World Health Organization
European Region

# Achieving health benefits from carbon reductions

Manual for the climate change mitigation, air quality and health tool

CLIMAQ-H

Version 1.0.

## Abstract

Climate change mitigation, air quality and health (CLIMAQ-H) is software developed by the WHO Regional Office for Europe for quantifying the consequences for human health and its related costs achieved by improving national air quality by reducing domestic carbon emissions. The tool is used to analyse the policies for mitigation of carbon emissions reported in nationally determined contributions submitted by the Conference of the Parties to the United Nations Framework Convention on Climate Change. CLIMAQ-H can be used to assess the outcome of climate policies and to facilitate decision-making in settings with limited data availability. The methods used are based on evidence from epidemiological studies that show relations between average long-term air pollution concentrations and the mortality and morbidity risks of exposed populations. Assessment of the impact of carbon reduction scenarios is relevant for evaluating the consequences of policies or for screening hypothetical scenarios. The support of an epidemiologist or health impact assessment expert is recommended when setting up and interpreting the results of CLIMAQ-H. This manual introduces users to analysis of the impact of air pollution on public health with data from different countries.

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## (CLIMAQ-H)

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# Contents

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## Abbreviations and acronyms

| | |
|---|---|
| BAU | business-as-usual |
| CLIMAQ-H | Climate change Mitigation, Air Quality and Health |
| CI | confidence interval |
| $CO_2$ | carbon dioxide |
| COP | Conference of the Parties |
| EMEP | European Monitoring and Evaluation Programme |
| IER | integrated exposure-response |
| ISO | International Organization for Standardization |
| NDC | nationally determined contribution |
| $NH_3$ | ammonia |
| $NO_x$ | unspecified mixture of nitrogen oxides |
| PM | particulate matter |
| $PM_{2.5}$ | particulate matter with a diameter < 2.5 µm |
| $PM_{10}$ | particulate matter with a diameter < 10 µm |
| RR | relative risk |
| $SO_2$ | sulfur dioxide |
| SRM | source receptor matrix |
| UNFCCC | United Nations Framework Convention on Climate Change |
| VSL | value of a statistical life |

# 1 Introduction

Climate change Mitigation, Air Quality and Health (CLIMAQ-H) is a software tool designed to quantify the health and economic benefits that can be achieved by improving national air quality through domestic climate policies specifically to mitigate carbon dioxide ($CO_2$) and other greenhouse gases, as proposed in the nationally determined contributions (NDCs) submitted to the 21st Conference of the Parties (COP) to the United Nations Framework Convention on Climate Change (UNFCCC) to support the objectives set forth in Article 2 of the Convention. The tool can be used to assess the outcome of climate policies for the target year 2030 and to facilitate decision-making in settings where limited data are available. In 2018, an Excel®-based tool, CarbonH, was developed for the Member States of the WHO European Region to quantify the health and economic gains from implementation of their NDCs (Spadaro et al., 2020; Pisoni et al., 2023). That tool has now been replaced with the updated version, called CLIMAQ-H (see Table A2 for the differences between the two versions).

This manual (CLIMAQ-H version 1.0, 2023) is available online (https://www.who.int/europe/tools-and-toolkits/climate-change-mitigation--air-quality-and-health-(climaq-h) and is also accessible from within the CLIMAQ-H software. This document provides basic information on how to install CLIMAQ-H, run the software and conduct example analyses to become familiar with some of the software's features. When interpreting the results delivered by CLIMAQ-H, it is advisable to seek the support of an epidemiologist and an expert in assessing the impact of air pollution or climate change.

## 1.1 UNFCCC

Sustainable human development can be defined as living in a world where consumption demands less of the ecosystem services that the Earth can deliver and does not compromise the needs of future generations. Economic and social development requires a holistic approach based on a sound economic analysis to promote environmental protection, while ensuring that everyone has equal opportunities and shares the benefits of social development, regardless of socioeconomic status and gender. The risks associated with different economic development strategies should therefore be assessed and the results communicated to decision-makers and the general public in a transparent, concise way that takes account of socioeconomic trade-offs and uncertainties for present and future generations.

The UNFCCC was adopted at the United Nations Conference on Environment and Development held in Rio de Janeiro in June 1992 and entered into force on 21 March 1994 (United Nations, 1992). At the Conference, the global community acknowledged the long-term negative environmental consequences associated with rapidly increasing anthropogenic emissions of climate-altering pollutants. National delegates reached consensus on the urgency for coordinated, comprehensive action at all levels of society – local, national, regional and global – to meaningfully mitigate future emissions and to adopt contingency plans to manage climate variation and long-term change. The purpose of contingency and adaptation interventions is to curb the most adverse effects of climate change on the natural and built environments, ecosystems and health systems, and to limit community exposure and related climate risks, including on health, and the potential for population displacement and increased social conflicts.

Article 2 of the UNFCCC reads as follows (United Nations, 1992):

> 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.

At the Conference, industrialized nations:

- committed themselves to lead efforts to limit climate-altering pollutants emissions;
- agreed to provide technical assistance, share technology with poorer countries, and establish financial mechanisms to support actions against climate change; and

- established a routine accounting and reporting framework for implementation of national policies and measures to mitigate climate change, making an inventory of emissions and considering arrangements for adaption (managing the unavoidable).

## 1.2 The Paris Agreement on Climate Change

In 2011, the seventeenth United Nations Climate Change COP (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. The aim was to stabilize ambient concentrations and prevent global mean surface temperature change from exceeding a threshold of 2 ℃ since the start of the industrial age by the end of the 21st century. Furthermore, countries would make additional efforts to limit the increase in ambient temperatures to below 1.5 ℃. The special report of the Intergovernmental Panel on Climate Change is 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.

The Paris Agreement, which was adopted by delegates to the twenty-first COP of the UNFCCC in Paris in 2015 (United Nations Framework Convention on Climate Change, 2014a,b), reflects the changing landscape of 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, loss and damage). The Agreement formalized countries' commitments to achieve climate-related policy goals and targets through their NDCs. In November 2016, the Paris Agreement came into force, and, by November 2021, 194 countries, including the world's two highest $CO_2$ emitters (China and the USA), had ratified or acceded to the Agreement. Collectively, these two countries account for 98% of global emissions.

## 1.3 Rationale for developing CLIMAQ-H

The Paris Agreement represents an opportunity and a challenge for nations to promote policy-making and political awareness of the co-benefits for health of reducing emissions of health-damaging pollutants through implementation of climate-friendly policies and adaptation actions, as outlined in the communications related to their pledged NDCs (United Nations Framework Convention on Climate Change, 2014a).

Greenhouse gas emissions could be reduced by improving energy efficiency, setting fuel quality standards, shifting to less polluting technologies and fuels for power generation or mobility, innovating industrial manufacture, reducing emissions from buildings, improving and changing land use and forestry, financial mechanisms (such as removal of government subsidies, carbon taxation or carbon trading), encouraging ("nudging") environmentally friendly consumer behaviour (e.g. eating less red meat), and imposing monetary disincentives or taxes on carbon-intensive products. Reduction of pollutants by controlling emissions of greenhouse gases from fossil fuel combustion is generally linearly correlated to decreases in carbon emissions. For regions in which carbon emissions could potentially be reduced by non-fossil fuel sources (e.g. land use, land use change and forestry), the relation is non-trivial.

Policies to reduce greenhouse gases can be a win–win strategy not only for climate change but also to mitigate air pollution (WHO, 2021a). Climate change policies are closely linked to emissions of air pollutants other than greenhouse gases. The short-lived climate pollutants, e.g. methane and black carbon, are directly or indirectly implicated in air quality. For example, black carbon is a component of particulate matter, which is known to have a significant impact on mortality (WHO, 2021b). Methane is both a greenhouse gas and a precursor of ozone, which has been linked to attributable premature mortality from all-causes and diseases of the respiratory system. Other air pollutants are affected by climate policies, including oxides of sulfur and nitrogen plus ammonia ($NH_3$), which are emitted during combustion of fossil fuels in the housing, transport and power generation sectors, and from agricultural activities. Sulfur dioxide ($SO_2$), unspecified mixtures of nitrogen oxides (NOx) and $NH_3$ are precursor emissions that contribute to chemical formation of secondary particulate matter (PM) with a diameter

< 2.5 μm ($PM_{2.5}$)[1] aerosols and ozone, which, in turn, contribute to adverse environmental and human health effects.

CLIMAQ-H can facilitate screening of carbon mitigation pathways by Member States by comparing the health benefits of implementing their NDC targets. All the calculations performed in CLIMAQ-H are based on methods and concentration–response functions established in epidemiological studies. CLIMAQ-H can be used to calculate the annual benefit of averted long-term mortality and morbidity due to exposure to ambient air pollution by primary emissions of $PM_{2.5}$ and changes in secondary PM aerosols due to reduced emissions of $SO_2$, $NO_2$ and $NH_3$. The health end-points and relative risks included in the software are based on recent epidemiological evidence.

[1] μm = one-millionth ($10^{-6}$) of a metre, or micron

# 2 Health and economic assessment methods and input data

CLIMAQ-H is an integrated tool for calculating the health and economic co-benefits linked to climate policies, the so-called "health climate bonus". The questions addressed by CLIMAQ-H are:

- How are the air pollution and health co-benefits affected by the domestic carbon reduction strategies specified in a country's NDC plan?
- What is the economic benefit of the health gains achieved through implementation of the NDC?

Health co-benefits arise from reduced emissions of major air pollutants into ambient air, such as PM, $SO_2$, NOx, $NH_3$ and organic compounds and micropollutants, such as heavy metals, as well as short-lived climate pollutants such as black carbon. Reduction of these pollutants would directly or indirectly influence local and national air quality and have a transboundary reach to neighbouring countries ("spill-over effects").

CLIMAQ-H is based on impact pathway analysis, in which the fate of pollutants is traced from the moment they are released into the environment, dispersed in the atmosphere and removed by deposition by interactions with the ground and clouds and by chemical transformation to secondary airborne species. Vulnerable population subgroups, such as people with medical conditions, children and the elderly, who are exposed to atmospheric contaminants by inhalation and/or ingestion are at high risk of adverse health effects, ranging from mild discomfort to more serious or life-threatening conditions that require medical attention or lead to premature death. Health gains are calculated from concentration–response functions, and the physical burden is monetized. The output of CLIMAQ-H can be used in decision analysis by informing policy-makers and stakeholders about the health gains to be achieved, as input to cost-effectiveness analyses or benefit-cost analyses or to promote consideration of more ambitious carbon reduction policies ("feedback loop").

CLIMAQ-H consists of a series of modules for quantifying health co-benefits related to (i) changes in population exposure due to emission reductions; (ii) reduced annual incidence of morbidity, postponed premature mortality and gains in the number of life years (i.e. projected increase in life expectancy); and (iii) economic valuation of the health co-benefits. The formulae for calculating population-weighted exposure, health benefits, life years gained, and economic benefits are described in the Annex.

## 2.1 User input and configuration

Reductions in emissions of pollutants from a "business-as-usual" (BAU) scenario in 2030, including primary $PM_{2.5}$, $SO_2$, $NO_x$ and $NH_3$, are entered into "Emission reduction input". Data may be entered for a single country or region or for a group of countries. For each country, countries or region selected, the tool provides a single estimate of the change in $PM_{2.5}$ exposure, health gains and economic benefits. The only input required from the user is emission reductions, as the software is preloaded with the necessary default data for the calculations. The default values can be modified by the user.

## 2.2 Calculation of exposure

Source-receptor matrices (SRMs) are used to calculate population exposure changes (Fig. 1). These matrices are used to calculate changes of concentrations in a receptor (receiver) country due to domestic reductions in emissions and contributions from emissions in neighbouring (emitter) countries that contribute to transboundary pollution at the regional level. The SRMs[2] have been calculated by the European Monitoring and Evaluation Programme (EMEP) software of the European Commission (Fagerli et al., 2019). An example is shown in Fig. 1. The estimated changes in SRM-derived concentrations (geographically averaged values) are augmented by country-specific urban adjustment (downscaling) coefficients (Annex, Table A4) to capture the influence of urban population density and source diversity in calculation of national population-weighted exposure.

[2] Currently, the European EMEP SRMs do not include Israel.

## Fig. 1. Example of an SRM in CLIMAQ-H

Change in background PM2.5 concentration (ng/m³) in a Receiver country (shown along a row)
for a PM10 emission reduction (kilo-tonnes, kt) in the Emitter country (shown at the top of a column)

| Receiver country | | ALB | ARM | AUT | AZE | BIH | BEL | BGR | BLR | CHE | CYP | CZE | DEU |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Emission reductions, kt | 2.85 | 0.90 | 4.20 | 1.95 | 3.90 | 4.95 | 7.05 | 8.85 | 2.25 | 0.30 | 7.65 | 30.90 |
| ALB | Albania | 227.6 | 0.0 | 0.5 | 0.0 | 2.0 | 0.1 | 3.5 | 0.1 | 0.1 | 0.0 | 1.0 | 1.1 |
| ARM | Armenia | 0.0 | 67.0 | 0.0 | 3.4 | 0.0 | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| AUT | Austria | 0.0 | 0.0 | 84.3 | 0.0 | 0.6 | 0.5 | 0.6 | 0.1 | 1.8 | 0.0 | 9.8 | 16.7 |
| AZE | Azerbaijan | 0.0 | 4.3 | 0.0 | 24.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| BIH | Bosnia and Herzegovina | 1.3 | 0.0 | 1.9 | 0.0 | 125.6 | 0.2 | 2.3 | 0.2 | 0.1 | 0.0 | 3.7 | 2.8 |
| BEL | Belgium | 0.0 | 0.0 | 0.8 | 0.0 | 0.0 | 229.2 | 0.2 | 0.1 | 0.3 | 0.0 | 2.3 | 25.7 |
| BGR | Bulgaria | 1.1 | 0.0 | 0.7 | 0.0 | 1.0 | 0.2 | 173.9 | 0.4 | 0.1 | 0.0 | 1.5 | 1.6 |
| BLR | Belarus | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | 0.2 | 0.3 | 58.7 | 0.1 | 0.0 | 1.6 | 2.2 |
| CHE | Switzerland | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | 0.5 | 0.0 | 0.0 | 84.7 | 0.0 | 1.0 | 16.3 |
| CYP | Cyprus | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | 0.0 | 0.4 | 0.1 | 0.0 | 24.4 | 0.1 | 0.2 |
| CZE | Czechia | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | 1.3 | 0.7 | 0.2 | 0.8 | 0.0 | 219.1 | 25.6 |
| DEU | Germany | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | 6.8 | 0.2 | 0.2 | 2.7 | 0.0 | 11.4 | 124.3 |
| DNK | Denmark | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | 1.4 | 0.1 | 0.5 | 0.1 | 0.0 | 2.3 | 10.7 |
| EST | Estonia | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | 0.3 | 0.1 | 2.0 | 0.0 | 0.0 | 0.5 | 1.4 |
| ESP | Spain | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | 0.2 | 0.0 | 0.0 | 0.1 | 0.0 | 0.1 | 0.3 |
| FIN | Finland | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 | 0.1 | 0.3 | 0.0 | 0.0 | 0.2 | 0.4 |
| FRA | France | 0.0 | 0.0 | 0.6 | 0.0 | 0.0 | 4.3 | 0.1 | 0.0 | 1.6 | 0.0 | 1.3 | 7.4 |
| SVN | Slovenia | 0.1 | 0.0 | 19.0 | 0.0 | 1.9 | 0.3 | 1.2 | 0.1 | 0.4 | 0.0 | 4.3 | 5.2 |
| SVK | Slovakia | 0.1 | 0.0 | 5.5 | 0.0 | 1.3 | 0.5 | 1.1 | 0.4 | 0.3 | 0.0 | 19.7 | 7.3 |
| TJK | Tajikistan | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| TKM | Turkmenistan | 0.0 | 0.2 | 0.0 | 0.2 | 0.0 | 0.0 | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 |
| TUR | Türkiye | 0.1 | 0.6 | 0.1 | 0.1 | 0.1 | 0.0 | 0.7 | 0.1 | 0.0 | 0.1 | 0.1 | 0.2 |
| UKR | Ukraine | 0.1 | 0.0 | 0.3 | 0.1 | 0.2 | 0.2 | 1.2 | 3.3 | 0.0 | 0.0 | 1.4 | 1.6 |
| UZB | Uzbekistan | 0.0 | 0.1 | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 |

| Receiver country | | SVN | SVK | TJK | TKM | TUR | UKR | UZB |
|---|---|---|---|---|---|---|---|---|
| | Emission reductions, kt | 1.95 | 3.45 | 1.05 | 3.30 | 114.75 | 32.40 | 4.95 |
| ALB | Albania | 0.3 | 0.7 | 0.0 | 0.0 | 0.6 | 0.6 | 0.0 |
| ARM | Armenia | 0.0 | 0.0 | 0.0 | 0.2 | 34.8 | 0.2 | 0.1 |
| AUT | Austria | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | 0.6 | 0.0 |
| AZE | Azerbaijan | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | 0.7 | 0.3 |
| BIH | Bosnia and Herzegovina | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | 1.0 | 0.0 |
| BEL | Belgium | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | 0.1 | 0.0 |
| BGR | Bulgaria | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | 5.8 | 0.0 |
| BLR | Belarus | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | 11.1 | 0.0 |
| CHE | Switzerland | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | 0.0 | 0.0 |
| CYP | Cyprus | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | 1.0 | 0.0 |
| CZE | Czechia | 2.3 | 9.2 | 0.0 | 0.0 | 0.1 | 1.1 | 0.0 |
| DEU | Germany | 0.3 | 0.8 | 0.0 | 0.0 | 0.0 | 0.5 | 0.0 |
| DNK | Denmark | 0.1 | 0.4 | 0.0 | 0.0 | 0.0 | 1.0 | 0.0 |
| EST | Estonia | 0.1 | 0.4 | 0.0 | 0.0 | 0.0 | 0.9 | 0.0 |
| ESP | Spain | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| FIN | Finland | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 | 0.2 | 0.0 |
| FRA | France | 0.2 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| SVN | Slovenia | 250.5 | 1.4 | 0.0 | 0.0 | 0.1 | 1.1 | 0.0 |
| SVK | Slovakia | 2.6 | 163.0 | 0.0 | 0.0 | 0.1 | 4.2 | 0.0 |
| TJK | Tajikistan | 0.0 | 0.0 | 20.4 | 0.7 | 0.5 | 0.1 | 6.6 |
| TKM | Turkmenistan | 0.0 | 0.0 | 0.4 | 21.6 | 1.4 | 0.6 | 5.9 |
| TUR | Türkiye | 0.0 | 0.1 | 0.0 | 0.0 | 247.0 | 1.4 | 0.0 |
| UKR | Ukraine | 0.2 | 1.5 | 0.0 | 0.1 | 5.0 | 97.7 | 0.1 |
| UZB | Uzbekistan | 0.0 | 0.0 | 1.8 | 2.3 | 0.8 | 0.7 | 32.8 |

Interpretation
Reducing PM10 emissions in Belgium by 4.95 kt would lower the PM2.5 concentration across Belgium by 229 ng/m³.

