EUCALC

Explore sustainable European futures

WP6 – Employment module documentation

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Short Description
This report describes the EUCalc employment module, and in particular: - *The scope and questions addressed by the module;* - *The methods used and calculation logic;* - *The sources and hypotheses to build the historical database and the reference scenario.*

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This deliverable contains original unpublished work except where clearly indicated otherwise.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
CAPEX	Capital Expenditure
CES	Constant Elasticity of Substitution
CGE	Computable General Equilibrium
EU	European Union
EU28	European Union 28 countries
EUCalc	European Calculator project
FTE	Full Time Equivalent
GDP	Gross Domestic Product
GHG	Greenhouse gas
GTAP	Global Trade Analysis Project
IO	Input-Output
kcal	kilocalories
LCOE	Levelized Cost of Electricity
LDV	Light Duty Vehicles (cars)
LFS	Labour Force Survey
MEUR	Million Euros
OPEX	Operative Expenditure
pkm	person-kilometre
ROW	Rest Of the World
t	ton
tkm	ton-kilometre
TPE	Transition Pathway Explorer
TWh	Terawatt hour
WP	Working Package

Glossary

Baseline	Reference scenario used in a CGE analysis
CGE (Computable General Equilibrium)	Non-linear model representing the behaviour of households, firms, government markets and prices at the equilibrium
Demand (factor)	Function linking the quantity of a factor that firms need with its price
Demand (goods)	Function linking the quantity of a good that households are willing to purchase with its price
Elasticity of substitution	Ratio of two inputs of a production (or utility) function with respect to the ratio of their marginal products (or utilities)
Factor of production	Resource needed by firms to produce a good. It generally includes Labour, Capital, Land
Final demand	Sum of household consumption, investment and government spending (+ export – import)
GDP (Gross Domestic Product)	Measure of the production/income/expenditure of a country
IO (Input-Output) method	Linear model linking the sectoral output to the sectoral final demand thanks to the matrix of technical coefficient
Market clearing	Supply equals demand
Production function	Function linking the inputs needed by a firm to the quantity of output it produces
Supply (factor)	Function linking the quantity of a factor supplied by households with its price
Supply (goods)	Function linking the quantity produced by firms with the prices of a good
Technical coefficient	In an IO framework, coefficient linking the quantity needed of an input to produce one unit of output.
Trade Balance	Export minus Import (expressed in quantity and/or value terms)
Utility function	Function representing the preferences of individuals, mapping for instance the allocation between different goods and leisure

1 Module introduction and associated challenges

There are numerous pathways to reach a same reduction of greenhouse gases emissions. One possibility is to rely on technological changes, for instance promoting renewables in the electricity mix, increasing energy efficiency in buildings or replacing fuel engines with electric vehicles. Alternatively, behavioural changes could help transition towards a low-carbon economy, with individuals adjusting their diets or favouring trains over planes and bikes over cars. Deciding on which pathway to follow requires to know the trade-offs between the different options. In other words, what are the environmental and socio-economic impacts of decarbonisation pathways?

The European Calculator project (EUCalc) aims to answer this question by designing a user-driven model in European Union countries (EU28) and Switzerland. Each user of the calculator can define its own pathway until 2050, acting on levers to modify a set of variables such as the share of renewables in the electricity mix, the meat consumption, passengers travel by public transport, freight transport by rail, and renovation and insulation of buildings. Then, the model computes several environmental and socio-economic indicators, providing information on greenhouse gases emissions, energy consumption, land, water and material uses, health and employment. The calculator is structured in several modules. The objective of this report is to present the Employment module, and in particular the scope of the module, the questions it addressed, and the methods and data used.

The Employment module aims at analyzing the impacts on employment for each user's scenarios, i.e. for various decarbonisation pathways. Using inputs from the sectoral modules (e.g. Lifestyles, Building, Transport, Industry, Agriculture, Electricity Supply), it provides information on the employment impacts per economic sector and per educational attainment of workers. These outputs are visible in "real time" (i.e. after a few seconds) in the online users' interface, called the Transition Pathways Explorer (TPE).

In the literature, there exists two main approaches to assess the general equilibrium impacts of environmental and energy policies on employment: Input-Output (IO) analysis and Computable General Equilibrium (CGE) model.[1] However, each approach has some limitations which prevent their use for the Employment module.

The IO analysis is a linear model. It does not account for price and substitutions effects, while resources and income constraints are overlooked. Hence, the IO method is better suited for small deviations in the economy than for large economic transition that could happen in EUCalc scenarios.

A CGE model is a non-linear model representing the behaviours of economic agents such as firms, households, government and the relations between them. However, due to its complexity, a CGE model is computationally time-expensive. Thus, these models could not provide results in a few seconds as expected in the TPE for user friendliness. Moreover, the CGE top-down approach is not as detailed as the

[1] See Berck and Hoffmann (2002) for a review and discussion of the existing methods to assess the impacts of environmental and natural resource policy on employment.

bottom-up approach of the calculator, so that some sectoral information would be lost. Finally, the behaviours of economic agents in a CGE depend on prices and income constraints while in EUCalc some pathways rely on large lifestyles changes (where individuals do not only consider prices). Hence, the two approaches are difficult to reconcile.

Consequently, the Employment module relies on a “in-between” approach, combining the advantages of each method while avoiding their main drawbacks. First, a reference scenario is simulated using the CGE model GEMINI-E3. Inputs from sectoral modules are then used to create some indicators of transition. These indicators are used to shock the reference scenario, reproduce the scenario defined by the user, and derive the impacts on employment thanks to a macroeconomic model.

The rest of the document is organized as follows. A brief overview of the trends and evolution of employment in Europe is provided in Section 2. The questions addressed by the module are presented in Section 3. In Section 4, we describe the calculation logic, i.e. the interaction between the Employment module and the rest of the calculator, the assumptions behind the economic model and the methods used to compute employment indicators. In Section 5, we discuss potential levers for the module, which are not yet implemented. The model parameters are detailed in Section 6. Finally, the historical data and the construction of the reference scenario are depicted in Section 7.

2 Trends and evolution of employment in Europe

In 2018, 227.8 million people are employed in the European Union representing about 60.4% of the working age population, i.e. persons aged 15-74 (Source: Eurostat, EU Labour Force Survey[2]). There are 133.8 million economically inactive persons, which stay outside the labour market due to education and training, retirement, staying at home to look after children, illness or incapacitated dependency. Of the 246.7 million economically active persons, 6.8% are unemployed in 2018, which is closed to the level before the 2008 economic crisis, as illustrated in Figure 1.

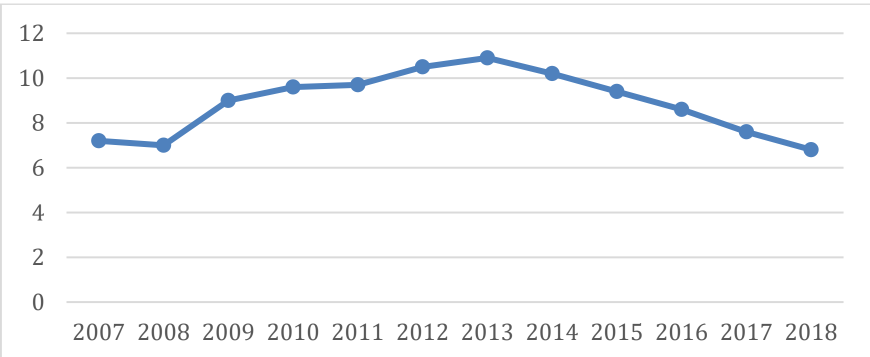

Figure 1 - Evolution of unemployment rate (in % of active population) in EU28 countries (Source: Eurostat, Labour Force Survey)

[2] Description of the EU Labour Force Survey: https://ec.europa.eu/eurostat/web/microdata/european-union-labour-force-survey

However, the unemployment rate varies substantially between countries, ranging from 2.2% (Czech Republic) to 19.3% (Greece), as highlighted in Figure 2. There are several determinants that explain such differences, such as employment protection legislation, union density and tax on wages.

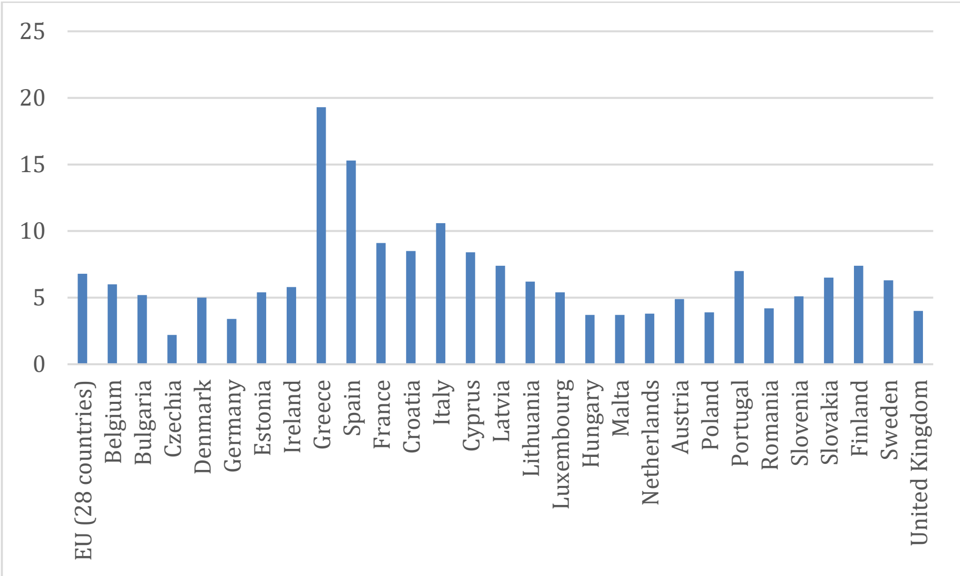

Figure 2 - Unemployment rate (in % of active population) per Member State in 2018 (Source: Eurostat, Labour Force Survey)

Decreasing unemployment is a policy priority of the European Commission. Therefore, the decarbonizing actions of European countries could be an opportunity to increase employment following the “double dividend paradigm”. In this paradigm, which was debated in the nineties, the revenue coming from an environmental taxation is recycled through a decrease on social contributions that stimulates job creation at the same time. Other channels can link the transition towards low-carbon economy and employment. For example, increasing energy efficiency can lead to a substitution of energy intensive goods with labour intensive goods. Furthermore, investing in the transition can also stimulate economic growth and create jobs. There is an extensive literature on the topic, which tends to support the idea that an energy transition has positive employment impacts (see e.g. Lehr et al., 2012; Cambridge Econometrics, 2015; and Hartwig et al., 2017).

