EUCALC

Explore sustainable European futures

Integration of the "Jobs, valued added and social impact" module

D8.7

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Short Description
This report details how the socio-economic modules (namely the Air Pollution and Human Health module and the Employment module) were integrated into the EUCalc model. It presents the calculation trees and the interactions between these modules and the rest of the calculator.

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This deliverable contains original unpublished work except where clearly indicated otherwise.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

2W	Two-wheels vehicles
EU	European Union
EU28	European Union 28 Member States
EUCalc	European Calculator project
HDV	Heavy-duty vehicles
GAINS	Greenhouse Gas-Air pollution Interactions and Synergies
IIASA	Institute for Applied Systems Analysis
IPA	Impact Pathway Approach
ISCED	International standard classification of education
LDV	Light-duty vehicles
PM	Particulate Matter
TPE	Transition Pathway Explorer
WP	Working Package

1 Executive Summary

This deliverable describes how the Air Pollution and Human Health module and the Employment module were integrated into the EUCalc model. The overall logic and the scope of each module are introduced. Their interactions with other EUCalc modules and their detailed calculation trees are explained.

The objective of this report is to provide a transparent description of the socio-economic modules. This serves two purposes. First, the credibility and trust in the model results depend on the ability of users to understand the methods and assumptions behind the model. Second, it allows researchers to build on the existing work to implement improvement and new features in the calculator.

2 Introduction

The model designed by the European Calculator project (EUCalc) enables end users to simulate a wide range of decarbonisation pathways in the European Union 28 member states (EU28) and in Switzerland and to visualize online their associated environmental and socio-economic impacts. The socio-economic impacts included in the model were determined thanks to an online stakeholders' survey and to the co-designed expert workshop held in Delft on December 1st, 2017. Stakeholders selected human health, employment and training and education as the most important issues. A detail report of this process is available in Deliverable 6.3 (Pashaei Kamali et al., 2018).

Air pollution can lead to a range of serious adverse outcomes, from increased admissions to hospital in the short term to premature mortality in the long term. Decarbonisation efforts could also help improve the air quality, for instance thanks to the replacement of fossil fuel engines vehicles with electric vehicles. The impacts on human health are computed in the Air Pollution and Human Health module. The methods and data used to quantify and to monetize the effects of air pollution on health are described in Deliverable 6.7 (Stettler et al., 2019).

Transitions toward low carbon societies could stimulate job creation due to substitution of energy intensive goods with labour intensive goods or to an increase in investment that stimulates economic growth. In addition, decarbonisation pathways might intensify the demand for highly-skilled workers, resulting in higher needs for training and education. These questions are tackled in the Employment module. A complete description of the Employment module is provided in Deliverables 6.6 and 6.8 (Thurm and Vielle, 2019a; 2019b).

The objective of this report is to explain how the methods designed to assess the socio-economic impacts were integrated into the calculator, i.e., how they were implemented in the KNIME software. This deliverable also aims to help the implementation of future improvement and new features in the calculator thanks to a transparent description of the model.

The rest of the deliverable is organised as follows. The calculation logic of the Air Pollution and Human Health module are detailed in Section 3. The integration of the Employment module is explained in Section 4. We conclude in Section 5 with some lessons learned.

3 Air Pollution and Human Health module

3.1 Overall logic

The Air Pollution and Human Health module quantitatively estimates the impacts on health of air pollution of the different decarbonisation pathways simulated in the calculator. A short presentation of the methods used is provided below. For a full description, including the underlying assumptions, the data sources, and the limitations of the module, please refer to Deliverable 6.7 (Stettler et al., 2019).

The methodology used is the impact pathway approach (IPA) which consists in six steps presented in Table 1 and illustrated in Figure 1.

Table 1: Stages of the impact pathway approach

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

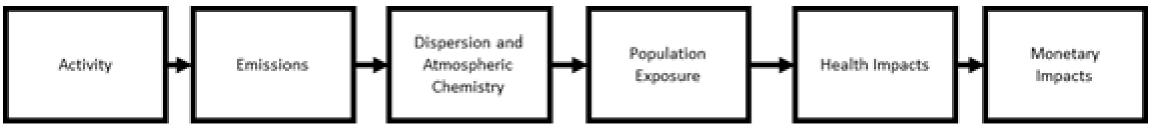

Figure 1: Impact pathway approach

The activity levels for different sectors in different countries and years (step 1) are obtained using inputs from the EUCalc sectoral modules (e.g., Transport, Buildings, Industry, Agriculture, Supply). Then, the population exposure to changes in air pollutant concentrations (steps 2 to 4) is derived from "population-average exposure factors", which were computed by the Greenhouse gas-Air pollution Interactions and Synergies (GAINS) model. This approach allows to quantify accurate emissions factors for each sector and country, accounting for different technological development pathways, and to incorporate the spatial distribution of emissions and the dispersion and transport of air pollutants across Europe. Finally, human health impacts (step 5) are calculated using the methodology developed in the ExternE studies, with updated data from the HRAPIE studies (Holland, 2014). The output of this process is the total mortality due to air pollution. This metrics is then monetarised using the Value of Statistical Life to estimate the costs of health impacts due to air pollution.

3.2 Scope

The Air Pollution and Human Health module calculates annual mean $PM_{2.5}$ levels, which include changes in the precursor emissions SO_2, NO_x, NH_3 and primary $PM_{2.5}$, for the EU28 countries and Switzerland. The technologies included, i.e. the pollutants' sources, are detailed in Table 2.

