EUCALC

Explore sustainable European futures

WP6 – Air pollution and human health documentation

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Main authors	Marc Stettler, Liang Ma, Daniel Mehlig, Amaury Anciaux, Patricia Osseweijer, Mike Holland
Partner in charge	TU Delft
Contributing partners	Imperial College London
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Short Description
This report describes the methodology for the Air Pollution and Human Health module, that lead to quantified and monetized impacts of air pollution on health. The report describes historical trends in air pollution in the EU, the overall calculation logic and scope, the sources and types of input data and validation data.

Quality check

Name of reviewer	Date
Luis Costa	24th May 2019

Statement of originality:

This deliverable contains original unpublished work except where clearly indicated otherwise. Acknowledgement of previously published material and of the work of others has been made through appropriate citation, quotation or both.

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List of abbreviations

BAU – Business as Usual

EEA – European Environment Agency

EU – European Union

EU-28 – The 28 EU Member States as of 1 July 2013

WP – Work PackageCBA – Cost-Benefit Analysis

IPA – Impact Pathway Approach

CRF – Concentration Response Function

RR – Relative Risk

YLL – Years of Life Lost

VSL – Vallue of a Statistical Life

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1 Introduction

Air pollution can lead to a range of serious adverse outcomes. Epidemiologic studies have shown that there are a large number of adverse health effects associated with air pollution, particularly with particulate matter with a diameter less than 2.5 microns, called $PM_{2.5}$. Exposure to air pollution has both long-term and short-term effects. The long-term effect on health relates to premature mortality due to cardiopulmonary (heart and lung) effects. In the short-term, high pollution episodes can trigger increased admissions to hospital and contribute to the premature death of people who are more vulnerable to daily changes in levels of air pollutants.

The choice to include health impacts as a social impact to be shown in the decarbonisation pathways explorer was made during the first stakeholder workshop. This module describes the approach, which was reviewed in an expert meeting and the intended outcomes of the module.

This human health assessment module aims to:

- Provide an objective and comparable estimate of the impacts of projected $PM_{2.5}$ air pollution between 2015 and 2050 across 28+1 EU countries in EUCalc;
- Provide input to the development and implementation of measures to improve air quality;
- Raise awareness of the harmful effects of pollution;
- It is an important tool for informing public policy decisions.

This document describes how the health risks of outdoor air pollution and its sources are estimated.

2 Trends and evolution of air pollution in Europe

This section gives an overview of the current trend of air pollution in Europe, mainly focusing on the emissions of main air pollutants (Section 2.1) and the attainment situation of regulations for $PM_{2.5}$ (Section 2.2). The main air pollutants reviewed in Section 2.1 include sulphur oxides (SO_x), nitrogen oxides (NO_x), ammonia (NH_3), non-methane volatile organic compounds (NMVOCs) and primary fine particulate matter ($PM_{2.5}$). SO_2, NO_x, NH_3 and VOCs are key precursors for secondary PM.

2.1 Emissions of the main air pollutants

Total emissions of all main air pollutants (SO_x, NO_x, NH_3, NMVOCs and primary $PM_{2.5}$) have decreased since 1990. Compared with the baseline year ($PM_{2.5}$: 2000; others: 1990), emissions in the EU-28 of

- NO_x decreased by 58%;
- SO_x decreased by 91%;
- NMVOCs decreased by 62%;
- NH_3 decreased by 23%;
- and $PM_{2.5}$ decreased by 28%

in 2016 (European Environment Agency, 2018b). While SO_x has the largest reduction, NH_3 has the smallest decrease with an approximately 3% increase in the agriculture sector in 2013-2016 (European Environment Agency, 2018a).

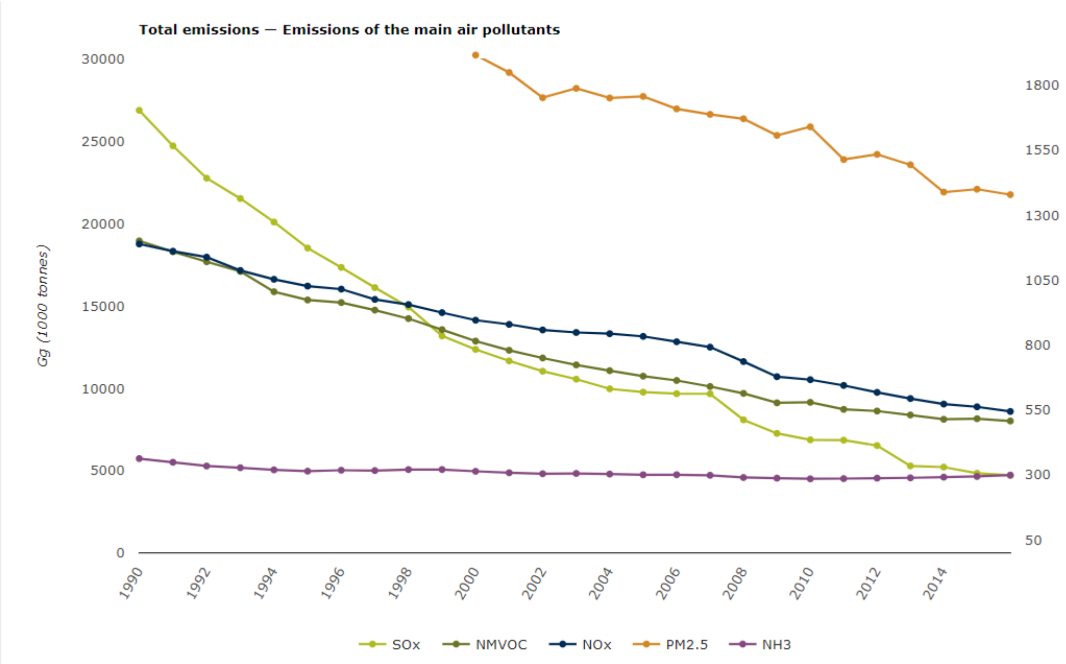
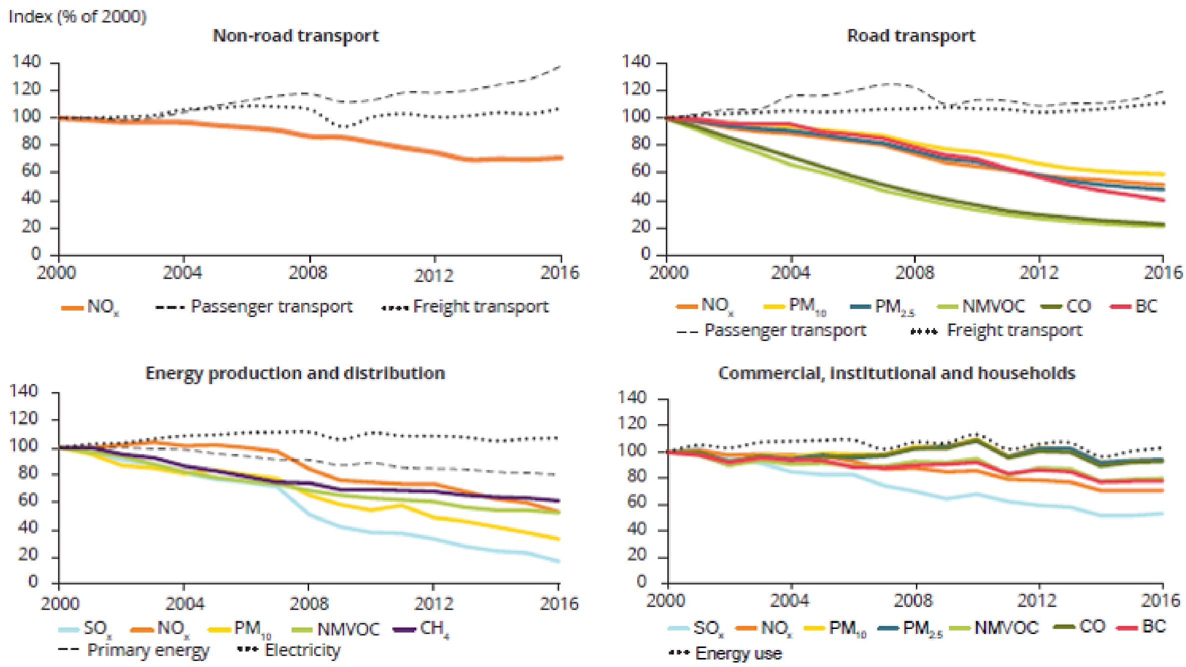


