

ACHIEVING HEALTH BENEFITS FROM CARBON REDUCTIONS

Manual for CaRBonH calculation tool





REGIONAL OFFICE FOR
Europe

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ABSTRACT

The Carbon Reduction Benefits on Health (CaRBonH) calculation tool allows quantification of the physical and economic consequences for human health achieved through improvements in country-level air quality from domestic carbon reductions, specifically policy mitigation actions and measures as reported in the NDCs submitted by the Conference of the Parties to the UNFCCC in support of the objectives as set out in Article 2 of the Convention.

Keywords

CARBON - ANALYSIS
AIR POLLUTANTS - ANALYSIS
DATA COLLECTION – METHODS
ENVIRONMENTAL MONITORING - METHODS
CLIMATE CHANGE
GREENHOUSE EFFECT
RISK ASSESSMENT
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List of abbreviations

| | |
|-----------------|---|
| CO ₂ | carbon dioxide |
| COP | Conference of Parties |
| CRF | concentration–response function |
| EMEP | European Monitoring and Evaluation Programme |
| GDP | gross domestic product |
| ISO | International Organization for Standardization |
| NDC | nationally determined contribution |
| NH ₃ | ammonia |
| NOx | unspecified mixture of nitrogen oxides |
| PM | particulate matter |
| PPM | primary particulate matter |
| SO ₂ | sulfur dioxide |
| UNFCCC | United Nations Framework Convention on Climate Change |
| ΔC | Change in PM _{2.5} ambient concentration |

(Intended) nationally determined contributions and the Paris Agreement

The United Nations Framework Convention on Climate Change

The United Nations Framework Convention on Climate Change (UNFCCC), which was adopted at the United Nations Conference on Environment and Development held in Rio de Janeiro in June 1992, entered into force on 21 March 1994 (1). At the Conference, the world community came together and acknowledged the long-term negative environmental consequences associated with rapidly increasing anthropogenic emissions of climate-altering pollutants. Country delegates reached a consensus on the urgency for coordinated, comprehensive actions at all levels of society – local, national, regional and global – to meaningfully mitigate future emissions as well as adapt to climate variability and long-term change. Contingency and adaptation interventions are meant to curb the most adverse effects of climate change on the natural and built environments, ecosystems and health systems, and act to limit community exposure and related climate risks, including health burdens, and the potential for population displacement and increased social conflicts.

Among the specific goals set by the UNFCCC, Article 2 reads as follows (1).

The ultimate objective of this Convention and any related legal instruments that the Conference of the Parties may adopt is to achieve, in accordance with the relevant provisions of the Convention, stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Such a level should be achieved within a time frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner.

In addition, industrialized nations:

- committed themselves to lead efforts to limit climate-altering pollutants emissions (Annex I);
- agreed to provide technical assistance, share technology with poorer countries and establish financial mechanisms in support of actions against climate change; and
- established a routine accounting and reporting framework for the implementation of national climate change mitigation policies and measures, tracking of emissions inventory and consideration of arrangements for adaption (manage the unavoidable).

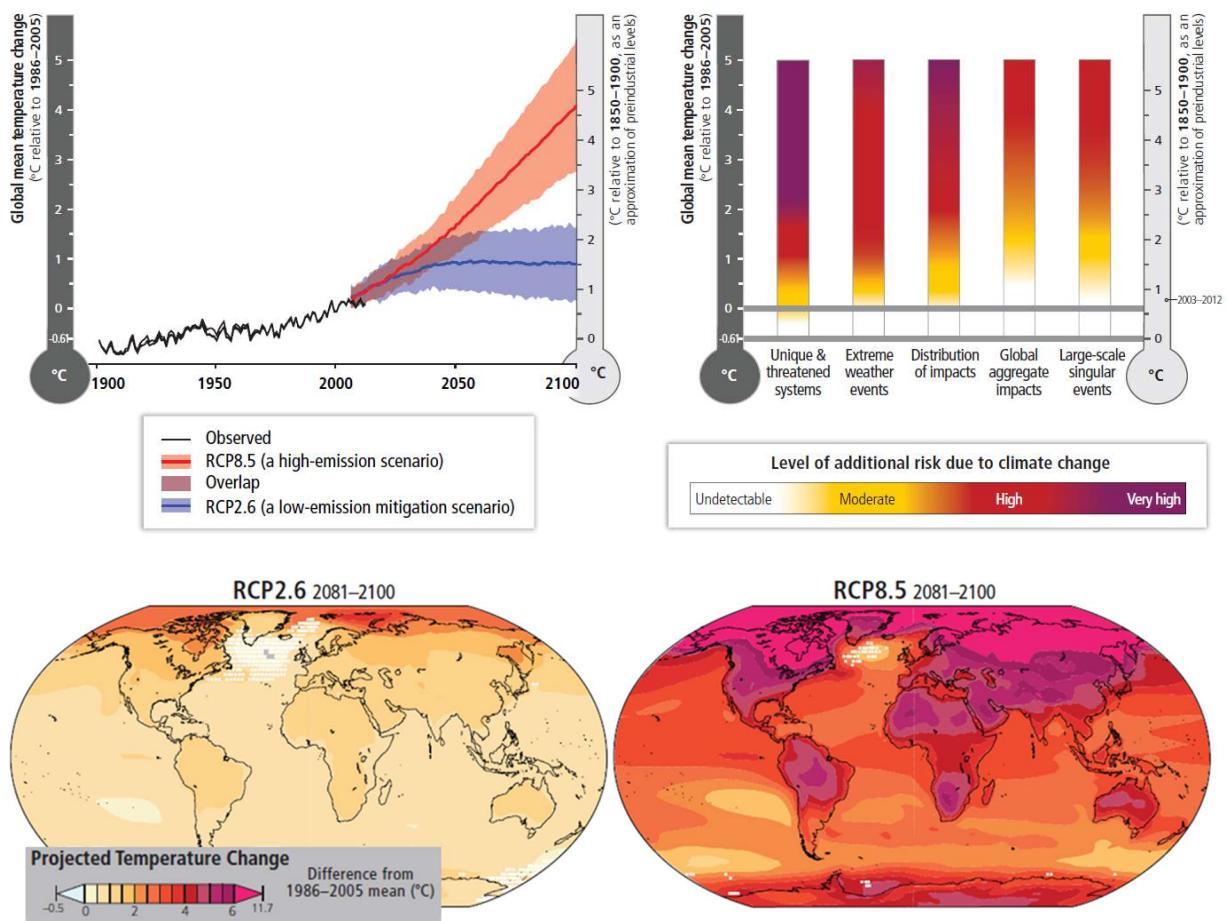
Sustainable human development may be defined as living in a world where consumption demands less of the ecosystem services that the earth can deliver without compromising the needs of future generations. Economic and social development requires a holistic approach underpinned by sound economic analysis that also promotes environmental protection while enabling all peoples to share equally in the opportunities and benefits of social development regardless of social or economic status and gender. The risks of different economic development strategies therefore need to be assessed and the results communicated to decision-makers and the general public in a transparent and concise way that takes account of socioeconomic trade-offs and uncertainties on present and future generations.

The Paris Agreement on Climate Change

In 2011, the United Nations Climate Change Conference of Parties (COP17) established the Durban Platform with the goal of adopting a legally binding instrument by 2015 in which all Parties would commit themselves to domestic action to mitigate greenhouse gas emissions beyond 2020 in an effort to stabilize ambient concentrations and prevent global mean surface temperature change from exceeding a threshold of 2 °C by the end of the 21st century. Furthermore, countries would attempt to make additional efforts to limit ambient temperatures to below 1.5 °C (Fig. 1). The IPCC SR1.5 report¹ forms an official collection of all known scientific, peer-reviewed, research on the impacts of 1.5°C of global warming on natural and human systems around the world.

¹ www.ipcc.ch/report/sr15/

Fig. 1. Global temperature changes and issues for concern due to increasing levels of climate change



Source: Intergovernmental Panel on Climate Change (2).

The Paris Agreement, which was adopted by delegates to the Conference of Parties of the UNFCCC in Paris in 2015 (COP21) (3), reflects a changing landscape in international climate policy with renewed emphasis on mitigating greenhouse gas emissions and preparing for and managing the current and projected consequences of a changing climate (adaptation). The Agreement formalized countries' commitments to achieve climate-related policy goals/targets through their nationally determined contributions (NDCs). The Agreement went into effect on 4 November 2016; by November 2017 it had been signed by 195 parties and ratified by 170 countries, collectively representing 87.9% of global industrialized emissions.

Linking carbon reductions to health benefits

The Paris Agreement represents an opportunity and a challenge for nations to promote policy-making and social awareness of the co-benefits on health from reducing emissions of health-damaging pollutants through implementation of climate-friendly policies and adaptation action, as outlined in the communications relating to their pledged NDCs (4).

Thus, it is worth examining which consequential environmental and health benefits have been achieved through reductions in domestic carbon emissions for the proposed climate policies under the NDCs submitted by Member States of the WHO European Region to the UNFCCC.

To answer this question, an Excel-based tool has been developed for the 53 Member States in the Region that quantifies the health and related economic gains from implementation of the NDCs. Such a tool can be used as a mechanism to assess the outcome of climate-driven policies and to promote decision-making in settings where there is limited data availability.

Overview of the Carbon Reduction Benefits on Health (CaRBonH) calculation tool

Scope of the tool

The aim of the Carbon Reduction Benefits on Health (CaRBonH) calculation tool is to quantify the physical and economic consequences for human health achieved through improvements in country-level air quality from domestic carbon reductions, specifically policy mitigation actions and measures as reported in the NDCs submitted by the Conference of the Parties to the UNFCCC in support of the objectives as set out in Article 2 of the Convention.

Description of the tool

A flowchart of the tool is presented in Fig. 2. The Excel workbook consists of nine worksheets, covering:

- (i) user input on pollutant emission reductions from carbon mitigation interventions by country (worksheet *Emission reductions*);
- (ii) endogenous calculations of changes in population exposure from saved emissions;
- (iii) calculation of health benefits in the susceptible population in terms of reduced incidences of annual morbidity, postponed mortality (deaths) and gains in years of life expectancy, together with an economic valuation of health benefits achieved from carbon reductions (worksheet *Summary of results*); and
- (iv) two worksheets with preloaded default statistics on demographic and epidemiological data by country for 2010, 2020 and 2030.

Health hazards are calculated using an impact pathway analysis, which explicitly traces the fate of pollutants from the moment they are released into the environment, followed by atmospheric dispersion and eventual removal by deposition and chemical transformation (Fig. 3). Health outcomes are calculated using epidemiological associations (risk functions that link population response to changes in ambient exposure level). The health benefits of reduced air pollution are transformed into economic costs using *unit health costs*, that is, cost per case of disease or death. Unit costs combine both market and non-market elements in determining an equivalent monetary value that accounts for direct impacts on the gross domestic product (GDP) of a nation, and indirect impacts on social welfare due to pain and suffering while someone is ill.

User input

Reductions in emissions of greenhouse gases and other pollutants, including primary particulate matter (PPM) of aerodynamic diameter less than 2.5 µm,² sulfur dioxide (SO₂), nitrogen oxides (NO_x), and ammonia (NH₃) are entered in the worksheet *Emission reductions* (Fig. 4, 5). Input is differentiated by emitter country for 2020 and 2030 (users may enter information for either or both years). GHG reductions are specified with respect to a particular base year, while reductions of other pollutants are compared against a business as usual emissions scenario. The Region is divided into 22 subdivisions, including countries belonging to the European Union (EU) after July 2013 (EU28),³ Belarus, Israel, the Republic of Moldova, the Russian Federation, Turkey, Ukraine and eastern European and central Asian countries. Data may be entered for a single country/region or for a group of countries (for example, Annex I countries only). Emission reductions by pollutant type for Andorra, Monaco and San Marino are added to EU28 values. For this block of countries, the tool calculates a single estimate of PM_{2.5} exposure change, health gains and economic benefits. When only PM₁₀ emissions data are available, PM_{2.5} to PM₁₀ mass conversion factors may be applied to estimate changes in PM_{2.5} emissions. These conversion factors vary by country; default values have been summarized in the worksheet *Effect PPM reduction on PM2.5*. Other than emission reductions, the tool requires no additional input from the user.