Looking at a more detailed picture, employment participation greatly varies depending on the educational attainment level of workers. In Figure 3, the employment rate is shown for three groups classified in function of their educational attainment level.[3] The employment rate is defined as the number of employed people within the age group 25-64 years. This indicator gives information about the difficulties that people with different levels of education face in the labour market. In 2018 in the EU28 countries, the employment rate is only 56.8% for persons with primary education while it is 82.6% for persons having achieved tertiary education. A similar trend is observed in all EU28 Members States.

[3] The educational attainment level is coded according to the International Standard Classification of Education (ISCED)

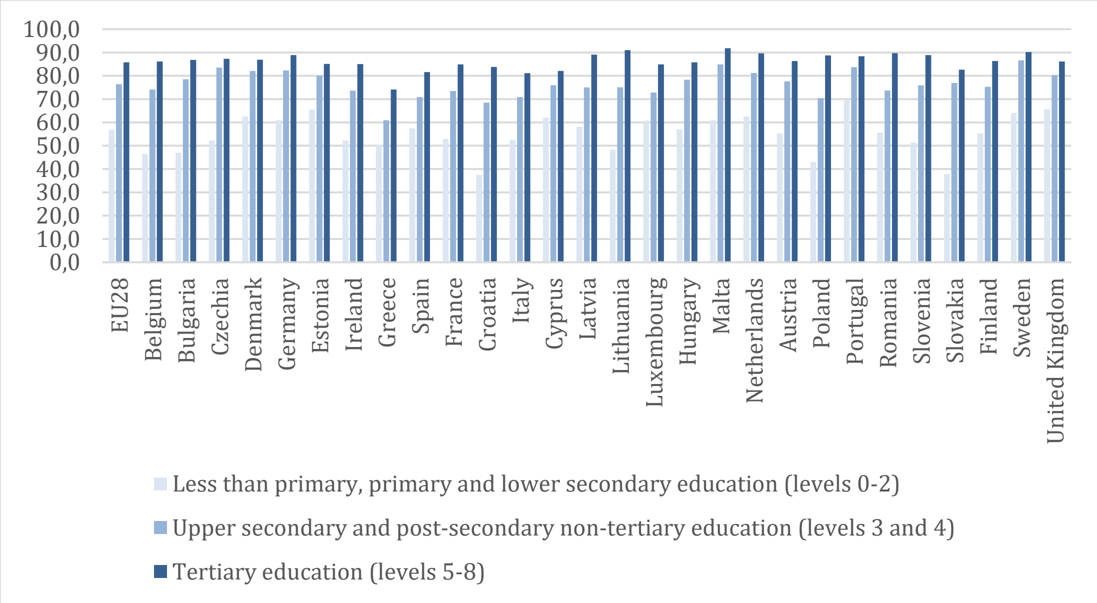

Figure 3 - Employment rate per educational level in EU28 Member States in 2018 (Source: Eurostat, Labour Force Survey)

The European Commission also promotes equal economic independence for women and men with the aim to increase female participation in the workforce, to reduce the gender pay gap and to increase female entrepreneurship and self-employment. In 2018, the women employment rate is 69.1% on average in the EU, while it is 81.3% for men. Gender equality refers to several dimensions. Figure 4 displays the shares of men and women employed (aged 20 to 64 years) for each EU28 Member State. In 26 countries the share of women is lower than 50%, and even lower than 45% in Malta, Greece, Italy, Romania and the Czech Republic. Finally, the gender pay gap (i.e. the difference between the average gross hourly earnings of male and female employees as % of male gross earnings) is 16.2 % in 2016 on average across EU28 countries, ranging from 5.2% in Romania to 25.3% in Estonia.

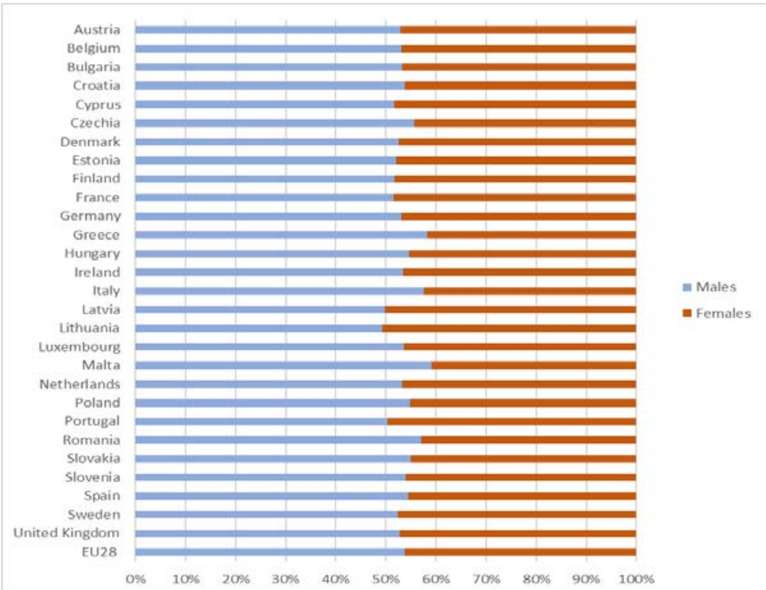

Figure 4 – Share of men and women employed per EU28 Member States in 2018 (Source: Eurostat, Labour Force Survey)

3 Questions addressed by the module

The questions addressed or not by the module were determined during the WP6 stakeholder workshop on socio-economic impacts held in Delft on December 1st, 2017. In this workshop, the invited experts highlighted the importance to implement employment indicators in the Transition Pathway Explorer.[4] They suggested to display the impacts on total employment, but also on employment per economic sector to provide information on the possible disruptions drivers of policies.

Furthermore, the experts strongly recommended to distinguish the employment impacts based on the educational level of workers. Indeed, people will not be affected in the same way by decarbonisation pathways depending on their skills since some industries have a higher demand in skilled than in unskilled labour. Displaying the employment impacts per skill level enables policy makers to better understand which population groups are more vulnerable to a low-carbon transition. Similarly, the model also computes the wages evolution, depending on the workers' skills.

Others potential indicators such as the gender composition, the unemployment rate by gender, the gender pay gap or the unemployment trap were found less relevant by experts. Indicators about unemployment have a negative connotation, and the module should thus prioritize employment indicators. Employment by gender is linked to numerous causes including skills/education levels, and family and child care policies. Hence, delineating employment per gender would be difficult to tackle in the module. One possibility would be to assume that labour differentiation per gender per sector stays the same, or evolve following historical trends, but these assumptions could lead to misleading results. Delineating the wage levels by gender was suggested as an option to cover the issue of gender pay gap, but this would require assumptions on the evolution of economic, institutional and -to certain extent- discriminatory causes affecting the pay gap.

The number of green jobs was another indicator considered problematic by experts. First, there is not a unified definition of green jobs, and therefore it is challenging to classify a job as green. The definitions proposed by the International Labor Organization (ILO) and the United Nations Environment Program (UNEP) are the most used ones. ILO defines green jobs as "jobs that contribute to preserve or restore the environment, be they in traditional sectors such as manufacturing and construction, or in new, emerging green sectors such as renewable energy and energy efficiency". On the other hand, green jobs sometimes refer only to jobs in environmentally-friendly sectors. Consequently, this creates difficulties in comparing the methods and results of different studies. Experts also noted that the issue of green jobs is more linked to innovation than employment, and that green jobs per se tell very little in relation to skilling and training required or the quality of jobs created.

Additional points raised by participants included the issue of permanent and temporary jobs. Nonetheless, the average working hours was not considered a priority indicator to assess employment impacts, since the average working hours is more related to employment condition and less to low-carbon transition.

[4] A detailed report of the workshop results is available in Deliverable 6.3, Pashaei Kamali et al. 2018.

Finally, the question of labour mobility between countries is not tackled by the module. Indeed, in the calculator, the population is controlled with a lever. Hence, the population is an exogenous input of the Employment module, and incorporating labour mobility would create consistency issues.

The following table recaps the questions addressed or not by the module.

Table 1 - Scope of the module

Theme	Questions	Ambition[5]	Progress
What are the types of impacts we want to take into account in the model?	What are the impacts of decarbonisation pathways on total employment?	Yes	• Method defined and tested for Germany; • Interactions with other modules defined; • Method partially implemented in KNIME.
	What are the impacts on employment for each economic sector?	Yes	
	What are the impacts on employment depending on the educational level of workers?	Yes	
	What are the impacts on wages depending on skill levels?	Yes	
	How education and training could change the impacts on employment?	Potentially	A "training and education" lever is considered but not yet implemented
Can we identify some potential breakthrough (technologies or societal) that could have an impact?	Impact of automation?	Partially	Through links with other modules but: • Difficult to model the impacts of "breakthrough technologies" due to a lack of data on their labour needs • A "automation" lever is considered but not yet implemented
	Impact of new regulation?	Partially	• Trough links with sectoral modules • A "regulation" lever is considered but not yet implemented
	Impact of outsourcing?	Yes	Trade levers allow the users to define the share of domestic production
	Impact of circular economy?	Partially	Through links with other modules
	Impacts of change in ecosystems on employment (jobs related to biodiversity water pollution, etc.)?	Partially	Through links with other modules
What are the impacts of other sectors?	The Employment module uses inputs from all the sectoral modules to reproduce the users' scenario.		• Main inputs implemented • Interface still evolving to include more inputs
What are the impacts of Employment on the other sectors?	The Employment module is an output of the calculator and does not provide feedbacks to sectoral modules		
Others output:	Input-Output tables for each users' scenarios	Yes	
	Value Added	Yes	
Questions not addressed by the model	Impact on Job Quality (temporary vs permanent)?	No	• Linked to regulation and not to decarbonisation pathways. • Not prioritized by stakeholders.
	Impacts on employment by gender?	No	• Doable but the results would lack reliability. • Not prioritized by stakeholders.
	Impacts on labour mobility between countries?	No	• Population is a Lifestyles lever

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

4 Calculation logic and scope of the module

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, which allows to compute the employment impacts of this scenario. The calculation logic follows several steps:

- A reference scenario is simulated using the Computable General Equilibrium model GEMINI-E3. The state of the economy in each country and for each year of interest is represented in reference Input-Output tables. The construction of the reference scenario and reference Input-Output tables is explained in Section 7;
- Using inputs from the sectoral modules, some "indicators of transition" are computed. The interactions with other modules are described in Section 4.4 while the indicators creation is explained is Section 4.5;
- The indicators of transition are used to shock the reference scenario and reproduce the scenario defined by the user. The macroeconomic model is described in Sections 4.2 and 4.3, while the calculation flows are detailed in Section 4.5.