Figure 1: Emission trends of the air pollutants (sulphur oxides, nitrogen oxides, ammonia, non-methane volatile organic compounds and primary fine particulate matter) over the 1990 to 2016 period (2000 to 2016 for PM). PM2.5 emissions are shown on the secondary y-axis. (European Environment Agency, 2018b)

According to the EEA (2018a), air pollutant emissions in most of the main sectors have significantly decreased since 2000. Emissions from agriculture and waste were relatively steady. Emissions of PM_{10}, $PM_{2.5}$ and CO from the commercial, industrial and households sector have increased.

A significant reduction in transport-related air pollutant emissions is evident in recent years, although there is an increase in transport activities. This is particularly due to the implementation of stricter regulations in vehicle emission standards and requirements in fuel quality. A similar trend has been seen in the industrial sectors. Relevant factors involve emission limits for combustion plants, regulations on stationary emission sources in the industry and energy sectors, and principles in permits and the control of installations (European Environment Agency, 2018a).



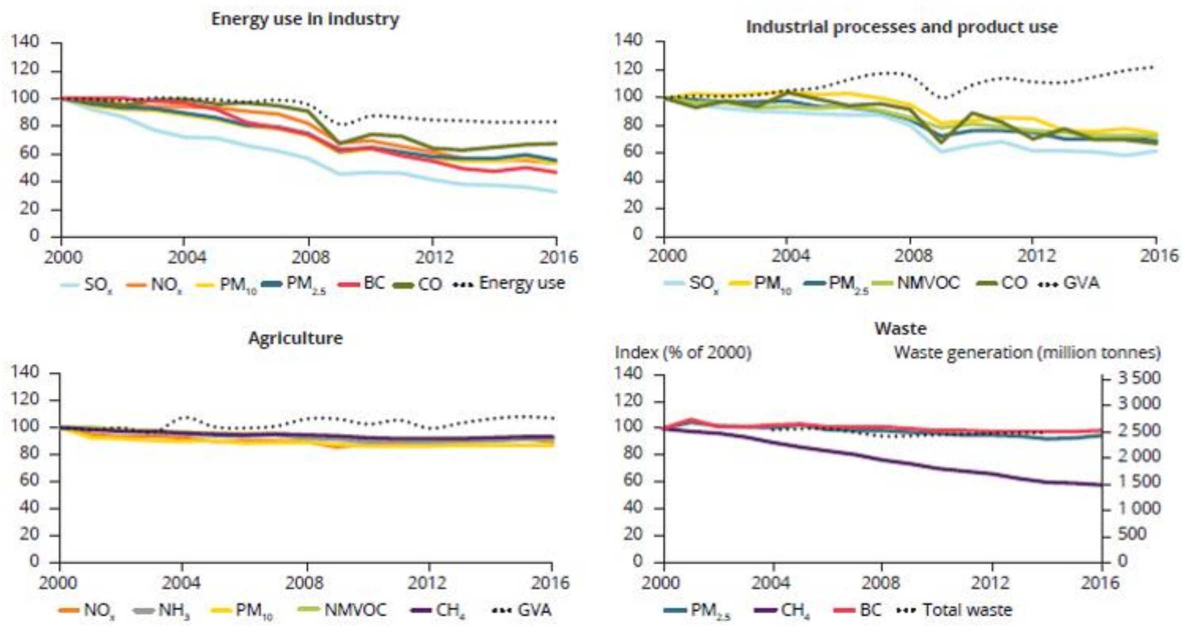


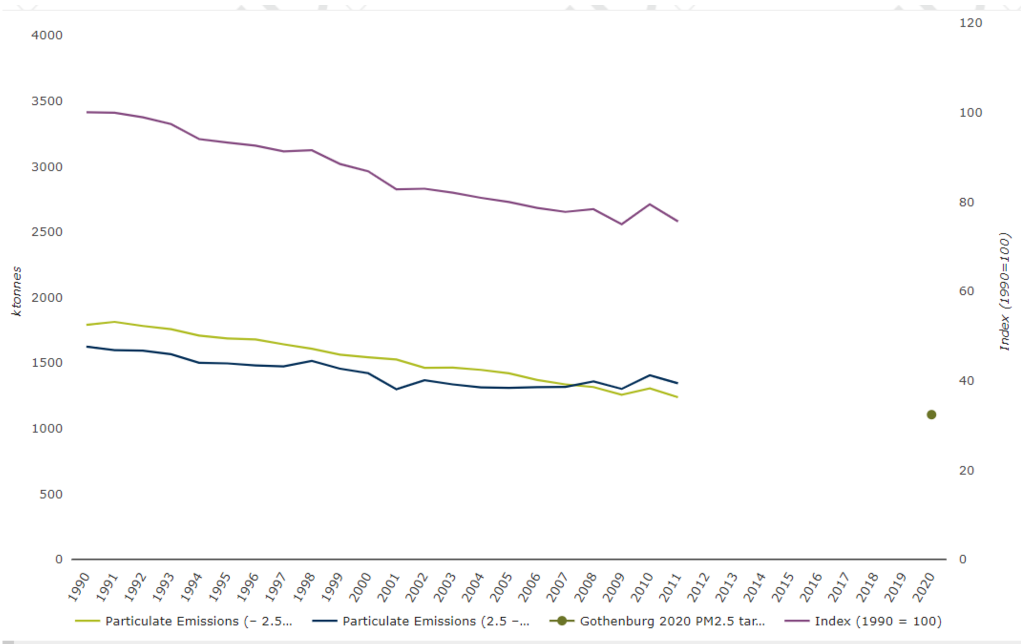
Figure 2: Development in EU-28 emissions from main source sectors of SO_X, NO_X, NH_3, PM_{10}, $PM_{2.5}$, NMVOCs, CO, BC and CH_4, 2000-2016 (% of 2000 levels). Also shown for comparison are key EU-28 sectoral activity statistics (% of 2000 levels) [1] (European Environment Agency, 2018a)

