)	
	DM	(Eze et al., 2015)		1.148 (1.024-1.288)	(Schneider et al., 2018)	

6 Discussion and Conclusions

There are currently no comparable analyses of morbidity related EBD for Europe available and we thus only selectively compared our estimates to the results from the GBD 2019 study. We therefore selected the countries with the highest absolute burden for the relevant risk-outcome pairs. The comparisons of the GBD 2019 data were only performed for $PM_{2.5}$, because NO_2 was not considered as a risk factor in GBD 2019 and hospital admissions, as used for O_3 in our assessment, were not considered as an outcome.

The highest YLDs due to $PM_{2.5}$-associated asthma in children under 15 years were estimated at 4 757 YLDs (95 % CI: 1 820-6 977) for Poland. Asthma was not considered in GBD 2019 and thus could not be compared.

The highest YLDs due to $PM_{2.5}$-associated COPD were estimated at 38 460 YLDs (95 % CI: 15 035-59 316) for Germany. For this risk-outcome pair the GBD 2019 study results account for 28 445 YLDs (95 % UI 16 881-43 803). The central estimate of our analysis is well within the uncertainty interval (UI; compared to CI the UI allows to include more sources of uncertainty) of the GBD 2019 result. However, the upper limit of our CI is about 27 % higher than the one provided by the IHME.

The highest YLDs due to $PM_{2.5}$-associated IHD were estimated at 3 044 YLDs (95 % CI: <1-13 240) for Poland. In GBD 2019 this risk-outcome pair accounts for 10 346 YLDs (95 % UI: 6 572-15 284). Here, the IHME estimate is more than three times higher compared to our central estimate and our estimate is also well below the lower limit of the UI. The IHME uses the same CRFs for mortality and morbidity analyses and the effect estimates are considerably higher already at lower concentrations.

The highest YLDs due to $PM_{2.5}$-associated LC were estimated at 814 YLDs (95 % CI: 351-1 265) for Italy. In the GBD 2019 study this risk-outcome pair accounts for 1 139 YLDs (95 % UI: 672-1 705). The results agree well, which might also be the result of the fact, that the effect measures for mortality and morbidity are very much comparable. The slight divergence might result from the exposure or health data. In general, the results seem to converge for this comparison.

The highest YLDs due to $PM_{2.5}$-associated stroke were estimated at 25 236 YLDs (95 % CI: 2 757-48 019) for Germany. This risk outcome pair accounts for 18 006 YLDs (95 % UI: 11 584-25 763) in the GBD 2019 study. Here the estimates of our analysis are higher than the central estimates of the IHME. They are more comparable with the upper end of the UI. The slopes of the CRF are quite comparable. With about 1.5 million prevalent cases our health data used is however higher as compared to the one from the GBD 2019 study, which encompasses about 1.3 million cases. This might be an explanation for the higher YLD estimates in the underlying analysis.

The highest YLDs due to $PM_{2.5}$-associated DM were estimated at 21 681 YLDs (95 % CI: 12 591-30 011) for Poland. In the GBD 2019 study this risk-outcome pair accounts for 56 882 YLDs (95 % UI: 34 086-84 514). Here again, the effect estimate of the IHME is more than twice as high as our central estimate. Furthermore, our estimate is also well below the lower limit of the UI. One reason for this difference could be that the baseline health data in the GBD 2019 study of 3.7 million is considerably higher than the 2.6 million prevalent cases reported by EHIS.

The analyses presented here are the first of the kind that largely use health data from European databases to estimate the morbidity associated disease burden resulting from ambient air pollution exposure. The main source of health data were the representative survey results from EHIS. This survey covers a wide range of self-reported prevalence data on many health outcomes that are of relevance when estimating the morbidity related burden of disease for outdoor air pollutants. We followed the prevalence approach to estimate the YLDs. Unfortunately, data on asthma was not available from EHIS for the age group <15 years. In this case we relied on the prevalence data modelled by the IHME. The other cases for which EHIS data were not used were lung cancer (IARC data were used) and hospital admissions for respiratory diseases (Eurostat data on hospital discharges were used).