The employment module then sends outputs to the Transition Pathway Explorer (i.e. the online interface) to display the following employment indicators:

- Total employment change;
- Sectoral employment change;
- Employment and wages evolution for different educational attainment level.

These outputs are defined with respect to the reference scenario.

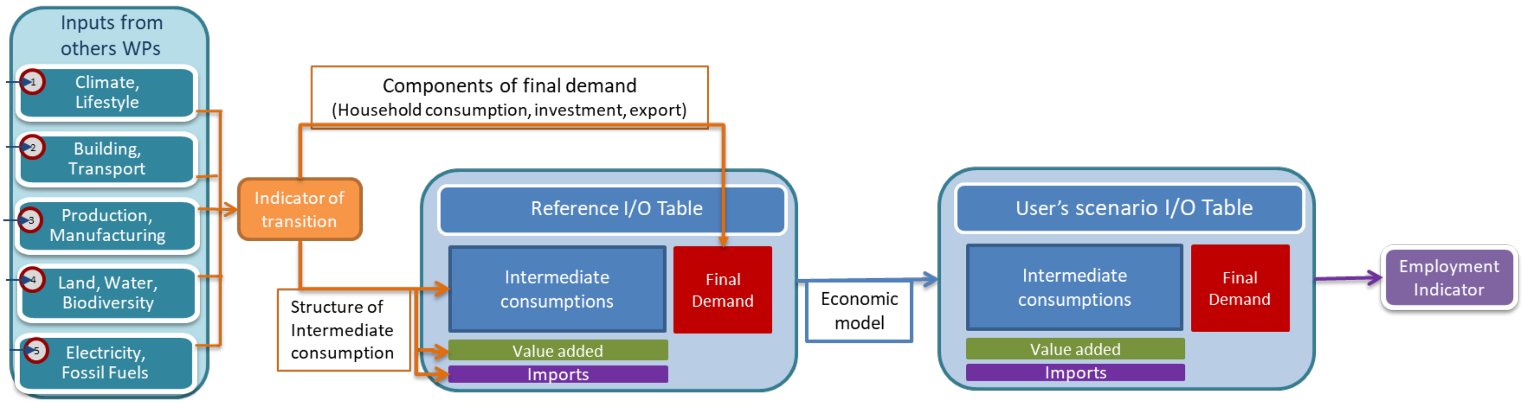

Figure 5 General logic of the employment module

4.2 Scope definition

In this section, we discuss the scope of the employment module, and in particular the spatial and time granularity, the industrial classification and the heterogeneity in worker skills.

4.2.1 Spatial and time granularity

The module computes the employment impact of decarbonisation in the EU28 countries and in Switzerland. Each country is treated independently: the trade flows are exogenous and derived using inputs from other modules.

The calculation runs from 2015 to 2050, with a time-step of 5 years. This allows to compute the temporal evolution while limiting the model computation time.

4.2.2 Industrial classification

The industrial classification was designed with the objectives to respect a few constraints. First, data should be available for each EU28 countries and Switzerland. Second, the number of sectors should be kept low to ensure the tractability of the model. Last but not least, the classification should be consistent with the other modules. In EUCalc, the accent is put toward modelling sustainable pathways. Thus, there is a trade-off between representing as best as possible the transition toward a more sustainable economy (i.e. more sectors) and designing a simple model (i.e. less sectors). In this spirit, the selected industrial classification includes 56 sectors (see Table 2) and is based on the EXIOBASE[6] version 3 classification. This database provides data for all countries considered with a detailed industrial disaggregation (163 sectors).

The industrial sectors were chosen in coordination with the other modules. In particular:

- Agriculture is disaggregated between *Crops, Vegetables & Fruits* (#1), *Livestock* (#2) and *Fish* (#4), in accordance with the EUCalc Lifestyles and Agriculture modules. In the Lifestyles module, users can define, among others, the evolution of food consumption and diet composition of individuals. Then the Agriculture module studies the supply of agricultural products. Even though the list of agriculture products is more detailed in these sectoral modules (see Deliverable 1.3, Costa et al., 2018), this disaggregation allows to correctly represent a shift away from animal-base products, as allowed by the lifestyle lever on diets. Similarly, we include three processed food sectors: *Processed Crops & Vegetables* (#5), *Processed Animal* (#6) and *Beverage* (#7). In addition, the *Forestry* (#3) sector accounts for the use of wood, studied in the Forestry module.
- Energy consumed is disaggregated between *Coal* (#8), *Crude Oil* (#9), *Petroleum products* (#10), *Gas* (#11), *Electricity distribution* (#12) and *Biogas* (#52). The consumption of each of these energy vectors per industrial sector is calculated in the EUCalc Buildings, Transport, Industry and Agriculture modules.
- Electricity supply is disaggregated between its transmission and distribution (#12) and 11 production sectors (#13 to 23). The EUCalc Electricity module studies the electricity supply, including the following sources: nuclear, coal, oil, gas, onshore and offshore wind, concentrated solar power, photovoltaics, hydroelectricity, marine power, biomass, and geothermal. Our representation is close, only aggregating onshore and offshore wind into one sector.
- The production and consumption of materials and mineral is tackled in the EUCalc Industry and Minerals module. We keep a representation close to

[6] More information on Exiobase: https://www.exiobase.eu/

theirs by including *Wood* (#24), *Pulp and paper* (#26), *Chemicals, plastic, rubber* (#27), *Fertilizer* (#28), *Glass* (#29), *Cement* (#30), *Other non-metallic minerals* (#31), *Iron and Steel* (#32), *Aluminium* (#33), *Copper* (#34), *Other metal* (#35), *Minerals mining* (#36). In addition, the consumption of water is studied for each sector in the Water module. Hence, we include a *Water* (#25) sector.
- Since the EUCalc Buildings module looks at the construction and renovation of buildings, we include a sector *Construction* (#37).
- Transport is disaggregated between *Rail Transport* (#38), *Road Transport* (#39), *Water Transport* (#40) and *Air Transport* (#41) to be consistent with the Transport module which studies the evolution of passenger and freight transport by road, rail, sea and air. Moreover, the EUCalc Transport module also analyses the production of new vehicles and transport infrastructure. Thus we include a *Transport machinery* (#43) sector.
- The EUCalc Buildings module computes the household purchase of appliances (fridge, washing-machine, dishwasher, etc.), so that we include an *Appliance* (#44) sector.
- The EUCalc Buildings module analyses the energy consumption of non-residential sectors such as *Trade* (#46), *Hotels and Restaurants* (#47), *Education* (#48) and *Health* (#49).

In the Transition Pathways Explorer, the sectoral results are aggregated in a smaller number of sectors for readability purposes. The representation used in the Pathways Explorer is not yet definitive but will follow the sectoral modules, namely Agriculture, Transport, Industry, Services, Energy and Electricity supply. The user can then “click” on a sector to display more details.

Table 2 – Industrial classification used in the Employment Module

EUCalc WP6 Sectors		Exiobase Correspondence	EUCalc WP6 Sectors		Exiobase Correspondence
01	Crops, Vegetables & Fruits	1-8	29	Glass	65, 66
02	Livestock	9-17	30	Cement	69, 70
03	Forestry	18	31	Other non-metallic mineral	67, 68, 71
04	Fish	19, 45	32	Iron and steel	25, 72, 73
05	Processed crops and vegetables	39, 41, 42, 43	33	Aluminium	28, 76, 77
06	Processed animal products	35, 36, 37, 38, 40	34	Copper	26, 80, 81
07	Beverage	44	35	Other metal	29-31, 74-75, 78-79, 82-86
08	Coal	20, 56	36	Mineral mining	24, 32, 33, 34
09	Crude oil	21, 23	37	Construction	113, 114
10	Petroleum product	57, 58, 116	38	Rail transport	120
11	Gas	22, 110	39	Road transport	121
12	Electricity distribution	107, 108, 109	40	Water transport	123, 124
13	Coal power	96	41	Air transport	125
14	Gas power	97	42	Transport nec	122, 126
15	Nuclear power	98	43	Transport machinery	91, 92, 115
16	Hydropower	99	44	Appliances	87, 88, 89, 90
17	Wind power	100	45	Other consumption good	46, 47, 48, 49, 93
18	Oil power	101	46	Trade	117, 118
19	Biomass power	102	47	Hotels and restaurants	119
20	Photovoltaics	103	48	Education	137
21	Solar thermal power	104	49	Health	138
22	Marine power	105	50	Recycling	94, 95
23	Geothermal power	106	51	Waste incineration	139-145
24	Wood manufacture	50, 51	52	Biogas	146, 147, 148
25	Water	111, 112	53	Composting	149, 150
26	Pulp and paper	52, 53, 54, 55	54	Wastewater	151, 152
27	Chemicals, plastic, rubber	59, 60, 63, 64	55	Landfill	153-158
28	Fertilizer	61, 62	56	Other services	127-136, 159-163

4.2.3 Skills heterogeneity

During the WP6 stakeholder workshop held in Delft on December 1st, 2017, the invited experts highlighted the importance to distinguish the employment impacts based on the educational level of workers, i.e. their skills (EUCalc Deliverable 6.3, Pashaei Kamali et al. 2018). Consequently, we allow for two types of workers in the model, namely the skilled and unskilled workers, defined following the International standard classification of education (ISCED):[7]

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

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

4.3 Economic model

The employment module calculations rely on a macroeconomic model. The main ingredients behind this model are presented below. The following description and equations are valid for each country and at each time step, but country and time indices are omitted for simplicity.

4.3.1 Firms

For each industrial sector (as defined in Table 2), a representative firm produces a homogenous output. We assume a nested constant-elasticity-of-substitution (CES) production function illustrated in Figure 6.

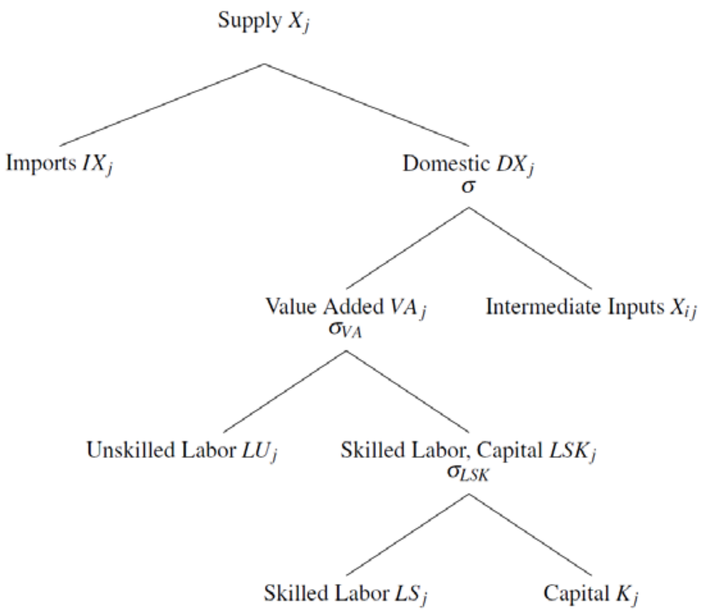

Figure 6 - Firms' production function in the Employment module

The total supply of good j, called X_j, consists of import IX_j and domestic production DX_j. Imports are exogenous and derived using inputs from other modules (See Section 4.4).