Table 2: Technologies considered in the Air Pollution and Human Health module

Sector	Process	Type	Vector	
Transport	Combustion	Vehicle	Light-duty vehicles (LDV)	
			Heavy-duty vehicles (HDV)	
			Bus	
			2-wheels (2W)	
			Planes	
			Sea-going ships	
			Inland waterways ships	
		Engines	Internal combustion engines	
			Plug-in hybrid vehicles (LDV, HDW, bus, 2W)	
		Energy carriers	Diesel	
			Gasoline	
			Natural gas	
			Jet fuel	
			Marine fuel oil	
	Abrasion	Vehicles	LDV	
			HDV	
			Bus	
			2W	
		Source	Tyres	
			Brakes	
Building	Heating	Heating System Type	Decentralised	
			District	
		Energy carriers	Natural gas	
			Heating oil	
			Solid biomass (includes wood)	
			Coal	
Industry	Production processes	Material	Steel	Blast furnace – Basic oxygen furnace
				Scrap – Electric arc furnace
				Hydrogen – Direct reduced iron
				Hisarna
			Cement	Dry kilns
				Wet kilns
				Geopolymer

			Aluminium	Primary
				Secondary
			Paper	Wood pulp
				Recycled
			Copper	Primary
				Secondary
			Ammonia	
			Chemicals (excluding ammonia)	
			Glass	
			Lime	
			Other industries	
	Combustion	Energy carriers	Natural gas	
			Biogas	
			Oil	
			Liquid biofuel	
			Coal	
			Solid biofuel	
			Waste	
Power	Combustion	Energy carriers	Coal	
			Natural gas	
			Oil	
Agriculture	Combustion	Energy carriers	Diesel	
			Gasoline	
			Coal	
			Natural gas	
	Fertilisation	Chemical	Nitrogen	
	Farming	Livestock	Dairy milk cows	
			Egg hens	
			Bovine	
			Pigs	
			Poultry	
			Sheep	
			Other animals	

3.3 Interactions with other modules

3.3.1 Inputs from other modules

3.3.1.1 Lifestyle

The Lifestyle module provides the evolution of the populations for each country and year as determined by the level of the population lever.

3.3.1.2 Buildings

The Buildings module provides the energy demand (in TWh) for each heating system type and each vector (see Table 2).

3.3.1.3 Transport

The Transport module provides:

- The energy demand (in TWh) for each vehicle type, engine type and energy carriers according to the included technologies (see Table 2). In addition, heavy-duty vehicles are split into three sub-categories: light, medium, and heavy.
- The distance travelled expressed in vehicle-km for LDV, bus, 2W, light HDV, medium HDV, and heavy HDV.

In GAINS, there is no distinction between regular fossil fuels and biofuels. Therefore, these vectors are aggregated in the Air Pollution and Human Health module. Similarly, the energy demand and activities of the three HDV categories are summed.

3.3.1.4 Industry

The Industry module provides:

- The energy demand (in TWh) for each subsector and energy carriers as defined in Table 2.
- The quantity of material produced for each subsector and production technology when available.

The energy demand and production of chemicals and ammonia are aggregated in the Air Pollution and Human Health module to respect the GAINS granularity.

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.

A few additional sectors that represent a small fraction of the total emissions are modelled in the Industry module. These sectors are not explicitly modelled but are accounted for in “Other industries”:

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

3.3.1.5 Agriculture

The Agriculture module provides:

- The direct energy consumption (in TWh) of the agricultural sector for each energy carriers (see Table 2).
- The quantity of livestock expressed in livestock unit (LSU)
- The application of nitrogen fertilizers (in tons).

3.3.1.6 Electricity

The Electricity module provides the energy demand (in TWh) for electricity production for each energy carriers as defined in Table 2.

3.3.2 Outputs

The Air Pollution and Human Health module sends to the Transition Pathway Explorer:

- The mortality attributable to pollution exposure per year and country;
- The cost of air pollution attributable mortalities.

3.4 Detailed calculation trees

This section details how the methods to compute health metrics were integrated into the KNIME software.

3.4.1 Pre-processing steps

First, data from the GAINS model has been pre-processed at the International Institute for Applied Systems Analysis (IIASA) before being used as input in EUCalc.

The population exposures are divided by the activity metrics (e.g., energy demand, production) and by the population to obtain "activity-based population-averaged exposure factors".