Interpretation
Reducing PM10 emissions in Germany by 30.9 kt would lower the PM2.5 concentration across Belgium by 25.7 ng/m³.

Country codes are provided in Annex Table A3.

As an alternative to using SRMs to convert reductions in pollutant emissions to changes in ambient air quality, the user may directly enter into the software the predicted change in the population-weighted $PM_{2.5}$ ambient air concentration from external modelling. Table 1 indicates the various combinations of input data on pollutant emissions reductions and concentration change in countries and the implication for calculations of the health impact.

## Table 1. Interpretation of combinations of emission reductions and $PM_{2.5}$ concentration changes

**Case 1: Single-country analysis with user-specified $PM_{2.5}$ concentration change as input**

When a change in $PM_{2.5}$ concentration is entered, CLIMAQ-H uses the value to calculate the health benefits, and reductions in air pollutant emission inputs, if any, values will not be used in the analysis and may be provided for information only.

**Emission Reduction Input**

Edit Region Selection | Import Data | Reset Data

| Country/Region | Primary $PM_{2.5}$ | $SO_2$ | $NO_x$ | $NH_3$ | $PM_{2.5}$ concentration change (μg/m$^3$) |
|---|---|---|---|---|---|
| Austria | 0.00 | 0.00 | 0.00 | 0.00 | value calculated by CLIMAQ-H |
| France | 0.00 | 0.00 | 0.00 | 0.00 | value calculated by CLIMAQ-H |
| Germany | 0.00 | 0.00 | 0.00 | 0.00 | value calculated by CLIMAQ-H |
| Italy | 0.00 | 0.00 | 0.00 | 0.00 | 1.2 |
| Switzerland | 0.00 | 0.00 | 0.00 | 0.00 | value calculated by CLIMAQ-H |

- The health benefits in Italy will be calculated from the $PM_{2.5}$ concentration change (1.2 μg/m$^3$) specified by the user.
- The $PM_{2.5}$ concentration change in the other countries is 0 (i.e. the health benefits will not be calculated).

**Case 2: Multiple-country analysis with user-specified emission reductions as inputs**

When a change in $PM_{2.5}$ concentration is entered, CLIMAQ-H uses the value to calculate health benefits, and reductions in air pollutant emissions, if any, are specified and will be used to calculate the change in $PM_{2.5}$ concentration in other countries due to cross-boundary transport of air pollution based on the SRMs. The total change in $PM_{2.5}$ concentration is the sum of the contribution from national emission reductions plus the reduced contribution from transboundary transport of air pollution from other countries.

**Emission Reduction Input**

Edit Region Selection | Import Data | Reset Data

| Country/Region | Primary $PM_{2.5}$ | $SO_2$ | $NO_x$ | $NH_3$ | $PM_{2.5}$ concentration change (μg/m$^3$) |
|---|---|---|---|---|---|
| Austria | 0.00 | 0.00 | 0.00 | 0.00 | value calculated by CLIMAQ-H |
| France | 0.00 | 0.00 | 0.00 | 0.00 | value calculated by CLIMAQ-H |
| Germany | 0.00 | 0.00 | 0.00 | 0.00 | value calculated by CLIMAQ-H |
| Italy | 20.00 | 10.00 | 0.00 | 0.00 | value calculated by CLIMAQ-H |
| Switzerland | 0.00 | 0.00 | 0.00 | 0.00 | value calculated by CLIMAQ-H |

- The health benefits in Italy will be calculated by CLIMAQ-H from the built-in SRMs.
- The change in the $PM_{2.5}$ concentration in Austria, France, Germany and Switzerland due to cross-boundary transport of air pollutants from Italy will be calculated by CLIMAQ-H from the built-in SRMs.

**Case 3: Multiple-country analysis with user-specified emission reductions plus $PM_{2.5}$ concentration change inputs**

**Emission Reduction Input**

Edit Region Selection | Import Data | Reset Data

| Country/Region | Primary $PM_{2.5}$ | $SO_2$ | $NO_x$ | $NH_3$ | $PM_{2.5}$ concentration change (μg/m$^3$) |
|---|---|---|---|---|---|
| Austria | 0.00 | 0.00 | 0.00 | 0.00 | value calculated by CLIMAQ-H |
| France | 0.00 | 0.00 | 0.00 | 0.00 | value calculated by CLIMAQ-H |
| Germany | 0.00 | 0.00 | 0.00 | 0.00 | value calculated by CLIMAQ-H |
| Italy | 20.00 | 10.00 | 0.00 | 0.00 | 1.2 |
| Switzerland | 0.00 | 0.00 | 0.00 | 0.00 | value calculated by CLIMAQ-H |

- The health benefits in Italy will be calculated from the $PM_{2.5}$ concentration change (1.2 μg/m$^3$) specified by the user.
- The change in $PM_{2.5}$ concentration in Austria, France, Germany and Switzerland due to cross-boundary transport of air pollutants from Italy will be calculated by CLIMAQ-H from the built-in SRMs (see Fig. 1).

**Exposure Reduction Results**

| Country/Region | Emission reductions in kilo-tonnes per year in 2030 | | | | $PM_{2.5}$ concentration change (μg/m$^3$) | |
|---|---|---|---|---|---|---|
| | Primary $PM_{2.5}$ | $SO_2$ | $NO_x$ | $NH_3$ | due to national emissions | total |
| Austria | 0 | 0 | 0 | 0 | 0 | 0.081 |
| France | 0 | 0 | 0 | 0 | 0 | 0.011 |
| Germany | 0 | 0 | 0 | 0 | 0 | 0.005 |
| Italy | 20 | 10 | 0 | 0 | 1.2 | 1.2 |
| Switzerland | 0 | 0 | 0 | 0 | 0 | 0.077 |

Table 1 (cont.)

**Case 4: Multiple-country analysis with user-specified emission reductions plus $PM_{2.5}$ concentration change inputs for multiple countries**

**Emission Reduction Input**

Edit Region Selection | Import Data | Reset Data

| Country/Region | Primary $PM_{2.5}$ | $SO_2$ | $NO_x$ | $NH_3$ | $PM_{2.5}$ concentration change (µg/m$^3$) |
|---|---|---|---|---|---|
| Austria | 20.00 | 0.00 | 0.00 | 0.00 | value calculated by CLIMAQ-H |
| France | 0.00 | 0.00 | 0.00 | 0.00 | value calculated by CLIMAQ-H |
| Germany | 0.00 | 0.00 | 0.00 | 0.00 | value calculated by CLIMAQ-H |
| Italy | 20.00 | 10.00 | 0.00 | 0.00 | 1.2 |
| Switzerland | 0.00 | 0.00 | 0.00 | 0.00 | value calculated by CLIMAQ-H |

- The health benefits in Austria will be calculated by CLIMAQ-H from the SRMs for national emission reductions plus cross-boundary transport of air pollutants from Italy.
- The health benefits in Italy will be calculated from the change in $PM_{2.5}$ concentration (1.2 µg/m$^3$) specified by the user plus cross-boundary transport of air pollutants from Austria.
- For France, Germany and Switzerland, the change in $PM_{2.5}$ concentration due to cross-boundary transport of air pollutants from Austria and Italy will be calculated from the SRMs (see Fig. 1).

**Exposure Reduction Results**

| Country/Region | Emission reductions in kilo-tonnes per year in 2030 | | | | $PM_{2.5}$ concentration change (µg/m$^3$) | |
|---|---|---|---|---|---|---|
| | Primary $PM_{2.5}$ | $SO_2$ | $NO_x$ | $NH_3$ | due to national emissions | total |
| Austria | 20 | 0 | 0 | 0 | 1.394 | 1.475 |
| France | 0 | 0 | 0 | 0 | 0 | 0.018 |
| Germany | 0 | 0 | 0 | 0 | 0 | 0.05 |
| Italy | 20 | 10 | 0 | 0 | 1.2 | 1.229 |
| Switzerland | 0 | 0 | 0 | 0 | 0 | 0.12 |

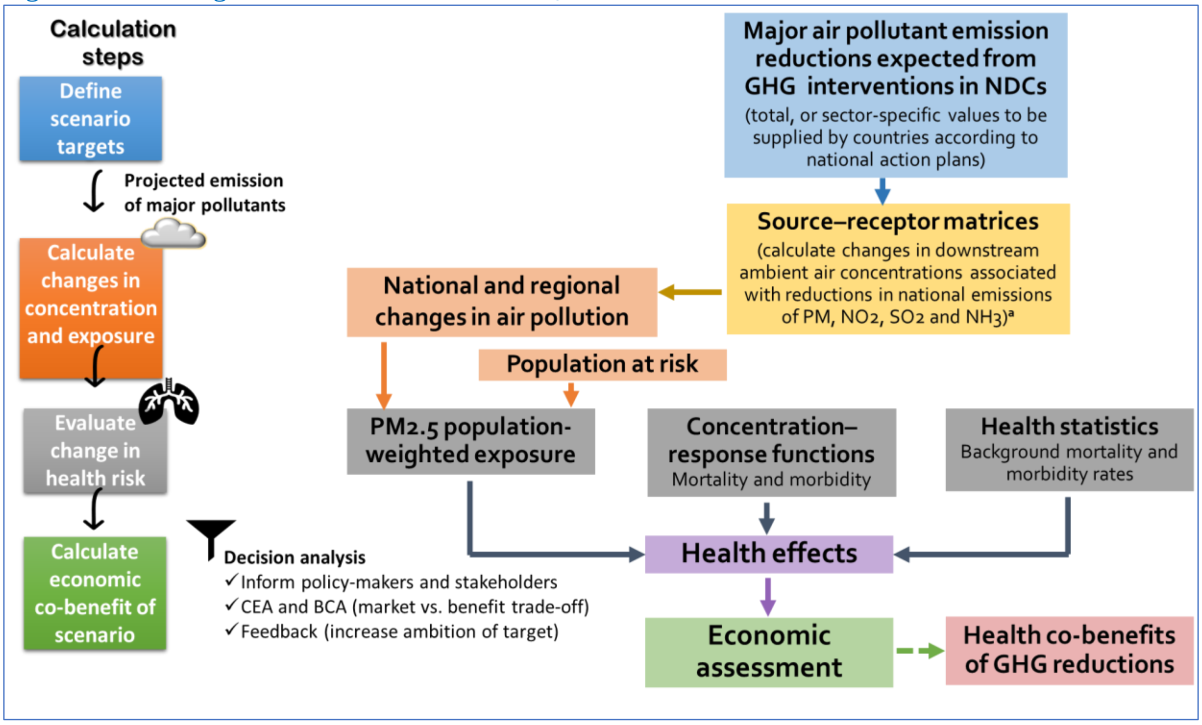
The total change in $PM_{2.5}$ concentration in Austria is the combined effect of national reductions in emissions (1.394 µg/m$^3$) and cross-boundary pollution transport from Italy (0.081 µg/m$^3$, see case 3). For Italy, the change in $PM_{2.5}$ concentration is the sum due to national reductions in emissions (1.2 µg/m$^3$) and the contribution of cross-boundary pollutant transport from Austria (0.029 µg/m$^3$).

## 2.3 Calculation of health benefits

Health benefits include fewer episodes of illnesses (morbidity) and averted premature mortality, especially among children, the elderly and people in the general population with medical conditions aggravated by exposure to ambient air pollution. Health benefits are calculated from concentration–response functions, which relate a change in the health outcome of concern (e.g. a decrease in the number of asthma attacks in children) to a change in the ambient air concentration of a specific pollutant (e.g. decreased $PM_{2.5}$ concentration due to implementation of NDC targets in 2030). Only the health benefits of reductions in $PM_{2.5}$ concentration (either directly by reductions in primary $PM_{2.5}$ emissions or indirectly by reduced formation of secondary $PM_{2.5}$ aerosols from precursor emission of $SO_2$, $NO_x$ and $NH_3$) are quantified in CLIMAQ-H. Changes in emissions are always specified relative to the projected emissions under the BAU scenario. Currently, the Chen & Hoek (2020) concentration–response function is used in CLIMAQ-H to calculate postponed all-cause (natural) mortality, while averted morbidity is assessed with the relative risks of the Health risks of air pollution in Europe project (WHO Regional Office for Europe, 2013).[3] As an alternative to Chen & Hoek (2020), the 2016 and 2020 versions of the integrated exposure-response functions of the Global Burden of Disease Study (Murray et al., 2020) may be used to calculate the number of postponed cause-specific premature deaths. The reduced health effects have economic consequences, such as the benefit–cost on local and national economic productivity, health-care budgets, and personal income and savings, and also have intangible benefits for society due to avoided disability from pain and suffering (Fig. 2).

[3] The risk functions are being revised. The new functions will be included in a follow-up version of the software.

Fig. 2. Methodological framework of CLIMAQ-H




BCA, benefit–cost analysis; CEA, cost–effectiveness analysis; GHG, greenhouse gases

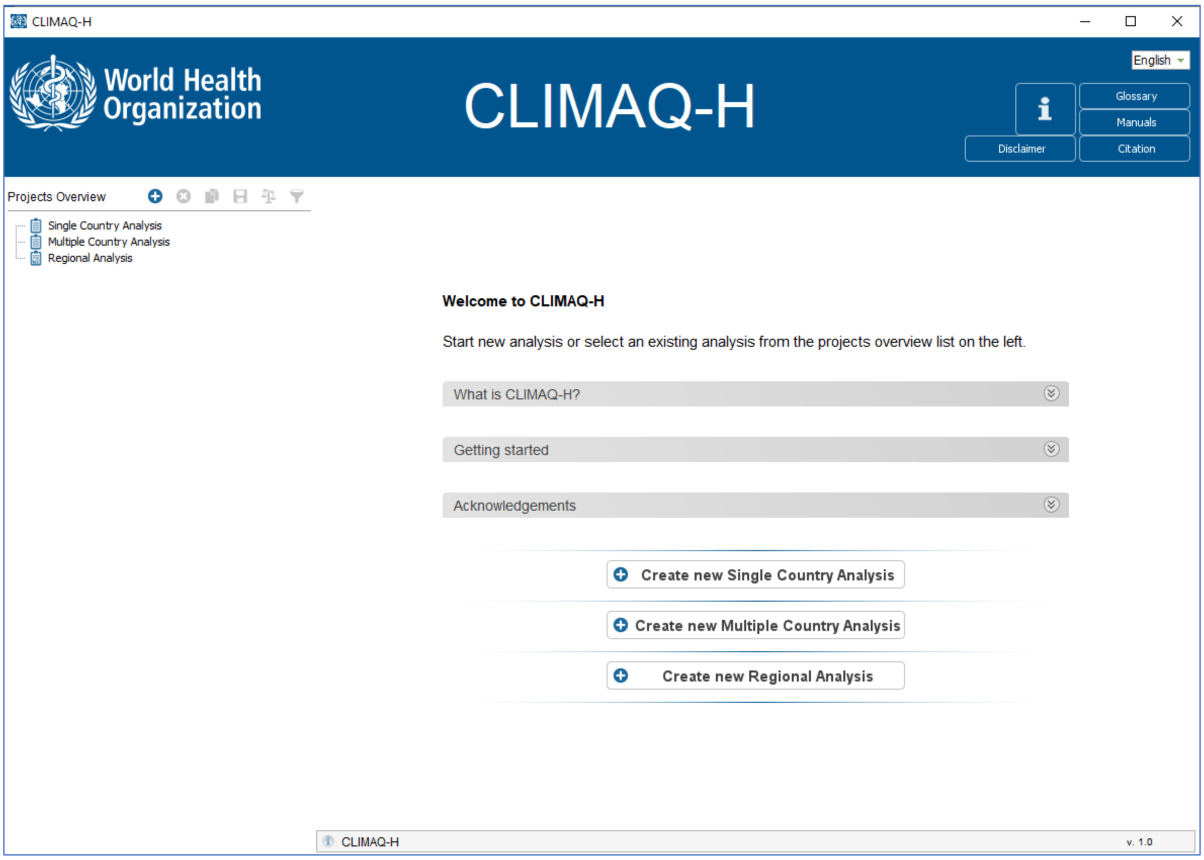
A $PM_{2.5}$ concentration change (relative to BAU in 2030) due to reductions in primary $PM_{2.5}$ emissions and to reductions in precursor emissions of $NO_2$, $SO_2$, $NH_3$ that contribute to formation of secondary $PM_{2.5}$ aerosols.

# 3 Installing CLIMAQ-H

CLIMAQ-H is a stand-alone application based on Java technology, which should be already available on users' computers. The program has been tested in Windows 7, Windows 10, Linux/Ubuntu 18, Linux/Debian 9 and Macintosh/macOS Catalina (10.15). Before installing CLIMAQ-H, it is recommended that you create a separate folder for CLIMAQ-H on your hard drive. Download CLIMAQ-H (zip file) to that folder, and expand the file. The root folder has two subfolders, "dist" and "resources", which should not be moved, deleted or renamed. Double-click on the file "CLIMAQ-H.exe" to run the program. CLIMAQ-H can run from an external data storage device such as a USB flash drive. Currently, CLIMAQ-H is programmed only in English.

As only a limited number of configurations could be tested, WHO declines all responsibility for errors, omissions or deficiencies regarding the use and maintenance of the tool and the accompanying documentation. For more information, click on the Disclaimer button in the upper-right corner of the welcome window (Fig. 3).