² 1 µm = one-millionth (10^{-6}) of a metre, or micron.

³ Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, the Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden and the United Kingdom of Great Britain and Northern Ireland.

Fig. 2. Carbon Reduction Benefits on Health (CaRBonH) software tool at a glance

What does user need to input?



User inputs at country- or regional-level

Emissions reductions (time period: 2020, 2030)

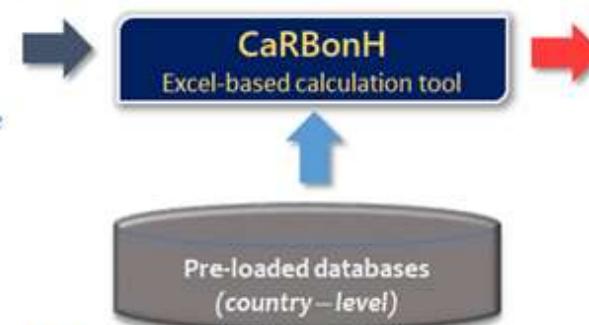
- Greenhouse gas GHG emission reductions as percentage and absolute change relative to a particular Base Year
- Ambient air pollution emission reductions of fine particulate matter (PM_{2.5}), Sulphur dioxide (SO₂), nitrogen oxides (NO_x), and ammonia (NH₃) as absolute change relative to future business as usual emissions scenario in either 2020 or 2030.

Data may be specified for a single country/region, or for a group of countries (e.g., Annex I countries only, or EU-28).

Default data



CaRBonH Calculator at a glance (Version 1.0R; Nov 10, 2018)



- **Demographics:** Population size by age group, life expectancy, natural mortality rate
 - **Exposure:** Source-Receptor matrices, anthropogenic share of total emissions, country-to-population weighted downscaling factors, and mass ratio of PM_{2.5} to PM₁₀
 - **Epidemiology:** Concentration-Response functions
 - **Economics:** Cost per case of illness, or death (value of statistical life, value of a life year)
- Data may be modified/supplemented by user.*

What does model deliver?



Tool output results are summarized in tables and also shown graphically

Population exposure changes

PM_{2.5} concentration changes are calculated using source-receptor matrices which characterise the country-level impact on air quality from the combined effect of lower domestic emissions and reduced regional (transboundary) pollution from neighbouring countries. Country-specific modifiers are applied to convert spatially averaged concentrations to population-weighted values.

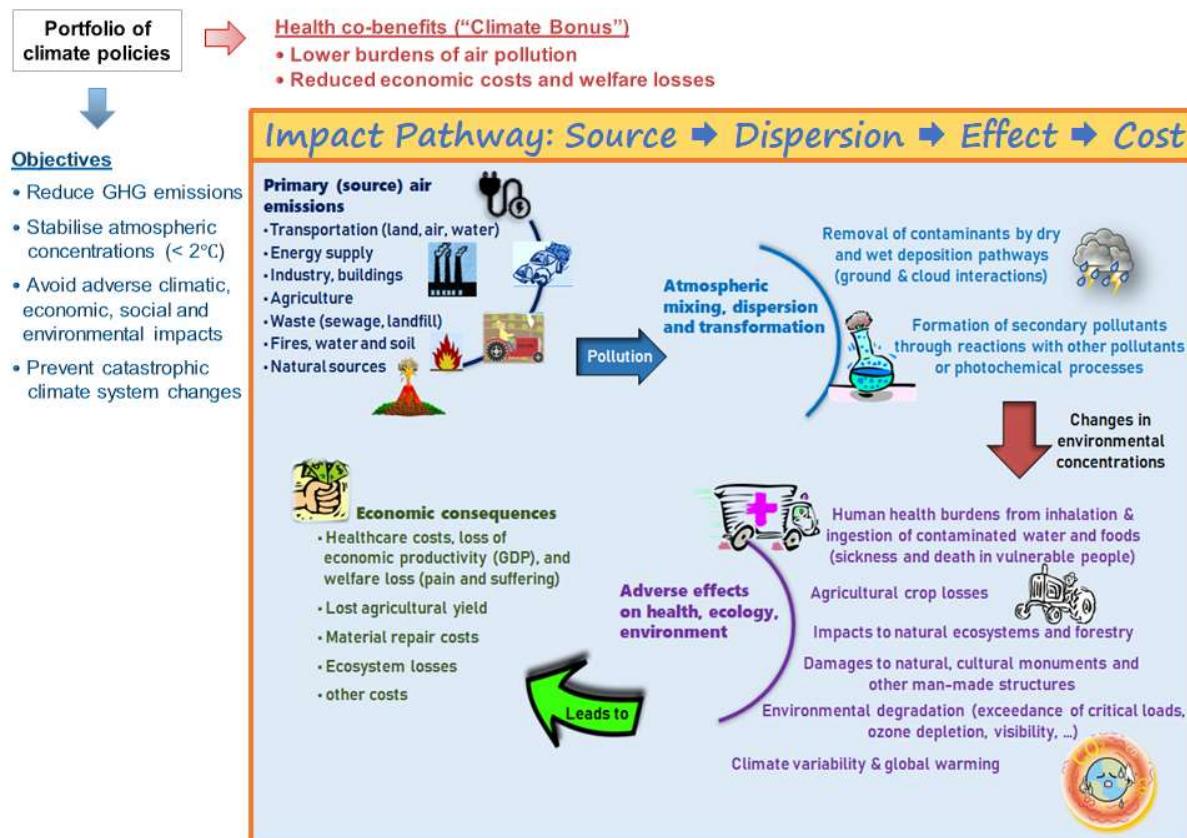
Physical health benefits

In addition to avoided premature mortality (deaths and life years gained), tool calculates prevented annual illnesses in the exposed population (averted cases of asthma, bronchitis, lost work days, hospital admission, etc.)

Economic benefits

Unit health costs are used to convert health effects into economic costs, taking into account healthcare expenditures, productivity economic losses, and welfare loss from pain and suffering. Both physical and economic benefits may be distinguished according to reductions in national and regional emissions.

Fig. 3. Methodological framework implemented in the CaRBonH calculation tool



Tool output – exposure calculations

Changes in PM_{2.5} concentrations due to reductions in domestic and regional PM_{2.5}, SO₂, NOx and NH₃ emissions are provided in the four worksheets *Effect xxx reduction on PM2.5*, where xxx stands for PPM, SO₂, NOx and NH₃. Country-to-country blame matrices, also known as source-receptor tables, are used to calculate population exposure changes. These matrices are look-up tables used to calculate concentration changes in a receptor (receiving) country due to domestic emission reductions as well as attributions from emissions changes in neighbouring emitter (polluter) countries that feed into transboundary pollution at the regional level (Table 1). These data have been calculated by the European Monitoring and Evaluation Programme of the European Commission (5), and have been supplemented with further calculations carried out with the uniform world model developed by Spadaro (6). The contribution to the total change in ambient PM_{2.5} concentrations from decreases in national and regional emissions is shown in Fig. 6. Country-specific modifier factors (Table 2) are used to compute changes in population-weighted exposures, starting with geographically averaged concentrations (Table 3, 4). The modifier factors are summarized by country in the worksheet *Effect PPM reduction on PM2.5*.

Tool output – health gains and economic benefit calculations

Output results are summarized in tables and shown graphically in the worksheet *Summary of results*. In addition to summarizing user input information and other country statistics, this worksheet shows the health and economic co-benefits of carbon mitigation interventions that may be achieved through improvements in air quality as a result of reductions in air pollutant emissions. CaRBonH apportions the results according to reductions in national emissions plus additional health benefits achieved from emission reductions that occur in other countries – the transboundary pollution effect (Fig. 7). Susceptible population subgroups, such as children and sick and elderly people, who are exposed to atmospheric contaminants are at a higher risk of suffering from adverse health symptoms ranging from mild discomfort to more serious life-threatening conditions. The quantified health benefits of reduced emissions include prevented cases of illness (morbidity), fewer premature deaths and life years gained from an extension in life expectancy among the exposed population (Table 5, Fig. 8).

Fig. 4. Air emissions avoided from implementation of NDC carbon reductions in 2030

USER INPUT
Ambient emission reductions for 2020 and 2030

Comments

- Annual data are specific to future reductions in emissions for a single country or a group of countries. The EU-28 is treated as one single region in the modeling of health impacts and costs. The cumulative emissions include the traditional 28 Member States of the European Union plus Andorra, Monaco, and San Marino.
- Definitions: PM_{2.5} = particulate matter of less than 2.5 µm aerodynamic diameter; SO₂ = sulfur dioxide; NOx = mixture of nitrogen oxides; NH₃ = ammonia; GHG = greenhouse gas emissions (in CO₂ equivalent)

Base year for GHG reductions: **1990**
Select base year
Enter comments

This worksheet shows pollutant emission reductions used as inputs in the WHO Policy Brief (June 2017). For the following four countries, GHG emissions increase in 2030 compared to base year 1990, but emissions grow slower by 2030 relative to the business as usual scenario for that year (baseline reduction target). Averted GHG emissions lead to reductions in emissions of other pollutants.

** Bosnia & Herzegovina: 0.8 MtCO₂ averted in 2030, or 2% reduction (18% higher than 1990),
 ** Israel: 23.9 MtCO₂ averted in 2030, or 23% reduction (11% higher than 1990),
 ** Macedonia, FYR: 5.2 MtCO₂ averted in 2030, or 30% reduction (29% higher than 1990),
 ** Turkey: 246 MtCO₂ averted in 2030, or 21% reduction (392% higher than 1990).

1 Mt (mega-tonne) = 1 Tera-grams (10¹² grams)

| Country/Region | Emission reductions in kilo-tonnes per year in 2030 | | | | | |
|------------------------|---|-----------|-------------------|-----------------|--------|-----------------|
| | GHG % base year | Reduction | PM _{2.5} | SO ₂ | NOx | NH ₃ |
| Albania | 23.6% | 1,700 | 0.10 | 0.45 | 0.29 | |
| Armenia | 27.7% | 6,900 | 0.43 | 0.73 | 4.70 | |
| Azerbaijan | 35.0% | 25,700 | 6.20 | 20.60 | 28.80 | |
| Belarus | 28.0% | 38,900 | 3.40 | 11.20 | 10.80 | |
| Bosnia and Herzegovina | -18.0% | -6,100 | 0.06 | 1.40 | 0.18 | |
| Georgia | 32.0% | 15,400 | 3.50 | 4.10 | 9.20 | |
| Iceland | 40.0% | 1,900 | 0.02 | 0.24 | 0.80 | |
| Israel | -11.1% | -8,200 | 0.29 | 9.90 | 7.00 | |
| Kazakhstan | 15.0% | 53,700 | 4.20 | 133.00 | 24.00 | |
| Kyrgyzstan | 59.1% | 17,900 | 0.17 | 1.30 | 1.30 | |
| Montenegro | 30.0% | 1,600 | 0.07 | 0.20 | 0.11 | |
| Norway | 40.0% | 20,800 | 0.58 | 8.30 | 11.40 | |
| Republic of Moldova | 65.5% | 28,400 | 0.14 | 0.23 | 0.23 | |
| Russian Federation | 27.5% | 926,000 | 126.00 | 518.00 | 130.00 | |
| Serbia | 9.8% | 7,900 | 0.30 | 3.60 | 0.95 | |
| Switzerland | 50.0% | 26,700 | 0.25 | 3.50 | 5.20 | |
| Tajikistan | 15.0% | 3,800 | 1.50 | 5.30 | 4.00 | |
| The FYR of Macedonia | -29.1% | -2,800 | 1.10 | 19.00 | 3.30 | |
| Turkey | -392.2% | -737,000 | 24.00 | 243.00 | 64.00 | |
| Turkmenistan | -167.7% | -85,200 | | | | |
| Ukraine | 40.0% | 378,000 | 4.10 | 22.00 | 8.80 | |
| EU-28 | 40.0% | 2,250,000 | 287.00 | 914.00 | 951.00 | |