At the first node of domestic production, firms substitute between value added VA_j and inputs from other sectors X_{ij}. The calibrated form of the domestic production function is:

$$DX_j = \overline{DX}_j \left[\theta_{VAj} \left(\frac{VA_j}{\overline{VA}_j} \right)^{\rho} + \sum_i \theta_{ij} \left(\frac{X_{ij}}{\overline{X}_{ij}} \right)^{\rho} \right]^{1/\rho}$$

Note that the variables with the overbar represent the reference scenario values. For instance, DX_j is the domestic production in the user's scenario while $\overline{DX_j}$ is the domestic production in the reference scenario. θ_{VAj} and θ_{ij} are the shares of value added and input i to produce the good j. They are calibrated from the reference scenario. However, some of them are exogenously shocked to reproduce the user's scenario (see Sections 4.4 and 4.5). The parameter ρ is linked to the elasticity of substitution σ such that $\rho = \sigma/(1-\sigma)$. The calibration of the elasticities of substitution is discussed in Section 6.

The value added is disaggregated between 3 productions factors: unskilled labour LU_j, skilled labour LS_j and capital K_j. Firms substitute between unskilled labour and a composite of skilled labour and capital, called LSK_j. Indeed, according to empirical evidence, unskilled labour has a high substitutability with respect to skilled labour and capital, whereas skilled labour and capital present a low degree of substitutability (Böhringer et al., 2005).

$$VA_j = \overline{VA}_j \left[\theta_{LU\,j} \left(\frac{LU_j}{\overline{LU}_j} \right)^{\rho_{VA}} + \theta_{LSK\,j} \left(\frac{LSK_j}{\overline{LSK}_j} \right)^{\rho_{VA}} \right]^{1/\rho_{VA}}$$

$$LSK_j = \overline{LSK}_j \left[\theta_{LS\,j} \left(\frac{LS_j}{\overline{LS}_j} \right)^{\rho_{LSK}} + \theta_{K\,j} \left(\frac{K_j}{\overline{K}_j} \right)^{\rho_{LSK}} \right]^{1/\rho_{LSK}}$$

As above, overbars represent the baseline values, $\theta_{(\cdot)}$ are the input shares calibrated from the reference scenario, and $\rho_{(\cdot)}$ are linked to the elasticities of substitutions and their calibration is discussed in Section 6.

Firms are cost-minimizer. They solve the following problem:

$$\begin{aligned}
\min \quad & w_{LU} LU_j + w_{LS} LS_j + r_K K_j + \sum_i p_i X_{ij} \\
\text{s.t.} \quad & DX_j = \overline{DX}_j \left[\theta_{VA\,j} \left(\frac{VA_j}{\overline{VA}_j} \right)^{\rho} + \sum_i \theta_{X\,ij} \left(\frac{X_{ij}}{\overline{X}_{ij}} \right)^{\rho} \right]^{1/\rho} \\
& \frac{VA_j}{\overline{VA}_j} = \left[\theta_{LU\,j} \left(\frac{LU_j}{\overline{LU}_j} \right)^{\rho_{VA}} + \theta_{LSK\,j} \left(\frac{LSK_j}{\overline{LSK}_j} \right)^{\rho_{VA}} \right]^{1/\rho_{VA}} \\
& \frac{LSK_j}{\overline{LSK}_j} = \left[\theta_{LS\,j} \left(\frac{LS_j}{\overline{LS}_j} \right)^{\rho_{LSK}} + \theta_{K\,j} \left(\frac{K_j}{\overline{K}_j} \right)^{\rho_{LSK}} \right]^{1/\rho_{LSK}}
\end{aligned}$$

Where w_{LU} and w_{LS} are the wages of unskilled and skilled workers, r_K the cost of capital and p_i the price of input *i* (including taxes).

Solving the firms' problem give the demand of unskilled labour, skilled labour and capital for each sector in function of the relative prices:

$$LU_j = \theta_{LU\,j} \theta_{VA\,j} DX_j \left(\frac{p_{VA\,j}}{w_{LU}} \right)^{\sigma_{VA}} \left(\frac{p_j}{p_{VA\,j}} \right)^{\sigma}$$

$$LS_j = \theta_{LS\,j} \theta_{LSK\,j} \theta_{VA\,j} DX_j \left(\frac{p_{LSK\,j}}{w_{LS}} \right)^{\sigma_{LSK}} \left(\frac{p_{VA\,j}}{p_{LSK}} \right)^{\sigma_{VA}} \left(\frac{p_j}{p_{VA\,j}} \right)^{\sigma}$$

$$K_j = \theta_{K\,j} \theta_{LSK\,j} \theta_{VA\,j} DX_j \left(\frac{p_{LSK\,j}}{r_K} \right)^{\sigma_{LSK}} \left(\frac{p_{VA\,j}}{p_{LSK}} \right)^{\sigma_{VA}} \left(\frac{p_j}{p_{VA\,j}} \right)^{\sigma}$$

Moreover, because of the simplified production function used and assuming a perfect worker and capital mobility between sector, it is possible to express all the prices in function of the wages and of the price of capital. As a result, the sectoral demand of unskilled labour, skilled labour and capital are expressed only in function of the sectoral domestic production, of the wages and of the price of capital.

4.3.2 Households

Households are described by one representative agent. They earn revenue from supplying skilled (LS) and unskilled (LU) labour and from returns on savings (K). They spend this income between the goods they consume (C) and their private investment (INV).

Households' behaviour is driven by the maximization of their utility (U) facing a tradeoff between their aggregate consumption (C) and their leisure ($l = \tilde{L} - LU - LS$) where $\tilde{L}$ is the households' time-endowment, which evolves with the working-age population. Let L be the total labor supply and α_{LS} the share of skilled households.[8] The households solve the following problem:

$$\max_{C,L} \quad U = \left[\theta_C \left(\frac{C}{\bar{C}}\right)^{\frac{\sigma_U - 1}{\sigma_U}} + (1-\theta_C)\left(\frac{\tilde{L}-L}{\bar{l}}\right)^{\frac{\sigma_U - 1}{\sigma_U}}\right]^{\frac{\sigma_U}{\sigma_U - 1}}$$
$$\text{s.t.} \quad C + INV = (w_{LU}(1-\alpha_{LS}) + w_{LS}\alpha_{LS})L + rK$$

As above, overbars represent the reference scenario values, θ_C is relative share of consumption with respect to leisure, calibrated from the reference scenario to obtain the reference level of unemployment, and σ_U is the elasticity of substitutions and its calibration is discussed in Section 6.

Solving the households' problem give the supply of skilled and unskilled labour in function of the wages and aggregate consumption:

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

As in a standard macroeconomic model, the allocation between aggregate consumption and leisure is a static choice. However, the savings is generally an intertemporal decision. In contrast, in this module the savings are computed using inputs from sectoral modules. As a result, a more detailed representation of savings and investments is not needed. Instead, the supply of capital is derived from the GDP equation, such that the sum of income is equal to the sum of expenditure:

$$w_{LU}LU + w_{LS}LS + r_K K = C + G + INV + EX - IX - \tau$$

Where G is the government spending, τ the government revenue, EX the export and IX the import. The aggregate consumption, the private investment, the trade balance, the government spending and revenue are all computed using inputs from sectoral modules (See Sections 4.4 and 4.5).

Finally, the allocation of aggregate consumption and investment between the different goods is also derived using inputs from sectoral modules (See Sections 4.4 and 4.5).

4.3.3 Market clearing

Assuming perfect consumption in all markets, the demand of each good and production factor is equal to its supply. These equations enable to close the system of non-linear equations. It is possible to show that this system boils down to only three non-linear equations with three unknowns, namely the unskilled and skilled wages and the cost of capital. Indeed, the prices can be determined knowing the

[8] The share of skilled households is currently set by the reference scenario. In further version, it could be linked to a training and education levers if the society decides to invest more in education.

unskilled and skilled wages and the cost of capital, and then in turn the domestic output, the intermediate inputs and the unskilled and skilled labour for each sector.

4.3.4 Voluntary vs involuntary unemployment

In the current version of the model, the labour supply is determined by the trade-off between consumption and leisure. In other words, unemployment is voluntary: it is the households' decision not to work more. There are several possibilities to model involuntary unemployment:

- Efficiency wages: in this framework, employers can increase the productivity of workers by paying wages that are above the market-clearing level (i.e. above the equilibrium wage when labour demand equals labour supply).
- Search and matching: this approach was developed by Diamond, Mortensen and Pissarides (Diamond, 1981, 1982; Mortensen & Pissarides, 1994). The idea is that finding a job is time and effort-consuming, while posting a vacancy is costly. Thus, a certain level of unemployment is unavoidable.
- Collective bargaining: wages result from negotiations between firms and trade unions, unemployment being an externality.

The suitability of each of these approaches depends on the local context, i.e. one approach may be more suited for one country than another. Although involuntary unemployment is not included in the current version of the model, it might be implemented if time allows and if sufficient data is available for the calibration of the model.

4.4 Interaction with other modules

4.4.1 Inputs

The employment module receives inputs from all sectoral modules (e.g. Lifestyles, Buildings, Transport, Industry, Agriculture, Electricity supply) for each country and time-step. Each input variable is used to create “transition indicators” that are allocated to one of the following economic flows of the macroeconomic model:

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

The inputs used and their link to the employment module are described below. The link corresponds to a cell of an Input-Output table. For instance, “Beverages; Household” refers to the household consumption of beverage; “Construction; Investment” refers to the investment in the construction sector; and “Electricity; Iron and steel” refers to the electricity demand of the sector iron and steel.

The process to create transition indicators is detailed in Section 4.5.

4.4.1.1 Lifestyles

In the Lifestyles module, the user can define the preferences of individuals using a set of levers. These levers control a large set of behaviours such as the food demand and diet composition, the appliance ownership, the consumption of material and the distance travelled by passengers. For each lever, a set of ambition levels (from 1 to 4) characterize the decarbonisation effort, from a continuation of historical trends to transformational changes.