Fig. 3. CLIMAQ-H Welcome screen



# 4 Running CLIMAQ-H

CLIMAQ-H was developed with a user-friendly interface. Before a proper analysis, it is recommended that you become familiar with the various functions and read the examples provided in this manual. As it is a stand-alone program, CLIMAQ-H does not require or establish an Internet connection. Data and results are saved automatically and presented in a project tree for easy management.

When the program is started, the welcome window is displayed (Fig. 2). The upper-left side of the window shows the project tree for Single Country, Multiple Country and Regional analyses. Next to the Projects Overview are six icons for managing analyses: add, delete, copy, export (comma-separated values), compare and filter data. CLIMAQ-H automatically saves projects as the user enters new data.

The version of CLIMAQ-H is displayed in the lower-right corner of the welcome window or by clicking on the information icon in the upper-right corner. Please click on the Disclaimer button (under the information button) to view and carefully read the disclaimer. The Glossary and Manuals buttons allow the user to download the CLIMAQ-H glossary and manual documents. The Citation button shows a suggested citation of CLIMAQ-H.

At the bottom of the welcome screen, the user can indicate the type of health and economic impact study they wish to conduct: single country, multiple countries or regional analysis.

## 4.1 Number formats

CLIMAQ-H processes and stores numerical data with decimal points, even if the language and number format settings of the target machine are different. CLIMAQ-H always uses the semicolon (;) as the separator character for a dataset (e.g. 2.85; 1.95; 3.75; 3.6). “Comma-separated” values with a semicolon as the separator character can be used for data input and output. An example of an invalid input is 2.85,1.95,3,75,3,6.

The procedure for defining the semicolon as the separator character depends on the operating system of the target machine. Please consult the help information of the respective system. In Windows 10, for example, the separator character is defined in “Control panel – clock and region – region – additional settings – list separator”.

## 4.2 Colour-coded data entry fields

Data entry fields are colour-coded to help the user to distinguish between mandatory and optional data and to indicate incorrect input data.

**Green** indicates mandatory fields that must be filled for CLIMAQ-H computations. When a new analysis is created, mandatory fields are populated by default data included in the file BAUconcentrations_2030.csv. Green also indicates correct values.

**White** indicates voluntary fields in the Demographics window. Fields are always white in tables with data in the Demographics tab. CLIMAQ-H performs some error checking, depending on the type of field. For example, entering a negative value into the “Population in 2030” field will not be accepted, and a zero value will be displayed instead.

**Red** indicates that an incorrect value was entered in a mandatory field. For example, the $PM_{2.5}$ BAU concentration in 2030 cannot be negative.

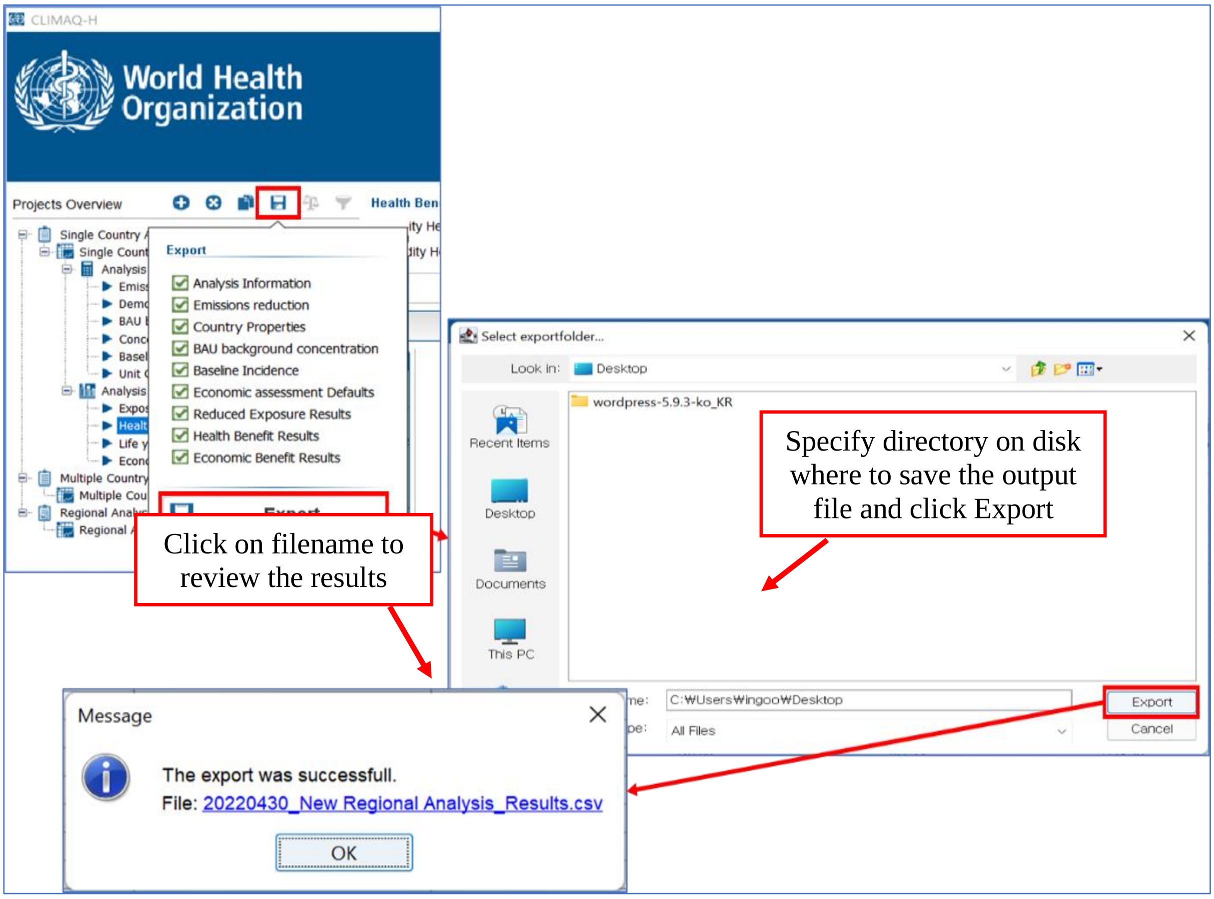
## 4.3 Exporting CLIMAQ-H results

CLIMAQ-H results may be exported by clicking on the icon and then ticking the appropriate boxes for the output data requested, as illustrated in Fig. 4. The user will be asked to specify a directory on the disk to which the output file is to be saved. A default filename will be generated by combining the date (year, month and day) and the type of geographical analysis (single or multiple countries or regional) (see example in Fig. 4). The file extension is .csv (data are separated by semicolons). Upon completion, the user may click on the filename in the pop-up message to review the results in a data processor or in Excel®.

The following data are accessible:

- analysis information
- emission reduction
- country projects
- BAU background concentration
- baseline incidence
- economic assessment default
- reduced exposure results
- health benefit results
- economic benefit results

Fig. 4. CLIMAQ-H export procedure



# 5 Emission reduction dataset

To run the examples, CLIMAQ-H provides an emissions datafile for countries in the WHO European Region (EmissionReductions_2030.csv, located in the "resources" sub-directory under CLIMAQ-H). Please note that this is only a dummy file created to run the examples presented in this manual.

The EmissionReductions_2030.csv file contains data on reductions of emissions of air pollutants, including $PM_{2.5}$, $SO_2$, $NO_x$ and $NH_3$, for 49 countries[4] in the WHO European Region.

Line 1 is the file header with the names of the columns of the data, and lines 2–50 contain the values. For example,

Line 1: Emitter country; PM2.5_Emission_reductions_kt; SO2_Emission_reductions_kt; NOx_Emission reductions_kt; NH3_Emission reductions_kt

Line 34: MKD;2.40;8.40;73.22;1.50. Interpretation of line 34: In 2030, the anticipated air emission reductions in North Macedonia (MKD, see the Annex for a list of International Organization for Standardization (ISO) country codes) will be 2.40, 8.40, 73.22 and 1.50 kt for $PM_{2.5}$, $SO_2$, NOx and $NH_3$; respectively.

## 5.1 Example A. Single-country analysis

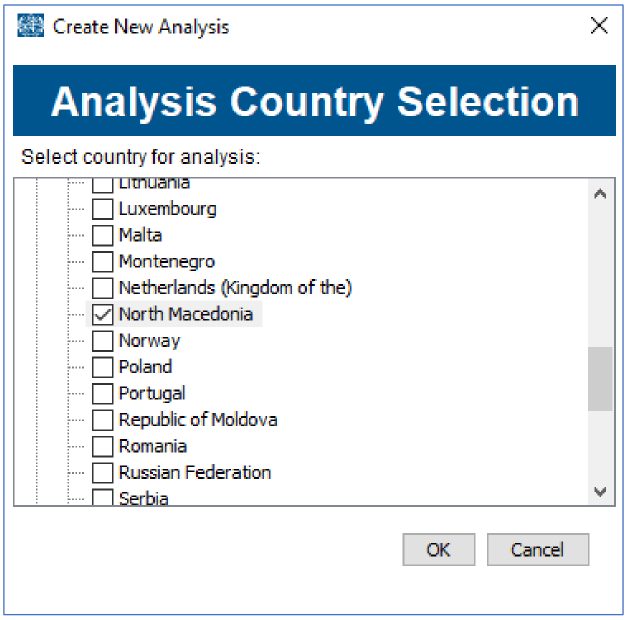
**Question to be addressed**: What health and economic co-benefits could be achieved by implementation of the climate policies in the Nationally Determined Contribution of a single country?

NB. The data used in this manual are solely for the examples. Users should provide their own, "real" values based on an analysis of reductions achieved in actual implementation of the climate policies envisioned in the NDCs.

### 5.1.1 Analysis configuration

Select a country from the list, such as North Macedonia, and click on "OK" (Fig. 5).

Fig. 5. CLIMAQ-H single-country analysis window

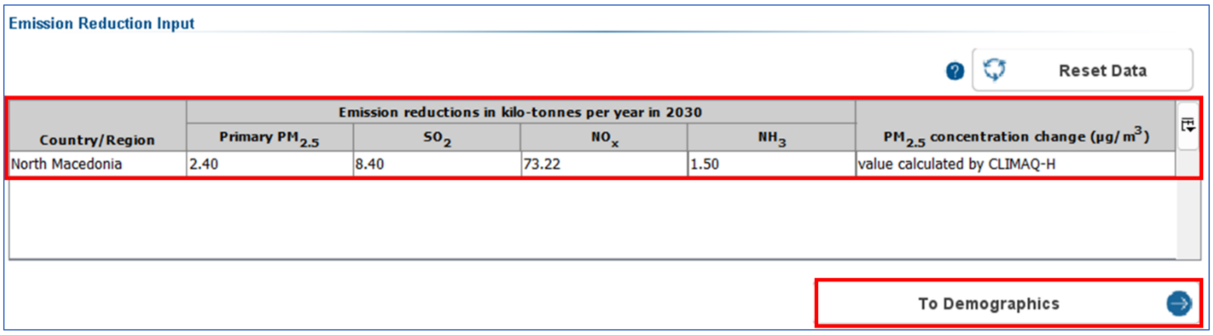



In the Emission reduction input screen (Fig. 6), enter the values indicated below and then click on the button "To Demographics".

Emission reduction in North Macedonia: $PM_{2.5}$: 2.40 kt, $SO_2$: 8.4 kt, $NO_x$: 73.22 kt, $NH_3$: 1.5 kt.

[4] Those not included are Andorra, Monaco, Israel and San Marino.

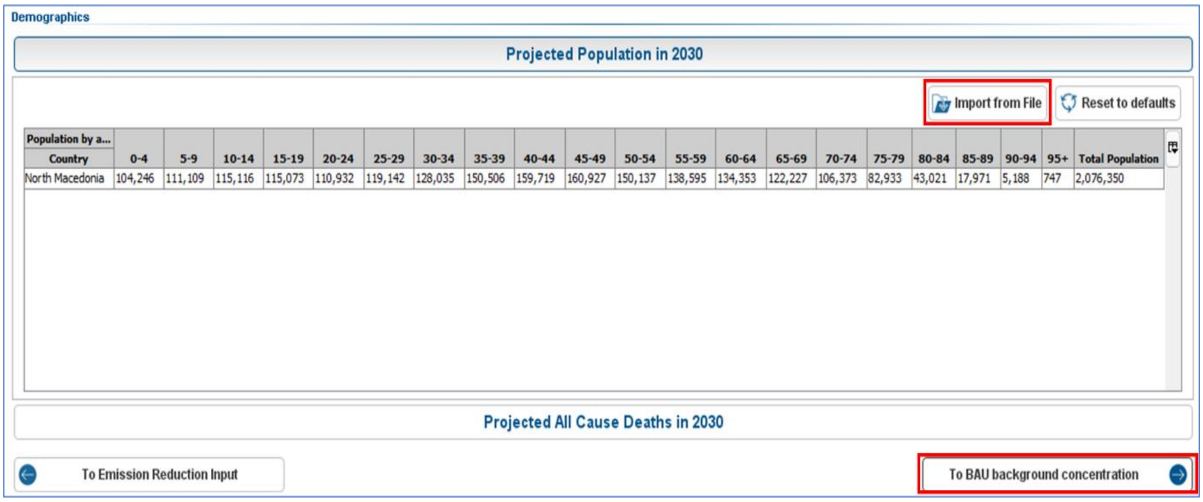
Fig. 6. CLIMAQ-H emission reduction input window




| Country/Region | Emission reductions in kilo-tonnes per year in 2030 | | | | $PM_{2.5}$ concentration change (µg/m$^3$) |
|---|---|---|---|---|---|
| | Primary $PM_{2.5}$ | $SO_2$ | $NO_x$ | $NH_3$ | |
| North Macedonia | 2.40 | 8.40 | 73.22 | 1.50 | value calculated by CLIMAQ-H |

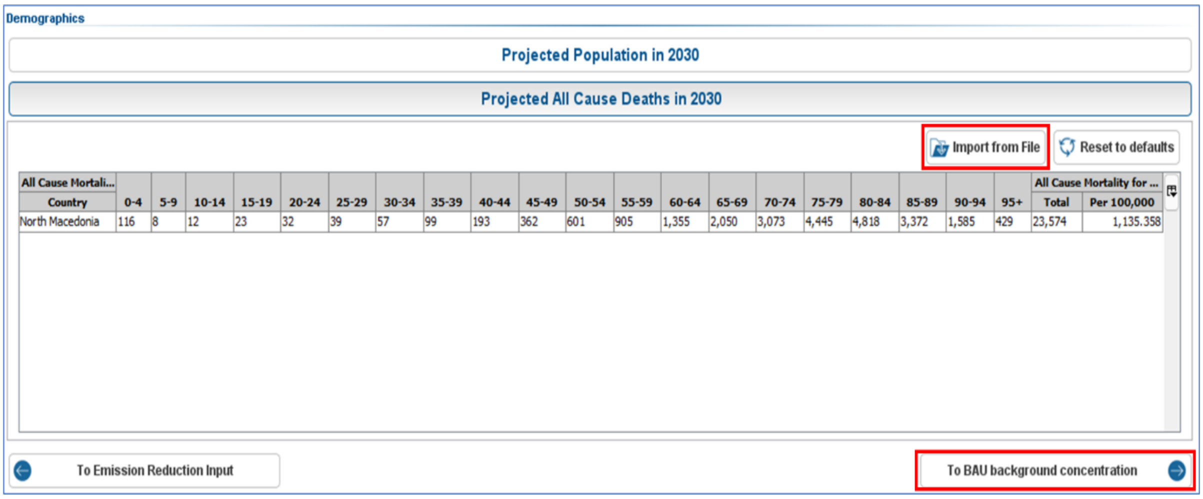
CLIMAQ-H provides default demographic data for each of the countries in the WHO European Region for "Projected population in 2030" (Fig. 7) and "Projected all-cause deaths in 2030" (Fig. 8). Users can use the default values provided by the software, change them manually or import data from a file. After specifying the demographic data, click on "To BAU background concentration" (Fig. 9).