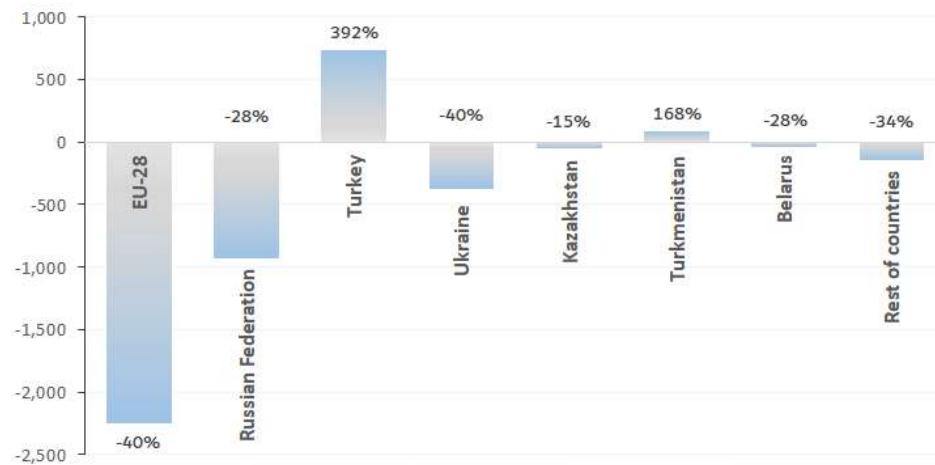
The FYR of Macedonia = The former Yugoslav Republic of Macedonia.

Notes.

- Reductions in greenhouse gas emissions are based on NDC pledges and historical data from the UNFCCC (Table 13). Negative values indicate an increase in emissions over the base year. NDC targets are typically specified relative to a base year (1990 in this example) compared to a future baseline (in this example, 2030 for Israel) or in terms of reduced carbon intensity (greenhouse gas emissions per unit of GDP, for example, in the case of Uzbekistan).
- For the other pollutants, emissions avoided in 2030 are estimated using published results by the Greenhouse gas – air pollution interactions and synergies Europe model (15). The model identifies synergies and trade-offs from limiting local and regional air pollution and mitigation of greenhouse gas emissions.
- By 2030, the proposed policies would reduce emissions of PM_{2.5} by 17%, SO₂ by 25%, and NOx by 13% from 1990 levels.

A copy of the WHO policy brief is available (11).

Fig. 5. Reduced emissions (mega-tonnes of carbon dioxide (CO₂) equivalent) of the greenhouse gases shown in Fig. 4, and relative changes in 2030 compared to 1990 levels (net emission reduction 2966 metric tons CO₂ equivalent)



Rest of countries = remaining countries shown in Fig. 4

Note. The chart shows the absolute and relative changes from implementation of proposed NDC pledges. Most countries have set targets to reduce carbon emissions below 1990 levels, while others (such as Turkey) have set emission caps or intend to reduce future emission growth rates relative to a business as usual scenario. Further reductions could be achieved through international cooperation, knowledge sharing and financial support.

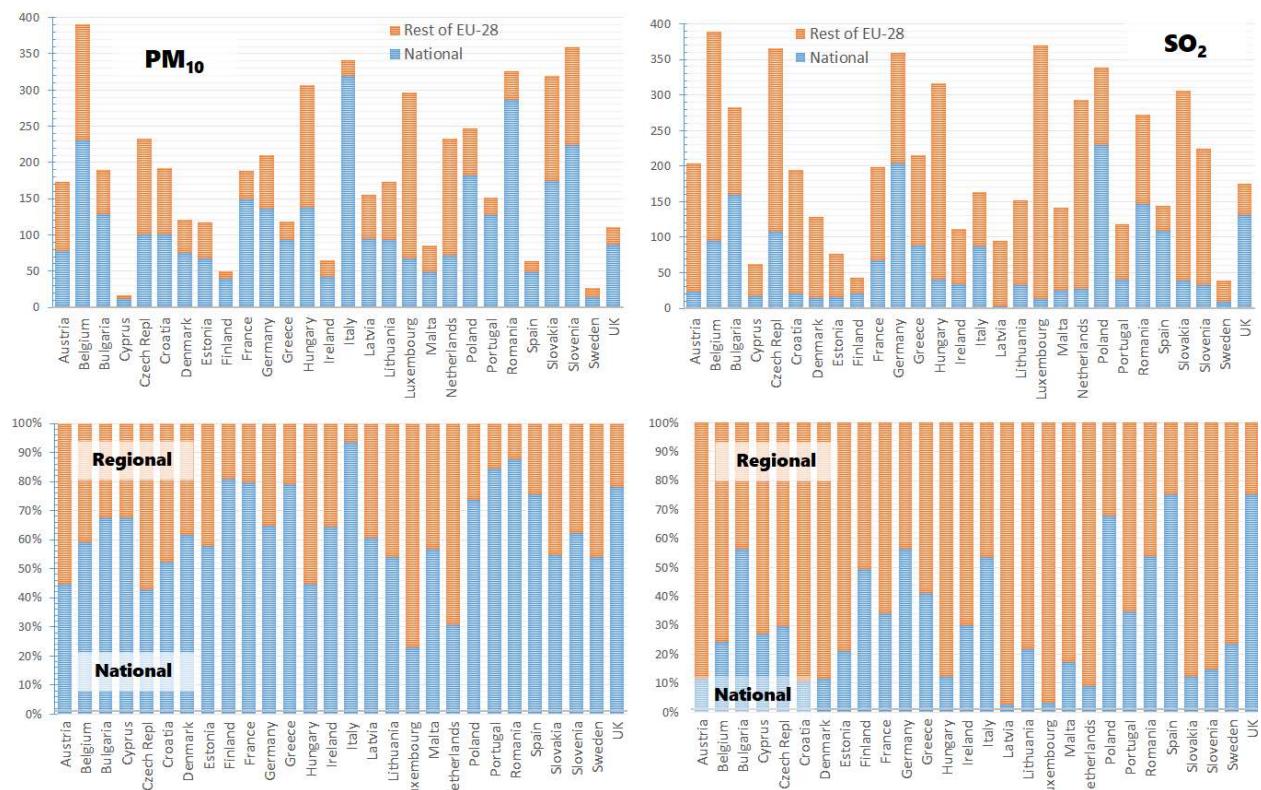
Table 1. Example of a source-receptor table for changes in PPM (PM₁₀) emissions

| | | Emitter country → | | | | | | | | | | | | |
|----------------------------|-------|-------------------|------|------|------|------|-------|-------|-------|------|------|-------|-------|------|
| | | AL | AM | AT | AZ | BA | BE | BG | BY | CH | CY | CZ | DE | DK |
| Emissions reduction (kt) → | | 1.65 | 0.90 | 4.95 | 3.60 | 3.90 | 6.45 | 6.30 | 10.50 | 2.70 | 0.30 | 5.85 | 34.20 | 4.80 |
| Albania | AL | 103.1 | 0.0 | 0.4 | 0.0 | 1.8 | 0.1 | 1.6 | 0.1 | 0.0 | 0.0 | 0.5 | 0.6 | 0.0 |
| Armenia | AM | 0.0 | 44.8 | 0.0 | 21.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Austria | AT | 0.0 | 0.0 | 77.3 | 0.0 | 0.6 | 0.4 | 0.2 | 0.3 | 1.9 | 0.0 | 9.2 | 18.3 | 0.3 |
| Azerbaijan | AZ | 0.0 | 3.9 | 0.0 | 99.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Bosnia and Herzegovina | BA | 1.4 | 0.0 | 2.1 | 0.0 | 79.0 | 0.2 | 0.7 | 0.3 | 0.1 | 0.0 | 2.3 | 2.2 | 0.1 |
| Belgium | BE | 0.0 | 0.0 | 0.4 | 0.0 | 0.0 | 230.2 | 0.0 | 0.3 | 0.5 | 0.0 | 1.5 | 43.2 | 1.2 |
| Bulgaria | BG | 0.6 | 0.0 | 0.6 | 0.0 | 0.9 | 0.1 | 128.2 | 0.8 | 0.1 | 0.0 | 0.8 | 1.1 | 0.1 |
| Belarus | BY | 0.0 | 0.0 | 0.4 | 0.0 | 0.2 | 0.3 | 0.5 | 94.9 | 0.1 | 0.0 | 1.2 | 2.2 | 0.5 |
| Switzerland | CH | 0.0 | 0.0 | 4.0 | 0.0 | 0.0 | 0.7 | 0.0 | 0.0 | 75.8 | 0.0 | 0.7 | 18.6 | 0.1 |
| Cyprus | CY | 0.1 | 0.0 | 0.0 | 0.0 | 0.1 | 0.0 | 0.4 | 0.1 | 0.0 | 11.0 | 0.0 | 0.1 | 0.0 |
| Czech Republic | CZ | 0.1 | 0.0 | 11.6 | 0.0 | 0.7 | 1.0 | 0.3 | 0.8 | 0.9 | 0.0 | 100.0 | 28.0 | 0.7 |
| Germany | DE | 0.0 | 0.0 | 6.5 | 0.0 | 0.1 | 8.8 | 0.0 | 0.5 | 3.9 | 0.0 | 6.9 | 135.9 | 3.3 |
| Denmark | DK | 0.0 | 0.0 | 0.2 | 0.0 | 0.0 | 3.1 | 0.0 | 0.6 | 0.1 | 0.0 | 0.7 | 13.6 | 75.0 |
| Estonia | EE | 0.0 | 0.0 | 0.1 | 0.0 | 0.1 | 0.4 | 0.2 | 3.3 | 0.0 | 0.0 | 0.3 | 1.7 | 1.3 |
| Spain | ES | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.3 | 0.0 | 0.0 | 0.1 | 0.0 | 0.0 | 0.5 | 0.0 |
| Finland | FI | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 | 0.0 | 0.3 | 0.0 | 0.0 | 0.1 | 0.3 | 0.4 |
| France | FR | 0.0 | 0.0 | 0.4 | 0.0 | 0.0 | 8.6 | 0.0 | 0.1 | 2.4 | 0.0 | 0.7 | 12.4 | 0.3 |
| Tajikistan | TI | 0.0 | 0.0 | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Turkmenistan | TM | 0.0 | 0.1 | 0.0 | 1.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Turkey | TR | 0.0 | 0.6 | 0.0 | 0.3 | 0.1 | 0.0 | 1.2 | 0.2 | 0.0 | 0.1 | 0.1 | 0.1 | 0.0 |
| Ukraine | UA | 0.1 | 0.0 | 0.3 | 0.2 | 0.3 | 0.2 | 1.7 | 7.2 | 0.0 | 0.0 | 0.8 | 1.2 | 0.2 |
| Uzbekistan | UZ | 0.0 | 0.1 | 0.0 | 0.4 | 0.0 | 0.0 | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| EU-28 | EU-28 | 0.2 | 0.0 | 3.2 | 0.0 | 0.6 | 4.4 | 4.4 | 1.1 | 0.8 | 0.0 | 4.0 | 16.5 | 1.8 |
| | | AL | AM | AT | AZ | BA | BE | BG | BY | CH | CY | CZ | DE | DK |

Source: European Modelling and Evaluation Programme (EMEP) (5).

