EUCALC
Explore sustainable European futures

New EUCalc module on socio-economic impacts

D6.8

August/2019

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 730459.

Project Acronym and Name	EU Calculator: trade-offs and pathways towards sustainable and low-carbon European Societies - EUCalc
Grant Agreement Number	730459
Document Type	Report
Work Package	WP6
Document Title	New EUCalc module on socio-economic impacts
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Partner in charge	EPFL
Contributing partners	Imperial College, UCPH, TUD
Release date	August 2019
Distribution	*Public*

Short Description

This report describes the EUCalc employment module, and in particular:

- *the scope and questions addressed by the module;*
- *the interactions with other modules;*
- *the economic model, associated assumptions and calculation logic;*

Quality check

Name of reviewer	Date
Francesco Clora	19/08/2019
Onesmus Mwabonje	19/08/2019

Statement of originality:

This deliverable contains original unpublished work except where clearly indicated otherwise.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

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List of abbreviations

BAU	Business As Usual
CAPEX	Capital Expenditure
CCUS	Carbon Capture Use and Storage
CES	Constant Elasticity of Substitution
CGE	Computable General Equilibrium
EU	European Union
EU28	European Union 28 countries
EUCalc	European Calculator
FTE	Full Time Equivalent
GDP	Gross Domestic Product
GHG	Greenhouse gas
GTAP	Global Trade Analysis Project
ILO	International Labor Organization
IO	Input-Output
ISCED	International standard classification of education
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

List of symbols

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
U	Representative household utility
VA_j	Value added in sector *j*
$w_{LS/LU}$	Wage of skilled/unskilled workers
X_j	Supply of good *j*
X_{ij}	Intermediate demand of good *i* in sector *j*
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
τ	Total government revenue

Glossary

Baseline	Reference scenario used in a CGE analysis
Computable General Equilibrium (CGE)	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)
Gross Domestic Product (GDP)	Measure of the production/income/expenditure of a country
Input-Output (IO) 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 Executive Summary

This deliverable describes the Employment module of the EUCalc project. More precisely, the scope of the module, the questions addressed, the calculation logic and the interactions with the other modules are detailed.

The Employment module assesses the employment impacts for each users' decarbonisation pathway. The scope and questions addressed by the module were defined during the WP6 stakeholder workshop.

The Employment module receives inputs from the sectoral modules (e.g. Lifestyle, Building, Transport, Industry, Agriculture, Electricity Supply) to derive in real-time the employment impacts per economic sector and per educational attainment of workers. Comprehensive interactions between the Employment module and the sectoral modules are achieved thanks to a detailed industrial classification, which enables a close interface with the sectoral modules.

Finally, a macroeconomic model was specifically designed for the Employment module. Relying on some simple assumptions, it allows for fast computation time while reconciling engineering-based calculators with macroeconomic theory.

2 Introduction: challenges to model employment impacts in EUCalc

The European Calculator (EUCalc) model enables end users to visualize online the environmental and socio-economic impacts of decarbonisation pathways in the European Union countries (EU28) and in Switzerland. The calculator adopts a modular approach. 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 economic rationale behind the module.

The Employment module aims at analysing the impacts on employment of various decarbonisation pathways. Using inputs from the sectoral modules (e.g. Lifestyle, 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. in 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 characteristics that 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 bottom-up approach of the calculator, so that some sectoral information could be lost. Finally, the behaviours of economic agents in a CGE depend on prices and income constraints while in EUCalc some pathways rely largely on lifestyles changes (where individuals do not only consider prices). Hence, the two approaches are difficult to reconcile.

In Deliverable 6.1 (Thurm et al., 2018), a preliminary methodology was suggested to implement employment impacts in the calculator. The method relied on a combination of IO analysis complemented by CGE runs. In particular, the idea was to use the CGE model GEMINI-E3 to simulate a reference scenario, allowing to compute reference IO tables for all countries until 2050. These IO tables were then modified using inputs from the sectoral modules to reproduce the users' scenarios, as in an IO analysis framework. This approach thus suffers from the same limitations than an IO analysis.

[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. See Perrier and Quirion (2018) for a comparison of the job channel creation in IO analysis and CGE model.