Fig. 7. CLIMAQ-H Demographics window: projected population in 2030




| Population by a... Country | 0-4 | 5-9 | 10-14 | 15-19 | 20-24 | 25-29 | 30-34 | 35-39 | 40-44 | 45-49 | 50-54 | 55-59 | 60-64 | 65-69 | 70-74 | 75-79 | 80-84 | 85-89 | 90-94 | 95+ | Total Population |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| North Macedonia | 104,246 | 111,109 | 115,116 | 115,073 | 110,932 | 119,142 | 128,035 | 150,506 | 159,719 | 160,927 | 150,137 | 138,595 | 134,353 | 122,227 | 106,373 | 82,933 | 43,021 | 17,971 | 5,188 | 747 | 2,076,350 |

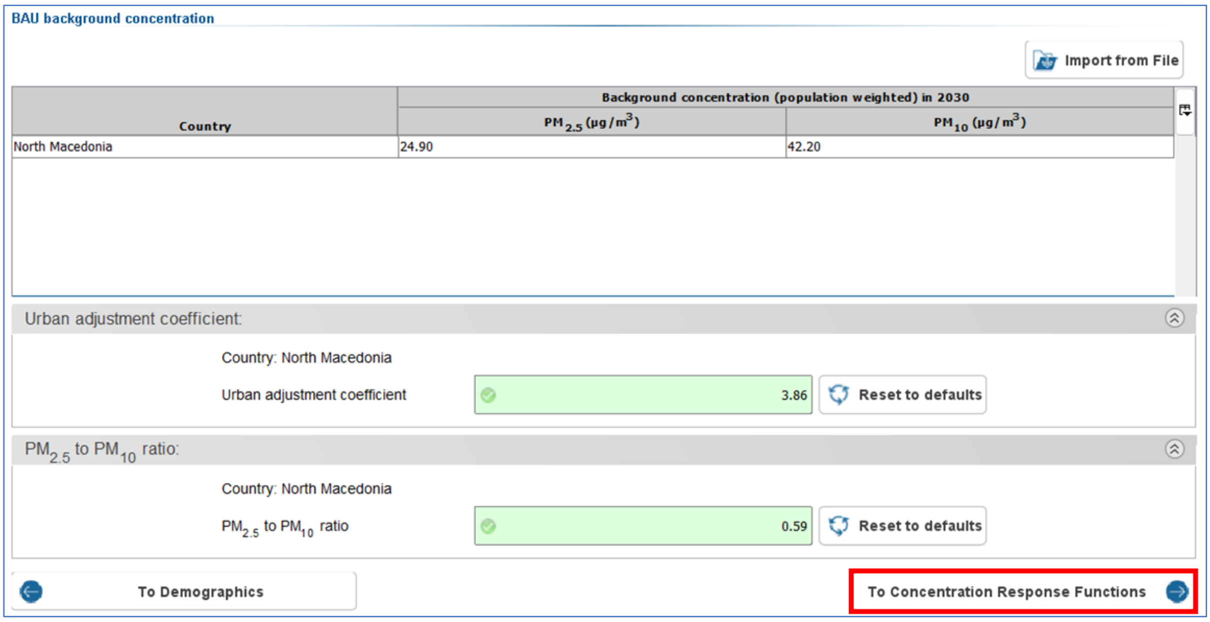
Fig. 8. CLIMAQ-H Demographics window: projected all-cause deaths in 2030




| All Cause Mortali... Country | 0-4 | 5-9 | 10-14 | 15-19 | 20-24 | 25-29 | 30-34 | 35-39 | 40-44 | 45-49 | 50-54 | 55-59 | 60-64 | 65-69 | 70-74 | 75-79 | 80-84 | 85-89 | 90-94 | 95+ | All Cause Mortality for ... Total | Per 100,000 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| North Macedonia | 116 | 8 | 12 | 23 | 32 | 39 | 57 | 99 | 193 | 362 | 601 | 905 | 1,355 | 2,050 | 3,073 | 4,445 | 4,818 | 3,372 | 1,585 | 429 | 23,574 | 1,135.358 |

In the BAU background concentration in 2030 window, enter 24.9 µg/m$^3$ for $PM_{2.5}$. (The equivalent particulate matter with a diameter < 10 µm [$PM_{10}$] concentration will be calculated automatically by the software from the $PM_{2.5}$ to $PM_{10}$ ratio indicated.) Then, click on "To Concentration Response Functions". If only $PM_{10}$ emissions data are available, country-specific $PM_{2.5}$ to $PM_{10}$ mass conversion factors (0.59 in this example; see Table A4 in the Annex for other values) will be applied to estimate the corresponding change in $PM_{2.5}$ emissions. CLIMAQ-H also provides default values for the urban adjustment coefficient, which is a country-specific coefficient for down-scaling the SRM-derived results for the country to the urban scale (for details, see the Annex). The default values for the PM mass ratio and urban adjustment coefficient can be changed by the user for a sensitivity analysis.

Fig. 9. CLIMAQ-H BAU background concentration window

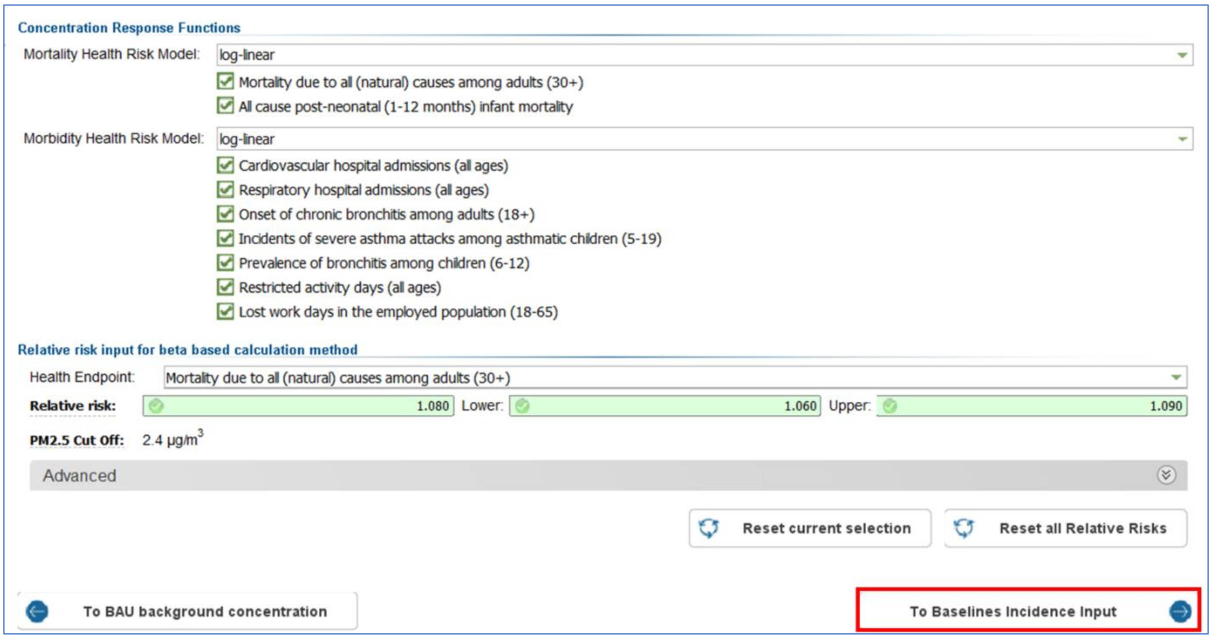



In the Health Risk Model window (Fig. 10), choose the:

- risk model for mortality (either log-linear or the Global Burden of Disease Study Integrated Exposure Response functions) and morbidity outcomes (log-linear); and
- health outcomes, by ticking the appropriate boxes. Default relative risk are available for each health endpoint.[5]

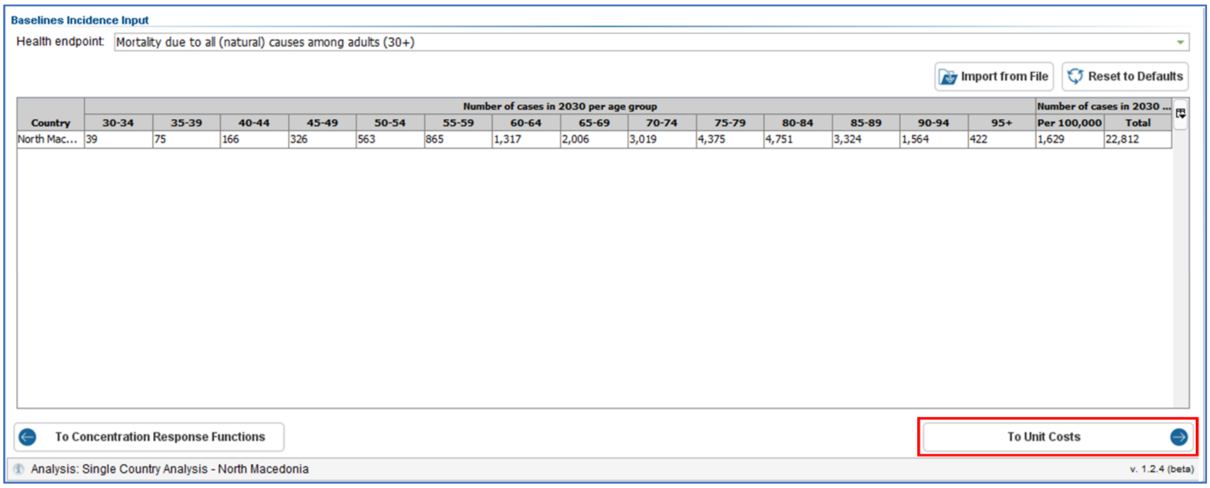
[5] Users can insert their own values instead of the default relative risks or beta (β) by clicking on the Advanced tab.

Fig. 10. CLIMAQ-H Concentration Response Functions window




Next, click on the button “To Baselines Incidence Input” (Fig. 11), and enter baseline data on mortality and morbidity. (Use the dropdown box to cycle through end-points.) CLIMAQ-H provides country-specific default values, which can be updated by the user.

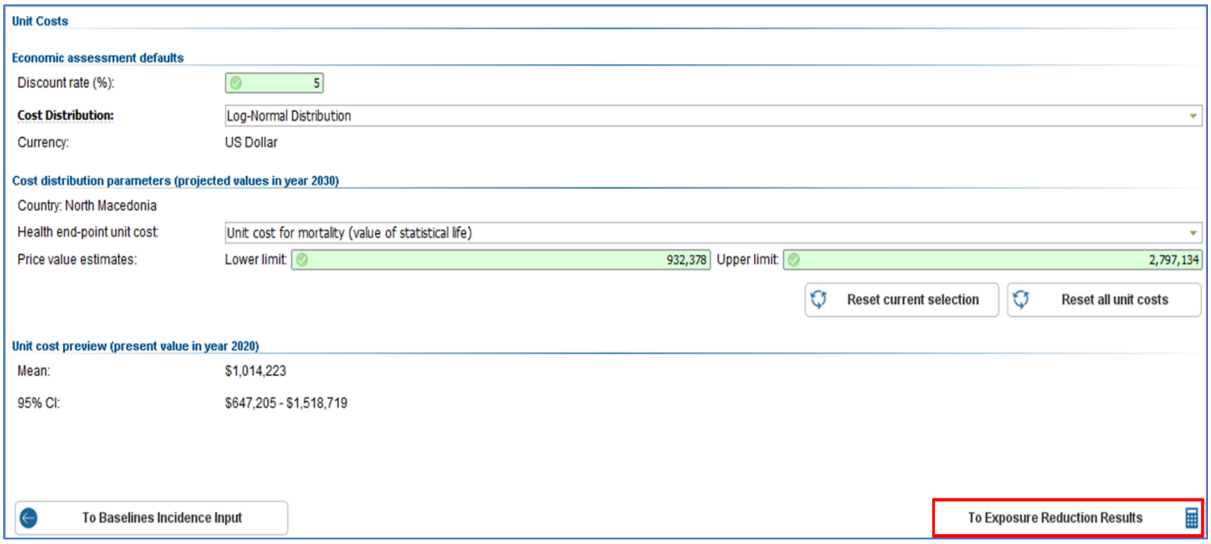
Fig. 11. CLIMAQ-H Baselines Incidence Input window




Finally, click on the button “To Unit Costs” at the bottom right of the screen to enter the economic variables (Fig. 12). CLIMAQ-H provides default data, which may be overwritten by the user. Enter 5% for the discount rate. CLIMAQ-H provides two cost distribution options: Triangular and Log-Normal; choose the log-normal distribution for this example. The user should specify estimates for the low and high bounds of the cost range. The central values and 95% confidence intervals (CIs) will be calculated by the tool and displayed at the bottom of the form.

Next, click on the button “To Exposure Reduction Results” to review the results.

Fig. 12. CLIMAQ-H Unit Cost window



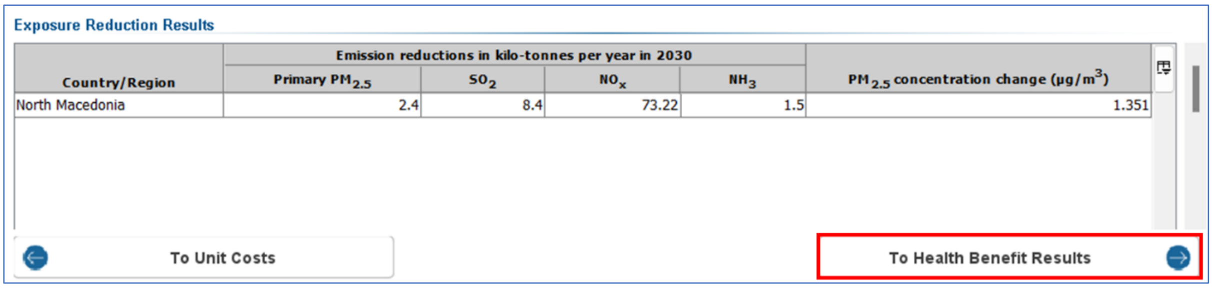

## 5.1.2 Results of the analysis

The CLIMAQ-H software delivers three outputs: (i) the reduced $PM_{2.5}$ concentration due to the offset of national emissions (that is, improvement in air quality over the BAU scenario), (ii) the health impacts in terms of postponed premature mortality or gains in life years lived plus averted incidents of morbidity, and (iii) the associated economic benefits of the calculated health gains.

### *Exposure reduction*

CLIMAQ-H calculates the change in $PM_{2.5}$ concentration (μg/m$^3$) due to national reductions in emissions of $PM_{2.5}$, $SO_2$, $NO_x$ and $NH_3$. As indicated in Fig. 13, the reduced pollutant emissions will contribute to a change in ambient air concentration equal to 1.351 μg/m$^3$.

Fig. 13. Exposure Reduction Results for the single country analysis




### *Health benefits*

Table 2 summarizes the numbers of averted premature deaths and prevented morbidity as compared with the BAU scenario. In addition to the mean values, the tool calculates the 95% CI of each result. Results are accessible in two tabs, one for mortality and one for morbidity (Fig. 14 and Fig. 15). CLIMAQ-H also expresses results as rates per 100 000 population at risk, such as per 100 000 adults aged ≥ 30 years for mortality or 100 000 asthmatic children 5–19 years for asthma attacks.

## Table 2. Health benefits (numbers of cases) in the single-country analysis

| Health outcome | North Macedonia | | |
|---|---|---|---|
| **Postponed premature deaths** | **95% confidence interval** | | |
| | **Central** | **Lower bound** | **Upper bound** |
| Mortality due to all (natural) causes in adults (≥ 30 years) | 236 | 179 | 264 |
| All-cause post-neonatal infant mortality (1–12 months) | < 1 | < 1 | < 1 |
| **Prevented morbidity** | | | |
| Cardiovascular hospital admissions (all ages) | 112 | 21 | 203 |
| Respiratory hospital admissions (all ages) | 71 | 0[a] | 149 |
| Restricted activity days (all ages) | 23 355 | 223 886 | 234 815 |
| Incidents of severe asthma attacks in asthmatic children (5–19 years) | 4 667 | 1 013 | 8 385 |
| Prevalence of bronchitis in children (6–12 years) | 513 | 0[a] | 1 147 |
| Lost work days in the employed population (18–65 years) | 8 651 | 7 363 | 9 930 |
| Onset of chronic bronchitis in adults (≥ 18 years) | 164 | 58 | 254 |

[a] The value is zero because the low bound of the 95% CI of the relative risk for this outcome is unity.

## Fig. 14. CLIMAQ-H results for health benefits: prevented mortality in North Macedonia (central values)

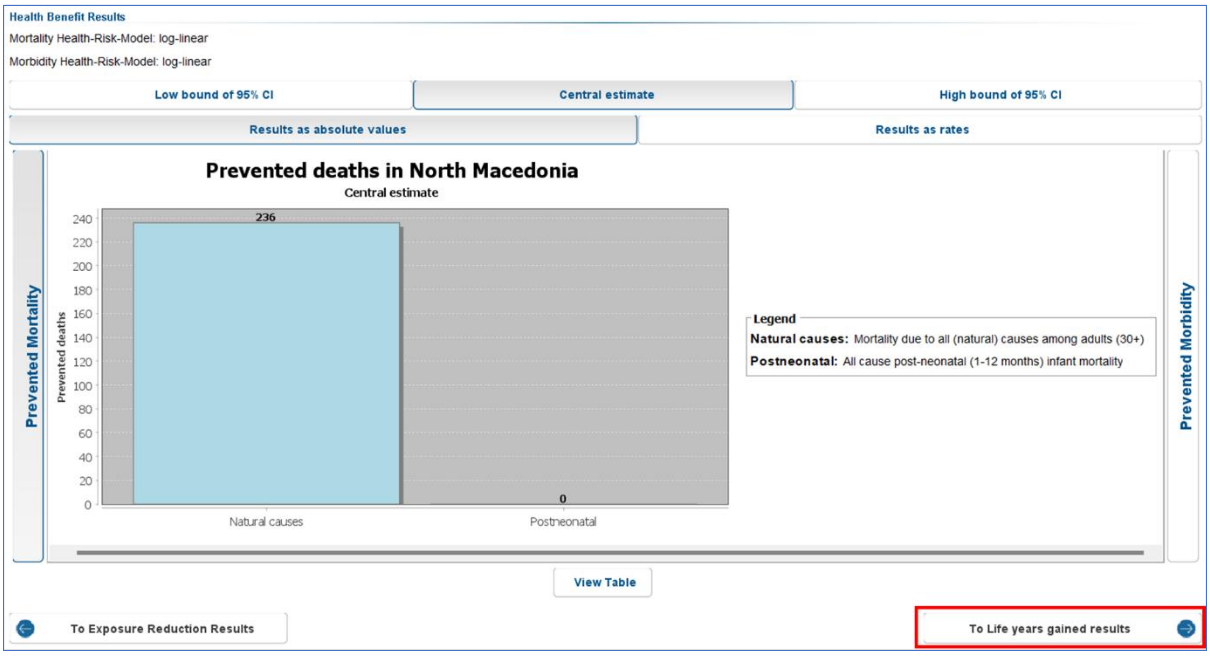
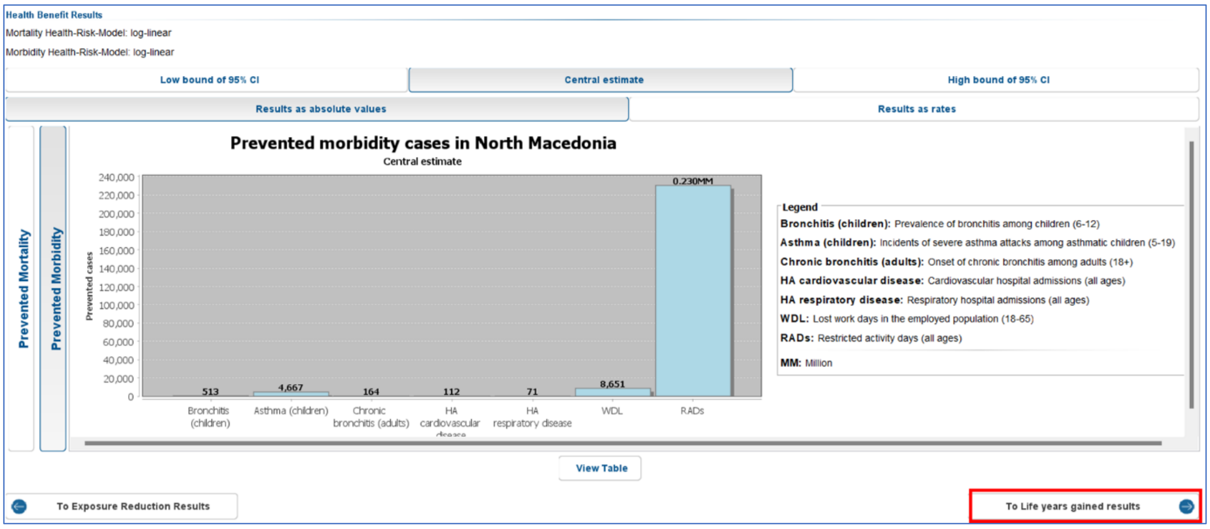