2.2 $PM_{2.5}$: Regulations and Attainment

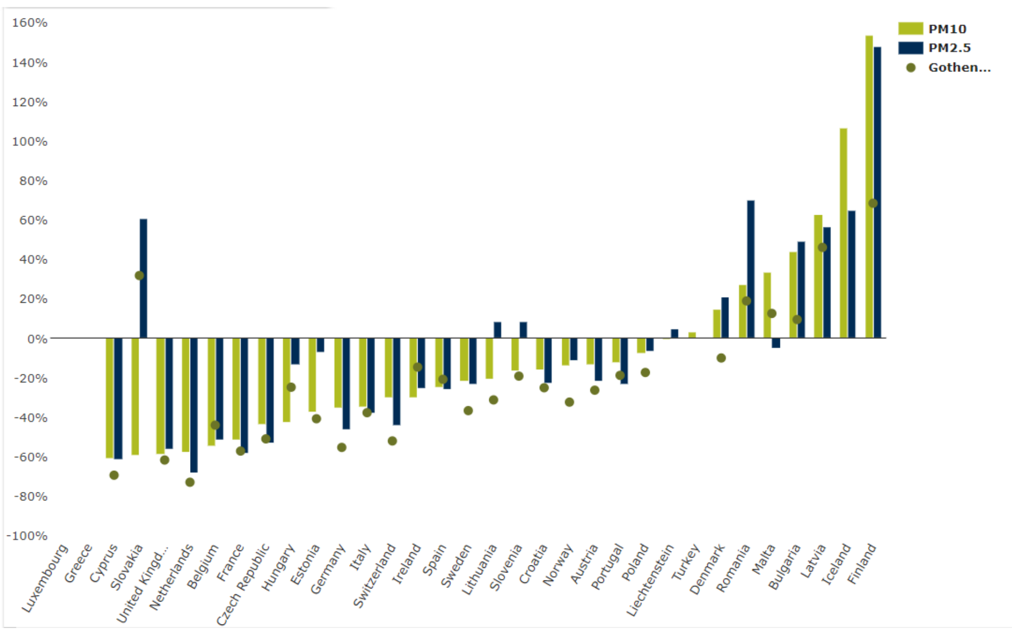
EU air pollution legislation has followed a twin-track approach by implementing both emission controls and air-quality standards.

Under the National Emission Ceilings Directive (NECD) and the 2012 amended Gothenburg Protocol, emission ceiling and emission reduction commitments in 2020 and 2030 of primary $PM_{2.5}$ are set for European countries, together with four other main air pollutants (SO_X, NO_X, NH_3, NMVOCs) (European Environment Agency, 2018b). Based on the officially reported emissions to the EEA, the EEA-33 regions are progressively achieving the Gothenburg 2020 $PM_{2.5}$ target in general. By 2011, 25 of EEA-33 regions have already achieved their targets specified in the protocol (European Environment Agency, 2014).

[1] Only pollutants for which the sector contributes more than 5 % to the total pollutant emissions are shown in the figures



(a) Emission trends of PM: 1990-2011 (EEA-33 regions overall)



(b) Percentage change in PM emissions in each EEA-33 region

Figure 3: Emissions of primary PM2.5 with Gothenburg 2020 target in EEA-33 regions: (a) trends in 1990-2011 (b) percentage change in 2011 (compared with 1990) (European Environment Agency, 2014)

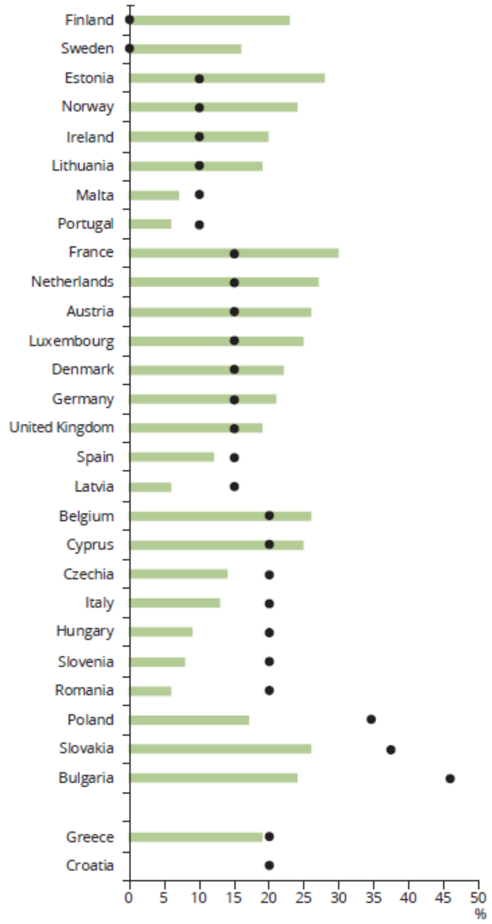
Considering the harmful impacts on human health and ecosystem, air quality standards are specified for key air pollutants by regulating their ambient concentrations. Currently, ambient concentrations of SO_2, NO_2 and other nitrogen oxides, PM_{10} and $PM_{2.5}$, lead, benzene (C_6H_6), carbon monoxide (CO) and ozone are regulated under the Directive 2008/50/EC. The directive also sets two additional targets for $PM_{2.5}$, the exposure concentration obligation and the national exposure reduction target (NERT) (European Environment Agency, 2018a). Table 1 lists the air quality standards for $PM_{2.5}$ given in the EU Ambient Air Quality Directives.

Averaging period	**Legal nature and concentration Comments**	**Comments**
Calendar year	Limit value: 25 $\mu g/m^3$	
Calendar year	Exposure concentration obligation: 20 $\mu g/m^3$	Average Exposure Indicator (AEI) in 2015 (2013-2015 average)
Calendar year	National Exposure reduction target: 0-20% reduction in exposure	AEI in 2020, the percentage reduction depends on the initial AEI

Table 1: Air Quality Standards for PM2.5, given in the EU Ambient Air Quality Directives (European Environment Agency, 2018a)

In 2016, the PM2.5 concentrations of four member states and four other reporting countries exceeded the annual limit value in 2016. More than half of the 29 countries considered[2] have already attained their NERT values (European Environment Agency, 2018a).

[2] Austria, Belgium, Cyprus, Denmark, Estonia, Finland, France, Germany, Ireland, Lithuania, Luxembourg, the Netherlands, Norway, Sweden and the United Kingdom.



Notes: Bars indicate the reduction of the AEI 2016 as a percentage of the AEI 2011 (AEI 2015 in the case of Croatia, see main text). Dots indicate the reduction to be obtained in the AEI 2020 as a percentage of the AEI 2011 (AEI 2015 in the case of Croatia). If the end of the bar is to the right of the dot, the NERT has already been reached in 2016.

For Croatia and Greece, where no stations have been designated for the AEI calculation, all urban and suburban background stations have been used instead.

For Hungary, which did not designate AEI stations or report $PM_{2.5}$ data from urban background stations in 2015 nor 2016, the reduction of the AEI 2014 (average 2012-2014) is presented. For Slovakia, which did not designate AEI stations in 2013 nor 2016, the reduction of the AEI 2015 (average 2014-2015) is presented.