Note. Interpretation of table entries: change in background concentrations of PM_{2.5} (ng/m³) in receiver country (row) due to a specified reduction in emissions of PPM (PM₁₀) in emitter country (column).

Fig. 6. PM_{2.5} change (ng/m³) for a uniform 15% reduction of PM₁₀ and SO₂ emissions in EU28 countries



Source: EMEP (5).

Note. Cuts in SO₂ emissions contribute to lower concentrations of sulfates, a secondary chemically derived component of PM_{2.5}, which have a stronger regional impact than reductions in emissions of primary PM.

Health effects are calculated using the WHO Health risks of air pollution in Europe – HRAPIE project set of recommended relative risks for Europe (7), which cover bronchitis and asthma attacks in children, chronic bronchitis and work lost days (WLD) in adults, and other illnesses that affect a person's normal daily routine (in other words, restricted activity days), or worse yet may require hospital admission because of cardiopulmonary system complications. The relative risk is defined as the ratio of health hazards for two populations exposed to different levels of pollution. These coefficients are determined through epidemiological studies, and relate an exposure increment to an increase in the prevalence of illness or baseline mortality in the population of concern. Relative risks are transformed into concentration-response functions (CRF) – the annual burden per person and per unit concentration – using country-specific data such as illness or mortality baseline rate and share of the population affected by the health outcome of concern (Fig. 9). Since demographic data vary by year, so do the CRFs.

Finally, an economic value is put on health benefits (Table 6, Fig. 10), taking into consideration the health care expenditure and productivity losses (market costs) prevented plus the social costs (welfare benefit) attributed to premature deaths averted or life-years gained (8). Postponed mortality is valued using the value of statistical life, the price that society is willing to pay to prevent an anonymous (statistical) death, while life extension is valued using the value of a life-year. Mortality benefits are not market costs; instead the economic benefits represent a gain in social well-being from reduced pain and suffering caused by environmental stressors such as air pollution. Morbidity costs are market expenditures (included in the transaction costs of doing business), and have a direct consequence on the country's GDP. At the level of the citizen, illness has direct consequences on the quality of life and indirect consequences on personal income and savings.

Table 2. Parameters used in CaRBonH for calculations of changes in population exposure in Table 3

| Country/Region | Modifier factors | Anthropogenic share of PM2.5 concentration | Ratio PM2.5 to PM10 |
|------------------------|------------------|--|---------------------|
| Albania | 2.1 | 82% | 0.51 |
| Armenia | 6.8 | 66% | 0.61 |
| Austria | 2.5 | 93% | 0.73 |
| Azerbaijan | 3.6 | 49% | 0.61 |
| Belarus | 2.9 | 88% | 0.61 |
| Belgium | 1.4 | 95% | 0.68 |
| Bosnia and Herzegovina | 4.8 | 85% | 0.61 |
| Bulgaria | 3.4 | 83% | 0.68 |
| Croatia | 2.4 | 87% | 0.61 |
| Cyprus | 1.6 | 73% | 0.44 |
| Czech Republic | 2.1 | 94% | 0.75 |
| Denmark | 2.0 | 83% | 0.46 |
| Estonia | 1.9 | 72% | 0.49 |
| Finland | 4.3 | 75% | 0.51 |
| France | 1.8 | 87% | 0.63 |
| Georgia | 4.4 | 61% | 0.61 |
| Germany | 1.4 | 90% | 0.70 |
| Greece | 1.7 | 73% | 0.38 |
| Hungary | 2.2 | 94% | 0.80 |
| Iceland | 0.7 | 8% | 0.62 |
| Ireland | 1.1 | 32% | 0.63 |
| Italy | 2.0 | 87% | 0.67 |
| Kazakhstan | 2.5 | 38% | 0.40 |
| Kyrgyzstan | 1.5 | 49% | 0.40 |
| Latvia | 3.7 | 82% | 0.68 |
| Lithuania | 2.9 | 87% | 0.68 |
| Luxembourg | 1.5 | 90% | 0.72 |
| Malta | 2.2 | 53% | 0.46 |
| Montenegro | 3.9 | 88% | 0.65 |
| Netherlands | 1.6 | 96% | 0.64 |
| Norway | 10.5 | 66% | 0.47 |
| Poland | 2.6 | 90% | 0.75 |
| Portugal | 2.6 | 67% | 0.71 |
| Republic of Moldova | 2.4 | 88% | 0.61 |
| Romania | 1.9 | 84% | 0.72 |
| Russian Federation | 6.1 | 72% | 0.61 |
| Serbia | 1.9 | 88% | 0.61 |
| Slovakia | 2.2 | 95% | 0.67 |
| Slovenia | 2.0 | 89% | 0.76 |
| Spain | 2.6 | 66% | 0.55 |
| Sweden | 3.6 | 68% | 0.31 |
| Switzerland | 1.9 | 89% | 0.70 |
| Tajikistan | 6.2 | 70% | 0.40 |
| The FYR of Macedonia | 3.9 | 83% | 0.59 |
| Turkey | 2.6 | 79% | 0.61 |
| Turkmenistan | 0.8 | 10% | 0.40 |
| Ukraine | 2.1 | 87% | 0.61 |
| United Kingdom | 2.3 | 84% | 0.69 |
| Uzbekistan | 3.5 | 54% | 0.40 |
| EU-28 | 2.3 | 84% | 0.65 |

The FYR of Macedonia = The former Yugoslav Republic of Macedonia.

Source: CaRBonH software (worksheet Effect PPM reduction on PM2.5).

Table 3. PM_{2.5} exposure change (ng/m³) from reduced PM_{2.5} emissions shown in Fig. 4

| Country/Region | ISO Country code | PM _{2.5} reduced | Receptor country → | | | | | | | | | | | | | | | | | | | | | | |
|--|------------------|---------------------------|--------------------|-------|--------|-------|-------|--------|-----|------|------|------|-------|------|-------|-------|-------|-------|-------|-------|-------|-----|-------|------|-------|
| | | | AL | AM | AZ | BY | BA | GE | IS | IL | KZT | KG | ME | NO | MD | RUE | RS | CH | TJ | MK | TR | TM | UA | UZ | EU-28 |
| Albania | AL | 0.1 | 25.8 | 0.0 | 0.0 | 0.0 | 0.8 | 0.0 | 0.0 | 0.0 | 0.0 | 5.6 | 0.0 | 0.0 | 0.0 | 0.9 | 0.0 | 0.0 | 5.7 | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 | |
| Armenia | AM | 0.4 | 0.0 | 239.4 | 11.1 | 0.0 | 0.0 | 9.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 | 0.0 | 1.2 | 0.1 | 0.0 | 0.2 | 0.0 |
| Azerbaijan | AZ | 6.2 | 0.0 | 411.1 | 1004.7 | 0.1 | 138.6 | 0.0 | 0.0 | 1.3 | 0.3 | 0.0 | 0.0 | 0.3 | 2.5 | 0.0 | 0.0 | 1.7 | 0.0 | 2.3 | 2.7 | 1.0 | 4.0 | 0.0 | |
| Belarus | BY | 3.4 | 0.1 | 0.0 | 0.0 | 0.0 | 147.3 | 0.7 | 0.1 | 0.0 | 0.2 | 0.0 | 0.3 | 0.2 | 4.5 | 2.3 | 0.5 | 0.0 | 0.5 | 0.3 | 0.0 | 8.2 | 0.1 | 1.4 | |
| Bosnia and Herzegovina | BA | 0.1 | 0.1 | 0.0 | 0.0 | 0.0 | 10.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.9 | 0.0 | 0.0 | 0.0 | 0.4 | 0.0 | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | |
| Georgia | GE | 3.5 | 0.0 | 190.1 | 142.0 | 0.5 | 0.0 | 1064.4 | 0.0 | 0.0 | 0.0 | 0.4 | 0.1 | 0.0 | 0.0 | 1.5 | 1.9 | 0.1 | 0.0 | 0.4 | 0.1 | 3.8 | 0.6 | 1.8 | 1.1 |
| Iceland | IS | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | |
| Israel | IL | 0.3 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 | 0.0 | 0.0 | 16.6 | 0.0 | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 | 0.5 | 0.0 | 0.0 | 0.0 | 0.1 | |
| Kazakhstan | KZT | 4.2 | 0.0 | 0.4 | 0.8 | 0.1 | 0.0 | 0.2 | 0.0 | 0.1 | 30.9 | 5.5 | 0.0 | 0.0 | 0.1 | 4.0 | 0.0 | 0.0 | 4.1 | 0.0 | 0.0 | 1.0 | 0.2 | 13.6 | 0.0 |
| Kyrgyzstan | KG | 0.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.5 | 7.7 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 1.4 | 0.0 | 0.0 | 0.0 | 0.0 | 1.8 | 0.0 |
| Montenegro | ME | 0.1 | 0.7 | 0.0 | 0.0 | 0.0 | 1.5 | 0.0 | 0.0 | 0.0 | 0.0 | 15.8 | 0.0 | 0.0 | 0.0 | 0.5 | 0.0 | 0.0 | 0.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.5 |
| Norway | NO | 0.6 | 0.0 | 0.0 | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 62.2 | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.5 |
| Republic of Moldova | MD | 0.1 | 0.0 | 0.0 | 0.0 | 0.2 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 16.1 | 0.0 | 0.1 | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 1.1 | 0.0 |
| Russian Federation | RUE | 126.0 | 0.9 | 10.7 | 40.5 | 49.8 | 1.5 | 37.7 | 0.0 | 0.2 | 38.1 | 0.4 | 1.2 | 4.9 | 17.4 | 245.4 | 1.5 | 0.0 | 2.3 | 2.8 | 5.7 | 3.7 | 52.6 | 18.4 | 3.4 |
| Serbia | RS | 0.3 | 4.2 | 0.0 | 0.0 | 0.1 | 4.0 | 0.0 | 0.0 | 0.0 | 0.0 | 6.3 | 0.0 | 0.2 | 0.0 | 21.2 | 0.0 | 0.0 | 9.8 | 0.1 | 0.0 | 0.1 | 0.0 | 0.3 | |
| Switzerland | CH | 0.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 18.9 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.3 | |
| Tajikistan | TJ | 1.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.5 | 4.8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 260.3 | 0.0 | 0.0 | 0.7 | 0.0 | 18.2 | 0.0 | |
| The FYR of Macedonia | MK | 1.1 | 18.0 | 0.0 | 0.0 | 0.1 | 1.4 | 0.0 | 0.0 | 0.2 | 0.0 | 3.4 | 0.0 | 0.4 | 0.0 | 11.2 | 0.0 | 0.0 | 264.9 | 0.2 | 0.0 | 0.2 | 0.0 | 0.6 | |
| Turkey | TR | 24.0 | 1.1 | 56.0 | 6.6 | 3.6 | 0.8 | 19.1 | 0.0 | 24.2 | 0.2 | 0.2 | 1.2 | 0.0 | 13.0 | 0.9 | 2.5 | 0.0 | 0.9 | 4.9 | 247.6 | 0.3 | 5.7 | 0.9 | 1.7 |
| Turkmenistan | TM | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | |
| Ukraine | UA | 4.1 | 0.3 | 0.3 | 0.7 | 6.1 | 0.5 | 0.6 | 0.0 | 0.0 | 0.6 | 0.0 | 0.4 | 0.0 | 16.1 | 2.6 | 0.6 | 0.0 | 0.0 | 1.0 | 1.1 | 0.1 | 44.6 | 0.5 | 0.5 |
| Uzbekistan | UZ | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | |
| EU-28 | EU-28 | 287.0 | 140.2 | 3.7 | 2.2 | 247.7 | 397.7 | 4.0 | 1.6 | 49.0 | 2.2 | 0.0 | 120.9 | 60.4 | 522.8 | 25.0 | 247.4 | 210.7 | -0.1 | 472.6 | 19.9 | 0.4 | 162.0 | 1.7 | 590.6 |
| <i>Total concentration change in Receptor country (ng/m³)</i> | | | 192 | 912 | 1,209 | 456 | 419 | 1,274 | 2 | 90 | 75 | 19 | 156 | 128 | 593 | 285 | 287 | 230 | 271 | 763 | 283 | 10 | 278 | 60 | 600 |
| <i>Share of total concentration change due to national emission reductions</i> | | | 13% | 26% | 83% | 32% | 2% | 84% | 9% | 18% | 41% | 41% | 10% | 49% | 3% | 86% | 7% | 8% | 96% | 35% | 88% | 0% | 16% | 0% | 98% |

The FYR of Macedonia = The former Yugoslav Republic of Macedonia.