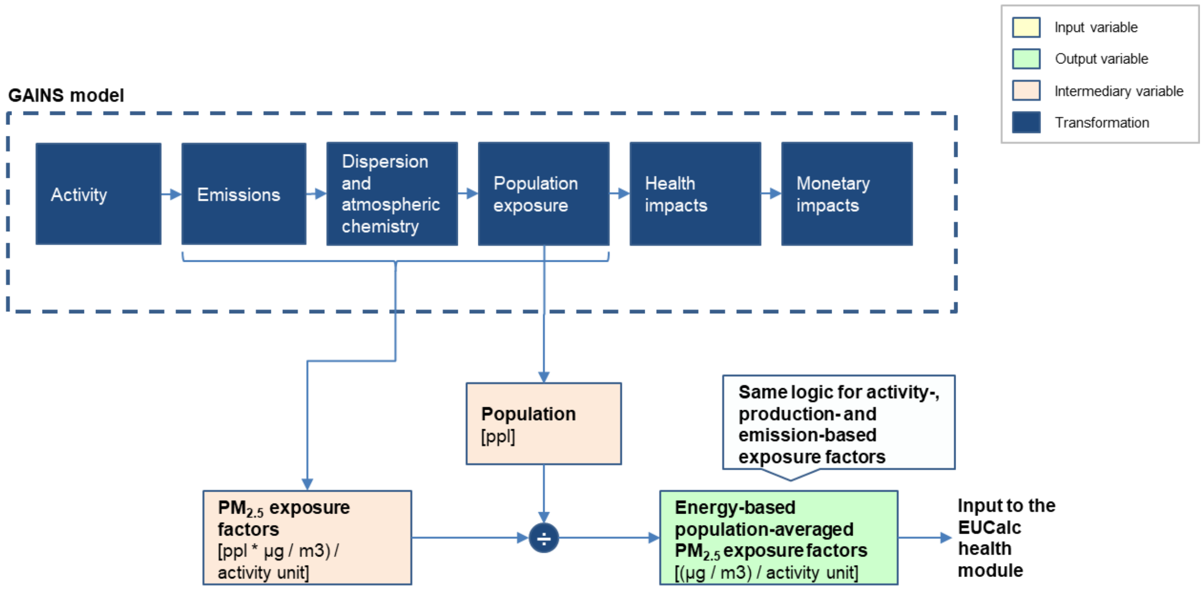

Figure 2: Pre-processing steps executed by IIASA on GAINS data

3.4.2 Mapping between GAINS and EUCalc

The objectives of the mapping are to:

- 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 aggregating the variables following the GAINS granularity.
- Convert activity-based data to emissions-based data to align granularity with GAINS (for vehicle emissions from brakes and tyres).

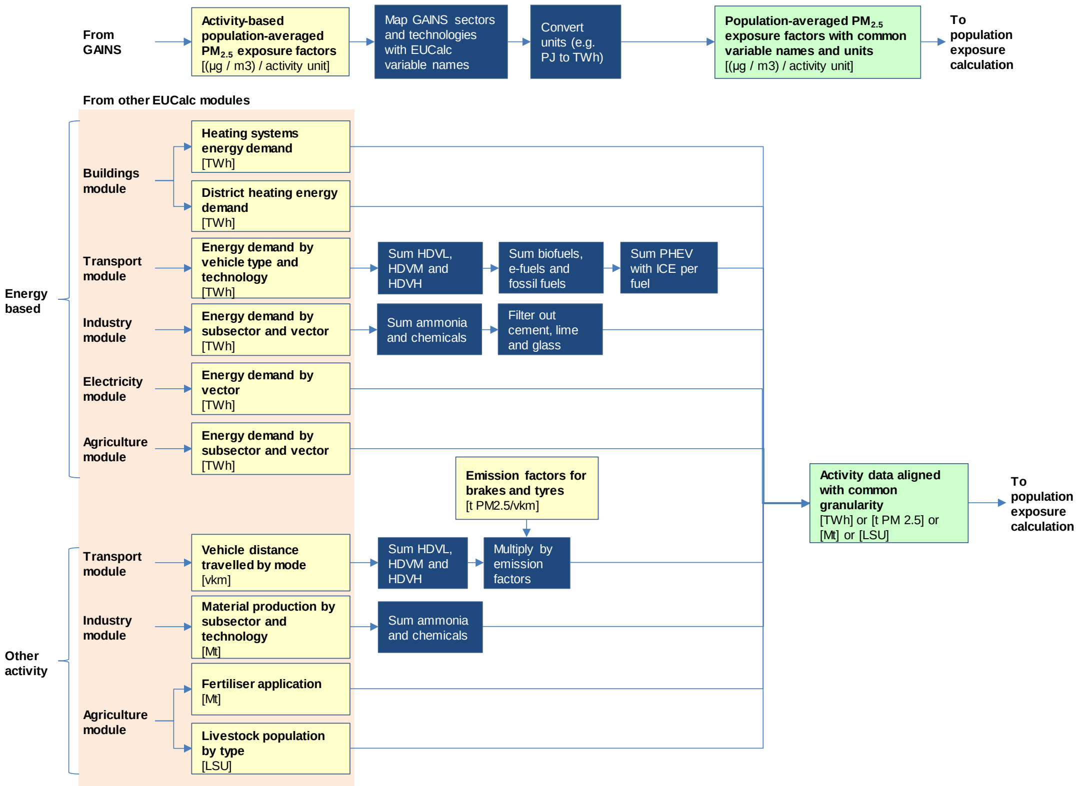

Figure 3: Mapping data from GAINS with EUCalc data

3.4.3 Population exposure

This tree computes the total population-averaged exposure to particulate matter for each country and year by summing the exposures due the activities of each sector.

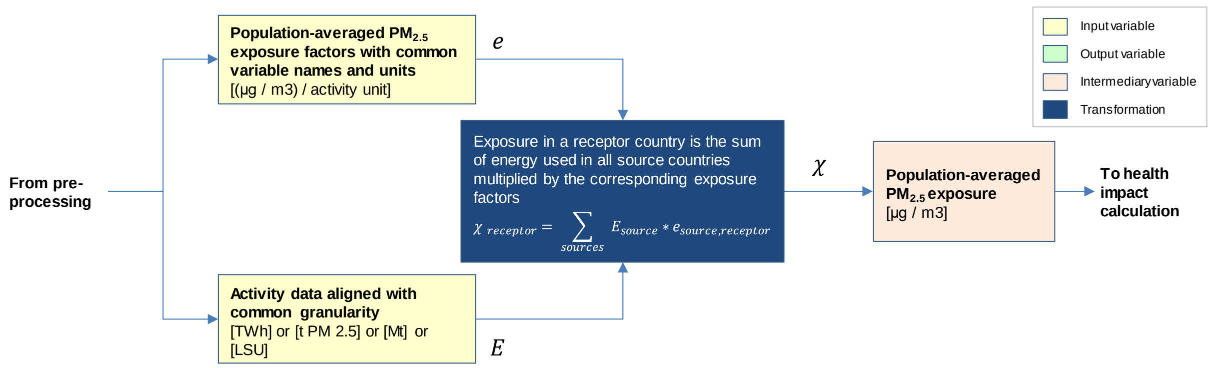

Figure 4: Calculation tree for population exposure to $PM_{2.5}$

3.4.4 Health and monetary impacts

From the population-averaged exposure, the relative risk (RR) of health impacts is calculated from a concentration response function derived from the HRAPIE study (Henschel & Chan, 2013):

$$RR = 1.06^{Exposure/10}$$

Then, the attributable fraction (AF) of an observed incident rate due to the change in relative risk is calculated:

$$AF = (RR - 1)/RR$$

The mortality due to air pollution (I) is computed using the attributable fraction, the baseline rate of incidence (B) and the population exposed (P):

$$I = AF \times B \times P$$

The population is obtained from the Lifestyles module. The baseline rate of incidence (mortality) is derived from the European Mortality Database (WHO, 2018). In the absence of information regarding future mortality rates, it was assumed constant in percentage of the population.