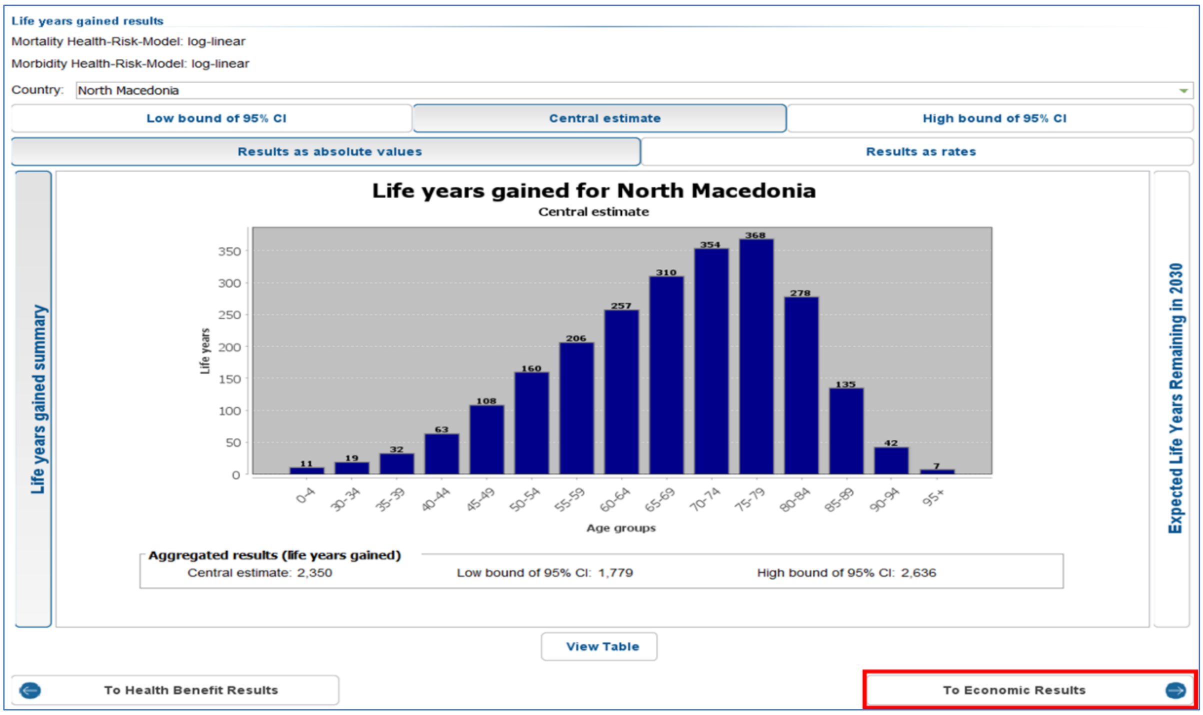
Fig. 15. CLIMAQ-H Health Benefits Results: prevented morbidity in North Macedonia (central values)




### *Life years gained*

CLIMAQ-H calculates the life years gained in each age group by reducing air pollution (Fig. 16). The tool also provides the expected remaining life expectancy by age cohort in 2030. In this example, the total number of life years gained is 2350 (95% CI: 1779 ; 2636).

Fig. 16. CLIMAQ-H Life years gained in North Macedonia



## *Economic results*

The economic benefits are summarized in Table 3 and graphically in Fig. 17 for infant and adult mortality and Fig. 18 for morbidity outcomes. The present value of the total economic benefit is US$ 252 (95% CI: US$ 121 ; US$ 425) million (nominal 2020 prices, 5% discount rate). The proportion of the total benefit due to postponed deaths is 94.8%, while the morbidity cost accounts for 5.2%.

Table 3. Results for economic benefit in North Macedonia

| Health outcome | Economic benefit[a] | | |
|---|---|---|---|
| **Postponed premature deaths** | **Central** | **Low estimate** | **High estimate** |
| Mortality due to all (natural) causes in adults (≥ 30 years) | 239 235 000 | 115 730 000 | 400 887 800 |
| All-cause post-neonatal infant mortality (1–12 months) | 141 300 | 45 600 | 363 800 |
| **Prevented morbidity** | | | |
| Cardiovascular hospital admissions (all ages) | 154 300 | 18 400 | 419 700 |
| Respiratory hospital admissions (all ages) | 78 500 | 0 | 246 000 |
| Restricted activity days (all ages) | 8 238 700 | 5 132 800 | 12 629 200 |
| Incidents of severe asthma attacks in asthmatic children (5–19 years) | 76 100 | 10 500 | 204 900 |
| Prevalence of bronchitis in children (6–12 years) | 125 000 | 0 | 418 600 |
| Lost workdays in the employed population (18–65 years) | 437 000 | 237 300 | 751 100 |
| Onset of chronic bronchitis in adults (≥ 18 years) | 3 974 000 | 906 200 | 9 244 500 |
| **Economic benefit** | | | |
| Sub-total for mortality | 239 376 300 | 115 775 700 | 401 251 600 |
| Sub-total for morbidity | 13 084 000 | 6 305 500 | 23 914 100 |
| Total economic benefit | 252 460 300 | 121 081 200 | 425,165,800 |

[a] US$ in 2020 nominal prices assuming a 5% discount rate

Fig. 17. CLIMAQ-H Economic Results: mortality graph window

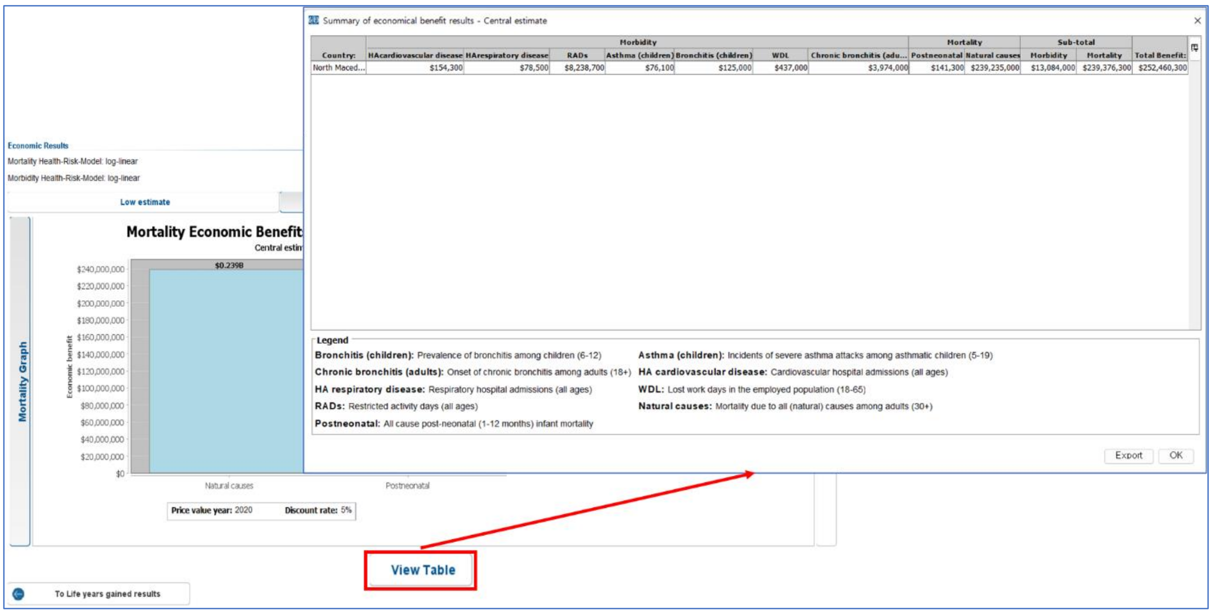
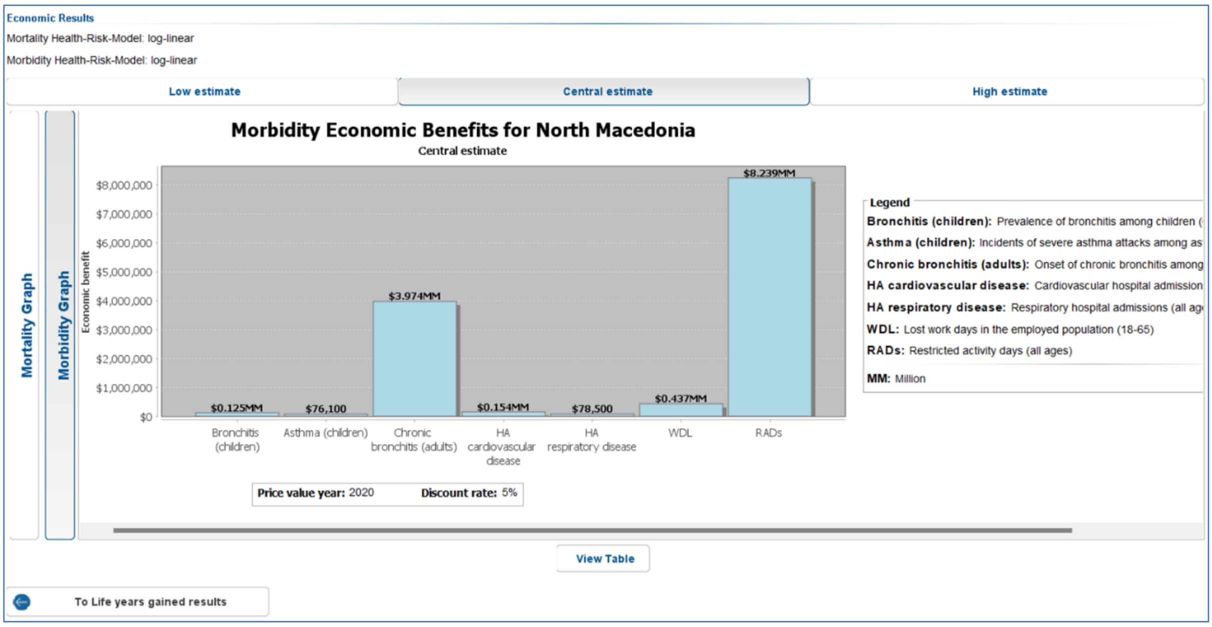


Fig. 18. CLIMAQ-H Economic results: morbidity graph window



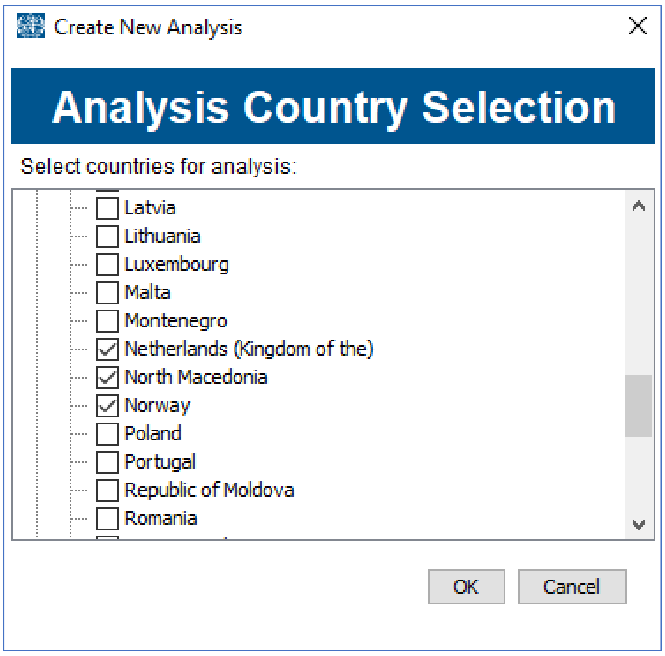

## 5.2 Example B. Multiple-country analysis

**Question to be addressed:** What are the health and economic co-benefits from implementation of the climate policies considered in the Nationally Determined Contributions of several countries?

### 5.2.1 Analysis configuration

The procedure is similar to that for a single-country, except that data must be provided for several countries (Fig. 19).

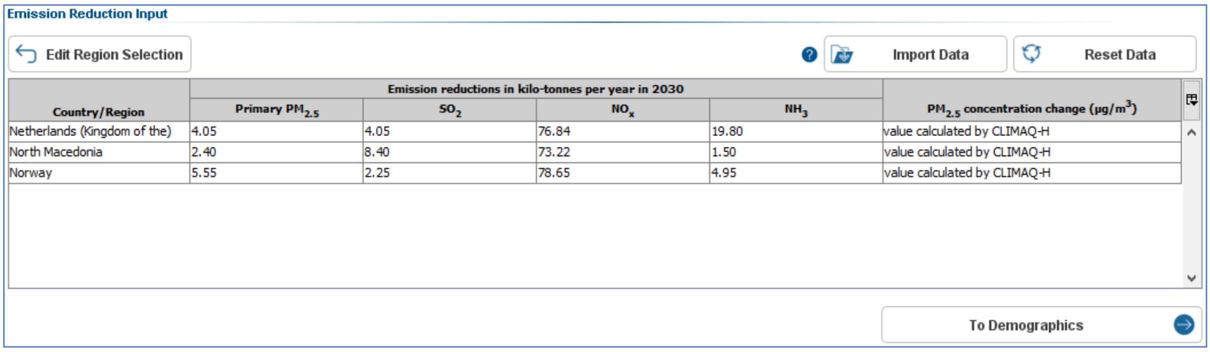
Fig. 19. CLIMAQ-H Multiple Country Analysis window



### 5.2.2 Input data

On the Emission Reduction Input screen, enter the following emission reductions: 4.05, 4.05, 76.84 and 19.80 for Netherlands (Kingdom of the); 2.40, 8.40, 73.22 and 1.50 for North Macedonia; and 5.55, 2.25, 78.65 and 4.95 for Norway (Fig. 20).

Fig. 20. CLIMAQ-H Emission Reduction Input window




| Country/Region | Primary $PM_{2.5}$ | $SO_2$ | $NO_x$ | $NH_3$ | $PM_{2.5}$ concentration change (µg/m$^3$) |
|---|---|---|---|---|---|
| | Emission reductions in kilo-tonnes per year in 2030 | | | | |
| Netherlands (Kingdom of the) | 4.05 | 4.05 | 76.84 | 19.80 | value calculated by CLIMAQ-H |
| North Macedonia | 2.40 | 8.40 | 73.22 | 1.50 | value calculated by CLIMAQ-H |
| Norway | 5.55 | 2.25 | 78.65 | 4.95 | value calculated by CLIMAQ-H |

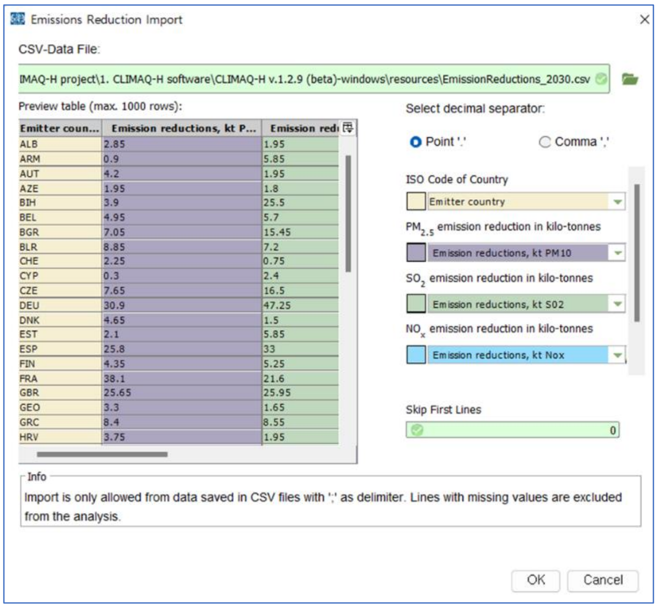
Alternatively, the data can be imported from a file (Fig. 21). In this exercise, the data from the file EmissionReductions_2030.csv were used.[6] The first line of the import file contains the column headers. For example, Emitter country; $PM_{2.5}$_Emission_reductions_kt; $SO_2$_Emission_reductions_kt; NOx_Emission reductions_kt; $NH_3$_Emission reductions_kt; $PM_{2.5}$_Concentration_change (ug/m$^3$). Each header is separated by a semicolon.

Numerical values are always processed and stored by CLIMAQ-H with decimal points, even if the language and number format settings of the target machine are different. The software makes use of csv files for data input and output ("csv" stands for "comma separated values"), but, as commas are used as a decimal delimiter in many languages, this can lead to confusion. The separation character used by CLIMAQ-H is always the semicolon (;). The procedures necessary for defining the semicolon as separation character depends on the operating system of the target machine. Please consult the respective system "help" information. When importing the data, select the "Point" radio button as the decimal separator.

Each record in the input file consists of six elements, each separated by a semicolon (;): The country three letter ISO3 code, $PM_{2.5}$ emission reduction (kt), $SO_2$ emission reduction (kt), NOx emission reduction (kt), $NH_3$ emission reduction (kt) and $PM_{2.5}$ concentration change (µg/m$^3$). For example, for North Macedonia, MKD;2.40;8.40;73.22;1.50;. Note that the record ends with a semicolon, which means the change in $PM_{2.5}$ concentration in North Macedonia will be calculated by CLIMAQ-H. When a non-zero concentration change is specified as in the example: MKD;2.40;8.40;73.22;1.50;0.8; the value of 0.8 µg/m$^3$ will be used to calculate the health benefits in North Macedonia, while the emission reductions will be used to calculate the health benefits in neighbouring countries from changes in the so-called "cross-boundary" pollutant transport (see rules discussed in Table 1).

[6] Reminder: These dummy data are provided solely for the examples in the manual.

Fig. 21. Emissions reduction Import window




For the demographic data (Fig. 7 and Fig. 8), use the default information provided by CLIMAQ-H, and click on the button "To BAU background concentration".