Source: CaRBonH software.

$$\text{Population weighted concentration change } \Delta C = \frac{\Delta C \text{ (receptor) per kt emission (emitter)}}{\text{emission (emitter)}} \times \frac{\text{Emissions reduction (emitter)}}{\text{reduction (emitter)}} \times \frac{\text{Country multiplier factor (receptor)}}{\text{factor (receptor)}}$$

$$\text{Country modifier factor} = \frac{\text{Urban level population weighted concentration change } \Delta C \text{ in country}}{\text{Total concentration change } \Delta C \text{ in country}} \times \text{Anthropogenic share} \quad \text{and} \quad \text{Total concentration change } \Delta C \text{ in country} = \frac{\Delta C \text{ (} \mu\text{g/m}^3 \text{) due to national emission reductions}}{\text{Share of } \Delta C \text{ attributed to national emission reductions}}$$

Note. EMEP spatially averaged country-level concentrations are transformed to population-weighted values using a country modifier factor (Table 2), which is calculated dividing the urban-level population-weighted mean concentration (16) by the total change in country concentration ΔC if ALL pollutant emissions from both national sources plus contributions from neighbouring countries in EMEP are reduced to zero. Finally, the modifier is multiplied by the anthropogenic contribution to ambient concentration. The total concentration change is the ratio of the attributable change due to national emission reductions and the share that these emission changes make to the total country-level concentration (see Fig. 6). The proportion contributed by national emissions is calculated using the EMEP country-to-country blame matrix (diagonal element divided by the sum of values along a row for a given receptor country or the EU28).

Table 4. Reduced population-weighted exposure in 2030 for emission reduction shown in Fig. 4

| Country/Region | ISO Country code | Population (thousands) | Reduced emissions (kt) | | | | PM2.5 concentration change ($\mu\text{g}/\text{m}^3$) [†] | |
|------------------------|------------------|------------------------|------------------------|------------|--------------|--------------|--|--------------------|
| | | | GHG (Mt) | PM2.5 | SO2 | NOx | NH3 | National emissions |
| Albania | AL | 2,954 | 1.70 | 0.10 | 0.45 | 0.29 | 0.00 | 0.051 |
| Armenia | AM | 2,993 | 6.90 | 0.43 | 0.73 | 4.70 | 0.00 | 0.832 |
| Azerbaijan | AZ | 10,727 | 25.70 | 6.20 | 20.60 | 28.80 | 0.00 | 3.015 |
| Belarus | BY | 8,977 | 38.90 | 3.40 | 11.20 | 10.80 | 0.00 | 0.333 |
| Bosnia and Herzegovina | BA | 3,584 | -6.10 | 0.06 | 1.40 | 0.18 | 0.00 | 0.058 |
| Georgia | GE | 3,868 | 15.40 | 3.50 | 4.10 | 9.20 | 0.00 | 1.848 |
| Iceland | IS | 364 | 1.90 | 0.02 | 0.24 | 0.80 | 0.00 | 0.002 |
| Israel | IL | 9,998 | -8.20 | 0.29 | 9.90 | 7.00 | 0.00 | 0.099 |
| Kazakhstan | KZT | 20,072 | 53.70 | 4.20 | 133.00 | 24.00 | 0.00 | 0.233 |
| Kyrgyzstan | KG | 7,097 | 17.90 | 0.17 | 1.30 | 1.30 | 0.00 | 0.023 |
| Montenegro | ME | 618 | 1.60 | 0.07 | 0.20 | 0.11 | 0.00 | 0.033 |
| Norway | NO | 5,945 | 20.80 | 0.58 | 8.30 | 11.40 | 0.00 | 0.298 |
| Republic of Moldova | MD | 3,839 | 28.40 | 0.14 | 0.23 | 0.23 | 0.00 | 0.026 |
| Russian Federation | RUE | 138,652 | 926.00 | 126.00 | 518.00 | 130.00 | 0.00 | 0.798 |
| Serbia | RS | 10,327 | 7.90 | 0.30 | 3.60 | 0.95 | 0.00 | 0.062 |
| Switzerland | CH | 9,223 | 26.70 | 0.25 | 3.50 | 5.20 | 0.00 | 0.314 |
| Tajikistan | TJ | 11,102 | 3.80 | 1.50 | 5.30 | 4.00 | 0.00 | 0.570 |
| The FYR of Macedonia | MK | 2,078 | -2.80 | 1.10 | 19.00 | 3.30 | 0.00 | 1.045 |
| Turkey | TR | 87,717 | -737.00 | 24.00 | 243.00 | 64.00 | 0.00 | 1.293 |
| Turkmenistan | TM | 6,160 | -85.20 | 0.00 | 0.00 | 0.00 | 0.00 | 0.095 |
| Ukraine | UA | 40,892 | 378.00 | 4.10 | 22.00 | 8.80 | 0.00 | 0.104 |
| Uzbekistan | UZ | 34,397 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.522 |
| EU-28 | EU-28 | 509,433 | 2,250.00 | 287.00 | 914.00 | 951.00 | 0.00 | 1.634 |
| All countries | | 931,017 | 2,966 | 463 | 1,920 | 1,266 | 0.00 | 1.471 |

[†] Contribution to total concentration change due to National emission reductions and change including transboundary pollution from emission reductions in neighbouring countries (All emissions column).

The FYR of Macedonia = The former Yugoslav Republic of Macedonia.

Source: CaRBonH software.

Note. Greenhouse gas changes are relative to base year 1990. For other pollutants, the changes are relative to the 2030 business as usual scenario.

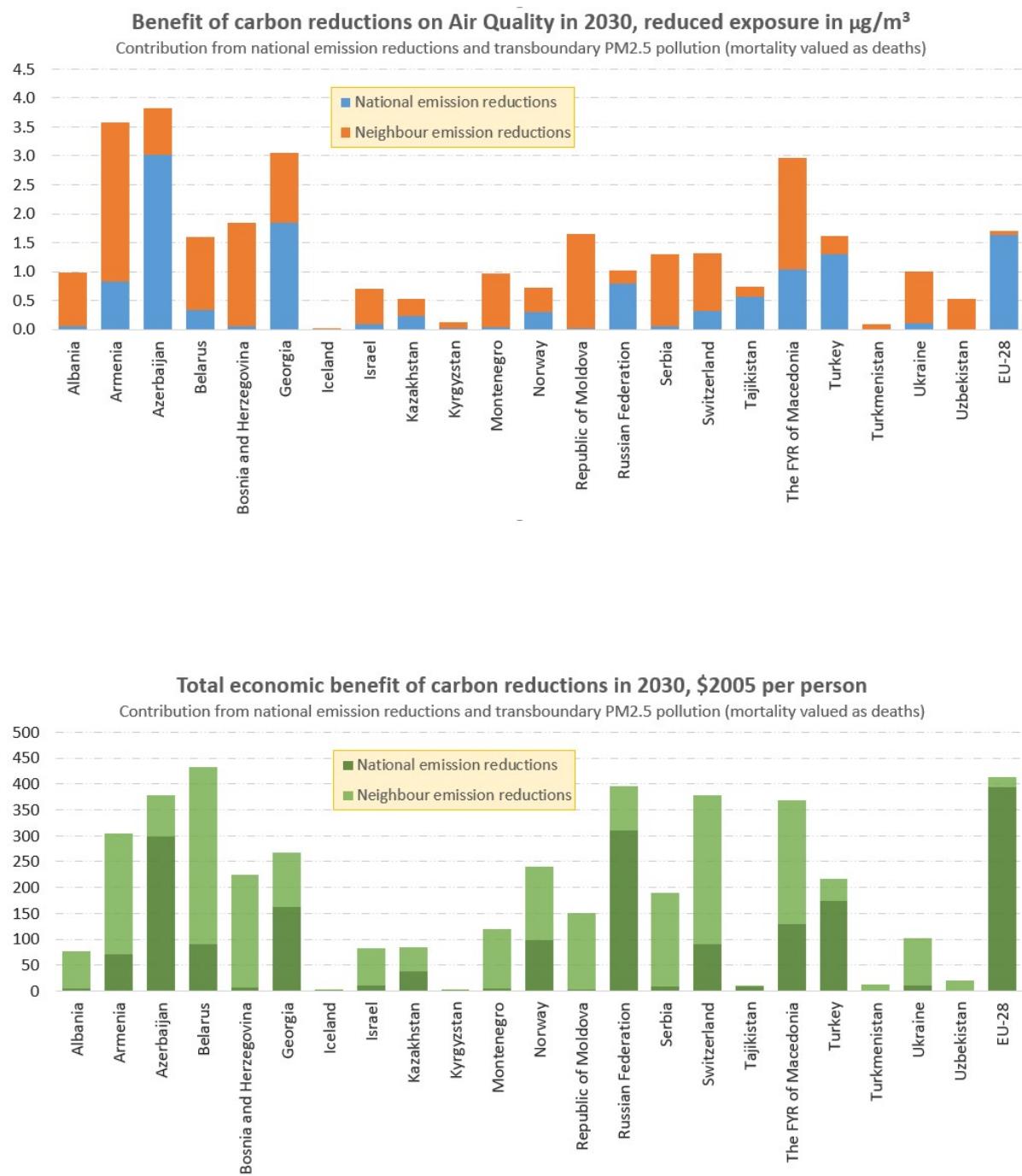
The user can navigate to different areas in the *Summary of results* worksheet using the Jump to box located at the top right corner of the worksheet (options include: view comments, review 2020 or 2030 summary tables, and go to the figures). The user has access to all the output results and interim calculations (for example, tables of concentration changes in the four worksheets *Effect xxx reduction on PM2.5*) and may use this information to prepare additional summary tables and graphs.

Software preloaded databases

The following worksheets contain default data and background information, which can be modified or supplemented by the user:

- *Exposure costs*: contains epidemiological data, illness and mortality costs for the 53 Member States for 2010, 2020 and 2030 (Fig. 11);
- *Demographics*: contains demographic data by country for 2010 plus projections for 2020 and 2030 according to published data by (9).
- *manual*: Health benefits of carbon reductions (this document).

Fig. 7. Air quality and economic benefits from domestic and regional emission cuts as shown in Fig. 4



The FYR of Macedonia = The former Yugoslav Republic of Macedonia.

Source: CaRBonH software.

Note. There are significant environmental, health and economic benefits to be achieved from concerted regional efforts to limit carbon emissions, leading to win-win opportunities across all Member States.

Additional resources

The following additional resources are available.

- *Achieving health benefits from carbon reductions – Role of (intended) nationally determined contributions.* PowerPoint presentation, including a validation exercise (10).
- *WHO Policy Brief: Healthy mitigation in the WHO European Region.* An application of the CaRBonH calculation tool (11).
- *Background on the UNFCCC: The international response to climate change* (12).
- *Climate Action Tracker* (13).
- *CAIT Climate Data Explorer* (14).