Finally, the costs of air population are computed using the Value of a Statistical Life (VSL), obtained from the OECD and the World Health Organization (WHO Regional Office for Europe, OECD, 2015):

$$Cost = I \times VSL$$

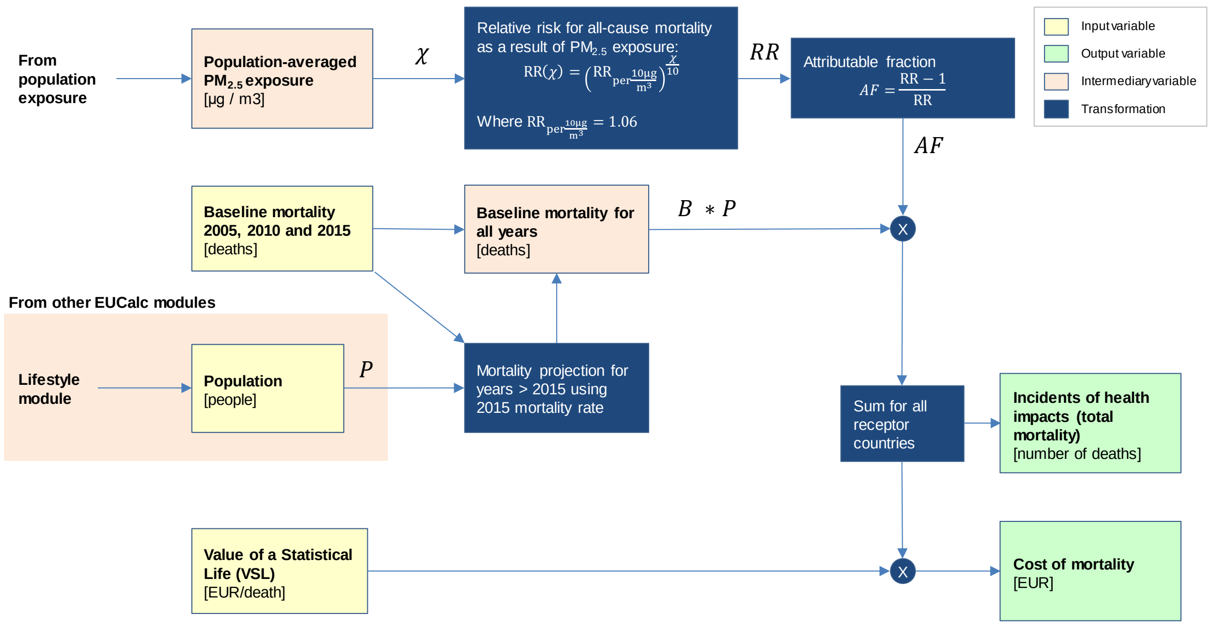

Figure 5: Calculation tree for health and monetary impact of exposure to $PM_{2.5}$

4 Employment module

A detailed description of the Employment module is provided in Deliverable 6.8 (Thurm and Vielle, 2019b) while the process to generate the library of inputs for the module is explained in Deliverable 6.6 (Thurm and Vielle, 2019a). Therefore, this section will only provide a short summary of the overall logic of the module, its scope and its interactions with other modules, before detailing the calculation trees implemented in the modelling framework (i.e., KNIME).

4.1 Overall logic

The employment module uses inputs from the sectoral modules (e.g. Lifestyles, Buildings, Transport, Industry, Agriculture, Electricity) to reproduce the scenario defined by the user in a macroeconomic model. The calculation logic, illustrated in Figure 6, follows several steps.

- A reference scenario is simulated using the Computable General Equilibrium model GEMINI-E3 and in the calculator in order to compute Input-Output tables that represent the state of the economy in each country and for each year of interest. The demographic and economic assumptions behind this reference scenario are detailed in Deliverable 7.1 (Yu and Clora, 2018). The simulation of the reference scenario and the construction of reference Input-Output tables are explained in Deliverable 6.6 (Thurm and Vielle, 2019a);
- Some "indicators of transition" are computed using inputs from the sectoral modules. The interactions with other modules are summarized in Section 4.3.
- The indicators of transition are used to modify the reference scenario and reproduce the scenario defined by the end user. The macroeconomic model used is described in Deliverable 6.8 (Thurm and Vielle, 2019b).
- Employment indicators are computed. They include:
    - Total employment change;
    - Sectoral employment change;
    - Employment change for different educational attainment level.
    - Wages evolution for different educational attainment level.