Figure 4: Percentage of reduction of AEI 2016 in relation to AEI 2011 and distance to the national exposure reduction target (European Environment Agency, 2018a)

3 Questions addressed by the module

Theme	**Questions**		**Ambition**[3]	**Progress**
What are the types of impact we	Population exposure	• What is the aggregated European population exposure to $PM_{2.5}$?	Yes	Ongoing

[3] Does this module ambition to answer that question?

want to take into account in the model?	to $PM_{2.5}$ pollution	• What is the spatial distribution of air pollution?	Yes, the module will calculate air pollution impacts of $PM_{2.5}$ in each EU28+1 member state.	Ongoing
	Health impact	• What is the mortality due to exposure to $PM_{2.5}$?	Yes	Ongoing
	Monetary impact	• What is the cost of health impact of air pollution?	Yes	Ongoing
What are the solutions to reduce air pollution and health impact?		• What is the impact of implementing pollution control technologies?	Partially. The module will evaluate the impact on air pollution of different technologies that can be used in different sectors, e.g. electric or hydrogen vehicles for transport, or renewable energy sources for power. However, the assumptions on emissions control technologies and regulations are implicit within the IIASA-GAINS inputs factors.	Ongoing
What is the impact of other sectors on health?		• What is the health impact of changes in sector dynamics in buildings, transport, industry, agriculture, power and oil refinery?	Yes	Ongoing
What is the impact of air pollution and health on the other sectors?	Lifestyle	• What is the impact of air pollution and health on lifestyle?	No, since this would be contrary to the EUCalc logic (it would create feedback loops)	N/A
	Agriculture and land use	• What is the impact of air pollution and health on agriculture and land use?		
	Other sectors	• What is the impact of air pollution and health on transport, industry, power generation, oil refinery?		

Table 2: Questions addressed by the health module

4 Calculation logic and scope of the module

4.1 Overall logic

4.1.1 Theoretical framework

The human health methodology aims to:

1. Provide quantitative estimates of the air pollution impacts of different 2050 calculator pathways across 28+1 EU countries in the EUCalc;
2. Enable users of EUCalc to interpret the air pollution impacts with policy relevant metrics;
3. Account for ongoing improvements in emissions control technologies that are not explicitly covered by the EUCalc methodology.

This section describes the methodology underlying the health effects calculations and:

- Defines the overall rationale for the health impact assessment, in particular by demonstrating how it builds on the impact pathway approach (IPA);

- Identifies a general framework for quantifying impacts of air pollutants on human health, including links to the other EUCalc core modules;

- Identifies the assumptions and data that will form the basis of the quantification of benefits.

The **impact pathway approach (IPA)** is a systematic method for identifying and tracing the effects of air pollution, from changes in emissions that result from changes in human activity, through to impacts on outcomes that society values (Department for Environment Food & Rural affairs, 2019).There are six component stages, as shown in Table 3. The IPA can also be represented diagrammatically, as in Figure 5.

Stage	Description
1	Estimating anthropogenic activity
2	Quantifying the resultant air pollutant emissions
3	Modelling the dispersion of emissions of air pollutants to understand changes in ambient pollutant concentrations in different locations
4	Quantifying the exposure of the population to changes in air pollutant concentrations
5	Estimating how those changes in exposure affect human health
6	Valuing those impacts using a single monetary metric

Table 3: Stages of the impact pathway approach

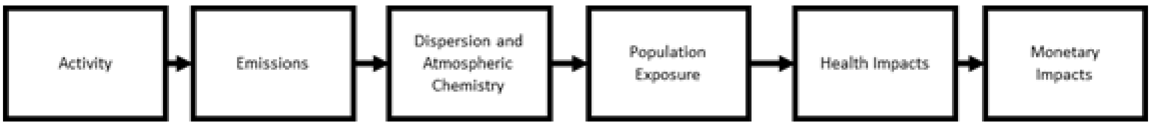


Figure 5: Impact pathway approach

4.1.2 Limitations of EUCalc approach for air pollution

In the process of developing the methodology to estimate air pollution impacts within EUCalc, we encountered a number of limitations that mean a full IPA would not be feasible, including:

1. **Emissions factors**. The standard method of conducting an emissions inventory is to multiply an activity value (e.g. PJ, vkm) by an appropriate emissions factor that accurately quantifies the mass of emissions per unit of activity (e.g. kg NO_x/PJ or kg NO_x/vkm). In Europe, the standard resources for emissions factors is the EMEP/EEA air pollutant emission inventory guidebook (European Environment Agency, 2016). However, it became clear that the technology definitions for each of the core energy conversion sectors within EUCalc (e.g. energy, transport, manufacturing) were not detailed

enough to allow us to choose the appropriate emissions factors. Note that this reflects the fact that the pollutant emissions factor for an energy conversion process can vary by an order of magnitude or more with negligible effect on energy efficiency (and CO_2 emissions) owing to the advancement of emissions control technologies (e.g. catalysts, filters and scrubbers). To resolve this, it would be necessary to specify emissions control technologies in each of the 28 + 1 EU countries for different sectors up to 2050.

2. **Spatial distribution of emissions.** To calculate emissions dispersion and resultant changes in concentrations due to pollutant emissions, it is necessary to know the source location of emissions. As EUCalc is a model aggregated to the country-level, there is no spatial information contained within the existing framework. Furthermore, it is therefore also not possible to represent the location of emissions with respect to population.

It was not possible to remedy the issues highlighted above and couple a full-scale IPA.

4.1.3 Chosen approach with IIASA-GAINS

To meet the aims of the module and to overcome the challenges posed by the aggregate country level of EUCalc, we have collaborated with Markus Amann and Fabian Wagner of the International Institute for Applied Systems Analysis (IIASA) to use their pre-existing work on integrated assessment of air pollution and climate policies and their Greenhouse gas-Air pollution Interactions and Synergies (GAINS) model. This approach enables: (1) quantification of accurate emissions factors for each sector and country, accounting for different technological development pathways, and; (2) incorporating the spatial distribution of emissions in each country and the dispersion and transport of pollution of transport across the EU.

In the following subsections we describe GAINS, and the approach to estimate air pollution exposure resulting from emissions in EUCalc, show an example calculation.

The approach and outstanding issues were discussed in an expert meeting in which solutions were agreed and implemented.

4.1.4 Introduction to GAINS

The GAINS model was developed by IIASA and is now employed for the international negotiations among participants under the Convention on Long-range Transboundary Air Pollution (IIASA, 2018).

The GAINS model can quantify the full pathway of the DPSIR (demand-pressure-state-impact-response) framework from the driving forces to the effects on human health and ecosystem of six air pollutants (SO_2, NO_x, NH_3, VOC, $PM_{2.5}$ and PM_{10}) and six greenhouse gases (CO_2, CH_4, N_2O the three F-gases). Examples of driving forces include economic activities, energy combustion, and agricultural production (Amann, 2012).

Source-receptor relationships have been developed to consider the atmospheric dispersion process. They quantify the impacts for the EU territory with the 50 km × 50 km grid resolution of the geographical projection of the EMEP model from changes in emissions of SO_2, NO_x, NH_3, VOC, $PM_{2.5}$ of the 25 Member States of the EU, Romania, Bulgaria, Croatia, Norway and Switzerland, and five sea areas (Amann, 2012).