Table 5. Averted morbidity and mortality from reductions in PM_{2.5} ambient concentrations in 2030

| Country/Region | Children | | Adults Bronchitis | Labor force WLD | All ages | | Mortality | |
|--------------------------|------------|--------------|----------------------|--------------------|---------------|-----------|-----------|------------|
| | Bronchitis | Asthma | | | RAD | HA | Deaths | YLL |
| Albania | 920 | 4,077 | 119 | 46,206 | 194,878 | 85 | 148 | 1,726 |
| Armenia | 1,730 | 7,664 | 433 | 141,982 | 750,800 | 521 | 629 | 6,843 |
| Azerbaijan | 8,418 | 37,293 | 1,512 | 558,198 | 2,857,027 | 1,939 | 2,151 | 29,305 |
| Belarus | 4,350 | 19,272 | 604 | 227,529 | 967,690 | 702 | 1,185 | 11,211 |
| Bosnia and Herzegovina | 1,503 | 6,659 | 301 | 100,513 | 449,007 | 330 | 481 | 4,668 |
| Georgia | 2,024 | 8,966 | 474 | 153,668 | 833,111 | 573 | 749 | 7,428 |
| Iceland | 2 | 11 | 0 | 93 | 438 | 0 | 0 | 3 |
| Israel | 1,656 | 7,336 | 235 | 106,321 | 484,453 | 200 | 210 | 2,578 |
| Kazakhstan | 2,527 | 11,195 | 345 | 137,573 | 744,813 | 490 | 551 | 7,066 |
| Kyrgyzstan | 233 | 1,031 | 25 | 10,855 | 60,039 | 38 | 32 | 491 |
| Montenegro | 92 | 408 | 24 | 9,507 | 40,688 | 29 | 39 | 367 |
| Norway | 1,501 | 6,649 | 175 | 114,060 | 244,053 | 181 | 199 | 2,134 |
| Republic of Moldova | 1,869 | 8,281 | 266 | 100,426 | 426,648 | 309 | 488 | 5,112 |
| Russian Federation | 43,294 | 191,803 | 5,809 | 1,802,951 | 9,858,072 | 6,827 | 11,553 | 114,370 |
| Serbia | 1,987 | 8,802 | 562 | 210,330 | 915,246 | 662 | 1,035 | 8,842 |
| Switzerland | 3,396 | 21,062 | 534 | 168,122 | 838,372 | 353 | 595 | 6,147 |
| Tajikistan | 2,496 | 11,060 | 225 | 101,744 | 578,006 | 362 | 259 | 4,476 |
| The FYR of Macedonia | 1,698 | 7,523 | 264 | 18,811 | 491,860 | 302 | 385 | 4,229 |
| Turkey | 55,004 | 243,683 | 5,213 | 862,218 | 10,795,510 | 5,495 | 5,012 | 84,276 |
| Turkmenistan | 135 | 597 | 20 | 7,996 | 40,760 | 27 | 29 | 466 |
| Ukraine | 12,146 | 53,809 | 1,709 | 244,980 | 3,128,289 | 1,981 | 3,669 | 33,793 |
| Uzbekistan | 4,204 | 18,625 | 591 | 242,125 | 1,251,492 | 833 | 807 | 12,710 |
| EU-28 | 252,229 | 1,460,736 | 37,364 | 13,489,777 | 58,489,391 | 33,191 | 53,171 | 481,472 |
| Total (thousands) | 403 | 2,137 | 57 | 18,856 | 94,441 | 55 | 83 | 830 |

WLD = work lost days; RAD = restricted activity days; HA = hospital admissions; YLL = years of life lost.

The FYR of Macedonia = The former Yugoslav Republic of Macedonia.

Source: CaRBonH software.

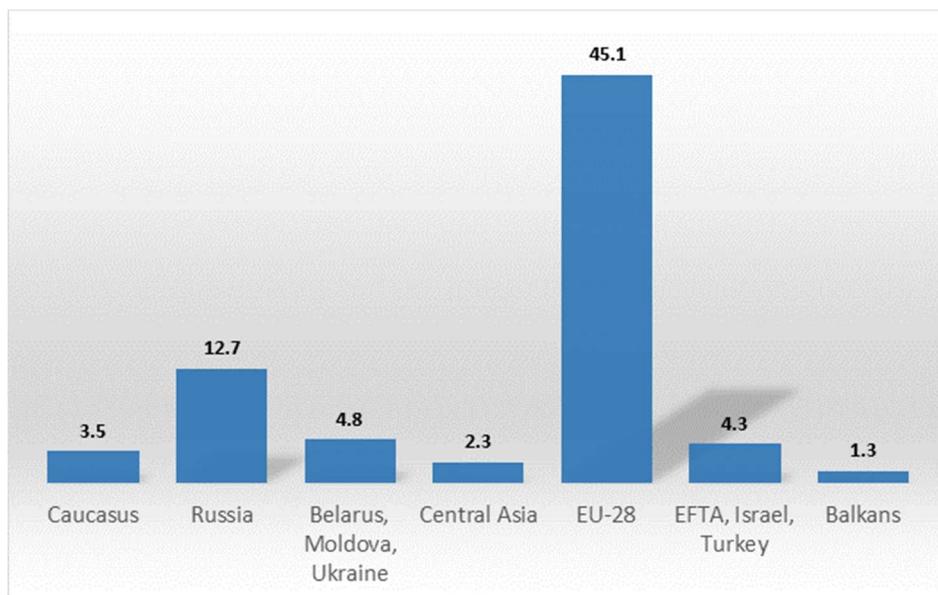
Notes.

- Implementation of NDC pledges with corresponding emission reductions shown in Fig. 4 lead to 74 000 premature deaths or 736 000 life-years gained annually. For the population alive in 2030, the reduced mortality risk is equivalent to an increase in life expectancy of around half a month (approximately 11 days gained per decrement of 1 µg/m³ of PM_{2.5}).
- Equation for calculating health benefits (applied individually to each country or region and health outcome):

$$\text{Health benefit} = \frac{\text{PM}_{2.5} \text{ concentration change}}{\text{Country population}} \times \frac{\text{Concentration-response function}}{\text{Population}}$$

- Default data on population (worksheet *Demographics*) and concentration–response functions (worksheet *Exposure costs*) are summarized in the preloaded databases.

Fig. 8. Averted annual mortality (prevented premature deaths) (thousands) from implementation of NDC pledges in the 53 Member States in 2030 for emission cuts shown in Fig. 4



Russia = Russian Federation; Moldova = Republic of Moldova.

Caucasus = Armenia, Azerbaijan, Georgia.

Central Asia = Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, Uzbekistan.

EU28 = Austria, Belgium, Bulgaria, Croatia, Czech Republic, Cyprus, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Netherlands, Malta, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, United Kingdom.

EFTA (European Free Trade Association) = Iceland, Norway, Switzerland.

Balkans = Albania, Bosnia and Herzegovina, Montenegro, Serbia, the former Yugoslav Republic of Macedonia.

Source: CaRBonH software.

Notes.

- The preventable mortality from reduced air pollutant emissions in 2030 is 74 000 deaths, of which 45 100 (61%) of total deaths are averted across EU member states. This figure represents around 10% of the health burden attributed to ambient air PM pollution in 2010. The health benefit in the Russian Federation equals 12 700 (or 17%) of avoidable deaths. The magnitude of these values is closely related to the exposed population size: the EU28 contribute 55% of the total exposed population, followed by the Russian Federation with 15%. In terms of years of life expectancy gained, the total benefit across Region is 736 000 life-years gained, of which 55% is attributed to EU28 countries.
- In addition to prevented mortality, improved air quality results in fewer cases of illnesses (morbidity), including 49 000 fewer hospital admissions, 1.9 million fewer incidences of asthma attacks and 350 000 prevented cases of bronchitis in children, 50 000 fewer cases of chronic bronchitis in adults and nearly 83 million restricted activity days averted plus an additional 17 million work lost days (Table 5).

Fig. 9. PM_{2.5} CRF used in the CaRBonH calculation tool (2010)

Annotations on the table:

- A yellow arrow points to the value **2.59E-04** in the 'Germany' row.
- A blue arrow points to the values **5.91E-05** and **6.11E-04** in the 'Germany' row.
- A blue arrow points to the bottom right corner of the table.