Even though we followed the prevalence approach and used only prevalence data for estimating the baseline BoD the CRFs were mainly derived using epidemiological studies that estimated the effect measures (HR, RR or RR) on incidence data. This is mainly related to the fact, that e. g. in cohort studies only incident events (new cases of a disease or deaths) and not prevalent cases are used to model the effects estimates.

There is also only a limited number of CRFs specifically available for the European context. The reported effect estimates of the ELAPSE project are an exception here, pooling results from different cohort studies in Europe. However, the spatial coverage is limited and the focus was primarily set on the adult population.

Regarding exposure, the data reported in the Eionet report ETC/ATNI 2021/1 on European air quality for 2019 were used. The uncertainties associated with these data are described in the ETC/ATNI report (Horálek et al., 2022).

Overall, for several countries, no morbidity burden could be modelled for specific health outcomes due to missing input data, e.g. on population and exposure data but mainly due to patchy health data. The countries concerned were often Andorra, Albania, Bosnia and Herzegovina, Lichtenstein, Monaco, Montenegro, North Macedonia, San Marino and Switzerland. Thus, the current estimates for the risk-outcome pairs sometimes differed with respect to country coverage. In order to be able to extend the estimations to as many countries as possible, methods for data gaps filling could be considered in further steps.

List of abbreviations

Abbreviation	Name	Reference
AD	Andorra	
AL	Albania	
AQG	Air quality guidelines	
AT	Austria	
BA	Bosnia & Herzegovina	
BE	Belgium	
BG	Bulgaria	
BoD	Burden of disease	
CH	Switzerland	
CI	Confidence interval	
COPD	Chronic obstructive pulmonary disease	
CRF	Concentration-response function	
CY	Cyprus	
CZ	Czechia	
d	Day	
DALY	Disability-adjusted life year	
DE	Germany	
DK	Denmark	
DM	Diabetes mellitus	
DW	Disability weight	
EBD	Environmental burden of disease	
ECIS	European cancer information system	www.ecis.jrc.ec.europa.eu
EE	Estonia	
EEA	European Environment Agency	www.eea.europa.eu
EHIS	European health interview survey	
ELAPSE	Effects of low-level air pollution: a study in Europe	www.elapseproject.eu
ES	Spain	
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
FI	Finland	
FR	France	
GBD	Global burden of disease	
GR	Greece	
HR	Hazard ratio; Croatia	
HRAPIE	Health risks of air pollution in Europe	
HU	Hungary	
IARC	International Agency for Research on Cancer	www.iarc.who.int
IE	Ireland	
IHD	Ischemic heart disease	
IHME	Institute for Health Metrics and Evaluation	www.healthdata.org

Abbreviation	Name	Reference
IS	Iceland	
ISAAC	International study on asthma and allergies in childhood	www.isaac.auckland.ac.nz
IT	Italy	
LC	Lung cancer	
LI	Liechtenstein	
LT	Lithuania	
LU	Luxembourg	
LV	Latvia	
m^3	Cubic meter	
MC	Monaco	
ME	Montenegro	
MI	Myocardial infarction	
MK	North Macedonia	
MT	Malta	
ND	No data	
NL	Netherlands	
NO	Norway	
NO_2	Nitrogen dioxide	
O_3	Ozone	
OR	Odds ratio	
PAF	Population attributable fraction	
PL	Poland	
PM	Particulate matter	
PT	Portugal	
ppb	Parts per billion	
RO	Romania	
RR	Relative risk	
RS	Serbia	
SE	Sweden	
SI	Slovenia	
SK	Slovakia	
SM	San Marino	
SOMO35	Sum of ozone means over 35 ppb	
TR	Türkiye	
UBA	German Environment Agency	www.umweltbundesamt.de/en
UC	Unit increase	
UI	Uncertainty interval	
US-EPA	United States Environmental Protection Agency	www.epa.gov/
WHO	World Health Organization	www.who.int/europe/health-topics/air-pollution#tab=tab_2
XK	Kosovo (under United Nations Security Council Resolution 1244/99)	
YLL	Year of life lost due to death	
YLD	Year lived with disability	
µg	Microgram	

References

Alexeeff, S. E., et. al., 2021, 'Long-Term PM2.5 Exposure and Risks of Ischemic Heart Disease and Stroke Events: Review and Meta-Analysis'*, Journal of the American Heart Association* 10(1), e016890.