Particularly for $PM_{2.5}$, the source-receptor relationships developed for GAINS describe the response in annual mean $PM_{2.5}$ levels to changes in the precursor emissions SO_2, NO_x, NH_3 and primary $PM_{2.5}$. In addition, a generalized methodology was developed to describe the urban increments in $PM_{2.5}$ concentrations in urban background air that is emitted from local sources (Amann, 2012).

The size of urban agglomerations and populations are critical to estimate the urban increment of $PM_{2.5}$ concentration and exposure in a given city. This information has been collected for 473 European cities in Europe with more than 100,000 inhabitants. Urban areas and diameters were derived from the JRC European population density data set and the www.citypopulation.de database, thereby linking population density for the individual urban agglomerations considered (Amann et al., 2011).

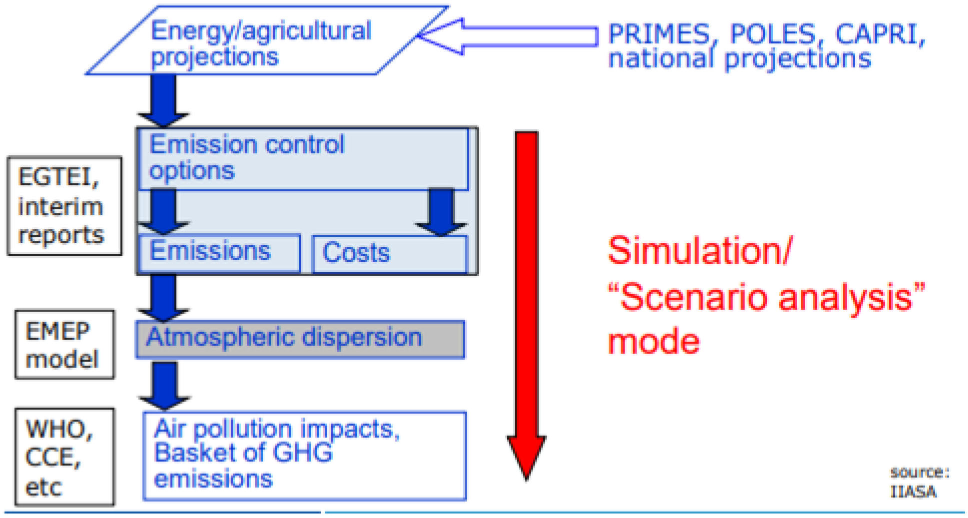


Figure 6: The GAINS model structure *(Stefan Åström, 2015)*

4.1.5 Integrating EUCalc and GAINS

The EUCalc model outputs activity for different sectors in different countries and in different years. This is stage 1 of the IPA.

The module makes use of the work that has already gone into GAINS to use derived 'population-average exposure factors' from GAINS that can be used to quantify population exposure directly by multiplying with the activity. This can be interpreted as combining steps 2-4 of the IPA.

Emissions are a function of fuel mix, energy consumption and emission control technologies. The fuel amount is factored out at the end to get to a per-PJ value. Concentration is a function of emissions in all EU member states and atmospheric transport. Exposure is a function of pollutant concentration and population in the receptor country, and by using population-averaged exposure factors, we are able to scale with the different population projections allowed as levers within EUCalc.

To reflect that emissions in one country can impact on air pollution in another, we use country to country factors; i.e. how emissions in country ***i*** affect the population weighted concentrations in country ***j***.

The units of the '**energy-based population-averaged exposure factors**' provided by IIASA are:

$$\langle(\mu g/m^3)\rangle_j / PJ_i \, ,$$

where $\boldsymbol{i}$ and $\boldsymbol{j}$ are the source and receptor countries, respectively. These can be multiplied with the energy consumption of each sector to obtain population-weighted pollutant concentrations from activity in different energy conversion sectors and countries.

Some sources of emissions are however not driven by combustion, and activity is best assessed by a different metric. This is the case for process emissions in industry and livestock and fertiliser application emissions in agriculture. In those cases, we chose alternative units for the denominator of the population-averaged exposure factors: tonne of material (process emissions, fertiliser application) and LSU (for livestock). The calculation logic is the same as for energy.

In cases where there is an imperfect alignment of sectors in EUCalc and GAINS, IIASA also provides '**emissions-based population-averaged exposure factors**' with units of (μg/m³)/tonne of emissions:

$$<(\mu g/m^3)>_j/(\text{tonne of emissions species})_i \, .$$

This made it possible to calculate emissions for sectors that are not already included in GAINS, or for sectors that are modelled in greater detail in EUCalc than in GAINS.

Collectively, all these factors are called '**activity-based population-averaged exposure factors**'.

4.1.6 Estimating human health impacts

Human health impacts are calculated using the methodology developed in the ExternE studies, with updated data from the HRAPIE studies (Holland, 2014).

The method consists of calculating the relative risk (RR) of a health impact due to a change in concentration of a pollutant. The RR is derived from a concentration response function (CRF) which is based on epidemiological evidence. RR is the equivalent to the ratio of conditional probability of incidence of a health impact due the concentration to probability of incidence without the concentration. For example, several meta-analyses have shown that the RR of all-cause mortality from exposure to $PM_{2.5}$ is robust to different cohorts and studies. The RR can be characterised as a 1.06 RR per 10 μg/m³ increase in $PM_{2.5}$ concentration (with an uncertainty range of 1.02 to 1.11) (Henschel & Chan, 2013). There is not enough scientific evidence to apply country-specific CRFs, therefore this will be treated as a constant across the EU28+1 and in time.

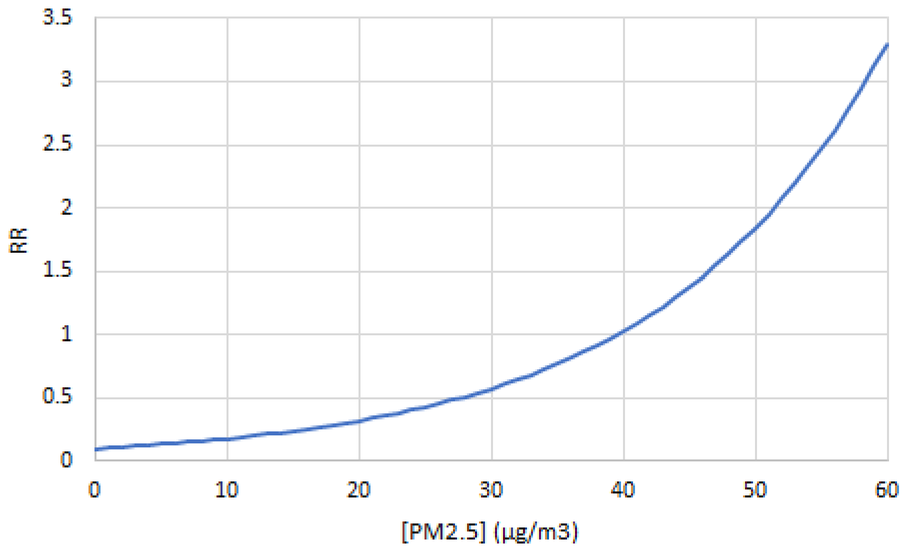


Figure 7: The relative risk of all-cause mortality associated with long term exposure to $PM_{2.5}$

The attributable fraction (AF) of an observed incident rate due to the change in concentration is defined as:

AF = (RR-1)/RR

Finally, the total incidents of a health impact due to the change in concentration can be calculated by multiplying the AF to the current baseline rate of incidence, B, and with the population exposed, P.