The first input variables received from the Lifestyles module are linked to the household food consumption. These inputs characterize a shift in household preferences: increasing the ambition levels of the diet composition lever means decreasing the share of animal product in the diet while increasing the share of vegetables and fruits. Since the lifestyles food groups are more detailed than the food-related sectors in the Employment module, the Lifestyles aggregate these food groups according to the following:

- Crops, vegetables and fruits: cereals, fruits, vegetables, rice, pulses, starch;
- Processed crops and vegetables: oil crops, vegetable oils, sweeteners, sugars;
- Animal products: bovine, sheep, pigs, poultry, animal fats, offal, eggs, milk, other animals;
- Fish: pelagic fish, demersal fish, sea food, other aquatic animals;
- Beverage: wine, beer, fermented beverages, alcoholic beverages, coffee, stimulants.

Each of these groups corresponds to one or two economic sector of the employment model (See Table 3).

The Lifestyles module also provides the household consumption of paper (for sanitary purposes, printing, etc.).

Finally, the Lifestyles module sends the active population, i.e. the population in age of working, which allows to define the total labour supply.

Other potential inputs (e.g. number of appliances own, passengers transport demand) transit through other modules and are not directly used in the Employment module.

Table 3 – Inputs from Lifestyles module

Variable [unit]	Description	Link with employment module
lfs_pop_active-pop [inhabitants]	Population in age of working (20-65)	Total labour supply
lfs_paper [t]	Household consumption of paper (for sanitary purposes, printing…)	(Paper, Household)
lfs_food_beverages [kcal]	Household demand of beverage (includes wastes)	(Beverage; Household)
lfs_food_veg-fruits-crops [kcal]	Household demand of crops, vegetables, fruits	(Crops, Vegetables and Fruits; Household) (Processed Crops and Vegetables; Household)
lfs_food_other-veg [kcal]	Household demand of processed food from vegetables and crops (e.g. oil, sugar)	(Processed Crops and Vegetables, Household)
lfs_food_animals [kcal]	Household demand of animal food	(Livestock; Household) (Process animal; Household)
lfs_food_fish [kcal]	Household demand of fish products	(Fish, Household)

4.4.1.2 Buildings

The Buildings module computes the energy and material consumption in buildings, and the associated GHG emissions. It uses inputs from the Lifestyles module (e.g. heating and cooling behaviour, appliances owned) and a set of levers controlling for instance the building and appliances energy efficiencies.

From the Buildings module, the Employment module receives the energy demand for residential and non-residential buildings for each energy vector. The residential buildings energy consumption corresponds to the household energy consumption. The non-residential buildings include the following sectors: Health, Education, Trade, Hotels and restaurants, Offices (which corresponds to Other services). The energy vectors include: electricity, oil (sector Petroleum product), gas, coal, wood logs (sector Forestry), pellets (sector Wood manufacture).

In addition, the Buildings module derives the construction and renovation of buildings, as well as the construction of network infrastructure for district heating (i.e. pipes). These values are converted into monetary unit and sent to the Employment module, corresponding to investment in the construction sector.

Finally, the Buildings module provides the purchases of new appliance by households. The considered appliances are: fridges, freezers, washing machines, dishwashers and dryers.

Table 4 – Inputs from Buildings module

Variable [unit]	Description	Link with employment module
bld_energy-demand_residential_vector [TWh]	Household energy demand of each energy vector	(Vector; Household)
bld_energy-demand_sector_vector [TWh]	Energy demand of a given energy vector in a given sector	(Vector; Sector)
bld_construction_sector [MEUR]	Construction of new buildings	(Construction; Investment)
bld_renovation_sector [MEUR]	Renovation of buildings	(Construction; Investment)
bld_construction_pipes [MEUR]	Construction of network infrastructure for district heating (pipes)	(Construction; Investment)
bld_appliances [MEUR]	Household purchases of new appliances	(Appliances; Household)

4.4.1.3 Transport

The Transport module analyses the evolution of passenger and freight transport, the energy and material consumption of the sector, and the associated GHG emissions. It uses input from the Lifestyles module (e.g. passenger travel distance) and a set of levers controlling for instance the modal share, the fuel mix and the vehicle efficiency.

From the Transport module, the Employment module first gets the energy demand of different transportation mode. The transportation modes are aggregated in the Transport module to correspond to an economic sector in the Employment module:

- The Household energy consumption includes the energy demand of Light duty vehicles (LDV), i.e. cars, and 2-wheels (2W), i.e. motorbikes;
- The Rail transport sector corresponds to the transportation modes rail, metro and tram;
- The Road transport sector corresponds to the transportation via bus and trucks;
- The Air transport sector corresponds to planes;
- The Water transport sector corresponds to boats, which are split in the Transport module between two modes: marine and inland waterways (IWW).

The energy demands of households and each transport sector are detailed into several energy vectors: diesel and gasoline (sector Petroleum product), electricity and gas. The Transport module also computes the demand of liquid and gaseous bioenergy and of hydrogen, but these vectors are not yet implemented in the Employment module.

Second, the Transport module provides variables representing the activity in the transport sectors:

- The passenger activity is the person distance travelled by households. It is provided for the following modes: LDV-2W, rail-metro-tram (sector Rail transport), bus (Road transport), planes (Air transport).

- The freight activity is the total freight transport demand, split into the modes: rail, trucks (Road transport), planes (Air transport), marine-IWW (Water transport).

The Transport module also computes the purchases of new vehicles, for each mode and different technologies and types of fuels. For instance, there are 4 car technologies: internal combustion engine, battery electric vehicles, fuel cell electric vehicles and plug-in hybrid electric vehicles. The purchases of LDV and 2W corresponds to the Household purchase of Transport Machinery. The other mode-technology vehicles are associated with the Investment in Transport machinery.

Finally, the Transport module computes the construction of transport infrastructure (e.g. electric-vehicles charging stations, trolley cables, etc.), which corresponds to Investment in the Construction sector.

Table 5 – Inputs from Transport module

Variable [unit]	Description	Link with employment module
tra_energy-demand_LDV-2W_vector [TWh]	Household energy demand of each energy vector	(Vector; Household)
tra_energy-demand_sector_vector [TWh]	Energy demand of a given energy vector in a given sector	(Vector; Sector)
tra_passenger-demand_mode [pkm]	Person-distance travelled using each transportation mode	(Mode, Household)
tra_freight-demand_mode[tkm]	Freight transport demand for each transportation mode	(Mode, all sectors)
tra_vehicle-purchase_LDV/2W_tech [MEUR]	Household purchases of new vehicles	(Transport Machinery; Household)
tra_vehicle-purchase_mode_tech [MEUR]	Purchases of new vehicles, for different mode and technologies	(Transport Machinery; Investment)
tra_construction_infrastructure [MEUR]	Construction of infrastructure	(Construction; Investment)

4.4.1.4 Industry

The Industry module receives the number of appliances and construction needs from the Buildings module, and the number of new vehicles and construction needs from the Transport module. Using levers controlling for instance the material switch or the recycling share, the module computes the material needs, the energy consumed in industry, and the associated GHG emissions.

From the Industry module, the Employment module first gets the energy demand of the following sectors: Iron and steel, Cement and lime, Chemicals, Ammonia (sector Fertilizers), Pulp and paper, Aluminium, Glass, Textile, Transport machinery. The energy demand is split into several energy vectors: electricity, oil (sector Petroleum product), gas, coal. The Industry module also computes the energy demand of liquid, gaseous and solid bioenergy, of hydrogen and of solid waste, but these vectors are not yet implemented in the Employment module.

Moreover, the Industry module provides the material needs for the sectors:

- Construction: construction and renovation of buildings, construction of transport and district heating infrastructures, construction of new power plants;
- Transport machinery: production of new vehicles (cars, motorbikes, bus, trucks, trains, metro, trams, planes, boats);
- Appliance: production of new appliances (fridges, freezers, washing machines, dryers, dishwashers, TV, computers, phones).

The material vectors include: steel, cement and lime, paper, chemicals, glass, aluminium and wood.

The Industry module also computes the investment in new technologies, in particular for the sectors Iron and steel, Cement and lime, Pulp and paper and Glass.

Finally, a trade lever (the “BAU” setting of which is calibrated using values from the Trade and transboundary module) allows to derive the domestic production thanks to the net import ratio, i.e. the net import (import minus export) with respect to the final demand. The Employment module uses this information to compute the net import in the industrial sectors.

Table 6 – Inputs from Industry module

Variable [unit]	Description	Link with employment module
ind_energy-demand_sector_vector [TWh]	Energy demand of a given energy vector in a given sector	(Vector; Sector)
ind_material-demand_sector_material [t]	Material demand of a given material vector in a given sector	(Material; Sector)
ind_investment_sector [MEUR]	Investment in new technologies in a given sector	(Sector, Investment)
ind_import_sector [-]	Net import ratio in a given sector	(Net Import; Sector)

4.4.1.5 Agriculture

The Agriculture module analyses the production of food products but also bioenergy. It feeds from the demand of food products derived in the Lifestyle module and from the bioenergy demand computed in the Buildings, Transport and Industry modules. Thanks to a set of levers, the users can modify the agricultural practices, moving away from conventional intensive agriculture towards organic farming, conservation agriculture, and agroforestry for example. The Agriculture module then computes the energy demand in the sector and the land-use, as well as the GHG emissions.

As in the Lifestyles module, the Agriculture module includes a much more detailed representation of food groups. These food groups are aggregated in the Agriculture module to obtain a representation consistent with the economic sectors of the Employment module.

From the Agriculture module, the Employment module first gets the energy demand disaggregated into electricity, gasoline and diesel (sector Petroleum product), coal and gas. This energy demand corresponds to the economic sector “Crops, Vegetables and fruits”, Livestock, Forestry and Fish.

Second, the Agriculture module provides the fertilizer needs to grow crops and vegetables. The fertilizers are split into mineral-based fertilizers (sector Fertilizer), and organic fertilizers such as animal manure (sector Livestock) and biocompost (sector Biocompost). In the Agriculture module, increasing the ambition levels leads to a shift from mineral-based to organic fertilizers.

The Agriculture module also computes the Livestock feed composition, detailed between crops and vegetables (e.g. barley, maize, wheat, starch, sugar-crops), processed crops (e.g. crop-based cakes), processed animal meals (e.g. meat, offal, fats, insects) and fish (e.g. fish-meals, algae from aquaculture). An increase in ambition levels is associated with a shift from traditional feed to more sustainable one such as insects or algae.

Finally, a trade lever allows to derive the domestic production thanks to the net import ratio. The Employment module uses this information to compute the net import in the agriculture sectors.