Asher, M. I., et. al., 2020, 'Trends in worldwide asthma prevalence', *European Respiratory Journal* 56(6), 2002094.

EC, 2022a, 'ECHI - European Core Health Indicators', European Commission (https://ec.europa.eu/health/indicators-and-data/european-core-health-indicators-echi/echi-european-core-health-indicators_en) accessed 9 June 2022.

EC, 2022b, 'ECIS - European Cancer Information System—Estimates of cancer incidence and mortality in 2020, for all countries', European Commission (https://ecis.jrc.ec.europa.eu) accessed 9 June 2022.

EEA, 2020, *Air quality in Europe—2020 report*, EEA Report No 9/2020, European Environment Agency.

EEA, 2021, *Air quality in Europe—2021 report*, EEA Report No 15/2021, European Environment Agency.

Eurostat, 2022, 'Population (national level) on 1 January by age and sex' (https://ec.europa.eu/eurostat/databrowser/view/DEMO_PJAN__custom_2989288/default/table) accessed 1 June 2022.

Eze, I. C., et. al., 2015, 'Association between Ambient Air Pollution and Diabetes Mellitus in Europe and North America: Systematic Review and Meta-Analysis', *Environmental Health Perspectives* 123(5), pp. 381-389.

GBD 2019 Diseases and Injuries Collaborators, 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(10258), pp. 1204-1222.

GBD 2019 Risk Factors Collaborators, 2020, 'Global burden of 87 risk factors in 204 countries and territories, 1990–2019: A systematic analysis for the Global Burden of Disease Study 2019', *The Lancet* 396(10258), pp. 1223-1249.

Hamra, G. B., et. al., 2014, 'Outdoor Particulate Matter Exposure and Lung Cancer: A Systematic Review and Meta-Analysis', *Environmental Health Perspectives* 122(9), pp. 906-911.

Horálek, J., et. al., 2022, *European air quality maps for 2019, PM10, PM2.5, Ozone, NO2 and NOx Spatial estimates and their uncertainties*, ETC/ATNI Report 1/2021 (https://www.eionet.europa.eu/etcs/etc-atni/products/etc-atni-reports/etc-atni-report-1-2021-european-air-quality-maps-for-2019-pm10-pm2-5-ozone-no2-and-nox-spatial-estimates-and-their-uncertainties) accessed 22 August 2022.

Huang, F., et. al., 2017, 'Relationship between exposure to PM2.5 and lung cancer incidence and mortality: A meta-analysis', *Oncotarget* 8(26), pp. 43322-43331.

Hvidtfeldt, U. A., et. al., 2021, 'Long-term low-level ambient air pollution exposure and risk of lung cancer - A pooled analysis of 7 European cohorts', *Environment International* 146, p. 106249.

IHME, 2022, 'GBD Compare', Institute for Health Metrics and Evaluation (https://vizhub.healthdata.org/gbd-compare/) accessed 9 June 2022.

Khreis, et. al., 2017, ‘Exposure to traffic-related air pollution and risk of development of childhood asthma: A systematic review and meta-analysis’, *Environment International* 100, pp. 1-31.

Liu, S., et. al., 2021, ‘Long-term exposure to low-level air pollution and incidence of asthma: The ELAPSE project’, *European Respiratory Journal* 57(6), p. 2003099.

Liu, S., et. al., 2021, ‘Long-term exposure to low-level air pollution and incidence of chronic obstructive pulmonary disease: The ELAPSE project’, *Environment International* 146, 106267.

Murray, C. J. L., 1994, ‘Quantifying the burden of disease: The technical basis for disability-adjusted life years’, *Bulletin of the World Health Organization* 72(3), pp. 429-445.

Pifarré i Arolas, H., et. al., 2021, ‘Years of life lost to COVID-19 in 81 countries’, *Scientific Reports* 11(1), 3504.

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(1), 863.

Prüss-Üstün, A., et. al. (eds), 2003, *Assessing the environmental burden of disease at national and local levels: Introduction and methods*, World Health Organization, Geneva, p. 71 (https://apps.who.int/iris/handle/10665/42750) accessed 9 June 2022.