I = AF × B × P

The health metric that is calculated is total mortality. This is done by using data from the HRAPIE study on mortality from $PM_{2.5}$ exposure to define a CRF. The baseline mortality rates (B) is derived from existing literature, including European Environment Agency (European Environment Agency, 2018a). Detailed databases on mortality are aggregated by the WHO for Europe which will be used to define the baseline rate (WHO, 2018).

The population is calculated based on inputs from the lifestyle module in EUCalc. In the GAINS model, population growth and distribution follow only one scenario into the future. EUCalc however provides the user with a lever for population, which defines four scenarios in which assumptions on population growth and urbanisation vary.

This creates a potential disconnect between the two models, which has been resolved by:

1. Exposure data from GAINS is divided by the underlying population scenario before it is used in EUCalc. This data is then multiplied by the EUCalc population, thereby adjusting for differences in population growth assumptions.
2. Since emissions that impact the most exposure tend to move with people, we estimate that different population distribution assumptions will not change the population-average exposure factors and potential changes to the spatial location of population and emissions are considered negligible.

4.1.7 Quantifying the costs of health impacts

It is common practice to estimate the costs associated with different health impacts of air pollution; most commonly premature deaths and years of life lost (YLL) (European Environment Agency, 2018a). Costs will be derived from existing literature, including from the EEA (Holland, M. et al., 2014; Holland, Mike, 2016).

Cost = I × Cost per incident

To evaluate the cost of mortality in this module the Value of a Statistical Life (VSL) is used to quantify the cost associated with a mortality, this is a common method is used throughout the European Region (WHO Regional Office for Europe, OECD, 2015). The OECD and the WHO have created an averaged VSL across the EU at $3 million US Dollars and also country specific VSL, allowing both European wide and country specific aggregated monetary impacts from mortality due to air pollution.

4.2 Scope definition

The scope of the health module is described below. It defines the granularity of the model in terms of time, countries, pollutants and technologies.

Pollutants

The health module calculates annual mean $PM_{2.5}$ levels, which include changes in the precursor emissions SO_2, NO_x, NH_3 and primary $PM_{2.5}$.

Countries

Similar to the rest of EUCalc, the EU28 and Switzerland are modelled.

Technologies

Technologies have been chosen to allow for a mapping between EUCalc and GAINS, which imply aggregating some of the underlying granularity on both sides.

In the health module, a technology is represented by its activity, modelled in the corresponding sector, and its exposure factor.

The exposure factors for different technologies in different countries change in time with 5-year timesteps from 2005 reflecting the evolution of emissions control technologies and regulations.

Transport

- Combustion
    - Vehicle types
        - Light-duty vehicles (LDV, corresponding to GAINS' category "LDV4C")
        - Heavy-duty vehicles (HDV, which includes the light-duty trucks that are classified in GAINS as "LDV4T")
        - Bus
        - 2-wheels (2W)
        - Aviation (only take-off and landing emissions)
        - Sea-going ships (small and large)
        - Inland waterways
    - Engine types
        - Internal combustion engines (ICE)
        - Plug-in hybrid electric vehicles (split by fuel use) for LDV, HDV, bus and 2W
    - Fuel type
        - Diesel

        - Gasoline
        - Natural gas
        - Jet fuel
        - Marine fuel oil
- Abrasion
    - Vehicle types
        - LDV (corresponding to GAINS' category "LDV4C")
        - HDV (which includes the light-duty trucks that are classified in GAINS as "LDV4T")
        - Bus
        - 2-wheels
    - Emission source
        - Tyres
        - Brakes

Buildings

- Heating
    - Heating system type
        - Decentralised
        - District
    - Energy vector
        - Natural gas
        - Heating oil
        - Solid biomass
        - Coal

Industry

- Type of material produced:
    - Steel
    - Cement
    - Ammonia
    - Chemicals (excluding ammonia)
    - Pulp and paper
    - Aluminium
    - Glass
    - Lime
    - Copper (primary and secondary)
- The type of material is further broken down by type of energy carrier used for production (for production emissions):
    - Biogas
    - Natural gas

    - Liquid biofuel
    - Oil
    - Solid biofuel
    - Coal
    - Waste
- Specifically, for process emissions, some technology are broken down into their main production process technologies:
    - Aluminium
        - Primary
        - Secondary
    - Cement
        - Dry kilns
        - Wet kilns
        - Geopolymer
    - Paper
        - Recycled
        - Wood pulp
    - Steel
        - Blast furnace – basic oxygen furnace (BF-BOF)
        - Scrap – electric arc furnace (Scrap-EAF)
        - Hydrogen – Direct reduced iron (Hydrogen-DRI)
        - Hisarna

Electricity production

- Natural gas
- Oil
- Coal

Agriculture

- Direct energy use
    - Diesel
    - Gasoline
    - Coal
    - Oil
    - Natural gas
- Fertilizer application (nitrogen)
- Livestock population
    - Dairy milk cows
    - Egg hens
    - Bovine
    - Pigs

  - Poultry
  - Sheep
  - Other animals

4.3 Interactions with other modules

4.3.1 Inputs from other modules

4.3.1.1 *Lifestyle*

The Lifestyle module of EUCalc provides the user with a lever for population, which defines four scenarios for population growth for each country and each year. This data varies with the scenario selected by the user.

4.3.1.2 *Buildings*

The buildings module provides energy demand data in TWh for each heating system type and each vector, as mentioned in the section Scope definition.

4.3.1.3 *Transport*

The transport module provides the following data:

- Energy demand in TWh for each vehicle type, engine type and fuel type according to the modelled technologies as specified in Scope definition, with the following exceptions:
  - Heavy-duty vehicles are split into three sub-categories: light, medium, heavy
  - Energy demand for PHEV vehicles include only the non-electric component
- Distance travelled expressed in vehicle-km for LDV, bus, 2W, HDVL, HDVM, HDVL.

Matching a common level with GAINS requires to sum the three HDV categories for both types of variables.

In addition, each fuel is split into 3 variants: regular fossil fuels, e-fuels and biofuels. This granularity is not modelled in GAINS, so e-fuels and biofuels have been aggregated with the corresponding fossil fuel for calculations.

Fuel consumption in the aviation sector is handled differently in EUCalc and in GAINS. In EUCalc, energy consumption represents the total consumption of the flight, while GAINS models only take-offs and landings. GAINS exposure factors have therefore been adapted by IIASA so that they can be multiplied by total flight consumption.

4.3.1.4 Industry

The industry module provides energy demand data in TWh for each subsector and each vector, as mentioned in the section Scope definition.

In addition, the module provides the quantity of material produced for each subsector and production technology when available.

Since GAINS doesn't differentiate ammonia from other chemicals, it has been aggregated with the chemical subsector for both energy and material production variables.