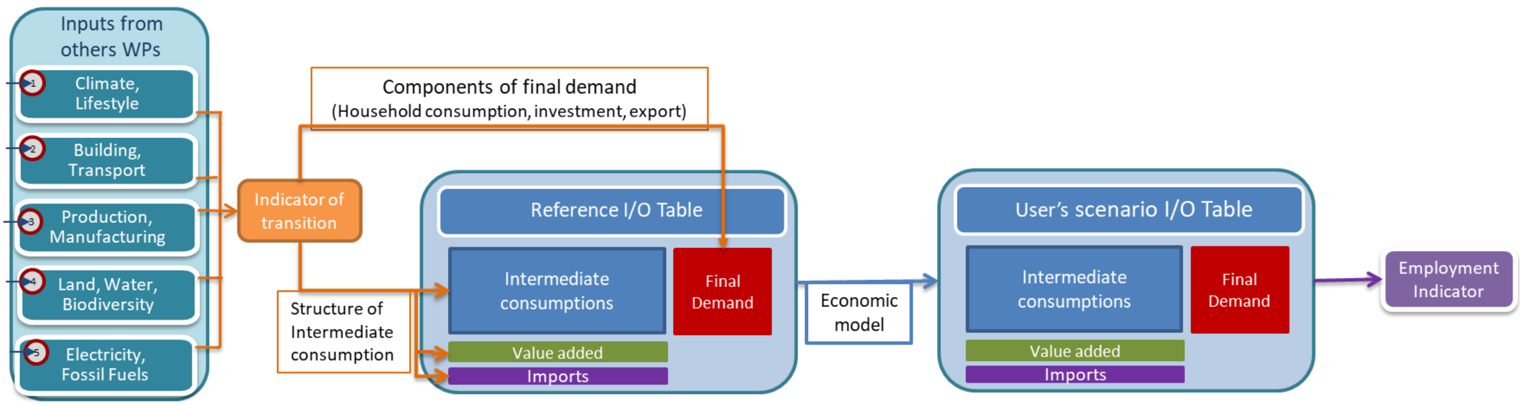

Figure 6: General logic of the Employment module

4.2 Scope

The Employment module computes employment indicators for each EU28 countries and Switzerland.

The industrial sectors included in the model are presented in Table 3.

Table 3: Industrial classification used in the Employment Module

EUCalc WP6 Sectors			
01	Crops, Vegetables & Fruits	29	Glass
02	Livestock	30	Cement
03	Forestry	31	Other non-metallic mineral
04	Fish	32	Iron and steel
05	Processed crops and vegetables	33	Aluminium
06	Processed animal products	34	Copper
07	Beverage	35	Other metal
08	Coal	36	Mineral mining
09	Crude oil	37	Construction
10	Petroleum product	38	Rail transport
11	Gas	39	Road transport
12	Electricity distribution	40	Water transport
13	Coal power	41	Air transport
14	Gas power	42	Transport nec
15	Nuclear power	43	Transport machinery
16	Hydropower	44	Appliances
17	Wind power	45	Other consumption good
18	Oil power	46	Trade
19	Biomass power	47	Hotels and restaurants
20	Photovoltaics	48	Education
21	Solar thermal power	49	Health
22	Marine power	50	Recycling
23	Geothermal power	51	Waste incineration
24	Wood manufacture	52	Biogas
25	Water	53	Composting
26	Pulp and paper	54	Wastewater
27	Chemicals, plastic, rubber	55	Landfill
28	Fertilizer	56	Other services

In addition, the module distinguishes two types of worker, defined following the International standard classification of education (ISCED):[1]

- Unskilled worker: primary and secondary education (ISCED levels 0-4);
- Skilled worker: tertiary education (ISCED levels 5-8).

[1] See UNESCO Institute for Statistics (2012) for a detailed definition of ISCED education levels.

4.3 Interactions with other module

4.3.1 Inputs

4.3.1.1 Lifestyle

The Lifestyle module provides:

- The household food consumption (expressed in kilocalories) of Crops, vegetables and fruits; Processed crops and vegetables; Animal products; Fish and Beverage;
- The household consumption of paper (in tons);
- The population in age of working (20-65).

4.3.1.2 Buildings and District Heating

The Buildings and District Heating modules sends to the Employment module:

- The energy demand (in TWh) in residential and non-residential buildings (Health, Education, Trade, Hotels and restaurants, and Offices). The energy carriers include: electricity, oil, natural gas, coal, wood logs, and pellets.
- The investment (in million euros) in renovation;
- The investment (in million euros) in network infrastructure for district heating systems (pipes);
- The household purchases of new appliances (in million euros): fridges, freezers, washing machines, dishwashers, dryers, computers, phones, TV.

4.3.1.3 Transport

From the Transport module, the Employment module gets:

- The energy demand (in TWh) for transportation of households and in the various transport sectors (rail, road, air, water). The energy carriers included are: diesel, gasoline, electricity and gas;
- The distance travelled by households (in person-km) with light-duty and two-wheels vehicles, rail transport (trains, metro, tram), bus, and planes;
- The freight activity (in tons-km) for each transport sector (rail, road, air water);
- The purchase of new vehicles (in million euros), for each transport technology.

4.3.1.4 Industry

The Industry module sends to the Employment module:

- The energy demand (in TWh) of the following sectors: iron and steel, cement, lime, chemicals, ammonia (sector Fertilizers), pulp and paper, aluminium, glass, textile, transport machinery and copper. The energy carriers included are: electricity, oil, gas, coal;
- The material needs (in tons) of the following sectors: construction, transport machinery, appliances. The material vectors include: steel, cement and lime, paper, chemicals, glass, aluminium and timber;
- The investment in new technology (in million euros) for the sectors: iron and steel, cement, lime, pulp and paper and glass;
- The domestic production share of iron and steel, cement, lime, chemicals, ammonia, pulp and paper, aluminium, glass, and copper.

4.3.1.5 CCUS

The Carbon Capture, Use and Storage (CCUS) module provides the investment (in million euros) in new carbon storage and carbon use technologies.