Schneider, A., et. al., 2018, Quantifizierung von umweltbedingten Krankheitslasten aufgrund der Stickstoffdioxid-Exposition in Deutschland, UBA Report No 01/2018 (Umwelt & Gesundheit), German Environment Agency, p. 172, (https://www.umweltbundesamt.de/sites/default/files/medien/421/publikationen/abschlussbericht_no2_krankheitslast_final_2018_03_05.pdf) accessed 9 June 2022.

US EPA, 2016, Integrated Science Assessment for Oxides of Nitrogen—Health Criteria, United States Environmental Protection Agency (https://ordspub.epa.gov/ords/eims/eimscomm.getfile?p_download_id=526855) accessed 9 June 2022.

US EPA, 2019, Integrated Science Assessment for Particulate Matter, United States Environmental Protection Agency (https://cfpub.epa.gov/ncea/isa/recordisplay.cfm?deid=347534#tab-3) accessed 9 June 2022.

US EPA, 2020, Integrated Science Assessment for Ozone and Related Photochemical Oxidants, United States Environmental Protection Agency (http://cfpub.epa.gov/ncea/isa/recordisplay.cfm?deid=348522) accessed 9 June 2022.

Vlajinac, H., et. al., 2008, ‘Years of life lost due to premature death in Serbia (excluding Kosovo and Metohia)’, *Public Health* 122(3), pp. 277-284.

WHO, 2013a, 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, Copenhagen, World Health Organization (https://apps.who.int/iris/handle/10665/153692) accessed 9 June 2022.

WHO, 2013b, Health risks of air pollution in Europe—HRAPIE project: New emerging risks to health from air pollution—Results from the survey of experts, World Health Organization (https://apps.who.int/iris/handle/10665/108632) accessed 9 June 2022.

WHO, 2021, WHO global air quality guidelines. Particulate matter (PM2.5 and PM10), ozone, nitrogen dioxide, sulfur dioxide and carbon monoxide, Geneva, World Health Organization (https://apps.who.int/iris/handle/10665/345329) accessed 9 June 2022.

Wolf, K., et. al., 2021, 'Long-term exposure to low-level ambient air pollution and incidence of stroke and coronary heart disease: A pooled analysis of six European cohorts within the ELAPSE project', *The Lancet Planetary Health* 5(9), pp. e620-e632.

World Bank, 2022, 'Completeness of death registration with cause-of-death information (%)', (https://data.worldbank.org/indicator/SP.REG.DTHS.ZS?end=2017&start=2009) accessed 9 June 2022.

Yang, B.-Y., et. al., 2020, 'Ambient air pollution and diabetes: A systematic review and meta-analysis', *Environmental Research* 180, 108817.

Zang, S. T., et. al., 2022, 'Long-term PM2.5 exposure and various health outcomes: An umbrella review of systematic reviews and meta-analyses of observational studies', *Science of The Total Environment* 812, 152381.

Annex 1 Health data and sources (morbidity)

Table A1.1 Data for selected morbidity health outcomes for 2019

Outcome	ICD 10 Code	Explanation	Source	Time	Age groups	Gender	Incidence /Prevalence	Code	Remarks	Link
Asthma	J45-46	Asthma (allergic asthma included)	European Health Interview Survey (EHIS)	2019	≥ 15 10 year age groups	Total, males, females	Prevalence (self-reported) [%]	hlth_ehis_cd1e	Proportion of individuals reporting to have ever been diagnosed with asthma and to have been affected by this condition during the past 12 months	http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=hlth_ehis_cd1e&lang=en
Asthma	J45-46	--	Global Burden of Disease Study (GBD)	2019	all ages 5 year age groups	Total, males, females	Prevalence [%]	--	--	https://vizhub.healthdata.org/gbd-results/
Chronic obstructive pulmonary disease (COPD)	J40-44 and J47	Chronic bronchitis, chronic obstructive pulmonary disease, emphysema	European Health Interview Survey (EHIS)	2019	≥ 15 10 year age groups	Total, males, females	Prevalence (self-reported) [%]	hlth_ehis_cd1e	Self-reported chronic diseases or conditions: During the past 12 months, have you had chronic obstructive pulmonary disease (chronic bronchitis, chronic obstructive pulmonary disease, emphysema)?	http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=hlth_ehis_cd1e&lang=en
Diabetes Mellitus	E10-14	Diabetes (gestational diabetes excluded)	European Health Interview Survey (EHIS)	2019	≥ 15 10 year age groups	Total, males, females	Prevalence (self-reported) [%]	hlth_ehis_cd1e	Proportion of individuals reporting to have ever been diagnosed with diabetes and to have been affected by this condition during the past 12 months.	http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=hlth_ehis_cd1e&lang=en