For the BAU background concentration (Fig. 9), use the following $PM_{2.5}$ concentrations: 10.90 µg/m$^3$ for Netherlands, 24.90 µg/m$^3$ for North Macedonia and 6.30 µg/m$^3$ for Norway (keep the default values for the $PM_{2.5}$ to $PM_{10}$ mass ratio and urban adjustment coefficient for each country). Click on the button "To Concentration Response Functions".

For the concentration–response functions (Fig. 10), select the log-linear risk model for mortality and morbidity, and use the default relative risk values. Click on the button "To Baseline Incidence Input".

For the baseline data (Fig. 11), use the default information provided by CLIMAQ-H for each country, and click on the button "To Unit Cost".

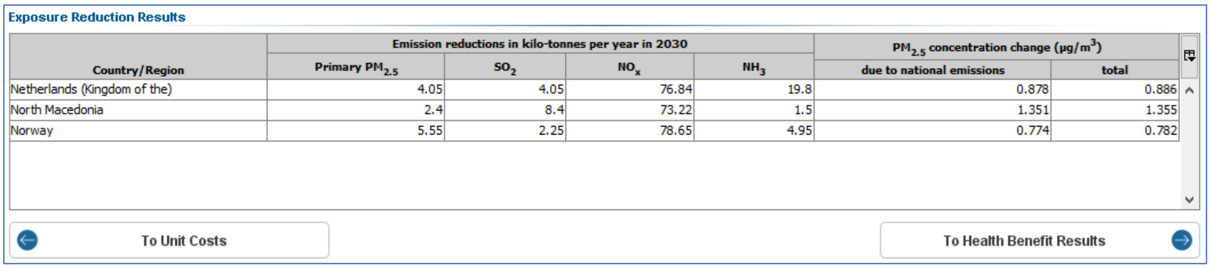
Finally, for the unit costs (Fig. 12), assume a 5% discount rate, choose Log-Normal distribution, and use the country-specific default data. Next, click on the button "To Exposure Reduction Results".

### 5.2.3 Results of the analysis

***Exposure reduction***

The $PM_{2.5}$ concentration changes in each country are shown in Fig. 22. For each country, the total reduction in the $PM_{2.5}$ concentration (the last column in the table) is the sum of the contribution attributable to reduced air emissions at national level plus the contribution of emission reductions in neighbouring countries from transboundary pollutant transport. In the case of Netherlands, for example, the national contribution to the change in total $PM_{2.5}$ concentration is 0.878 µg/m$^3$, while combined transboundary air pollution from North Macedonia and Norway contributes an additional 0.008 µg/m$^3$.

Fig. 22. Exposure Reduction results for the multiple-country analysis


Exposure Reduction Results

| Country/Region | Emission reductions in kilo-tonnes per year in 2030 | | | | $PM_{2.5}$ concentration change (μg/m$^3$) | |
|---|---|---|---|---|---|---|
| | Primary $PM_{2.5}$ | $SO_2$ | $NO_x$ | $NH_3$ | due to national emissions | total |
| Netherlands (Kingdom of the) | 4.05 | 4.05 | 76.84 | 19.8 | 0.878 | 0.886 |
| North Macedonia | 2.4 | 8.4 | 73.22 | 1.5 | 1.351 | 1.355 |
| Norway | 5.55 | 2.25 | 78.65 | 4.95 | 0.774 | 0.782 |



## *Health benefits*

Click on the button "To Health Benefit Results" to view the CLIMAQ-H output data. Table 4 shows the numbers of postponed premature deaths and of prevented morbidity (central values), and Table 5 shows the life years gained (central values) for individual countries and for all three. Additional data are available, including the lower and higher bounds of the 95% CI and incidence rates per 100 000 population at risk. The distribution of life years gained by country and subpopulation is presented in Fig. 23. Country-specific data are accessed from the drop-down list.

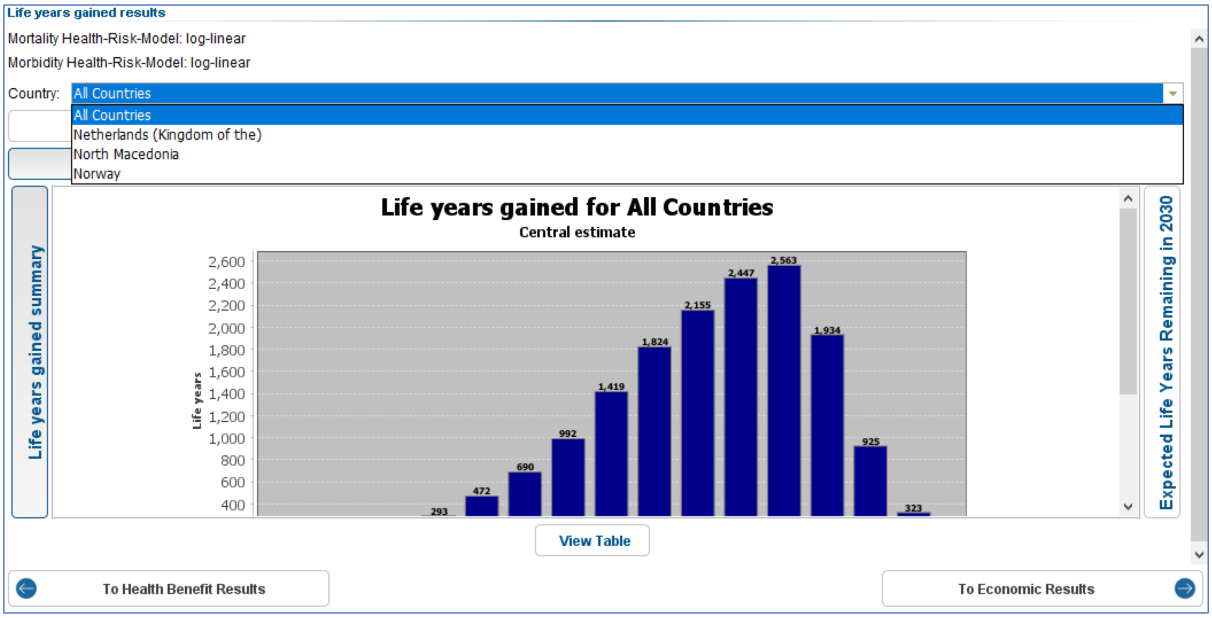
Table 4. Health benefits (numbers of cases, central values) in the multiple-country analysis

| Health outcome | Netherlands (Kingdom of) | North Macedonia | Norway | All three |
|---|---|---|---|---|
| **Postponed premature deaths** | | | | |
| Mortality due to all (natural) causes in adults (≥ 30 years) | 1169 | 237 | 284 | 1690 |
| All-cause post-neonatal infant mortality (1–12 months) | 1 | < 1 | < 1 | 1 |
| **Prevented morbidity** | | | | |
| Cardiovascular hospital admissions (all ages) | 221 | 112 | 99 | 431 |
| Respiratory hospital admissions (all ages) | 212 | 71 | 120 | 404 |
| Restricted activity days (all ages) | 1 053 569 | 230 107 | 270 779 | 1 544 454 |
| Incidents of severe asthma attacks in asthmatic children (5–19 years) | 32 787 | 4 682 | 10 044 | 47 513 |
| Prevalence of bronchitis in children (6–12 years) | 2 620 | 515 | 1 127 | 4 262 |
| Lost work days in the employed population (18–65 years) | 268 376 | 8 679 | 133 784 | 410 839 |
| Onset of chronic bronchitis in adults (≥ 18 years) | 875 | 164 | 337 | 1 376 |

Table 5. Life years gained (central values) in the multiple-country analysis

| Life years gained | Netherlands (Kingdom of) | North Macedonia | Norway | All three |
|---|---|---|---|---|
| Central estimate | 11 240 | 2 357 | 2 787 | 16 385 |
| Lower bound of 95% CI | 8 505 | 1 784 | 2 109 | 12 398 |
| Higher bound of 95% CI | 12 611 | 2 644 | 3 127 | 18 383 |

## Fig. 23. Life years gained in North Macedonia




### *Economic results*

The economic results (central estimates) are shown in Table 6 (the same results can be viewed in graphical format). The total benefit (mortality plus morbidity) is US$ 4.56 billion (nominal US$ in 2020 prices at a 5% discount rate). The cumulative mortality benefit is US$ 4.27 billion, and the overall morbidity benefit, aggregated for various health end-points and countries, is US$ 0.30 billion, or 6.4% of the total benefit. CLIMAQ-H also provides low and high estimates of the economic value for each health outcome, separately.

Table 6. Economic benefits (US$[a], central values) in the multiple-country analysis

| Health outcome | Netherlands (Kingdom of the) | North Macedonia | Norway | All three |
|---|---|---|---|---|
| **Postponed premature mortality** | | | | |
| Mortality due to all (natural) causes in adults (≥ 30 years) | 3 008 284 100 | 240 016 300 | 1 014 939 400 | 4 263 239 800 |
| All cause post-neonatal mortality (1–12 months) | 1 557 600 | 141 700 | 502 800 | 2 202 300 |
| **Prevented morbidity** | | | | |
| Cardiovascular hospital admissions (all ages) | 1 165 600 | 154 800 | 593 000 | 1 913 400 |
| Respiratory hospital admissions (all ages) | 897 500 | 78 800 | 578 600 | 1 555 000 |
| Restricted activity days (all ages) | 95 775 000 | 8 265 700 | 32 974 800 | 137 015 600 |
| Severe asthma attacks in asthmatic children (5–19 years) | 1 357 300 | 76 400 | 576 800 | 2 010 600 |
| Prevalence of bronchitis in children (6–12 years) | 1 682 600 | 125 400 | 984 100 | 2 792 200 |
| Lost work days in the employed population (18–65 years) | 34 388 900 | 438 400 | 23 784 100 | 58 611 500 |
| Onset of chronic bronchitis among adults (≥ 18 years) | 58 657 600 | 3 986 900 | 29 991 800 | 92 636 500 |
| **Economic benefit** | | | | |
| Sub-total for mortality | 3 009 841 800 | 240 158 100 | 1 015 442 200 | 4 265 442 100 |
| Sub-total for morbidity | 193 924 800 | 13 126 700 | 89 483 600 | 296 535 100 |

| Total benefit for mortality and morbidity | 3 203 766 600 | 253 284 800 | 1 104 925 800 | 4 561 977 300 |
|---|---|---|---|---|

[a] US$ in nominal 2020 prices at a 5% discount rate

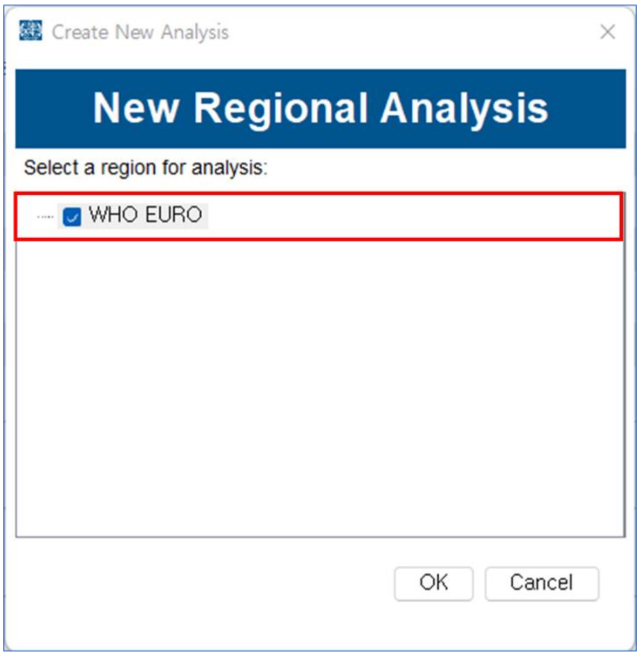
## 5.3 Example C. Regional Analysis

**Question to be addressed:** What regional health and economic co-benefits could be achieved by implementation of the climate policies in the Nationally Determined Contributions?

### 5.3.1 Configuration of the analysis

Select the WHO European (WHO EURO) Region (Fig. 24), and click on **"OK"**.

Fig. 24. CLIMAQ-H Regional Analysis window




### 5.3.2 Input data

**Reminder:** The inputs for this example are dummy data provided for the sole purpose of running this exercise.

On the Emission Reduction Input screen, click on "Import Data" to load the file "EmissionReductions_2030.csv" (Fig. 25), located in the "resources" sub-directory under CLIMAQ-H. Click on the button "To Demographics" to continue.

For demographic data, use the default information provided by CLIMAQ-H, and click on the button "To BAU background concentration" to continue.

For the BAU background concentration, click on "Import Data" to load the file "BAUconcentrations_2030" (Fig. 26), which is located in the "resources" sub-directory under CLIMAQ-H. Click on the button "To Concentration Response Functions" to continue.

For the concentration response functions, select the log-linear risk model for mortality and morbidity, and use the default relative risk values. Click on the button "To Baseline Incidence Input" to continue.

For the baseline data, use the default information provided by CLIMAQ-H for each country, and click on the button "To Unit Cost" to continue.

Finally, for the unit costs, assume a 5% discount rate, choose Log-Normal distribution, and use the country-specific default data. Click on the button “To Exposure Reduction Results” to review the results.

Fig. 25. Emissions Reduction Import window

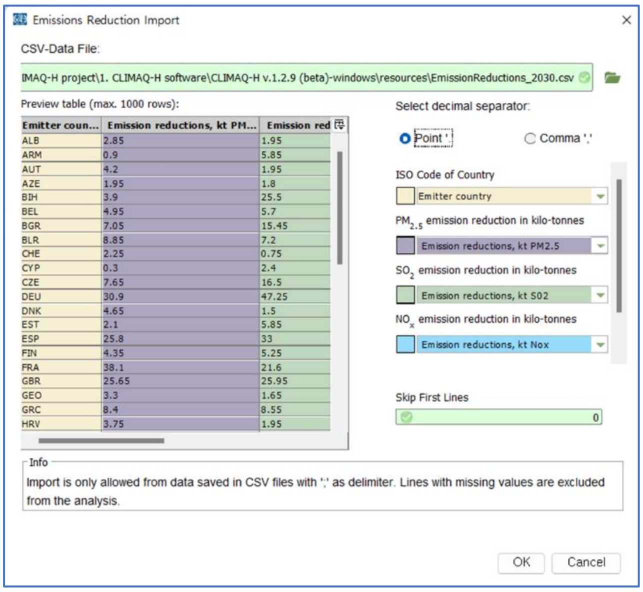
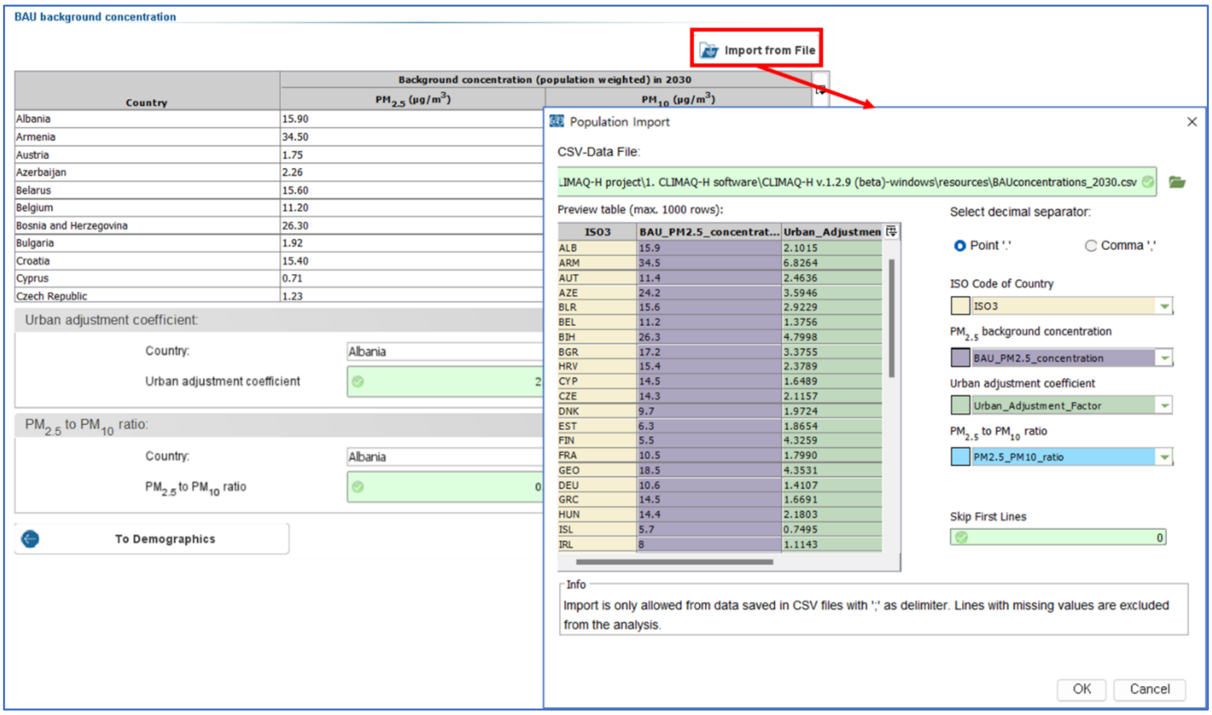



Fig. 26. BAU background concentration import window




### 5.3.3 Results of the analysis

#### *Exposure reduction*

The projected reductions in concentration are summarized in Fig. 27. For each country in turn, CLIMAQ-H shows the change in the $PM_{2.5}$ concentration attributable to national emission reductions (penultimate column in the figure), and the total concentration change, including the contribution of reduced transboundary pollutant transport (last column in the figure). Changes in exposure are relative to the expected national BAU concentration in 2030. For France, reduced national emissions contribute to a decrease of 1.105 μg/m$^3$, while the cumulative effect on ambient air quality from emission reductions elsewhere in the Region contribute to an additional decrease of 0.654 μg/m$^3$. Altogether, the total improvement in air quality is 1.759 μg/m$^3$.