4.3.1.6 Agriculture

From the Agriculture module, the Employment module gets:

- The energy demand (in TWh) of the agriculture sectors. The energy carriers include are: electricity, gasoline, diesel, coal and natural gas;
- The fertilizer needs to grow crops and vegetables (in tons), including mineral-based fertilizers, animal manure and biocompost;
- The livestock feed composition (in kcal), detailed between crops and vegetables, processed crops, processed animal meals, and fish;
- The domestic production share of agriculture sectors.

4.3.1.7 Electricity and Storage

The Electricity and Storage modules send to the Employment module he operational expenditures of each power source and the investment needed for the construction of new power plants. The power sources included are:

- Nuclear
- Coal
- Gas
- Oil
- Wind offshore and inshore
- Concentrated solar power
- Photovoltaics
- Hydropower
- Marine power
- Geothermal
- Biomass power

4.3.2 Outputs

The employment module sends to the Transition Pathway Explorer for each country and time step the following employment indicators, all defined with respect to the reference scenario:

- Total employment change;
- Sectoral employment change;
- Employment change for skilled and unskilled workers;
- Wages evolution of skilled and unskilled workers.

4.4 Detailed calculation trees

The Employment module calculation can be divided into three main components:

1. Creating indicators of transition;
2. Modification of the reference scenario;
3. Computing the employment indicators by solving the macroeconomic model.

4.4.1 Indicators of transition

The Employment module receives inputs from the sectoral modules (e.g. Lifestyle, Buildings, Transport, Industry, Agriculture, Electricity supply). Each input variable is used to create "transition indicators" that corresponds to one of the following economic flows:

- Household consumption of a good;
- Investment in a sector;
- Intermediate demand by one sector of a given good;
- Net trade (import-export).

Therefore, the first step consists of aggregating the input variables received from the sectoral modules to map the economic flows and sectors of the Employment module:

- The Household consumption of Electricity includes the electricity demand in Buildings (for heating and appliances use) and in Transports for electric vehicles;
- The Household purchase of appliances is the sum of the purchase of each type of appliances;
- The cement and lime inputs (from the Industry module) are aggregated, corresponding to the Cement sector of the Employment module;
- The Investment in the Construction sector includes the renovation of buildings, the construction of transport and district heating infrastructure, the construction of infrastructure for carbon storage, and the construction of new power plants;
- The Household purchase of Transport Machinery is the sum of the light-duty and two-wheels vehicles.
- The Investment in Transport Machinery is the sum of the investments in all technologies of the rail sector, bus, trucks, boats and planes;
- The Investment in each industrial sector is the sum of the investments in all the technologies of this sector.

Then, for each economic flow, a transition indicator is created when information is available. These transition indicators are simply the change with respect to the reference scenario, as defined in Deliverable 6.6 (Thurm and Vielle, 2019a).

For example, for households' purchase of vehicles:

$$indicator\_household\_vehicle - purchase = \frac{vehicle\ purchase\ [MEUR]}{reference\ vehicle\ purchase\ [MEUR]}$$

Figure 7 shows the calculation flow to compute the transition indicators related to the Household purchases and the Investment in Transport machinery. The first block, "Column Filter" selects the relevant input variables. The second one computes the reference household vehicle purchase and reference investment by summing over all transportation modes and technologies. The third block does the same operation but for the user's scenario. Finally, the fourth and fifth blocks compute the indicator, as defined above.

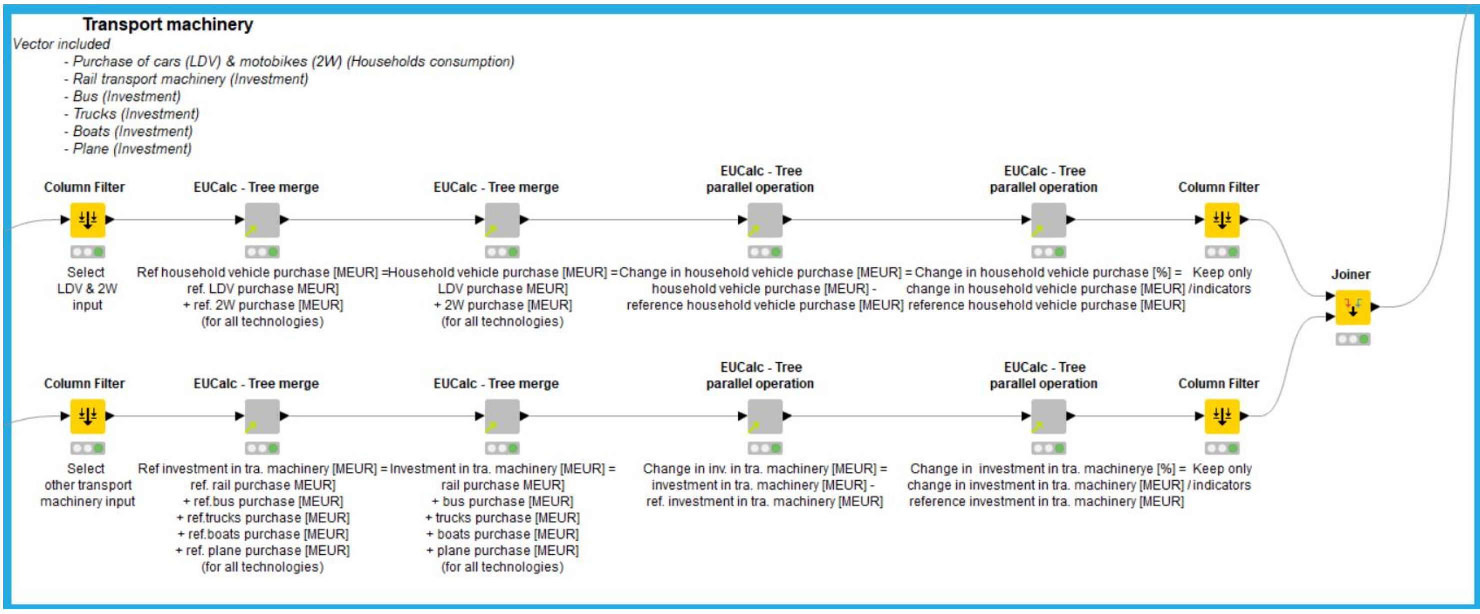

Figure 7: Example of calculation flow to compute a transition indicator

The indicators of transition are computed for the following economic flows:

- Energy consumption (Electricity, Petroleum product, Gas, Coal) of households, and in agriculture sectors (Crops, vegetables and fruits, Livestock, Forestry, Fish), in industry sectors (Iron and steel, Cement and lime, Chemicals, Fertilizers, Pulp and paper, Aluminium, Glass, Textile, Transport machinery), in transport sectors (Rail transport, Road transport, Air transport, Water transport) and in some service sectors (Health, Education, Hotels and restaurants, Trade, Other services);
- Household food consumption of Crops, vegetables and fruits, Livestock, Processed crops and vegetables, Processed animal, Fish and Beverage;
- Households consumption of Rail transport, Road transport (bus), Air transport;
- Household material use of Pulp and paper;
- Material use (Iron and steel, Cement and lime, Pulp and paper, Chemicals, Glass, Aluminium and Wood) of the Construction, Appliances and Transport machinery sectors;
- Household purchases of Appliances and Transport machinery;
- Investment in Construction, Transport machinery and industrial sectors;
- Freight demand of Rail transport, Road transport, Air transport and Water Transport;
- Demand of fertilizers (Chemicals, Livestock, Biocompost) of the Crops, vegetables and fruits sector;
- Demand of animal feed (Crops, vegetables and fruits, Processed crops and vegetables, Processed animal, Fish) of the Livestock sector;
- Electricity mix: energy produced by each power source.

4.4.2 Modification of the reference scenario

Using the indicators computed before, the inputs of the economic model (described in Deliverable 6.8, Thurm and Vielle, 2019b) are adjusted in order to represent the user-defined scenarios as a combination of lever settings.

First, the active population, given by the Lifestyles module, is used to update the representative household time-endowment.

Second, two matrices are created for each country and year of interest. The first one gathers the reference scenario values of the sectoral input shares (share of a good *i* used to produce a good *j*), and, for each economic sector, the household consumption, the investment, the government spending, and the net imports. The second table follows the same structure, but with the values of the indicators of transitions. When there is no indicator for a sector (for instance investment in the water sector), a value of one is taken. The two tables are then multiplied. Finally, the sum of the input shares for each sector is normalized to unity to ensure the coherence of the model. We therefore obtain the inputs for the economic model that are consistent with the scenario defined by the users.

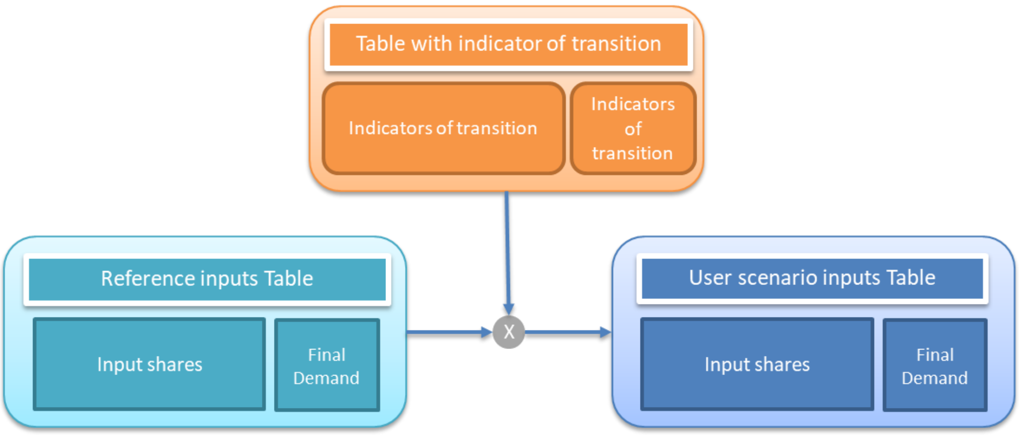

Figure 8: Calculation logic to modify the reference scenario

4.4.3 Computation of employment impacts

The last step consists in computing the employment indicators. It requires to solve a system of three non-linear equations (market clearing of skilled labour, unskilled labour and capital) with three unknowns (unskilled and skilled wages and the cost of capital). This allows to sequentially determine the prices, the domestic demand and the intermediate demand, which gives the unskilled and skilled labour for each sector, with respect to the reference scenario. The outputs are then sent to the Transition Pathways Explorer. The following system of equations is implemented in a python node and is solved thanks to a non-linear solver:

$$w_{LU}^{\sigma_{VA}} LU = \sum_j \theta_{LU\,j}\theta_{VA\,j} p_{VA\,j}^{\sigma_{VA}-\sigma} p_j^{\sigma} DX_j$$

$$w_{LS}^{\sigma_{LSK}} LS = \sum_j \theta_{LS\,j}\theta_{LSK\,j}\theta_{VA\,j} p_{LSK\,j}^{\sigma_{LSK}-\sigma_{VA}} p_{VA\,j}^{\sigma_{VA}-\sigma} p_j^{\sigma} DX_j$$

$$r_K^{\sigma_{LSK}} K = \sum_j \theta_{K\,j}\theta_{LSK\,j}\theta_{VA\,j} p_{LSK\,j}^{\sigma_{LSK}-\sigma_{VA}} p_{VA\,j}^{\sigma_{VA}-\sigma} p_j^{\sigma} DX_j$$