Outcome	ICD 10 Code	Explanation	Source	Time	Age groups	Gender	Incidence /Prevalence	Code	Remarks	Link
Ischemic heart disease (coronary heart disease)	I20-25	Coronary heart disease or angina pectoris	European Health Interview Survey (EHIS)	2019	≥ 1510 year age groups	Total, males, females	Prevalence (self-reported) [%]	hlth_ehis_cd1e	Self-reported chronic diseases or conditions: During the past 12 months, have you had a coronary heart disease or angina pectoris?	http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=hlth_ehis_cd1e&lang=en
Lung cancer	C33-34	--	European Cancer Information System (ECIS)	2020	all ages 15 year age groups	Total, males, females	Incidence [%, number of cases]	--	--	https://ecis.jrc.ec.europa.eu/
Lung cancer	C33-34	--	International Agency for Research on Cancer (IARC)	2020	all ages 5 year age groups	Total, males, females	Prevalence [number of cases]	--	--	https://gco.iarc.fr/today/online-analysis-table?v=2020&mode=cancer&mode_population=continents&population=900&populations=900&key=asr&sex=0&cancer=39&type=0&statistic=5&prevalence=0&population_group=0&ages_group%5B%5D=0&ages_group%5B%5D=17&group_cancer=1&include_nmsc=0&include_nmsc_other=1
Myocardial infarction (heart attack)	I21-23, (consequences of former MI included partly also under I25)	Myocardial infarction (heart attack) or chronic consequences of myocardial infarction	European Health Interview Survey (EHIS)	2019	≥ 15 10 year age groups	Total, males, females	Prevalence (self-reported) [%]	hlth_ehis_cd1e	Self-reported chronic diseases or conditions: During the past 12 months, have you had a myocardial infarction (heart attack) or chronic consequences of myocardial infarction?	http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=hlth_ehis_cd1e&lang=en
Respiratory diseases: Hospital admissions	J00-J99	The data describe hospital discharges per 100 000 inhabitants	Eurostat	2019	all ages 5 year age groups	Total, males, females	Number of in-patients per 100,000 inhabitants	hlth_co_disch2	--	https://ec.europa.eu/eurostat/databrowser/view/HLTH_CO_DISCH2__custom_2775751/default/table?lang=en

Outcome	ICD 10 Code	Explanation	Source	Time	Age groups	Gender	Incidence /Prevalence	Code	Remarks	Link
Stroke	I60-I69	Stroke (cerebral haemorrhage, cerebral ischaemia) or chronic consequences of stroke	European Health Interview Survey (EHIS)	2019	≥ 15 10 year age groups	Total, males, females	Prevalence (self-reported) [%]	hlth_ehis_cd1e	Self-reported chronic diseases or conditions: During the past 12 months, have you had a stroke (cerebral haemorrhage, cerebral ischaemia) or chronic consequences of stroke?	http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=hlth_ehis_cd1e&lang=en