| Country | WHO Region | Children | | Adults Chronic bronchitis | Labor force WLD | All ages (morbidity) | | All ages Mortality | |
|------------------------|------------|-----------------|----------|---------------------------|-----------------|----------------------|---------------------|--------------------|-----------------|
| | | Bronchitis | Asthma | | | RAD | Hospital admissions | Deaths | YLL |
| Albania | Eur-B | 4.51E-04 | 2.00E-03 | 3.22E-05 | 1.63E-02 | 6.60E-02 | 2.79E-05 | 3.92E-05 | 5.31E-04 |
| Andorra | Eur-A | 3.52E-04 | 2.18E-03 | 3.98E-05 | 1.51E-02 | 6.70E-02 | 3.34E-05 | 4.86E-05 | 5.33E-04 |
| Armenia | Eur-B | 1.80E-04 | 7.98E-04 | 3.37E-05 | 1.41E-02 | 6.94E-02 | 4.74E-05 | 4.91E-05 | 6.02E-04 |
| Austria | Eur-A | 2.84E-04 | 1.76E-03 | 4.17E-05 | 1.83E-02 | 6.42E-02 | 5.65E-05 | 5.11E-05 | 5.79E-04 |
| Azerbaijan | Eur-B | 2.02E-04 | 8.93E-04 | 3.10E-05 | 1.46E-02 | 6.88E-02 | 4.66E-05 | 3.81E-05 | 6.61E-04 |
| Belarus | Eur-C | 2.94E-04 | 1.30E-03 | 3.95E-05 | 1.73E-02 | 6.56E-02 | 4.87E-05 | 7.74E-05 | 8.89E-04 |
| Belgium | Eur-A | 3.24E-04 | 2.01E-03 | 4.09E-05 | 1.53E-02 | 6.69E-02 | 2.90E-05 | 5.36E-05 | 5.78E-04 |
| Bosnia and Herzegovina | Eur-B | 2.96E-04 | 1.31E-03 | 4.00E-05 | 1.70E-02 | 6.60E-02 | 4.87E-05 | 5.61E-05 | 6.97E-04 |
| Bulgaria | Eur-B | 2.67E-04 | 1.18E-03 | 4.21E-05 | 1.62E-02 | 6.68E-02 | 4.93E-05 | 8.27E-05 | 8.18E-04 |
| Croatia | Eur-A | 2.91E-04 | 1.29E-03 | 4.13E-05 | 2.05E-02 | 6.25E-02 | 3.54E-05 | 6.77E-05 | 6.93E-04 |
| Cyprus | Eur-A | 3.50E-04 | 1.55E-03 | 3.66E-05 | 1.69E-02 | 6.59E-02 | 1.42E-05 | 3.73E-05 | 5.39E-04 |
| Czech Republic | Eur-A | 2.73E-04 | 1.21E-03 | 4.14E-05 | 2.75E-02 | 5.56E-02 | 4.31E-05 | 5.52E-05 | 6.63E-04 |
| Denmark | Eur-A | 3.49E-04 | 2.17E-03 | 4.00E-05 | 1.54E-02 | 6.67E-02 | 3.02E-05 | 5.29E-05 | 6.04E-04 |
| Estonia | Eur-C | 2.97E-04 | 1.32E-03 | 4.02E-05 | 1.56E-02 | 6.74E-02 | 4.88E-05 | 6.50E-05 | 7.40E-04 |
| Finland | Eur-A | 3.19E-04 | 1.41E-03 | 4.07E-05 | 1.55E-02 | 6.73E-02 | 5.69E-05 | 5.26E-05 | 5.88E-04 |
| France | Eur-A | 3.52E-04 | 2.18E-03 | 3.98E-05 | 1.51E-02 | 6.70E-02 | 3.34E-05 | 4.86E-05 | 5.33E-04 |
| Georgia | Eur-B | 1.45E-04 | 6.41E-04 | 3.75E-05 | 1.40E-02 | 6.96E-02 | 4.85E-05 | 6.26E-05 | 6.71E-04 |
| Germany | Eur-A | 2.59E-04 | 1.61E-03 | 4.32E-05 | 2.56E-02 | 5.71E-02 | 5.01E-05 | 5.91E-05 | 6.11E-04 |
| Greece | Eur-A | 2.81E-04 | 1.74E-03 | 4.27E-05 | 1.56E-02 | 6.69E-02 | 2.97E-05 | 5.74E-05 | 6.11E-04 |
| Hungary | Eur-C | 2.86E-04 | 1.27E-03 | 4.14E-05 | 1.81E-02 | 6.49E-02 | 5.45E-05 | 7.19E-05 | 7.72E-04 |
| Iceland | Eur-A | 4.07E-04 | 1.80E-03 | 3.63E-05 | 1.59E-02 | 6.66E-02 | 2.17E-05 | 3.47E-05 | 4.80E-04 |
| Ireland | Eur-A | 4.16E-04 | 2.58E-03 | 3.68E-05 | 1.60E-02 | 6.57E-02 | 3.01E-05 | 3.47E-05 | 5.23E-04 |
| Israel | Eur-A | 2.37E-04 | 1.05E-03 | 3.21E-05 | 1.53E-02 | 6.80E-02 | 2.79E-05 | 2.92E-05 | 4.11E-04 |
| Italy | Eur-A | 2.68E-04 | 1.66E-03 | 4.37E-05 | 1.52E-02 | 6.74E-02 | 3.01E-05 | 5.28E-05 | 5.75E-04 |
| Kazakhstan | Eur-C | 1.96E-04 | 8.69E-04 | 3.12E-05 | 1.37E-02 | 6.97E-02 | 4.64E-05 | 4.85E-05 | 7.12E-04 |
| Kyrgyzstan | Eur-B | 2.56E-04 | 1.13E-03 | 2.60E-05 | 1.30E-02 | 7.01E-02 | 4.46E-05 | 3.51E-05 | 5.62E-04 |
| Latvia | Eur-C | 2.69E-04 | 1.19E-03 | 4.07E-05 | 1.61E-02 | 6.70E-02 | 5.58E-05 | 7.95E-05 | 8.05E-04 |
| Lithuania | Eur-C | 2.90E-04 | 1.28E-03 | 3.95E-05 | 1.45E-02 | 6.84E-02 | 7.02E-05 | 8.30E-05 | 8.17E-04 |
| Tajikistan | Eur-B | 3.07E-04 | 1.36E-03 | 2.25E-05 | 1.22E-02 | 7.08E-02 | 4.31E-05 | 3.11E-05 | 5.09E-04 |
| The FYR of Macedonia | Eur-B | 3.49E-04 | 1.54E-03 | 3.75E-05 | 3.25E-03 | 7.95E-02 | 4.77E-05 | 5.05E-05 | 6.81E-04 |
| Turkey | Eur-B | 5.28E-04 | 2.34E-03 | 3.04E-05 | 6.04E-03 | 7.59E-02 | 3.77E-05 | 3.13E-05 | 5.82E-04 |
| Turkmenistan | Eur-B | 2.62E-04 | 1.16E-03 | 2.66E-05 | 1.33E-02 | 6.99E-02 | 4.48E-05 | 4.24E-05 | 7.13E-04 |
| Ukraine | Eur-C | 2.77E-04 | 1.23E-03 | 4.03E-05 | 6.54E-03 | 7.65E-02 | 4.89E-05 | 8.35E-05 | 9.88E-04 |
| United Kingdom | Eur-A | 3.35E-04 | 2.08E-03 | 3.97E-05 | 1.07E-02 | 7.15E-02 | 2.94E-05 | 5.01E-05 | 5.66E-04 |
| Uzbekistan | Eur-B | 2.54E-04 | 1.13E-03 | 2.66E-05 | 1.32E-02 | 7.00E-02 | 4.48E-05 | 3.84E-05 | 6.30E-04 |
| EU-28 | | 3.00E-04 | 1.74E-03 | 4.13E-05 | 1.76E-02 | 6.50E-02 | 3.83E-05 | 5.43E-05 | 6.06E-04 |

WLD = work lost days; RAD = restricted activity days; YLL = years of life lost.

The FYR of Macedonia = The former Yugoslav Republic of Macedonia.

Source: preloaded database in CaRBonH software (worksheet *Exposure costs*).

Notes.

- CRFs have units: excess (additional) annual cases of illness (morbidity) or premature mortality (expressed as number of deaths or years of life lost) per person and for an incremental change in ambient PM_{2.5} concentration of 1 µg/m³.
- CRFs are linear, meaning there is a constant change in health risk for the same increase in exposure over the entire range of plausible concentrations. In addition, it is assumed that exposure functions do not have a threshold below which there are no ill effects in the vulnerable population. Thus,
annual burden for a specific health endpoint = ambient concentration increase × exposed population × CRF for that illness.
- CRFs are calculated using the following expressions (17) (it is assumed that everyone in a country is exposed at the weighted mean concentration):

$$CRF = \left(\frac{RR - 1}{RR} \right) \left(\frac{1}{\Delta C} \right) \cdot \frac{\text{Prevalence}}{\text{rate}} \cdot f_{pop}$$

$$CRF (\text{life years lost, YLL}) = \text{Exp}(8.161 - 0.04478 \cdot LE) \cdot f_{pop,30+} \cdot 10^{-5}$$

where relative risks is the relative risk of the health outcome in question (7), prevalence rate is the number of cases of illness per year (or mortality rate) per person in the population at risk of illness, ΔC is the change in PM_{2.5} population-weighted concentration in units of µg/m³, fpop is the share of the total population affected by the health outcome of concern (age group), fpop,30+ is the group aged 30 years and older and LE is life expectancy at birth (both sexes).

Table 6. Economic benefits from reduced PM_{2.5} emissions in 2003 (US\$ million, 2005 prices)

| Country/Region | | | | | | | | | TOTAL (M\$2005) | |
|---------------------------|--------------|--------------|--------------|--------------|---------------|--------------|----------------|----------------|-----------------|----------------|
| | Children | | Adults | | Labor force | | All ages | | Mortality | |
| | Bronchitis | Asthma | Bronchitis | WLD | RAD | HA | Deaths | YLL | Deaths | YLL |
| Albania | 0.3 | 0.1 | 4.0 | 3.3 | 9.8 | 0.1 | 212 | 93 | 229 | 111 |
| Armenia | 0.6 | 0.2 | 14.1 | 9.5 | 35.7 | 0.8 | 848 | 349 | 909 | 410 |
| Azerbaijan | 3.5 | 1.1 | 62.0 | 48.7 | 176.5 | 3.2 | 3,769 | 1,942 | 4,064 | 2,237 |
| Belarus | 3.3 | 1.0 | 45.0 | 35.4 | 106.5 | 2.4 | 3,698 | 1,323 | 3,892 | 1,517 |
| Bosnia and Herzegovina | 0.6 | 0.2 | 11.7 | 7.9 | 25.1 | 0.7 | 762 | 280 | 808 | 326 |
| Georgia | 0.6 | 0.2 | 15.2 | 9.9 | 38.2 | 1.0 | 973 | 365 | 1,038 | 430 |
| Iceland | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 | 0.0 | 1 | 0 | 1 | 0 |
| Israel | 1.4 | 0.4 | 19.8 | 18.2 | 58.6 | 0.8 | 719 | 335 | 819 | 434 |
| Kazakhstan | 1.7 | 0.5 | 23.3 | 19.5 | 74.7 | 1.4 | 1,566 | 760 | 1,687 | 881 |
| Kyrgyzstan | 0.0 | 0.0 | 0.3 | 0.3 | 1.2 | 0.0 | 18 | 10 | 20 | 12 |
| Montenegro | 0.0 | 0.0 | 1.0 | 0.8 | 2.6 | 0.0 | 69 | 25 | 73 | 29 |
| Norway | 2.4 | 0.7 | 28.6 | 37.3 | 56.5 | 1.6 | 1,303 | 530 | 1,430 | 657 |
| Republic of Moldova | 0.5 | 0.1 | 7.4 | 5.6 | 16.8 | 0.5 | 544 | 216 | 575 | 246 |
| Russian Federation | 45.9 | 13.9 | 594.5 | 405.6 | 1,569.6 | 23.1 | 52,186 | 19,536 | 54,838 | 22,189 |
| Serbia | 0.8 | 0.3 | 23.2 | 18.8 | 58.0 | 1.0 | 1,862 | 601 | 1,964 | 704 |
| Switzerland | 4.5 | 1.8 | 71.7 | 45.1 | 159.0 | 2.6 | 3,204 | 1,251 | 3,488 | 1,535 |
| Tajikistan | 0.2 | 0.1 | 2.2 | 2.1 | 8.3 | 0.2 | 105 | 69 | 118 | 82 |
| The FYR of Macedonia | 0.8 | 0.2 | 11.8 | 1.7 | 32.3 | 0.6 | 717 | 298 | 765 | 346 |
| Turkey | 44.6 | 13.4 | 413.3 | 146.9 | 1,301.4 | 16.7 | 17,141 | 10,899 | 19,077 | 12,835 |
| Turkmenistan | 0.1 | 0.0 | 1.1 | 0.9 | 3.3 | 0.1 | 67 | 41 | 72 | 46 |
| Ukraine | 3.2 | 0.9 | 44.8 | 13.2 | 119.0 | 2.5 | 3,960 | 1,380 | 4,144 | 1,563 |
| Uzbekistan | 0.8 | 0.2 | 10.8 | 9.2 | 33.5 | 0.7 | 612 | 365 | 668 | 420 |
| EU-28 | 246.4 | 95.1 | 3,703.5 | 2,662.9 | 8,201.8 | 175.7 | 195,093 | 71,441 | 210,179 | 86,527 |
| Total (million \$) | 362.2 | 130.4 | 5,109 | 3,503 | 12,088 | 235.5 | 289,429 | 112,108 | 310,858 | 133,536 |

WLD = work lost days; RAD = restricted activity days; HA = hospital admissions; YLL = years of life lost.

The FYR of Macedonia = The former Yugoslav Republic of Macedonia.

Source: CaRBonH software.

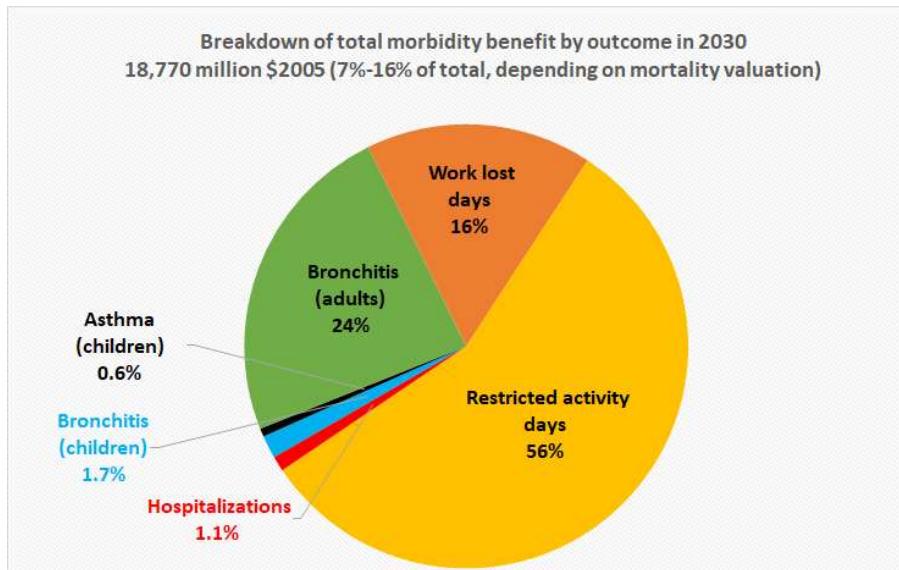
Notes.