Fig. 27. Exposure Reduction results for the regional analysis

**Exposure Reduction Results**

| Country/Region | Emission reductions in kilo-tonnes per year in 2030 | | | | $PM_{2.5}$ concentration change (μg/m$^3$) | |
|---|---|---|---|---|---|---|
| | Primary $PM_{2.5}$ | $SO_2$ | $NO_x$ | $NH_3$ | due to national emissions | total |
| Albania | 2.85 | 1.95 | 3.75 | 3.6 | 1.155 | 1.888 |
| Armenia | 0.9 | 5.85 | 3 | 2.85 | 2.05 | 4.172 |
| Austria | 4.2 | 1.95 | 21.75 | 10.35 | 0.912 | 2.606 |
| Azerbaijan | 1.95 | 1.8 | 11.85 | 12.75 | 1.207 | 2.07 |
| Belarus | 8.85 | 7.2 | 21.45 | 20.7 | 0.675 | 2.082 |
| Belgium | 4.95 | 5.7 | 26.4 | 10.05 | 0.856 | 2.429 |
| Bosnia and Herzegovina | 3.9 | 25.5 | 4.65 | 3.15 | 1.561 | 3.68 |
| Bulgaria | 7.05 | 15.45 | 15.45 | 7.35 | 1.701 | 3.185 |
| Croatia | 3.75 | 1.95 | 8.25 | 5.7 | 0.874 | 2.794 |
| Cyprus | 0.3 | 2.4 | 2.25 | 0.9 | 0.242 | 0.822 |
| Czechia | 7.65 | 16.5 | 24.45 | 10.05 | 1.421 | 3.271 |
| Denmark | 4.65 | 1.5 | 16.8 | 11.4 | 0.723 | 2.029 |
| Estonia | 2.1 | 5.85 | 4.95 | 1.5 | 0.229 | 0.711 |
| Finland | 4.35 | 5.25 | 19.5 | 4.65 | 0.316 | 0.61 |
| France | 38.1 | 21.6 | 121.05 | 90.9 | 1.105 | 1.759 |
| Georgia | 3.3 | 1.65 | 5.7 | 4.65 | 1.699 | 2.534 |
| Germany | 30.9 | 47.25 | 178.2 | 100.95 | 1.244 | 2.21 |
| Greece | 8.4 | 8.55 | 38.25 | 8.4 | 0.448 | 0.862 |
| Hungary | 10.35 | 4.2 | 17.85 | 13.2 | 1.702 | 4.111 |
| Iceland | 0.3 | 7.5 | 3.45 | 0.75 | 0.005 | 0.012 |
| Ireland | 4.05 | 1.95 | 16.5 | 17.7 | 0.217 | 0.407 |
| Italy | 29.4 | 17.25 | 106.35 | 57.6 | 2.816 | 3.292 |
| Kazakhstan | 36.6 | 104.7 | 62.364 | 35.1 | 0.436 | 0.684 |

To Unit Costs | To Health Benefit Results

## *Health benefits*

The postponed premature deaths and averted morbidity are summarized in Table 7, with the central estimates for selected countries and the regional total (individual country data are accessed from a drop-down box; Fig. 23). Total life years gained are shown in Table 8. CLIMAQ-H also calculates the incidence rates per 100 000 population at risk, and the 95% CI for each health outcome. The results are also available in graphical format.

Table 7. Health benefits (numbers of cases, central values) in the regional analysis

| Health outcome | Netherlands (Kingdom of the) | North Macedonia | France | WHO EURO Region |
|---|---|---|---|---|
| **Postponed premature mortality** | | | | |
| Mortality due to all (natural) causes in adults (≥ 30 years) | 2 778 | 356 | 6 224 | 105 789 |
| All-cause post-neonatal infant mortality (1–12 months) | 2 | < 1 | 4 | 247 |
| **Prevented morbidity** | | | | |
| Cardiovascular hospital admissions (all ages) | 712 | 246 | 2 183 | 50 533 |
| Respiratory hospital admissions (all ages) | 685 | 157 | 2 343 | 43 202 |
| Restricted activity days (all ages) | 3 398 917 | 506 715 | 8 393 534 | 130 912 529 |
| Incidents of severe asthma attacks in asthmatic children (5–19 years) | 105 532 | 10 261 | 260 990 | 3 619 573 |
| Prevalence of bronchitis in children (6–12 years) | 8 368 | 1 120 | 20 431 | 340 070 |
| Lost work days in the employed population (18–65 years) | 863 785 | 19 024 | 1 718 571 | 26 203 616 |
| Onset of chronic bronchitis in adults (≥ 18 years) | 2 778 | 356 | 6 224 | 105 789 |

Table 8. Life years gained (central values) in the regional analysis

| Life years gained | Netherlands (Kingdom of the) | North Macedonia | France | WHO EURO Region |
|---|---|---|---|---|
| Central estimate | 36 065 | 5 154 | 87 604 | 1 602 665 |
| Lower bound of 95% CI | 27 338 | 3 907 | 66 351 | 1 211 354 |
| Higher bound of 95% CI | 40 425 | 5 777 | 98 220 | 1 803 751 |

### *Economic results*

The economic results (central values) for selected countries and the WHO EURO Region are summarized in Table 9. The economic value of the mortality benefit is US$ 290 billion (nominal 2020 prices), and the total morbidity benefit is US$ 17 billion. The overall regional benefit is valued at US$ 307 billion.

Table 9. Economic benefit (US$[a], central values) in the regional analysis

| Health outcome | Netherlands (Kingdom of the) | North Macedonia | France | WHO EURO Region |
|---|---|---|---|---|
| **Postponed premature mortality** | | | | |
| Mortality due to all (natural) causes in adults (> 30 years) | 9 656 632 300 | 524 702 500 | 18 642 582 200 | 289 959 482 800 |
| All cause post-neonatal infant mortality (1–12 months) | 5 006 900 | 310 200 | 9 275 400 | 383 697 400 |
| **Prevented morbidity** | | | | |
| Cardiovascular hospital admissions (all ages) | 3 766 700 | 340 300 | 8 853 000 | 131 210 100 |
| Respiratory hospital admissions (all ages) | 2 897 700 | 173 100 | 7 601 600 | 94 799 300 |
| Restricted activity days (all ages) | 308 371 900 | 18 115 200 | 667 094 300 | 8 908 505 300 |
| Incidents of severe asthma attacks in asthmatic children (5–19 years) | 4 370 900 | 167 400 | 9 469 500 | 115 084 500 |
| Prevalence of bronchitis in children (6–12 years) | 5 376 300 | 273 000 | 11 341 200 | 158 229 700 |
| Lost work days in the employed population (18–65 years) | 110 737 600 | 961 000 | 193 003 600 | 2 675 584 700 |
| Onset of chronic bronchitis in adults (≥ 18 years) | 186 425 200 | 8 638 700 | 354 906 000 | 5 054 743 100 |
| **Economic benefit** | | | | |
| Sub-total for mortality | 9 661 639 300 | 525 012 700 | 18 651 857 700 | 290 343 180 200 |
| Sub-total for morbidity | 621 946 700 | 28 668 900 | 1 252 269 400 | 17 138 157 100 |
| Total benefit for mortality and morbidity | 10 283 586 000 | 553 681 700 | 19 904 127 200 | 307 481 337 300 |

[a] US$ in nominal 2020 prices at a 5% discount rate.

## 5.4 Comment on single- and multiple-country and regional analyses

Changes in $PM_{2.5}$ concentration in a country depend on the type of analysis (see Table 10). In the practice examples, changes in the $PM_{2.5}$ concentration in a single country are calculated by use only of data on national emissions and not on emissions in neighbouring countries, whereas, in multiple-country and regional analyses, emissions in neighbouring countries are included in the analysis of the changes in $PM_{2.5}$ concentrations.

Table 10. Comparison of changes in $PM_{2.5}$ concentrations for North Macedonia in single- and multiple-country and regional analyses

| Emissions considered | Single-country analysis | Multiple-country analysis | Regional analysis |
|---|---|---|---|
| Due to national emissions | 1.351 μg/m$^3$ | 1.351 μg/m$^3$ | 1.351 μg/m$^3$ |
| Total (including emissions from neighbouring countries) | – | 1.355 μg/m$^3$ | 2.981 μg/m$^3$ |

## 5.5 Example D. Analysis for a country outside WHO European Region

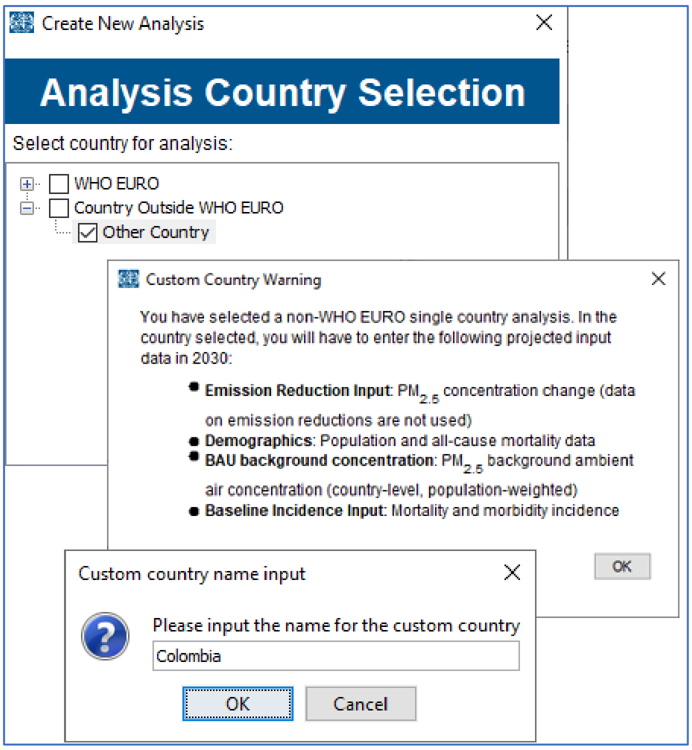
Although CLIMAQ-H was developed for the WHO European Region, the software can be used to calculate the health and economic benefits for a country outside the European Region if the necessary information is available for the calculations, as CLIMAQ-H does not provide default data for countries outside the European Region. As an example, consider the published WHO analysis of the health and economic co-benefits of climate policies in Colombia based on real data (WHO, 2023). (WHO, 2023).

**Question to be addressed**: What are the health and economic benefits of Colombia's Nationally Determined Contribution?

Start by creating a new Single Country Analysis (Fig. 28). Select "Country Outside WHO EURO", and then click on the box "Other Country". A pop-up window will be displayed asking the user to enter the following input data: (1) the population-weighted $PM_{2.5}$ ambient air concentration change (Emission Reduction Input window) and $PM_{2.5}$ background concentration (BAU background concentration window); (2) information on population and all-cause mortality (Demographics window); (3) baseline data on mortality and morbidity (Baseline Incidence Input); and (4) the unit cost values (Unit Costs window). Click on "**OK**" to close the pop-up window.

Click on "**OK**" a second time to enter the country's name, and then enter the relevant data, or click on "**Cancel**" to abandon the analysis. The input data for this example are summarized in Table 11, and the CLIMAQ-H results are presented in Table 12 (A, number of prevented cases, and B, economic benefits).

Fig. 28. Create a new analysis for a country outside the WHO European Region



## Table 11. Demographic and health data in 2030 for Colombia

| Demographic data | | | | |
|---|---|---|---|---|
| Age group (years) | Population | Deaths (all causes) | Deaths (natural) | Life expectancy (years) |
| < 5 | 3 564 983 | 4 102 | | 81.5 |
| 5–9 | 3 813 717 | 427 | | 77.0 |
| 10–14 | 4 031 800 | 604 | | 72.0 |
| 15–19 | 4 027 205 | 2 500 | | 67.1 |
| 20–24 | 4 020 651 | 5 440 | | 62.3 |
| 25–29 | 4 156 084 | 5 365 | | 57.7 |
| 30–34 | 4 361 848 | 5 236 | 1 890 | 53.0 |
| 35–39 | 4 290 876 | 6 062 | 2 884 | 48.3 |
| 40–44 | 3 938 245 | 4 760 | 2 943 | 43.7 |
| 45–49 | 3 645 902 | 6 072 | 4 504 | 38.9 |
| 50–54 | 3 222 587 | 9 977 | 8 304 | 34.2 |
| 55–59 | 2 864 484 | 15 130 | 13 496 | 29.7 |
| 60–64 | 2 722 413 | 20 792 | 19 299 | 25.4 |
| 65–69 | 2 399 629 | 24 770 | 23 520 | 21.3 |
| 70–74 | 1 856 135 | 25 858 | 24 872 | 17.3 |
| 75–79 | 1 282 600 | 31 394 | 30 482 | 13.4 |
| 80–84 | 790 780 | 38 263 | 37 390 | 9.82 |
| 85–89 | 415 569 | 41 094 | 40 332 | 6.83 |
| 90–94 | 180 554 | 29 057 | 28 603 | 4.68 |
| ≥ 95 | 92 021 | 17 581 | 17 304 | 2.62 |
| All | 55 678 083 | 294 484 | 255 823 | |

| Health data | | | |
|---|---|---|---|
| End-point | Baseline (no. of cases) | Relative risk (95% CI) | Unit cost[a] US$ (low ; high) |
| Post neonatal mortality | 1 686 | 1.04[b] (1.02 ; 1.07) | 483 528 ; 1 021 074 |
| Adult mortality, ≥ 30 years | 255 823 | 1.08[c] (1.06 ; 1.09) | 483 528 ; 1 021 074 |
| CHA | 235 919 | 1.009[c] (1.002 ; 1.017) | 2 713 ; 2 991 |
| RHA | 351 262 | 1.019[c] (1 ; 1.04) | 2 713 ; 2 991 |
| Bronchitis (children)[d] | 17 504 | 1.08[b] (1 ; 1.19) | 72 ; 145 |
| Asthma (children)[e] | 58 678 841 | 1.028[b] (1.006 ; 1.051) | 5 ; 13 |
| Chronic bronchitis (adults)[f] | 3 850 | 1.117[b] (1.04 ; 1.189) | 4 842 ; 75 581 |
| WDL | 160 967 809 | 1.046[c] (1.039 ; 1.053) | 11 ; 20 |
| RAD | 793 412 683 | 1.047[b] (1.042 ; 1.053) | 8 ; 15 |

CHA, cardiovascular hospital admissions (424 cases per 100 000 people of all ages); RHA, respiratory hospital admissions (631 cases per 100 000 people of all ages); RAD, restricted activity days (14.25 days per year for people of all ages); WDL, lost work days in the employed population aged 18–65 (7.1 days per worker, 64.2 labour participation rate)
The population-weighted change in $PM_{2.5}$ concentration change in 2030 is 2.25 μg/m$^3$ and the $PM_{2.5}$ BAU background concentration is 25.4 μg/m$^3$ ($PM_{2.5}$ to $PM_{10}$ ratio is 0.40).
[a] US$ in nominal 2020 prices at a 4.9% discount rate and assuming a triangular cost distribution.
[b] RR for an increment of 10 μg/m$^3$ of $PM_{10}$
[c] RR for an increment of 10 μg/m$^3$ of $PM_{2.5}$
[d] Prevalence rate in children aged 6–12 years is 0.32%.
[e] Prevalence rate of severe attacks in children with asthma aged 5–19 years (7.95% of age group) is 62 cases per year.
[f] Incidence rate in adults aged ≥ 18 years is 0.92%.

Table 12. Health and economic benefits of a reduction in air pollution due to implementation of the nationally determined contribution in Colombia

## A. Health benefits

| Health outcome | Number of prevented cases | | |
|---|---|---|---|
| **Number of postponed premature deaths** | **Central** | **Lower bound of 95% CI** | **Upper bound of 95% CI** |
| Mortality due to all (natural) causes in adults (≥ 30 years) | 4 392 | 3 332 | 4 913 |
| All cause post-neonatal infant mortality (1–12 months) | 37 | 19 | 63 |
| **Prevented morbidity** | | | |
| Cardiovascular hospital admissions (all ages) | 475 | 106 | 893 |
| Respiratory hospital admissions (all ages) | 1 484 | 0[a] | 3 086 |
| Restricted activity days (all ages) | 5 632 000 | 4 690 000 | 6 573 000 |
| Incidents of severe asthma attacks in asthmatic children (5–19 years) | 902 700 | 196 700 | 1 616 000 |
| Prevalence of bronchitis in children (6–12 years) | 742 | 0[a] | 1632 |
| Lost work days in the employed population (18–65 years) | 1 621 000 | 1 380 000 | 1 860 000 |
| Onset of chronic bronchitis in adults (≥ 18 years) | 232 | 84 | 357 |

[a] The value is 0, because the lower bound of the 95% CI of the relative risk for this outcome is unity.

## B. Economic benefits

| Health outcome | Economic benefit (US$[a]) | | |
|---|---|---|---|
| **Postponed premature deaths** | **Central** | **Lower estimate** | **Higher estimate** |
| Mortality due to all (natural) causes in adults (≥ 30 years) | 2 047 741 000 | 1 122 695 000 | 2 925 973 000 |
| All cause post-neonatal infant mortality (1–12 months) | 17 153 000 | 6 293 000 | 37 499 000 |
| **Prevented morbidity** | | | |
| Cardiovascular hospital admissions (all ages) | 839 800 | 180 300 | 1 638 000 |
| Respiratory hospital admissions (all ages) | 2 624 000 | – | 5 662 000 |
| Restricted activity days (all ages) | 40 140 000 | 25 532 000 | 57 918 000 |
| Incidents of severe asthma attacks in asthmatic children (5–19 years) | 5 036 000 | 718 800 | 12 125 000 |
| Prevalence of bronchitis in children (6–12) | 49 870 | – | 138 400 |
| Lost workdays in the employed population (18–65) | 15 569 000 | 10 267 000 | 21 891 000 |
| Onset of chronic bronchitis in adults (≥ 18 years) | 5 790 000 | 664 000 | 14 984 000 |
| **Economic benefit** | | | |
| Sub-total for mortality | 2 064 895 000 | 1 128 987 000 | 2 963 472 000 |
| Sub-total for morbidity | 70 048 000 | 37 362 000 | 114 356 000 |
| Total economic benefit | 2 134 943 000 | 1 166 349 000 | 3 077 828 000 |

[a] US$ in nominal 2020 prices at a 4.9% discount rate and a triangular cost ditribution.