Table A1.2 Source of European health data

Source	Data category	Description	Remarks	Links
EUROSTAT	Mortality, Morbidity	Health statistics measure both objective and subjective aspects of people's health. They cover different kinds of health-related aspects, including key indicators on the functioning of the health care systems and health and safety at work.	.	Data - Health - Eurostat (europa.eu)
European Health Information Gateway	Mortality, Morbidity			European Health Information Gateway (who.int)
European Health for All database (HFA-DB)		Since the mid-1980s, Member States of the WHO European Region have been reporting essential health-related statistics to the Health for All (HFA) family of databases, making it one of WHO's oldest sources of data. As it is based on reported data, rather than estimates, the HFA family of databases is also particularly valuable.	.	https://gateway.euro.who.int/en/datasets/european-health-for-all-database/
European mortality database (MDB)		European mortality database allows age- and sex-specific analysis of mortality trends by broad disease-groups, as well as dis-aggregated to 67 specific causes of death. Data reach back to 1980.	.	http://www.who.int/healthinfo/mortality_data/en/
European database on human and technical resources for health (HlthRes-DB)		HlthRes-DB provides a wide range of statistics on human and technical resources for health and offers data on non-monetary health care resources collected through the joint work of the Statistical Office of the European Union (Eurostat), the Organisation for Economic Co-operation and Development (OECD) and WHO/Europe. It contains nearly 200 indicators on human and technical resources for health.	.	https://gateway.euro.who.int/en/datasets/european-database-on-human-and-technical-resources-for-health/
Environment and Health Information System (ENHIS)		ENHIS is an evidence-based information system aiming to support public health and environmental policies in the WHO European Region. The system is an interactive database, composed of country-level indicators and regional assessments (fact sheets). The fact sheets also include information on how data is obtained and how the indicators are calculated. ENHIS indicators provide information on exposures, health outcomes and policy actions related to the environment and health priority areas for the European Region known as Regional Priority Goals (RPGs)	.	Environment and Health Information System (ENHIS) data source - European Health Information Gateway (who.int)
Health 2020 indicators		Health 2020 core indicators were agreed by the WHO European Region Member States for monitoring progress towards the Health 2020 targets. Some of these indicators are based on official WHO sources and other are based on non-WHO sources, such as UNESCO and UNDP. Data from WHO sources can be accessed and queried at national level, while	.	https://gateway.euro.who.int/en/datasets/health-2020-indicators/

Source	Data category	Description	Remarks	Links
		data from non-WHO sources is available in aggregated form, for groups of Member States.		
Child and adolescent health		The dataset present information about child and adolescent health. It provides a set of statistics based on indicators related to the health and well-being of children and adolescents. The statistics were collated from a variety of databases as a joint effort between WHO programs, collaborating centres and partners. The database was constructed for the purpose of supporting the WHO Europe strategy Investing in Children (2014), providing the relevant information for monitoring progress on child and adolescent health indicators in the 53 member states of the WHO European Region.	.	https://gateway.euro.who.int/en/datasets/cah/
Joint Monitoring Framework (JMF)		The joint monitoring framework (JMF) is used for reporting on indicators under three monitoring frameworks: the Sustainable Development Goals (SDGs), Health 2020 and the Global Action Plan for the Prevention and Control of Noncommunicable Diseases (NCDs) 2013–2020. The Regional Committee for Europe adopted the JMF in September 2018.	.	https://gateway.euro.who.int/en/datasets/joint-monitoring-framework-jmf/
Status of child and adolescent health policies in Europe		Member States of the European Region of WHO have adopted the European strategy for Child and Adolescent Health and Development 2015-2020. Its aim is to support member states in developing strategies and policies to reduce the burden of avoidable disease, disability and mortality of children and adolescents, and for them to achieve their full potential and development. The data presented here was collected by the Child and Adolescent Health Programme at the Division of Noncommunicable Diseases and Promoting Health through the Life course, World Health Organization Regional Office for Europe. The dataset is based on selected aspects reported by Member States in the baseline survey on the implementation of the European child and adolescent health strategy 2015-2020 as well as data from the WHO country profiles on child and adolescent health. Questionnaires were sent to ministries of health of the 53 countries in the WHO EURO region on areas related to the strategy, to document how well policies are aligned with the Strategy. Albania, Greece, Italy,	.	https://gateway.euro.who.int/en/datasets/cahb_survey/