Several other variables computed in the Agriculture module are not yet integrated in the Employment module, but are considered for implementation. In particular:

- The demand of crops and livestock coproducts to produce gaseous bioenergy;
- The demand of livestock coproducts and processed animal coproducts to produce liquid bioenergy;
- The number of persons needed per unit of agriculture output. This variable would represent the various needs in labour of different agriculture practices.

Table 7 – Inputs from Agriculture module

Variable [unit]	Description	Link with employment module
agr_energy-demand_sector_vector [TWh]	Energy demand for each energy vector in a given sector	(Vector; Sector)
agr_fertilizer_sector [t]	Demand of fertilizers to grow crops and vegetables	(Sector; Crops, vegetables and fruits)
agr_liv-food_sector [kcal]	Livestock feed from a given sector	(Sector; Livestock)
ind_import_sector [-]	Net import ratio in a given sector	(Import; Sector)

4.4.1.6 Electricity

In the Electricity module, the users can define the electricity mix by actioning some levers. Then, the module computes the electricity production. A balancing strategy ensures the coherence between the production and consumption of electricity, which is obtained from the other sectoral modules (e.g. Buildings, Transport, Industry, Agriculture).

The power source included closely matched the economic sectors of the Employment module:

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

From the Electricity module, the Employment module gets the Electricity produced from each power source, which is converted in monetary unit using the Operational Expenditure (OPEX).

Furthermore, the Electricity module provides the investment needed for the construction of new power plants.

Table 8 – Inputs from Electricity module

Variable [unit]	Description	Link with employment module
elc_supply_source [MEUR]	Production of electricity using a given power source	(Source; Electricity)
elc_construction_source [MEUR]	Construction of new power plants for each power source	(Construction; Investment)

4.4.1.7 Other modules

Several modules were recently incorporated into the calculator. These modules are not yet linked to the Employment modules, but several interactions are considered:

- The Water module could provide the water consumption of households and of agriculture, industry and power production sectors;
- The Mineral modules could provide the demand and net import of minerals;
- The Oil refinery modules could provide the net import of fossil fuels;
- The CCUS (Carbon Capture, Use and Storage) module could provide the investment needed to install CCUS technologies;
- The District heating module could provide the investment needed to construct district heating installations (note that district heating network infrastructure are already integrated, via inputs from the Buildings module);
- Finally, various climate scenarios (and the associated temperature change) are defined in the Climate module. This module could thus provide the change in worker productivity due to climate change.

4.4.2 Outputs

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

- Total employment change;
- Sectoral employment change;
- Employment and wages evolution for different educational attainment level.

4.5 Calculation tree

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

1. Creating indicators of transition;
2. Modification of the reference scenario;
3. Solving the macroeconomic model defined in section 4.3.

4.5.1 Indicators of transition

The first step consists in aggregating the input variables received from the sectoral modules (section 4.4) per economic flows. For example:

- The Household consumption of Electricity includes the electricity demand in Buildings (for heating and appliances use) and in Transports for electric vehicles.
- The Investment in the Construction sector includes the construction and renovation of buildings, the construction of transport and district heating infrastructure and the construction of new power plants.

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. The reference scenario is discussed in section 7. In this calculation flow, the Employment module uses as inputs the same input variables as defined in section 4.4, but whose values correspond to the reference scenario.

For example, for the electricity consumption of households:

$$indicator\_household\_electricity = \frac{electricity\ demand\ [TWh] - reference\ electricy\ demand\ [TWh]}{reference\ electricity\ demand\ [TWh]}$$

We proceed similarly for the other economic flows for which information is available:

- 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.

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. The other indicators calculation logic follows a similar approach.

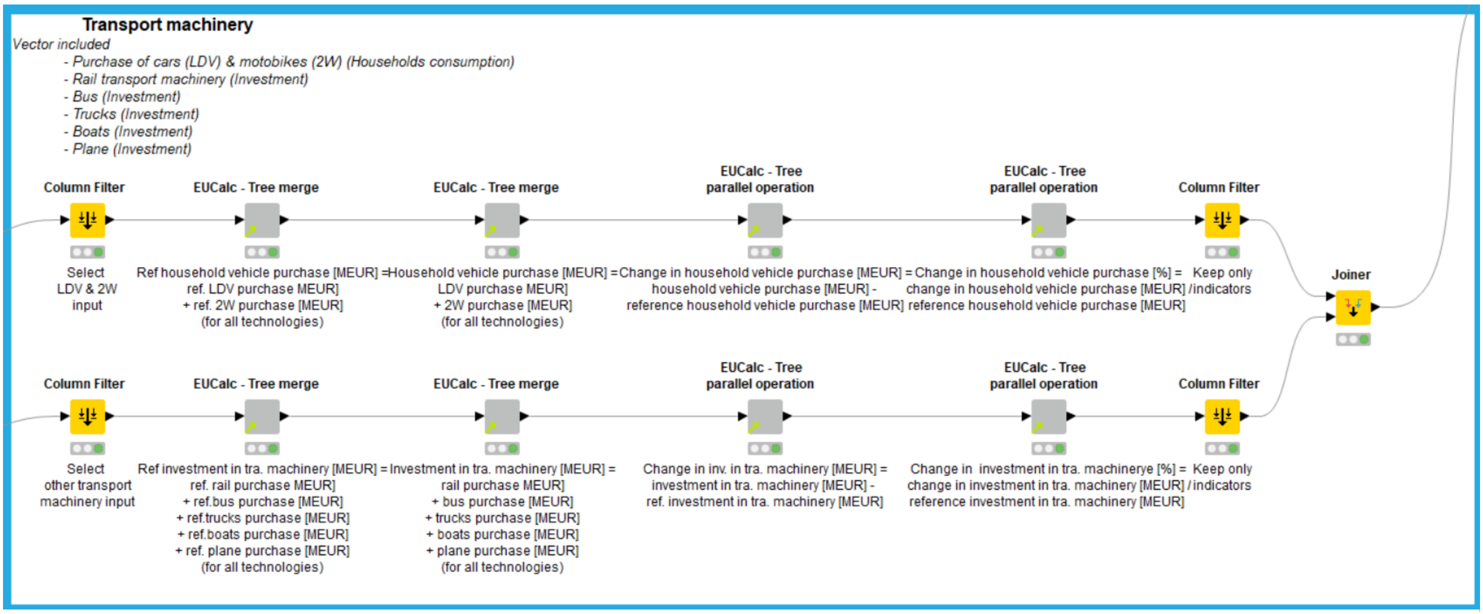

Figure 7 Example of calculation flow to compute a transition indicator

4.5.2 Modifying the reference scenario

Using the indicators computed before, the reference scenario is "shocked". That is, the population dynamics, final demand, input shares and trade balance are adjusted in order to represent the user-defined scenarios as a combination of lever settings.

4.5.2.1 Population dynamics

The active population, given by the Lifestyles module, is used to update the representative household time-endowment $\tilde{L}$.

4.5.2.2 Final demand: households' consumption and investment

Information from sectoral modules is used to modify the households' consumption and investment vectors:

$$C_i = \overline{C_i} \cdot (1 + indicator\_household\_sector\ i)$$

$$INV_i = \overline{INV_i} \cdot (1 + indicator\_investment\_sector\ i)$$

As before, the overbars represent the variable in the reference scenario.

4.5.2.3 Input shares

The user's scenario leads to a change in the structure of the economy. To represent these changes, the input shares θ_{ij} in the firms' production function are modified using the transition indicators:

$$\theta_{ij} = \overline{\theta_{ij}} \cdot (1 + indicator\_sector\ i\_sector\ j)$$

For each sector, the sum of the input shares is then normalized to unity to ensure the coherence of the model.

4.5.2.4 Trade balance

The trade balance is modified using the information gained from the net import variables.

4.5.3 Solving the macroeconomic model

Finally, the system of three non-linear equations for the three unknowns (unskilled and skilled wages and the cost of capital) is solved. 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.

5 Potential levers and ambition levels

In the current version of the module, there is no lever. Some potential lever candidates are:

- A training and education lever: this lever would allow the user to modify the share of skilled and unskilled workers in the population (which is currently fixed, based on the reference scenario).
- An automation lever: this lever would influence the share of capital and labour in the firm production functions.
- A policy lever: this lever would for instance allow the user to change regulations concerning the allowed working time, which would affect the labour supply.

Although these levers might be relevant for the model by extending the scope of the questions addressed, a key issue lies in the definition of ambition levels. In the rest of the calculator, increasing the ambition level means increasing the efforts toward decarbonisation or sustainable transition. The definition of these ambition levels is standardized, from continuing historical trends to transformational changes.[9] However, the definition of ambition levels for levers in the Employment module would be subjective and their calibration could be challenging. The choice to implement or not these levers will be discussed in an upcoming “public call for evidence”, which will gather feedback from future users of the tool.

6 Description of parameters

The only (but crucial) parameters in the model are the elasticities of substitutions. The current values used are detailed in the following tables. These values are adapted from the literature and requires refinement. In addition, a sensitivity analysis will be performed to test the influence of each parameter on the model results.

Table 9 - Elasticities of substitution values

Elasticity	Value	Sources
σ	0.25	Capros et al. (2013)
σ_U	1 (0.7-1.2)	Pissarides (1998)

[9] A few levers, such as population or urban share, are not defined in term of ambition levels toward decarbonisation, but still respect the definition “from continuing historical trends to transformational changes”.

Table 10 – Value added elasticities of substitutions (Source: adapted from Capros et al., 2013)

Economic sectors		σ_{VA}	σ_{LSK}	Economic sectors		σ_{VA}	σ_{LSK}
01	Crops, Vegetables & Fruits	0.23	0.23	29	Glass	0.73	0.73
02	Livestock	0.23	0.23	30	Cement	0.73	0.73
03	Forestry	0.23	0.23	31	Other non-metallic mineral	0.73	0.73
04	Fish	0.23	0.23	32	Iron and steel	1.26	1.26
05	Processed crops and vegetables	1.17	1.17	33	Aluminium	1.26	1.26
06	Processed animal products	1.17	1.17	34	Copper	1.26	1.26
07	Beverage	1.17	1.17	35	Other metal	1.26	1.26
08	Coal	0.2	0.2	36	Mineral mining	0.2	0.2
09	Crude oil	0.2	0.2	37	Construction	1.4	1.4
10	Petroleum product	1.26	1.26	38	Rail transport	1.68	1.68
11	Gas	0.73	0.73	39	Road transport	1.68	1.68
12	Elec. transmission & distribution	1.26	1.26	40	Water transport	1.68	1.68
13	Coal power	1.26	1.26	41	Air transport	1.68	1.68
14	Gas power	1.26	1.26	42	Transport nec	1.68	1.68
15	Nuclear power	1.26	1.26	43	Transport machinery	1.26	1.26
16	Hydropower	1.26	1.26	44	Appliances	1.26	1.26
17	Wind power	1.26	1.26	45	Other consumption good	1.26	1.26
18	Oil power	1.26	1.26	46	Trade	1.3	1.3
19	Biomass power	1.26	1.26	47	Hotels and restaurants	1.3	1.3
20	Photovoltaics	1.26	1.26	48	Education	1.3	1.3
21	Solar thermal power	1.26	1.26	49	Health	1.3	1.3
22	Marine power	1.26	1.26	50	Recycling	1.3	1.3
23	Geothermal power	1.26	1.26	51	Waste incineration	1.3	1.3
24	Wood manufacture	1.26	1.26	52	Biogas	1.3	1.3
25	Water	1.26	1.26	53	Composting	1.3	1.3
26	Pulp and paper	1.26	1.26	54	Wastewater	1.3	1.3
27	Chemicals, plastic, rubber	1.26	1.26	55	Landfill	1.3	1.3
28	Fertilizer	1.26	1.26	56	Other services	1.3	1.3

7 Historical database and reference scenario

The objective of the employment module is to analyse what are the employment impacts of decarbonisation pathways. This requires elaborating a reference scenario (baseline) to compare the employment impacts with and without decarbonisation.