As a rule, combustion emissions are calculated based on the energy demand from the industry sector, and process emissions are calculated based on the quantity of material. However, GAINS models cement, lime and glass differently: all emissions are calculated based on material production. For these three subsectors, direct energy consumption from the industry module is therefore ignored.

Note that the industry sector models a few additional sectors that represent a small fraction of the total. These sectors have not been included in this first release of the Health module:

- Transport Equipment
- Food, beverages and tobacco
- Textiles and leather
- Machinery Equipment
- Wood and wood products
- Other Industrial Sectors

4.3.1.5 Agriculture

The agriculture module provides the direct energy consumption of the agricultural sector by energy vector in TWh. In addition, it provides activity metrics for livestock and nitrogen fertiliser application respectively in LSU and in tons.

Note that fertiliser production is included in the industry sector.

4.3.1.6 *Electricity*

The electricity module provides energy demand data in TWh for each energy vector used for production of electricity, as mentioned in the section Scope definition.

4.3.2 Outputs to other modules

4.3.2.1 *Transition pathway explorer*

The only output of the health module is to the pathway explorer and consists of:

- Mortality attributable to pollution exposure per year for each EU28+1 country
- Cost of air pollution attributable mortalities

4.4 Detailed calculation trees

4.4.1 Pre-processing steps

Data from the GAINS model has been pre-processed at IIASA before being used as input in the health module. The steps performed in this pre-processing are:

- Extraction of exposure factors by dividing the population exposure by the activity metrics, to have exposure factors per activity unit.
- Division by the GAINS population variable to obtain population-averaged exposure factors.

As mentioned earlier, the activity metrics can be either energy (in PJ), production- or usage-related metrics (tons or LSU) or emissions (in tons).

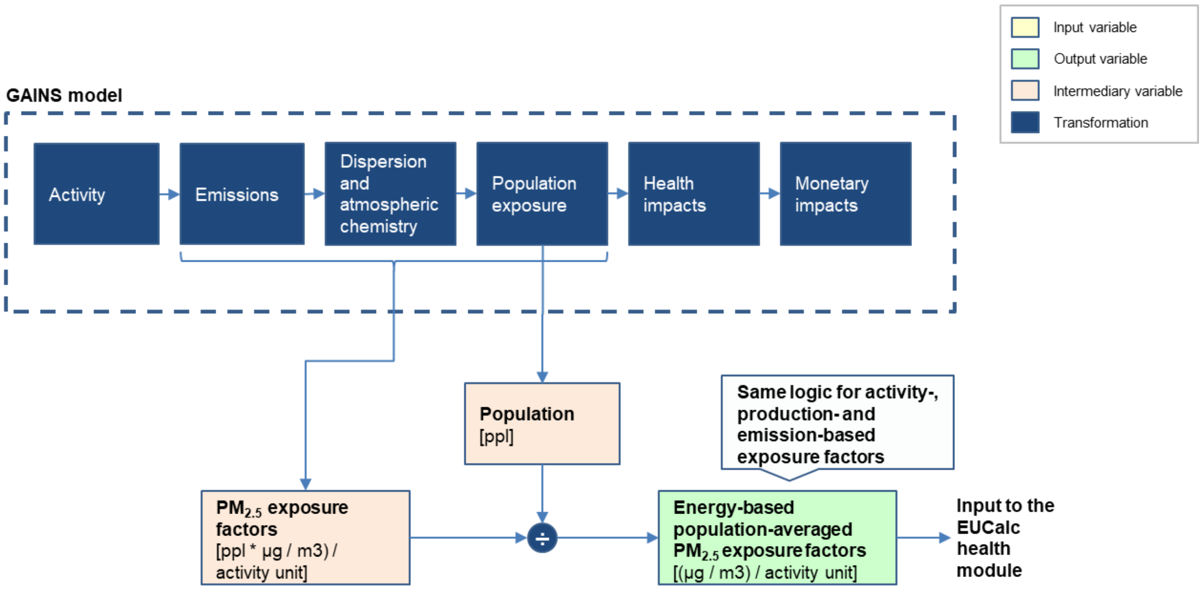


Figure 8: Pre-processing steps executed by IIASA on GAINS data

4.4.2 Mapping between GAINS and EUCalc

The mapping step has the following objectives:

- Prepare the exposure factors from GAINS to be mapped to EUCalc data by aligning the variable names and converting the units
- Prepare the EUCalc activity data to be mapped to the exposure factors by summing variables across dimensions that are too granular (e.g. HDV subdivision)
- Convert activity-based data to emissions-based data to align granularity with GAINS (for vehicle emissions from brakes and tyres).

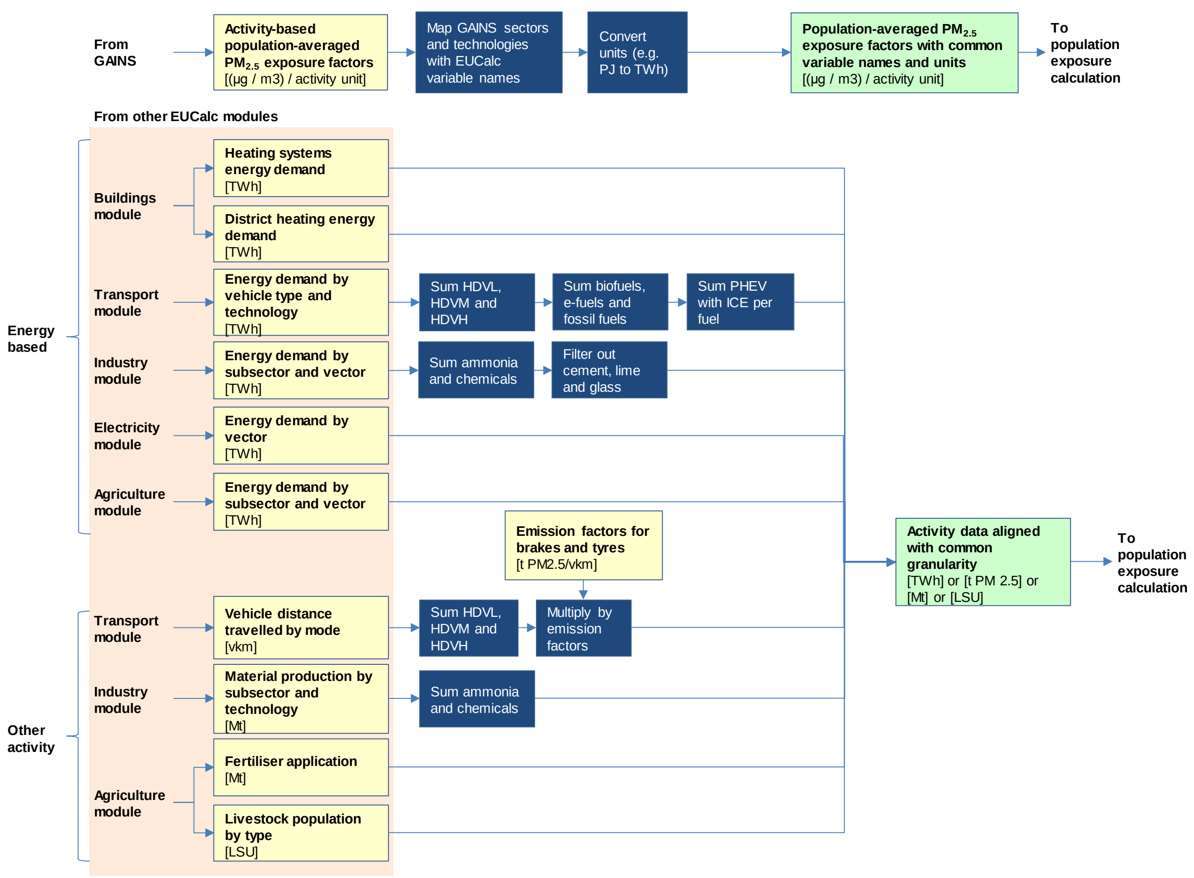


Figure 9: Mapping data from GAINS with EUCalc data

4.4.3 Population exposure

The population exposure tree uses input from the pre-processing step and from the lifestyle module to calculate the average $PM_{2.5}$ exposure for each EU28+1 country and the aggregated European population.