Source	Data category	Description	Remarks	Links
		Monaco, San Marino did not participate in the survey and are marked as "did not participate''. In cases where countries did not respond to a particular question, these were marked as "no response'' and where no responses were required, these were marked as "answer not required''.		
European Health Interview Survey (EHIS)	Morbidity	The European Health Interview Survey (EHIS) aims at measuring on a harmonised basis and with a high degree of comparability among Member States (MS) the health status (including disability), health determinants (lifestyle) of the EU citizens and use of health care services and limitations in accessing it. The general coverage of the survey is the population aged 15 or over living in private households residing in the territory of the country. EHIS was developed between 2003 and 2006. It consists of four modules on health status, health determinants, health care, and background variables (socio-demographic characteristics of the population). Three waves of EHIS have currently been implemented. The first wave of EHIS (EHIS wave 1 or EHIS round 2008) was conducted between 2006 and 2009 in 17 EU Member States as well as Switzerland and Turkey. The second wave (EHIS wave 2 or EHIS round 2014) was conducted between 2013 and 2015 in all EU Member States, Iceland, Norway and Turkey according to the Commission Regulation 141/2013. The third wave of EHIS was conducted in 2019.	Self-reported health data, mainly accessible via Eurostat/ECHI indicators	European Health Interview Survey (EHIS) (europa.eu)
European Core Health Indicators (ECHI)	Morbidity	The European Core Health Indicators (ECHI), formerly known as European Community Health Indicators are the result of a long-term cooperation between the EU Member States and the European Commission. Three ECHI projects (1998-2001, 2001-2004, 2005-2008) funded under the EU Health Programmes established the first lists of ECHI indicators, aiming to create a comparable health information and knowledge system to monitor health at EU level. Definitions and data collection are in place for nearly 60 out of 88 ECHI indicators	.	https://ec.europa.eu/health/indicators-and-data/european-core-health-indicators-echi/echi-european-core-health-indicators_en
				https://webgate.ec.europa.eu/dyna/echi/?indlist=21a
European Cancer Information System (ECIS)	Mortality, Morbidity	The ECIS database contains the aggregated results computed from data submitted by population-based European cancer registries participating in the ENCR-JRC project on "Cancer Incidence and Mortality in Europe". These data are the basis to estimate national incidence and mortality for 2020, as a joint outcome of a collaborative exercise of the JRC and the International Agency for Research on Cancer (IARC), in collaboration with the European Network of Cancer Registries and the International Association of Cancer Registries. For survival, the ECIS web application	.	ECIS contributing initiatives and studies | ECIS (europa.eu)

Source	Data category	Description	Remarks	Links
		includes the results of the EUROCARE study, latest published edition (EUROCARE-5).		
				Cancer burden statistics and trends across Europe | ECIS (europa.eu)
European Cardiovascular Disease Statistics (EHN)	Mortality, Morbidity	The European Heart Network (EHN) is a Brussels-based alliance of foundations and associations dedicated to preventing cardiovascular diseases (CVD), supporting patients, representing patient interests and funding research throughout Europe. The EHN plays a leading role in the prevention and reduction of cardiovascular diseases, in particular heart disease and stroke, through advocacy, networking, capacity-building, representing patient interests, and research so that they are no longer a major cause of premature death and disability throughout Europe.	Data source: GBD study	CVD Statistics (ehnheart.org)
IDF Diabetes Atlas	Mortality, Morbidity	The IDF Diabetes Atlas 10th edition reports a continued global increase in diabetes prevalence, confirming diabetes as a significant global challenge to the health and well-being of individuals, families and societies.	.	https://diabetesatlas.org
Global Health Data Exchange (GHDx), Global burden of disease study (GBD)	Mortality, Morbidity	The GHDx directly supports IHME's mission to improve the health of the world's populations by providing the best information on population health. It was created as a dedicated place for anyone interested in global health and demography to quickly find and share information about data along with actual datasets.	.	Global Health Data Exchange | GHDx
OECD Health Statistics 2021	Mortality, Morbidity	The online database OECD Health Statistics 2021 has been released on July 2nd, and updated in November following the release of Health at a Glance 2021: OECD Indicators. The OECD Health Database offers the most comprehensive source of comparable statistics on health and health systems across OECD countries. It is an essential tool to carry out comparative analyses and draw lessons from international comparisons of diverse health systems.	.	OECD Statistics
OECD iLibrary - Health at a Glance Europe	Mortality, Morbidity	Health at a Glance: Europe 2020 - State of Health in the EU Cycle	Summarizes data from different sources	https://www.oecd-ilibrary.org/social-issues-migration-health/health-at-a-glance-europe_23056088
WHO Mortality Database	Mortality	The WHO Mortality Database is a compilation of mortality data as reported annually by Member States from their civil registration systems.	.	WHO Mortality Database - WHO