With:

$$LU = (1-\alpha_{LS})\left[\tilde{L} - C\left(\frac{\bar{l}}{\bar{\bar{C}}}\right)^{1-\sigma_U}\left(\frac{\theta_C}{1-\theta_C}(w_{LU}(1-\alpha_{LS})+w_{LS}\alpha_{LS})\right)^{-\sigma_U}\right]$$

$$LS = \alpha_{LS}\left[\tilde{L} - C\left(\frac{\bar{l}}{\bar{\bar{C}}}\right)^{1-\sigma_U}\left(\frac{\theta_C}{1-\theta_C}(w_{LU}(1-\alpha_{LS})+w_{LS}\alpha_{LS})\right)^{-\sigma_U}\right]$$

$$K = \frac{C+IN}{r} - \frac{w_{LU}(1-\alpha_{LS})+w_{LS}\alpha_{LS}}{r}\left[\tilde{L} - C\left(\frac{\bar{l}}{\bar{\bar{C}}}\right)^{1-\sigma_U}\left(\frac{\theta_C}{1-\theta_C}(w_{LU}(1-\alpha_{LS})+w_{LS}\alpha_{LS})\right)^{-\sigma_U}\right]$$

$$p_j^{\sigma} DX_j = \left((\mathbf{I}-\mathbf{A})^{-1}(\mathbf{p}^{\circ(\sigma-1)}\circ(\mathbf{INV}+\mathbf{C}+\mathbf{G}+\mathbf{EX}-\mathbf{IX}))\right)_j$$

$$p_j = \left[\left((\mathbf{I}-\mathbf{A^t})^{-1}\theta_{\mathbf{VA}}\circ\left[\theta_{\mathbf{LU}}w_{LU}^{1-\sigma_{VA}} + \theta_{\mathbf{LSK}}\circ\left(\theta_{\mathbf{LS}}w_{LS}^{1-\sigma_{LSK}} + \theta_{\mathbf{K}}r_K^{1-\sigma_{LSK}}\right)^{\circ\frac{1-\sigma_{VA}}{1-\sigma_{LSK}}}\right]^{\circ\frac{1-\sigma}{1-\sigma_{VA}}}\right)_j\right]^{\frac{1}{1-\sigma}}$$

$$p_{VAj} = \left(\theta_{LUj}w_{LU}^{1-\sigma_{VA}} + \theta_{LSKj}\left(\theta_{LSj}w_{LS}^{1-\sigma_{LSK}} + \theta_{Kj}r_K^{1-\sigma_{LSK}}\right)^{\frac{1-\sigma_{VA}}{1-\sigma_{LSK}}}\right)^{\frac{1}{1-\sigma_{VA}}}$$

$$p_{LSKj} = \left(\theta_{LSj}w_{LS}^{1-\sigma_{LSK}} + \theta_{Kj}r_K^{1-\sigma_{LSK}}\right)^{\frac{1}{1-\sigma_{LSK}}}$$

Where:

C	Total households' consumption
C_j	Households' consumption of good j
DX_j	Domestic production of good j
EX_j	Export of good j
G	Total government spending
INV	Total private investment
INV_j	Investment in sector j
IX_j	Import of good j
K_j	Capital demand in sector j
l	Households' leisure
L	Total labour supply (by households)
$\tilde{L}$	Households' time-endowment
LS	Total labour supply of skilled workers
LS_j	Skilled labour demand in sector j
LSK_j	Aggregate of capital and skilled labour in sector j
LU	Total labour supply of unskilled workers
LU_j	Unskilled labour demand in sector j
p_j	Price of good j
r_K	Cost of capital
VA_j	Value added in sector j
$w_{LS/LU}$	Wage of skilled/unskilled workers
α_S	Share of skilled workers in the active population
$\sigma_{(.)}$	Elasticity of substitution
θ_{ij}	Input share of good (or production factor) i to produce good j
θ_C	Relative share of consumption with respect to leisure

5 Lessons learned

This report shows how two socio-economic modules, namely the Air Pollution and Human Health module and the Employment module, were integrated into the EUCalc model. The socio-economic issues considered were determined by involving stakeholders thanks to an online survey and a co-designed workshop. Even though only the most important issues were implemented, it would be possible to enlarge the scope of the EUCalc model by introducing new socio-economic indicators. For instance, air pollution effects on morbidity could be added to the Air Pollution and Human Health module and poverty analysis and distributional effects (inequalities) could be obtained by refining the macroeconomic model used in the Employment module.

However, the current logic of the calculator and the characteristics of socio-economic issues also make challenging a deeper integration of socio-economic issues.

First, quantifying socio-economic impacts and defining trustworthy socio-economic indicators can be onerous. It requires research on the causal relations between social issues, sectoral economic activities and lifestyles as well as reliable datasets. It would therefore be interesting to also implement qualitative social impacts in calculators.

Second, the emergence of new low-carbon technologies is associated with uncertainties about their socio-economic impacts. Knowledge about these impacts could sometimes only be acquired once the technology is already widely adopted.

Finally, in EUCalc, the idea was to derive socio-economic impacts using inputs from the sectoral modules (e.g., buildings, transport, industry, agriculture, power). The calculator follows a sequential approach, and the socio-economic modules are at the end of the chain. This constrained the scope of these modules. For instance, the population evolution being given by a lifestyle lever, the impacts of labour mobility (due to differences in wages and skills across countries) could not be assessed. Similarly, because the consumption and production of several commodities (e.g. food, materials, transport) were already fully computed in the sectoral modules, reconciliating the sectoral modules outputs with general equilibrium analysis was at times quite a challenging task. Introducing more economic rationale in all the modules would greatly help to better integrate economic constraints and assess socio-economic impacts.

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