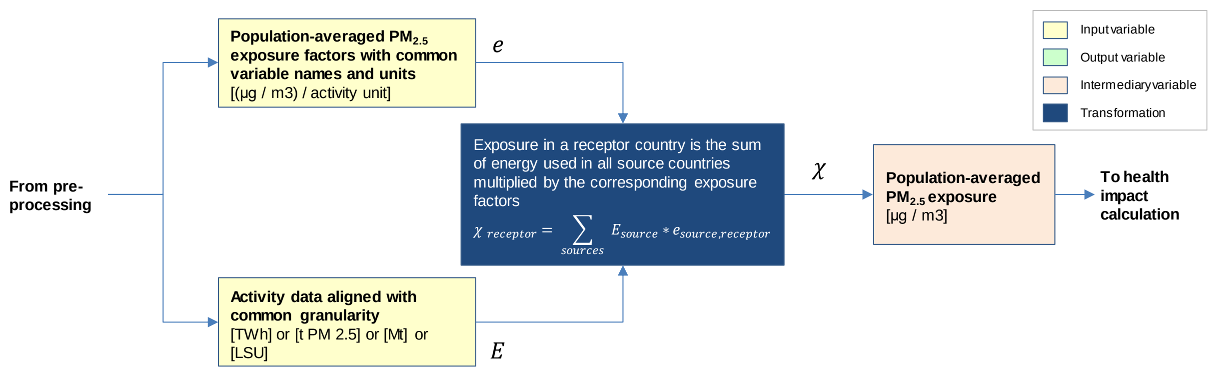


Figure 10: Calculation tree for population exposure to $PM_{2.5}$

4.4.4 Health and monetary impacts

This step uses the result of the previous step together with additional inputs (European Mortality Database (WHO, 2018) and Value of a Statistical Life data (WHO Regional Office for Europe, OECD, 2015) and the population data from the lifestyle module to calculate the health and monetary impacts.

Since baseline mortality is only available for years up to 2015, baseline mortality for future years have been assumed constant in percentage of the population, as provided by the lifestyle module.

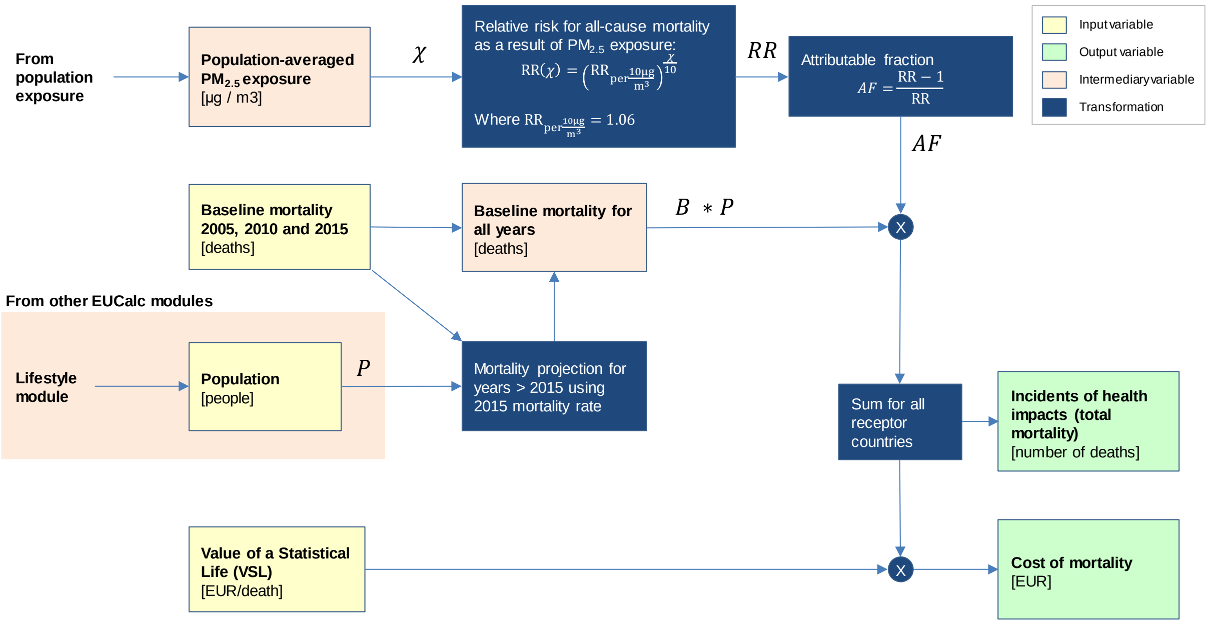


Figure 11: Calculation tree for health and monetary impact of exposure to $PM_{2.5}$

4.5 Validation and calibration

The calculated health impacts and monetary costs will be compared to other estimates of the health impacts and costs of air pollution across Europe (European Environment Agency, 2018a). However, since EUCalc does not include all sectors of the economy and all sources of pollution including biogenic sources, the estimates from this module should be lower than estimates that do include the full range of sources.

5 Description of constant or static parameters

5.1 Constants

- Concentration Response Function (CRF), defined by the Relative Risk for concentrations of PM2.5, is constant.

5.2 Static parameters

- Exposure Factors (derived from the GAINS model)
- Emission Factors (from the GAINS model)
- Baseline mortality rates (European Morbidity Database – WHO)
- Value of Statistical Life (Economic cost of the health impact of air pollution in Europe - WHO and OECD)

6 Historical Database

This section describes each historical dataset that is used in the model. When the base year (2015) data is not available in the required granularity (e.g. all countries, all technologies), we apply some hypothesis to fill the gaps.

Dataset	**Description**	**Source**
Exposure Factors	Factors derived from the GAINS model.	IIASA
Emission factors for brakes and tyres	Factors used in the GAINS model.	DOI: 10.22022/AIR/08-2019.51 http://dare.iiasa.ac.at/51/ IIASA
Baseline Mortality Rate (European Mortality Database)	Data of mortality rates in the EU. Contains European average and country specific values.	WHO
Value of a Statistical Life	Economic cost of a human life in Europe. Contains European	WHO and OECD

	average and country specific values.	

Table 4: Historical Databases used in WP6.

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