Source	Data category	Description	Remarks	Links
WHO Global Health Observatory	Mortality, Morbidity	The GHO data repository is WHO's gateway to health-related statistics for its 194 Member States. It provides access to over 1000 indicators on priority health topics including mortality and burden of diseases, the Millennium Development Goals (child nutrition, child health, maternal and reproductive health, immunization, HIV/AIDS, tuberculosis, malaria, neglected diseases, water and sanitation), non communicable diseases and risk factors, epidemic-prone diseases, health systems, environmental health, violence and injuries, equity among others.	.	Global Health Observatory (who.int)
International Studies on Asthma and Allergy in Childhood (ISAAC)	Morbidity	The International Study of Asthma and Allergies in Childhood, is a unique worldwide epidemiological research programme established in 1991 to investigate asthma, rhinitis and eczema in children due to considerable concern that these conditions were increasing in western and developing countries.	.	ISAAC - The International Study of Asthma and Allergies in Childhood (auckland.ac.nz)
				Data 1992-2005: http://discover.ukdataservice.ac.uk/catalogue?sn=8131
Websites				
Global Asthma Network				Global Asthma Network
European Respiratory Society				European Respiratory Society - ERS (ersnet.org)
European Observatory on health systems and policies				Home (who.int)
UPCOMING: European Health Data Space				https://ec.europa.eu/health/ehealth-digital-health-and-care/european-health-data-space_en

Source	**Data category**	**Description**	**Remarks**	**Links**
Articles/Posters				
Khan, Asif et al. (2020): Prevalence of Asthma in France, Germany, Italy, Spain, and the United Kingdom, based on the 2018 European National Health and Wellness Survey. Chest, Volume 158, Issue 4, A27				DOI:https://doi.org/10.1016/j.chest.2020.08.067

Annex 2 Results of morbidity related disease burden

Table A2.1 PM25-Asthma (children) 2019

The Table is attached as separate excel file available together with this report ETC HE 2022/11 from https://www.eionet.europa.eu/etcs/all-etc-reports.

Table A2.2 PM25-COPD 2019

The Table is attached as separate excel file available together with this report ETC HE 2022/11 from https://www.eionet.europa.eu/etcs/all-etc-reports.

Table A2.3 PM25-IHD 2019

The Table is attached as separate excel file available together with this report ETC HE 2022/11 from https://www.eionet.europa.eu/etcs/all-etc-reports.

Table A2.4 PM25-LC 2019

The Table is attached as separate excel file available together with this report ETC HE 2022/11 from https://www.eionet.europa.eu/etcs/all-etc-reports.

Table A2.5 PM25-Stroke 2019

The Table is attached as separate excel file available together with this report ETC HE 2022/11 from https://www.eionet.europa.eu/etcs/all-etc-reports.

Table A2.6 PM25-DM 2019

The Table is attached as separate excel file available together with this report ETC HE 2022/11 from https://www.eionet.europa.eu/etcs/all-etc-reports.

Table A2.7 NO2-Asthma (adults) 2019

The Table is attached as separate excel file available together with this report ETC HE 2022/11 from https://www.eionet.europa.eu/etcs/all-etc-reports.

Table A2.8 NO2-Stroke 2019

The Table is attached as separate excel file available together with this report ETC HE 2022/11 from https://www.eionet.europa.eu/etcs/all-etc-reports.

Table A2.9 NO2-DM 2019

The Table is attached as separate excel file available together with this report ETC HE 2022/11 from https://www.eionet.europa.eu/etcs/all-etc-reports.

Table A2.10 O3-Hosp. adm. resp. disease 2019

The Table is attached as separate excel file available together with this report ETC HE 2022/11 from https://www.eionet.europa.eu/etcs/all-etc-reports.

European Topic Centre on
Human health and the environment
https://www.eionet.europa.eu/etcs/etc-he

The European Topic Centre on Human health and the environment (ETC HE) is a consortium of European institutes under contract of the European Environment Agency.

European Environment Agency
European Topic Centre
Human health and the environment