- The economic cost of prevented illnesses and mortality in 2030 is US\$ 277 billion (2005 prices) if valuing postponed premature deaths (or US\$ 97 billion if valuing life-years gained). Put another way, these results represent between 0.5% and 1.2% of the annual GDP of the 53 Member States. The EU28 contribution is 64% (or 75% if valuing mortality as life-years gained). The prevented health morbidity alone contributes about US\$ 19 billion (Fig. 4).
- Equations for calculating economic benefits (applied individually to each country or region and health outcome):
$$\text{economic benefit} = \frac{\text{population}}{\text{exposure}} \times \frac{\text{exposure}}{\text{cost}} \quad \text{and} \quad \frac{\text{exposure}}{\text{cost}} = \text{CRF} \times \frac{\text{cost per case of illness}}{\text{(or death, years of life lost)}}$$

Default data on exposure costs are summarized in the worksheet *Exposure costs*.

- Morbidity costs are market expenditures (included in the transaction costs of doing business); they have a direct consequence on a country's GDP and, at the level of the citizen, impact the quality of life and indirectly affect personal income and savings. Mortality benefits are not market costs; instead the economic benefits represent a gain in social well-being, or welfare, from reduced pain and suffering associated with air pollution as a risk factor.

Fig. 10. Morbidity benefits from implementation of NDC pledges for emission reductions shown in Fig. 4



Source: CaRBonH software.

Fig. 11. Costs of illness and mortality for selected countries (US\$ per case at 2005 prices, undiscounted)

Unit costs for Year 2010

| Country | Children | | Adults | | Labor force | All ages (morbidity) | | All ages | |
|------------------------|------------|--------|--------------------|-----|-------------|----------------------|---------------------|----------|------|
| | Bronchitis | Asthma | Chronic bronchitis | WLD | | RAD | Hospital admissions | VSL | VOLY |
| Albania | 205 | 14 | 19,868 | 43 | 31 | 698 | 868,753 | 32,852 | |
| Andorra | 894 | 58 | 92,479 | 180 | 127 | 5,491 | 3,612,824 | 136,619 | |
| Armenia | 110 | 7 | 10,640 | 23 | 16 | 377 | 464,700 | 17,573 | |
| Austria | 877 | 57 | 91,456 | 175 | 124 | 5,734 | 3,514,318 | 132,894 | |
| Azerbaijan | 241 | 17 | 23,293 | 51 | 36 | 780 | 1,025,922 | 38,795 | |
| Belarus | 322 | 22 | 31,263 | 68 | 48 | 1,118 | 1,363,403 | 51,557 | |
| Belgium | 827 | 54 | 85,079 | 167 | 118 | 4,884 | 3,355,896 | 126,903 | |
| Bosnia and Herzegovina | 198 | 13 | 20,068 | 41 | 29 | 1,037 | 813,665 | 30,769 | |
| Bulgaria | 307 | 21 | 30,519 | 64 | 45 | 1,343 | 1,282,574 | 48,501 | |
| Croatia | 438 | 29 | 43,486 | 91 | 64 | 1,911 | 1,827,923 | 69,123 | |
| Cyprus | 610 | 41 | 59,486 | 128 | 91 | 2,213 | 2,577,686 | 97,475 | |
| Czech Republic | 583 | 39 | 58,090 | 121 | 86 | 2,617 | 2,429,471 | 91,870 | |
| Denmark | 870 | 57 | 89,413 | 176 | 125 | 5,097 | 3,533,706 | 133,627 | |
| Estonia | 478 | 33 | 46,646 | 101 | 71 | 1,726 | 2,022,992 | 76,499 | |
| Finland | 781 | 52 | 79,138 | 160 | 113 | 4,081 | 3,210,378 | 121,401 | |
| France | 787 | 51 | 81,404 | 158 | 112 | 4,833 | 3,180,175 | 120,258 | |
| Georgia | 112 | 7 | 11,540 | 23 | 16 | 659 | 455,837 | 17,237 | |
| Germany | 829 | 54 | 86,340 | 166 | 117 | 5,339 | 3,332,009 | 126,000 | |
| Greece | 637 | 42 | 64,531 | 130 | 92 | 3,328 | 2,617,761 | 98,991 | |

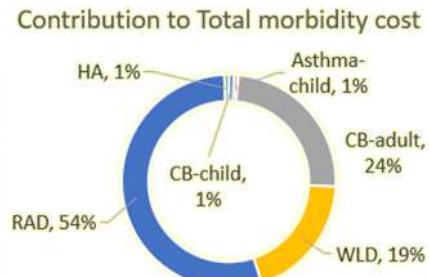
Year 2030

| Country | Children | | Adults | | Labor force | All ages (morbidity) | | All ages | |
|------------------------|------------|--------|--------------------|-----|-------------|----------------------|---------------------|----------|------|
| | Bronchitis | Asthma | Chronic bronchitis | WLD | | RAD | Hospital admissions | VSL | VOLY |
| Albania | 340 | 23 | 33,479 | 71 | 50 | 1,381 | 1,424,703 | 53,875 | |
| Andorra | 1,166 | 76 | 120,552 | 235 | 166 | 7,157 | 4,709,550 | 178,092 | |
| Armenia | 325 | 22 | 32,515 | 67 | 48 | 1,526 | 1,347,988 | 50,974 | |
| Austria | 1,122 | 73 | 116,561 | 225 | 159 | 7,119 | 4,515,455 | 170,752 | |
| Azerbaijan | 417 | 28 | 40,981 | 87 | 62 | 1,647 | 1,752,250 | 66,261 | |
| Belarus | 750 | 50 | 74,634 | 155 | 110 | 3,360 | 3,121,750 | 118,049 | |
| Belgium | 1,081 | 71 | 110,815 | 219 | 155 | 6,213 | 4,399,651 | 166,373 | |
| Bosnia and Herzegovina | 385 | 25 | 38,957 | 79 | 56 | 1,991 | 1,583,886 | 59,895 | |
| Bulgaria | 519 | 35 | 51,889 | 107 | 76 | 2,429 | 2,152,404 | 81,393 | |
| Croatia | 598 | 40 | 59,863 | 124 | 88 | 2,800 | 2,483,652 | 93,919 | |
| Cyprus | 591 | 40 | 57,605 | 124 | 88 | 2,126 | 2,499,478 | 94,518 | |
| Czech Republic | 834 | 55 | 84,089 | 171 | 121 | 4,190 | 3,439,541 | 130,066 | |
| Denmark | 1,138 | 75 | 115,757 | 232 | 164 | 6,143 | 4,662,679 | 176,319 | |
| Estonia | 954 | 64 | 94,469 | 199 | 141 | 4,065 | 3,987,594 | 150,791 | |
| Finland | 1,053 | 70 | 106,615 | 215 | 152 | 5,493 | 4,326,183 | 163,595 | |
| France | 1,021 | 67 | 104,840 | 206 | 146 | 5,966 | 4,145,563 | 156,765 | |
| Georgia | 317 | 21 | 32,147 | 65 | 46 | 1,682 | 1,299,473 | 49,140 | |
| Germany | 1,061 | 69 | 109,693 | 213 | 151 | 6,523 | 4,283,355 | 161,975 | |
| Greece | 867 | 57 | 87,958 | 177 | 126 | 4,573 | 3,561,224 | 134,668 | |

Source: preloaded database in CaRBonH software (worksheet Exposure costs).

Notes.

- Health outcomes. Children: bronchitis (6–12 years); asthma symptom days (5–19 years). Adults: new cases of chronic bronchitis (27+ years); work lost days due to absenteeism (labour force aged 18–64 years). All ages: restricted activity days; hospital admissions; mortality (valuation based on the value of statistical life applied to number of deaths, or the value of a life-year applied to loss of life expectancy).



Abbreviations

- HA – Hospital admissions
 RAD – Restricted activity days
 WDL – Work loss days (absenteeism)
 CB – Chronic bronchitis
 VSL – Value of a statistical life
 VOLY – Value of a life year

- *Cost adjustment from country A to country B (benefit transfer method).* Ideally, national or regional studies should be used to value local economic losses due to air pollution. In the absence of such data, however, the equation below may be used to transfer unit health costs from another site (study) to the current location (18). The adjustment takes into account differences in income levels between the two places, with all other socioeconomic conditions assumed to be similar. Here, Y is the GDP per capita (at purchasing power parity prices), and β is an income elasticity factor, whose values are 0.8, 0.9 and 1.0, respectively, for high, upper middle and lower middle-income countries (8).

$$Cost_{Country\ B} = Cost_{Country\ A} \cdot \left(\frac{Y_{Country\ B}}{Y_{Country\ A}} \right)^\beta$$

- *Cost adjustment over time (income growth effect).* Future costs are calculated using the following expression, where t_{ref} and t represent, respectively, the reference and future times. Future GDP/capita growth is based on the real income growth rate (constant currency, no inflation). Often, the elasticity of marginal utility of consumption δ is assumed to be equal to the income elasticity β .

$$Cost(t) = Cost(t_{ref}) \cdot \left(\frac{Y_t}{Y_{t_{ref}}} \right)^\delta$$

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Annex 1. Historical emissions of aggregate greenhouse gases in CO₂ equivalent metric tons (without land use, land use change and forestry)

| Country/Region | 1990 | 2000 | 2010 | 2015 |
|------------------------|---------|--------------|--------------|---------------|
| Albania | 4.34 | 5.78 | 8.13 (2009) | |
| Andorra | | No data | | |
| Armenia | 25.00 | 5.53 | 7.20 | |
| Azerbaijan | 73.40 | 40.60 | 48.00 | 51.80 (2012) |
| Belarus | 137.00 | 81.30 | 93.90 | 89.60 |
| Bosnia and Herzegovina | 34.00 | 15.20 | 28.00 | 31.10 (2011) |
| Georgia | 38.70 | 10.60 | 12.90 | 16.60 (2013) |
| Iceland | 3.54 | 3.87 | 4.65 | 4.54 |
| Israel | | 67.20 | 77.30 | 78.60 (2013) |
| Kazakhstan | 389.00 | 193.00 | 309.00 | 301.00 |
| Kyrgyzstan | 28.40 | 9.28 | 12.80 | |
| Monaco | 0.10 | 0.11 | 0.09 | 0.08 |
| Montenegro | 5.71 | 5.61 | 4.02 | 3.86 (2011) |
| Norway | 51.70 | 54.60 | 55.20 | 53.90 |
| Republic of Moldova | 43.40 | | | |
| Russian Federation | 3768.00 | 2273.00 | 2601.00 | 2651.00 |
| San Marino | | | 0.27 | |
| Serbia | 80.80 | 66.30 (1998) | | |
| Switzerland | 53.40 | 52.40 | 54.40 | 48.00 |
| Tajikistan | 24.20 | 6.75 | 8.18 | |
| The FYR of Macedonia | 13.30 | 12.10 | 11.50 (2009) | |
| Turkey | 214.00 | 296.00 | 407.00 | 475.00 |
| Turkmenistan | | 50.30 | 66.40 | |
| Ukraine | 962.00 | 427.00 | 413.00 | 323.00 |
| Uzbekistan | 180.00 | 198.00 | 199.00 | 205.00 (2012) |
| EU | 5643.00 | 5152.00 | 4775.00 | 4308.00 |

The FYR of Macedonia = The former Yugoslav Republic of Macedonia.

Source: Greenhouse gas inventory data – detailed data by party [online database]. Bonn: United Nations Framework Convention on Climate Change; 2018 (http://di.unfccc.int/detailed_data_by_party, accessed 23 June 2018).

The WHO Regional Office for Europe

The World Health Organization (WHO) is a specialized agency of the United Nations created in 1948 with the primary responsibility for international health matters and public health. The WHO Regional Office for Europe is one of six regional offices throughout the world, each with its own programme geared to the particular health conditions of the countries it serves.

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