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# Annex.
# Formulae for health and economic assessment in CLIMAQ-H; key differences between CarbonH and CLIMAQ-H; and additional data

## Formulae for health and economic assessment in CLIMAQ-H

For a receiver country, the health benefit of future reductions in emission is calculated from the expression:

$$\begin{matrix} Health \\ benefit \end{matrix} = \begin{bmatrix} Baseline\ incidents\ for\ the \\ health\ outcome\ of\ interest \end{bmatrix} \times \left[1 - \frac{RR\left(C_{back} - c_f - \Delta C_{tot}\right)}{RR\left(C_{back} - c_f\right)}\right]$$

where,

$C_{back}$ is the country-level population-weighted $PM_{2.5}$ concentration (µg/m$^3$) for the BAU scenario in 2030;

$c_f$ is the counterfactual concentration (2.4 µg/m$^3$), based on the lower bound of the CI used in the integrated exposure response functions of the Global Burden of Disease Study (Murray et al., 2020);

$\Delta C_{tot}$ is the change in the total $PM_{2.5}$ population-weighted concentration in 2030 due to national and regional reductions in air pollutant emissions in 2030; and

RR is the relative risk.

The total concentration change ($\Delta C_{tot}$) in the receiver country is the sum of the changes in $PM_{2.5}$ concentration due to national reductions in emissions ($\Delta C_{national}$) plus the change due to reduction of cross-boundary transport of pollutants from neighbouring (emitter) countries ($\Delta C_{regional}$). The individual contributions to the change in the $PM_{2.5}$ concentration are calculated with EMEP SRMs. $\Delta C_{tot}$ is given by:

$$\Delta C_{tot}(receiver\ country) = \left(\Delta C_{national} + \Delta C_{regional}\right) \times \begin{pmatrix} Urban\ adjustment\ coefficient \\ of\ receiver\ country \end{pmatrix}$$

where,

$$\Delta C_{national} = \begin{pmatrix} \Delta C\ in\ receiver\ country \\ per\ unit\ emission\ in\ \underline{receiver}\ country \\ using\ the\ SRM\ tables \end{pmatrix} \times \begin{pmatrix} Pollutant\ reduction \\ in\ \underline{receiver}\ country \end{pmatrix}$$

$$\Delta C_{regional} = \sum \begin{pmatrix} \Delta C\ in\ receiver\ country \\ per\ unit\ emission\ in\ \underline{emitter}\ country \\ using\ the\ SRM\ tables \end{pmatrix} \times \begin{pmatrix} Pollutant\ reduction \\ in\ \underline{emitter}\ country \end{pmatrix}$$

The urban adjustment coefficient is a country-specific downscaling factor applied to the nationally averaged change in $PM_{2.5}$ exposure, which is derived with the EMEP SRMs, for calculating the local population-weighted exposure. These scalars are calculated by comparing the change in the $PM_{2.5}$ concentration when both national and regional emissions are reduced to 0, using EMEP SRM data and comparing the result to the urban concentrations estimated by WHO (WHO, 2016).

The RR is the ratio of incidents of a particular health outcome (morbidity or mortality) between two groups of individuals, each exposed to different levels of ambient air pollution. In the case of premature mortality, the RR is the ratio of number of deaths in two populations exposed to different levels of air pollution. For health risk assessments when $PM_{2.5}$ < 45 µg/m$^3$), the log-linear risk functions of the Health risks of air pollution in Europe project (WHO Regional Office for Europe, 2013) (Table A1) are recommended. Although these associations may be applied in situations with higher ambient air concentrations of $PM_{2.5}$, the results may be less accurate. For cause-specific mortality end-points, the cause-specific mortality integrated exposure-response (IER) functions proposed in the Global Burden of Disease Study (Murray et al., 2020) are recommended (Fig. A1).

### Table A1. Log-linear relative risks used in CLIMAQ-H

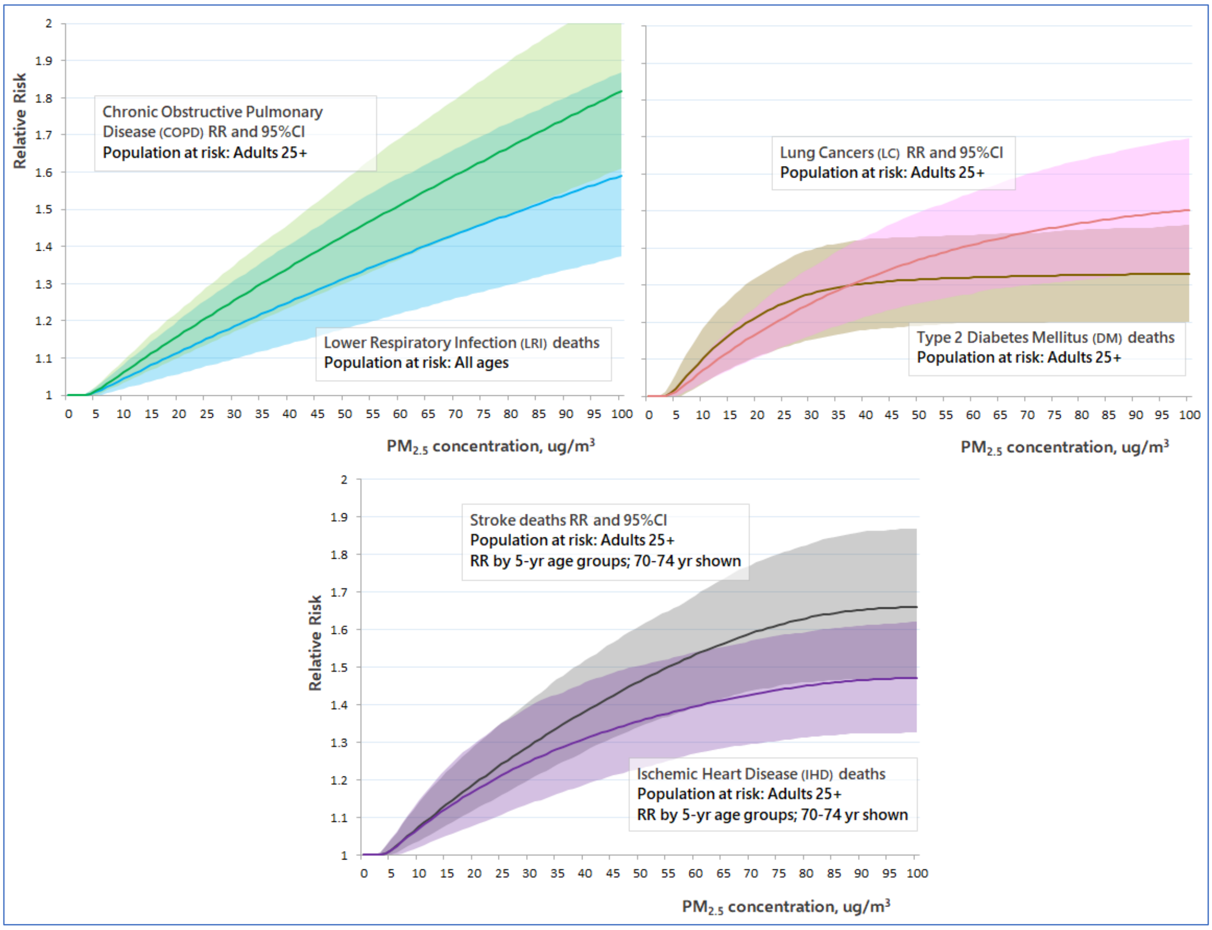
| Pollutant | Health end-point | Age group at risk | RR[a] (95%CI) |
|---|---|---|---|
| $PM_{2.5}$ | Adult natural mortality [b] | ≥ 30 years | 1.08 (1.06 ; 1.09) |
| | Respiratory hospital admission | All ages | 1.019 (1 ; 1.0402) |
| | Cardiovascular hospital admissions | All ages | 1.0091 (1.0017 ; 1.0166) |
| | Lost workdays in the employed population | 18–65 years | 1.046 (1.039 ; 1.053) |
| | Restricted activity days | All ages | 1.047 (1.042 ; 1.053) |
| $PM_{10}$ | Post-neonatal natural mortality | 1–12 months | 1.04 (1.02 ; 1.07) |
| | Incidents of severe asthma attacks in asthmatic children | 5–19 years | 1.028 (1.006 ; 1.051) |
| | Prevalence of bronchitis in children | 6–12 years | 1.08 (1 ; 1.19) |
| | Incidence of chronic bronchitis in adults | ≥ 18 years | 1.117 (1.04 ; 1.189) |

Source: WHO Regional Office for Europe (2013).

[a] RR, relative risk per 10 μg/m³ increment in PM concentration. In the case of adult mortality, a reduction of 10 μg/m³ $PM_{2.5}$ concentration leads to an 8% reduction in the attributable mortality.

[b] All-cause mortality minus accidental deaths due to injuries and other external causes (such as violence or self-harm)

### Fig. A1. The Integrated Exposure Response functions of the Global Burden of Disease Study, 2019



*Source*: Adapted from Murray et al. (2020).

The economic benefit is the health benefit multiplied by the unit cost (cost per case of illness or death) summed for all morbidity endpoints and mortality:

$$\begin{matrix} Economic \\ benefit \end{matrix} = \sum_{\substack{health \\ end\text{-}point}} \begin{pmatrix} Health \\ benefit \end{pmatrix} \times \begin{pmatrix} Unit \\ cost \end{pmatrix}$$

The unit cost is the sum of the market costs, including costs of illness (direct and indirect resource costs, such as for medicines, physicians, health care, rehabilitation and caregivers), economic gains in productivity (opportunity cost for individuals and society) and non-market (intangible) benefits, such as gains in quality of life (welfare) and averted pain and suffering. Market costs have a direct bearing on a country's gross domestic product and, at the level of the citizen, affect personal income and savings (socioeconomic status). Postponed premature deaths are priced with the value of a statistical life (VSL). The VSL is based on a person's willingness to pay for a marginal reduction in the risk of death and it represents the price that society is willing to pay to prevent an anonymous fatality. A related concept is the VSL-year, which is the willingness of a person to pay to extend their life by 1 year. Further details of unit costs, including the VSL and the VSL-year, are provided by Lindhjem et al. (2011), the Organisation for Economic Co-operation and Development (2012, 2015), Narain & Sall (2016), Viscusi & Masterman (2017), Robinson et al. (2019) and Hammitt (2020). Country-specific VSL values are provided by the Organisation for Economic Co-operation and Development (2023). CLIMAQ-H is preloaded with default unit costs for each country in the WHO European Region, which can be modified by the user.

## Key differences between CarbonH and CLIMAQ-H

CLIMAQ-H has more capability than its predecessor, CarbonH (Table A2):

- better methods to calculate the health and economic benefits of climate mitigation actions;
- replacement of EU28 by 27 countries plus the United Kingdom (28 countries in total);
- updated default input data;
- greater flexibility to manipulate or replace modelling parameters and default data;
- greater choice of risk models for quantifying health benefits, such as inclusion of the non-linear IER functions of the GBD Study 2016 and 2020;
- consideration of uncertainty at each step of the impact pathway analysis; and
- an improved user-interface offers the same working experience with all WHO tools (e.g. AirQ+).

The main difference between the results of the two tools is due to use of updated SRM tables and the choice of concentration–response functions.

## Table A2. Key differences between CLIMAQ-H and CarbonH

| Feature | CarbonH | CLIMAQ-H | Note |
|---|---|---|---|
| **General** | | | |
| Export the results | Yes | Yes | |
| Import the input data | Yes | Yes | In CarbonH, the input data can be changed manually. |
| Draw graphs | Yes | Yes | |
| Geographical coverage | WHO European Region | WHO European Region | CLIMAQ-H can assess the health benefits for single countries outside the WHO EURO, provided all the necessary input data are available.[a] |
| **Analysis configuration** | | | |
| Analysis options | 3 | 3 | Single, multiple and regional |
| Demographics | Yes | Yes | |
| Age-specific population | Yes | Yes | CarbonH: 5 age groups<br>CLIMAQ-H: 21 age groups |
| BAU background concentration | No[b] | Yes | |
| Source receptor matrix | Yes | Yes | CarbonH: EMEP 2015 tables<br>CLIMAQ-H: EMEP 2019 tables |
| **Health benefits** | | | |
| Concentration–response functions | HRAPIE[c] | HRAPIE<br>IER[d] | |
| Number of health end-points | 8 | 15 | CarbonH: morbidity, mortality (adults)<br>CLIMAQ-H: morbidity, mortality (infant, adults, cause-specific) |
| Life years gained | Yes | Yes | |
| **Economic analysis** | | | |
| Discount rate | No | Yes | |
| Price unit | US$ | US$ | CarbonH: US$ at 2005 prices<br>CLIMAQ-H: US$ at 2020 prices |
| Cost distribution | No | Yes | CLIMAQ-H: Log-Normal or Triangular |

[a] In the future, CLIMAQ-H will be extended to include other geographical regions.
[b] Use of BAU in CLIMAQ-H arises from the use of the non-linear IER functions of the Global Burden of Disease Study.
[c] WHO Regional Office for Europe (2013).
[d] Vos et al. (2017) and Murray et al. (2020).

## Additional information

Table A3. Population-weighted $PM_{2.5}$ annual concentrations[a] in 2030

| Country | ISO alpha3 code | $PM_{2.5}$ concentration (μg/m$^3$) |
|---|---|---|
| Albania | ALB | 15.9 |
| Armenia | ARM | 34.5 |
| Austria | AUT | 11.4 |
| Azerbaijan | AZE | 24.2 |
| Belarus | BLR | 15.6 |
| Belgium | BEL | 11.2 |
| Bosnia and Herzegovina | BIH | 26.3 |
| Bulgaria | BGR | 17.2 |
| Croatia | HRV | 15.4 |
| Cyprus | CYP | 14.5 |
| Czechia | CZE | 14.3 |
| Denmark | DNK | 9.7 |
| Estonia | EST | 6.3 |
| Finland | FIN | 5.5 |
| France | FRA | 10.5 |
| Georgia | GEO | 18.5 |
| Germany | DEU | 10.6 |
| Greece | GRC | 14.5 |
| Hungary | HUN | 14.4 |
| Iceland | ISL | 5.7 |
| Ireland | IRL | 8.0 |
| Italy | ITA | 14.4 |
| Kazakhstan | KAZ | 25.9 |
| Kyrgyzstan | KGZ | 35.6 |
| Latvia | LVA | 12.0 |
| Lithuania | LTU | 10.4 |
| Luxembourg | LUX | 8.7 |
| Malta | MLT | 12.9 |
| Montenegro | MNE | 19.0 |
| Netherlands (Kingdom of the) | NLD | 10.9 |
| North Macedonia | MKD | 24.9 |
| Norway | NOR | 6.3 |
| Poland | POL | 19.0 |
| Portugal | PRT | 7.4 |
| Republic of Moldova | MDA | 12.5 |
| Romania | ROU | 13.3 |
| Russian Federation | RUS | 9.4 |
| Serbia | SRB | 21.6 |
| Slovakia | SVK | 15.9 |
| Slovenia | SVN | 14.0 |
| Spain | ESP | 9.3 |
| Sweden | SWE | 6.0 |
| Switzerland | CHE | 9.0 |
| Tajikistan | TJK | 49.1 |
| Türkiye | TUR | 22.9 |
| Turkmenistan | TKM | 25.4 |
| Ukraine | UKR | 13.4 |
| United Kingdom | GBR | 9.8 |
| Uzbekistan | UZB | 38.7 |

[a] These values are provided for the sole purpose of running the examples in the manual.

## Table A4. Urban adjustment coefficient[a] and $PM_{2.5}$ to $PM_{10}$ ratio by country

| Country | Adjustment coefficient | $PM_{2.5}$ to $PM_{10}$ ratio |
|---|---|---|
| Albania | 2.1 | 0.64 |
| Armenia | 6.8 | 0.63 |
| Austria | 2.5 | 0.71 |
| Azerbaijan | 3.6 | 0.63 |
| Belarus | 2.9 | 0.61 |
| Belgium | 1.4 | 0.64 |
| Bosnia and Herzegovina | 4.8 | 0.74 |
| Bulgaria | 3.4 | 0.57 |
| Croatia | 2.4 | 0.63 |
| Cyprus | 1.6 | 0.43 |
| Czechia | 2.1 | 0.58 |
| Denmark | 2.0 | 0.57 |
| Estonia | 1.9 | 0.53 |
| Finland | 4.3 | 0.51 |
| France | 1.8 | 0.65 |
| Georgia | 4.4 | 0.48 |
| Germany | 1.4 | 0.69 |
| Greece | 1.7 | 0.51 |
| Hungary | 2.2 | 0.63 |
| Iceland | 0.7 | 0.72 |
| Ireland | 1.1 | 0.58 |
| Italy | 2.0 | 0.67 |
| Kazakhstan | 2.5 | 0.61 |
| Kyrgyzstan | 1.5 | 0.63 |
| Latvia | 3.7 | 0.69 |
| Lithuania | 2.9 | 0.60 |
| Luxembourg | 1.5 | 0.67 |
| Malta | 2.2 | 0.44 |
| Montenegro | 3.9 | 0.63 |
| Netherlands (Kingdom of the) | 1.6 | 0.59 |
| North Macedonia | 3.9 | 0.62 |
| Norway | 10.5 | 0.47 |
| Poland | 2.6 | 0.75 |
| Portugal | 2.6 | 0.44 |
| Republic of Moldova | 2.4 | 0.61 |
| Romania | 1.9 | 0.70 |
| Russian Federation | 6.1 | 0.50 |
| Serbia | 1.9 | 0.70 |
| Slovakia | 2.2 | 0.67 |
| Slovenia | 2.0 | 0.78 |
| Spain | 2.6 | 0.51 |
| Sweden | 3.6 | 0.41 |
| Switzerland | 1.9 | 0.70 |
| Tajikistan | 6.2 | 0.63 |
| Türkiye | 2.6 | 0.46 |
| Turkmenistan | 0.8 | 0.63 |
| Ukraine | 2.1 | 0.63 |
| United Kingdom | 2.3 | 0.64 |
| Uzbekistan | 3.5 | 0.63 |

[a] The urban adjustment coefficient is a factor applied to the change in the national $PM_{2.5}$ concentration to capture the urban population-weighted exposure.

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## The WHO Regional Office for Europe

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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