The demographic and economic assumptions behind the reference scenario were defined by partners from WP7, and are detailed in Deliverable 7.1 (Yu and Clora, 2018). These assumptions mainly build on the EU-Reference Scenario 2016.

As described in section 4, the economic model uses as inputs the economic flows and the structure of the economy in the reference scenario. These inputs are derived from reference Input-Output (IO) tables, i.e. tables representing the state of the economy in each country and year of interest.

Computing the IO tables requires several steps:

1. Constructing historical IO tables (section 7.1);
2. Simulating the reference scenario in a CGE model (section 7.2.1);
3. Constructing the reference IO tables (section 7.2.2).

Finally, the Employment module also needs the inputs variables from each sectoral module for the reference scenario to create the transition indicators. Hence, the reference scenario is also reproduced in the calculators by carefully selecting the appropriate levers values (section 7.3).

7.1 Historical Input-Output Tables

The Exiobase[10] version 3 provides IO tables for all the selected sectors and studied countries between 1991 and 2011. It also includes data on employment, disaggregated per educational level and gender.

We modified the Exiobase industrial classification (163 sectors) to obtain the 56 sectors detailed in Table 2 (page 16).

However, to be consistent with other modules, we need to adjust the Exiobase data in the electricity industry branches. In Exiobase, the electricity sector is disaggregated between *Electricity Transmission and Distribution* and 11 sectors related to electricity production. However, the electricity production sectors also include part of the transmission. In EUCalc, *Electricity Transmission and Distribution* corresponds to the electricity consumed in each module (e.g. Buildings, Transport, Industry, Agriculture) while the production is computed in the Electricity supply module. Consequently, we modify the original Exiobase IO tables so that all the electricity consumed by firms, households and government is provided by the sector *Electricity Transmission and Distribution*.

In an IO table, a column details the inputs needed to produce a good, while a row details the intermediate demand (demand of firms) and final demand (demand of households and government). Since we consider that the power sectors (#13 to 23) only includes the electricity production, the inputs of electricity should only come from the *Electricity Transmission and Distribution* (#12) sector. Thus, for each sector (column), we sum the electricity consumed (sectors #12 to 23) into *Electricity Transmission and Distribution* (#12). We proceed similarly for the electricity consumption of households and government. The column *Electricity Transmission and Distribution* (#12) describes the inputs needed to produce electricity. Hence, the electricity mix is represented in this column by the inputs in electricity production (rows #13 to 23). We modify the cells corresponding to the electricity mix (column #12, rows #13 to 23) by replacing their value with the sum of the intermediate and final demand of electricity production. This ensures that the table is balanced, i.e. that the supply of a product is equal to its demand.

We obtain the historical IO tables for each country, which in turn allows to find the historical input shares (θ_{ij} in section 4.3).

[10] More information on Exiobase: https://www.exiobase.eu/

7.2 Reference Input-Output tables

7.2.1 Simulating the reference scenario with GEMINI-E3

Using the Computable General Equilibrium (CGE) model GEMINI-E3, the reference scenario is simulated for the period 2011-2050 with yearly timesteps.

GEMINI-E3 is a worldwide multi-country, multi-sector, CGE model, which has been specifically designed to assess energy and climate change policies. A brief description of GEMINI-E3 is provided here. For further information, a detailed description is available in Bernard and Vielle (2008).

GEMINI-E3 is currently built on a comprehensive energy-economy dataset, the GTAP-9 database (Aguiar et al, 2016). The reference year of the model is 2011. We use a version designed to assess European climate policies. Thus, the EU28 member states and Switzerland are described separately. The rest of the World is aggregated in one region called ROW.

The industrial classification is presented in Table 11. The vast number of regions (30) requires an aggregated number of sectors for limiting the computational times. This means that the classification used in GEMINI-E3 differs with the one of the Employment module. Nonetheless, the two representations are consistent and closely related.

Table 11 – Industrial classification in GEMINI-E3

Sector	
01	Coal
02	Oil
03	Natural gas
04	Petroleum products
05	Electricity
06	Agriculture
07	Energy intensive industries
08	Other goods and services
09	Road transport
10	Sea transport
11	Air transport

Figure 8 represents the structure of the production sectors in the model. Production technologies are described through nested Constant Elasticity of Substitution (CES) functions. First, demand (which includes final demand and intermediate consumption) is separated between Imports and Domestic production using the Armington assumption (Armington, 1969). Then, Domestic production required four aggregated and substitutable inputs: Energy, Materials, Labour and Capital. For Energy, two levels of substitution are distinguished, first between fossil energy and electricity, and then between the fossil energy sources (i.e. between coal, oil products and natural gas). Materials are differentiated between Transport and Other material, i.e. agriculture, an aggregate of energy intensive industries and the other goods and services. Such a production structure is well-suited to study economic and sustainable transitions (e.g. Bernard and Vielle, 2009; Gonseth et al., 2017; Babonneau et al., 2018).

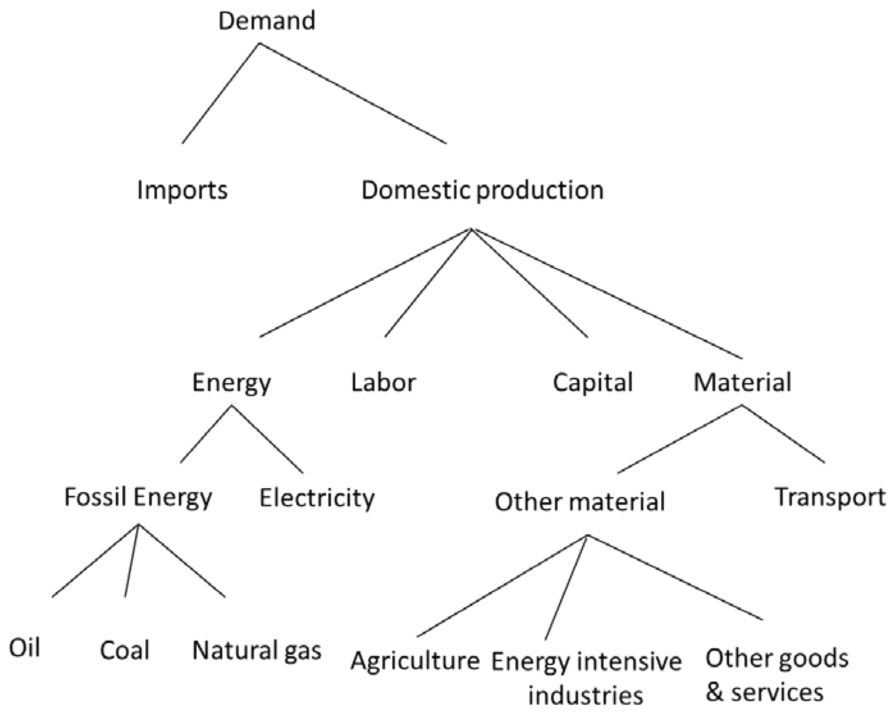

Figure 8 - Nested CES structure of the production

Finally, the representative household maximizes a nested CES utility function (see Figure 9). At the first level of the consumption function, households choose between housing demand, transport needs and other consumptions. In transport and housing consumptions, energy can be substituted by spending more on a capital good that is represented by vehicles in the first case and by buildings in the second, i.e. by purchasing vehicles and buildings that are more energy-efficient, but also more expensive.

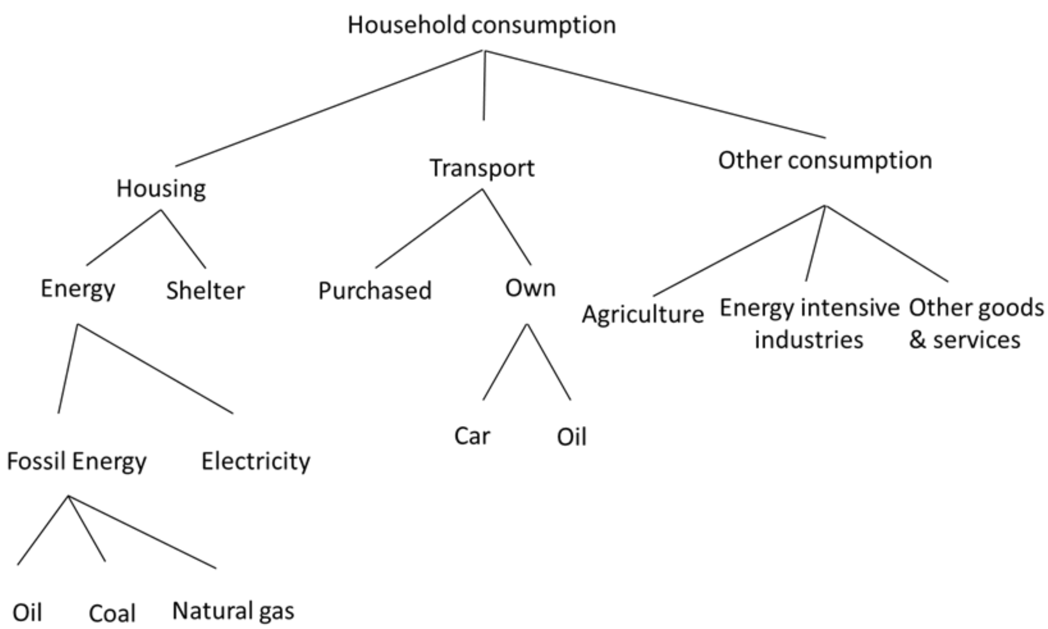

Figure 9 - Nested CES structure of household consumption

7.2.2 Reconstructing the reference scenario IO Tables

GEMINI-E3 simulations provide reference IO Tables between 2011 and 2050 with the industrial classification of Table 11. Based on this information, reference IO tables are reconstructed with the industrial representation of the Employment module. The methodology consists of modifying the 2011 IO Table computed in section 7.1 based on the following steps illustrated in Figure 10:

1. The starting point is the 2011 IO tables built in section 7.1;
2. The intermediate and final consumption are modified:
   a. Each components of the final demand (i.e. Households consumption, Government consumption, Investment, Exports) is multiplied by the change with respect to year 2011 computed by GEMINI-E3, at the aggregated level;
   b. The structure of the final demand components is updated. When the classification of the Employment module corresponds exactly to the one used by GEMINI-E3, it is done directly. For example, coal, crude oil, petroleum product, gas, electricity, sea transport and air transport consumption are represented both by the Employment module and by GEMINI-E3. When it is not the case, the change at the aggregated level is considered. For example, the share of the consumption of agriculture goods in the reference IO tables (i.e. sectors #1 to #4 in the Employment module) is assumed to follow the share of the good *Agriculture* (#06, Table 11) computed by GEMINI-E3;
   c. The intermediate consumption is adjusted to consider variations computed by GEMINI-E3, either at the sectoral level or at the aggregated level depending on the concordance between the representations;
3. The imports of each goods are adjusted based on the results of GEMINI-E3 simulations, either at the sectoral level or at the aggregated level depending on the concordance between the representations;
4. Finally, a RAS algorithm (Lecomber, 1975) is used to balance the new IO tables, i.e. to equilibrate the supply and the demand in all sectors.

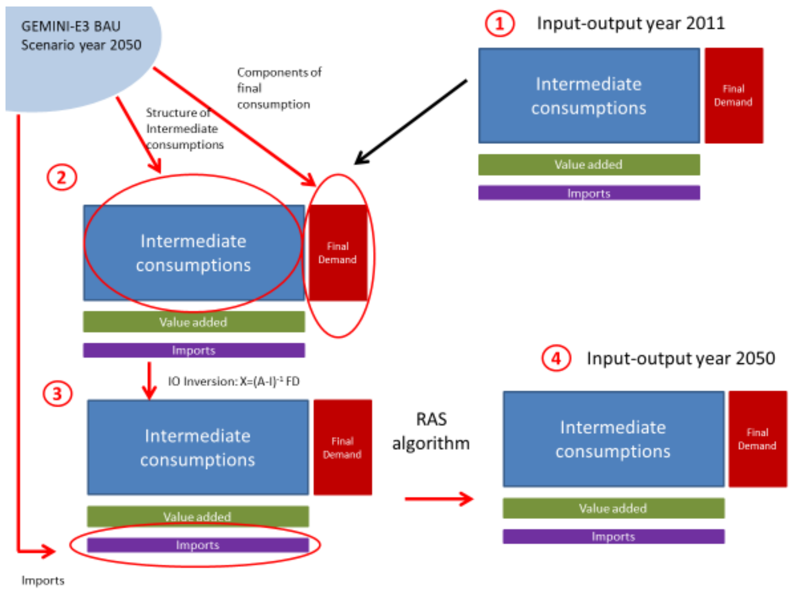

Figure 10 Steps to compute reference IO tables

This procedure gives the reference IO tables for each country, which are consistent with the reference scenario computed by GEMINI-E3, and which consider not only economic growth but also changes in the economic structure.

7.3 The reference scenario in EUCalc

The EU-Reference Scenario 2016 is reproduced in the calculator by selecting the appropriate levers values. Thanks to this simulation exercise, each sectoral module can send to the Employment module the inputs variables corresponding to the reference scenario, which allows to compute the transition indicators.

Table 12 shows some levers value positions corresponding to the reference scenario. These values are presented for indicative purposes only. Indeed, the calculator is still evolving and improving, and each iteration modifies the appropriate “reference” lever values. However, it is worth noting that the reference scenario is a lowly ambitious scenario in the calculator, most levers reference levels being between 1 (pursuing historical trends) and 2.

Table 12 – Ambition levels corresponding to the reference scenario

Module	Lever	Reference level
Lifestyles	Population	B
Lifestyles	Travel demand	1
Lifestyles	Floor intensity	1.5
Lifestyles	Appliances number	1.8
Lifestyles	Appliances use	1.8
Lifestyles	Biophysical requirement	2
Lifestyles	Diet composition	1
Lifestyles	Food waste	4
Lifestyles	Paper package	2
Transport	Passenger modal share	1.3
Transport	Passenger technology share	1.1
Transport	Freight demand	1.3
Transport	Freight modal share	1.1
Transport	Freight efficiency	1.1
Transport	Passenger efficiency	1.3
Transport	Freight fuel mix	1
Transport	Passenger fuel mix	1
Buildings	Heating and cooling efficiency	1.5
Buildings	Appliances efficiency	1.5
Buildings	Technology and fuel share	1.5
Industry	Material efficiency	1.5
Industry	Material switch	1.5
Industry	Technology share and recycling	1.5
Agriculture	Climate smart livestock	1
Agriculture	Climate smart cropping	1.6
Electricity	Nuclear	3
Electricity	Fossil fuel	1
Electricity	Wind	1
Electricity	Solar	1.1
Electricity	Other renewables	1

8 References

Aguiar, A., Narayanan, B. and McDougall, R. 2016, An Overview of the GTAP 9 Data Base. Journal of Global Economic Analysis 1, no. 1: 181-208.

Armington, PS. 1969. A theory of demand for products distinguished by place of production. *IMF Staff Papers* 16:159–78

Babonneau, F., Thalmann, P., and Vielle, M. 2018. Defining deep decarbonization pathways for Switzerland: an economic evaluation. *Climate Policy*, 18(1), 1-13.

Bernard, A., and Vielle, M., 2008. GEMINI-E3, a general equilibrium model of international-national interactions between economy, energy and the environment. *Computational Management Science*, 5(3):173-206.

Bernard, A., and Vielle, M. 2009. Assessment of European Union transition scenarios with a special focus on the issue of carbon leakage. *Energy Economics*, 31, S274-S284.

Böhringer, C., Boeters, S. and Feil, M., 2005. Taxation and unemployment: an applied general equilibrium approach. *Economic Modelling*, *22*(1), pp.81-108.

Camdrige Econometrics. 2015. Assessing the Employment and Social Impact of Energy Efficiency. Final report available at: https://ec.europa.eu/energy/sites/ener/files/documents/CE_EE_Jobs_main%2018Nov2015.Pdf

Capros, P., Van Regemorter, D., Paroussos, L., Karkatsoulis, P., Fragkiadakis, C., Tsani, S., Charalampidis, I. and Revesz, T., 2013. GEM-E3 model documentation. *JRC-IPTS Working Papers, JRC83177, Institute for Prospective and Technological Studies, Joint Research Centre. ftp://sjrcsvqpx102p. jrc. es/pub/EURdoc/EURdoc/JRC83177. pdf*.

Costa, L., Baudry G., Taylor, E., Matton, V., Pradhan, P., Kochat, J. 2018. Deliverable 1.3: Lifestyles in Europe: Perspectives and scenarios – Public deliverable of the EUCalc project

Diamond, P.A., 1981. Mobility costs, frictional unemployment, and efficiency. *Journal of political Economy*, *89*(4), pp.798-812.

Diamond, P.A., 1982. Aggregate demand management in search equilibrium. *Journal of political Economy*, *90*(5), pp.881-894.

European Commission, DG Energy, DG Climate Action & DG Mobility and Transport 2016. EU Reference Scenario 2016. Energy, transport and GHG emissions Trends to 2050.

European Commission (DG ECFIN) & Economic Policy Committee (AWG) 2014. The 2015 Ageing Report Underlying Assumptions and Projection Methodologies. *European Economy Report No. 8*.

European Commission (DG ECFIN) & Economic Policy Committee (AWG) 2015. The 2015 Ageing Report Economic and budgetary projections for the 28 EU Member States (2013-2060. *European Economy Report No. 3*.

Gonseth, C., Thalmann, P., and Vielle, M. 2017. Impacts of global warming on energy use for heating and cooling with full rebound effects in Switzerland. *Swiss Journal of Economics and Statistics*, 153(4), 341-369.

Hartwig, J., Kockat, J., Schade, W., and Braungardt, S. (2017). The macroeconomic effects of ambitious energy efficiency policy in Germany–Combining bottom-up energy modelling with a non-equilibrium macroeconomic model. Energy, 124, 510-520.

Lecomber, J. 1975. A Critique of Methods of Adjusting, Updating and Projecting Matrices. In *Estimating and Projecting Input-Output Coefficients*. London. Input-Output Publishing Company. Pages 1–25.

Lehr, U., Lutz, C., and Edler, D. (2012). Green jobs? Economic impacts of renewable energy in Germany. Energy Policy, 47, 358-364.

Mortensen, D.T. and Pissarides, C.A., 1994. Job creation and job destruction in the theory of unemployment. *The review of economic studies*, *61*(3), pp.397-415.

Pashaei Kamali F., Thurm B., Rankovic A., Vielle M., Posada J. and Osseweijer P., 2018. Deliverable 6.3: Identification of the parameters relevant to assess socio-economic impacts and consultation workshop – Public deliverable of the EUCalc project

Peters, J.C. 2016. The GTAP-Power Data Base: Disaggregating the Electricity Sector in the GTAP Data Base. *Journal of Global Economic Analysis* 1:209-250

Pissarides, C.A., 1998. The impact of employment tax cuts on unemployment and wages; the role of unemployment benefits and tax structure. *European Economic Review*, *42*(1), pp.155-183.

Thurm, B. Spierenburg L. and Vielle M. 2018. Deliverable 6.1: Documentation on the GEMINI-E3 module and interface and on the way the library is generated – Public deliverable of the EUCalc project

Tukker, A., Poliakov, E., Heijungs, R., Hawkins, T. Neuwahl, F. Rueda-Cantuche, J., Giljum, S., Moll, S., Oosterhaven, J. Bouwmeester, M. 2009. Towards a global multi-regional environmentally extended input–output database, *Ecological Economics*, 68(7):1928-1937.

UNESCO Institute for Statistics. (2012). *International standard classification of education: ISCED 2011*. Montreal: UNESCO Institute for Statistics.

Yu, W. and Clora, F. 2018. Deliverable 7.1: Formulation of baseline projections and documentation on modeling approach review – Public deliverable of the EUCalc project