Consequently, a refined approach was developed, also taking advantage of feedback obtained from experts during the stakeholders' workshops and the call for evidence. While the first step of the method is unchanged (i.e. GEMINI-E3 is used to simulate a reference scenario and compute reference IO tables), a new macroeconomic model was designed, specifically for the Employment module, to replace the IO analysis. This deliverable presents this model and the updates with respect to the preliminary approach defined in Deliverable 6.1.

The rest of the document is organized as follows. The questions addressed by the module are presented in Section 3. In Section 4, we describe the calculation logic, i.e. the scope of the module, the interactions 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 conclude by pointing out potential future improvement.

3 Questions addressed by the module

The questions addressed 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.[2] 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.

Other 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 a 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 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 hour was not considered a priority indicator to assess employment impacts, since the average working hour is more related to employment condition and less to low-carbon transition.

[2] 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[3]	Rationale
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	• Decarbonisation pathways reproduced thanks to interaction with sectoral modules • Macroeconomic model with a detailed sectoral representation and two skill levels of workers
	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 (in Agriculture and Industry) 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

[3] 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 (see Figure 1) 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 the associated reference Input-Output tables and input data are explained in Deliverable 6.6. The demographic and economic assumptions behind this reference scenario are detailed in Deliverable 7.1 (Yu and Clora, 2018). These assumptions mainly build on the EU-Reference Scenario 2016 (European Commission, 2015; 2016);
- 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 modify the reference scenario and reproduce the scenario defined by the end 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.

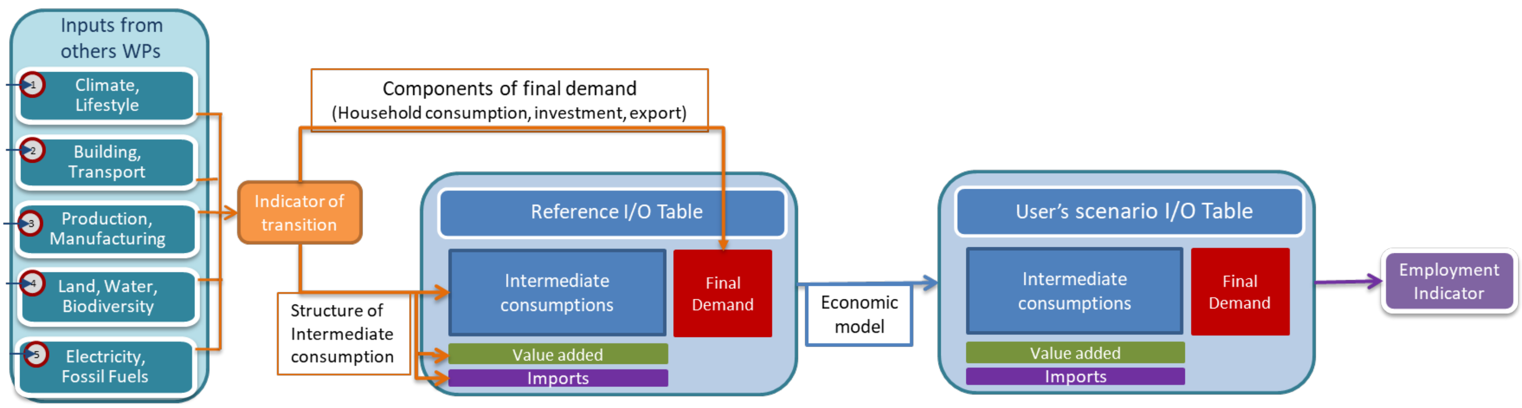

Figure 1 - General logic of the Employment module

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 workers' 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. 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[4] 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 Land Use and 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,

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

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 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 *Appliances* (#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).

Methodology update (with respect to Deliverable 6.1):

The industrial classification defined in Deliverable 6.1 was adjusted in two ways:

1. *The original plan was to use the GTAP 9 database. However, we decided to switch to Exiobase because this database is open-source, it provides historical data (from 1995 to 2011), and its classification is closer to the sectoral EUCalc modules, allowing for a closer interface (see Section 4.4).*
2. *The number of sectors was increased (from 39 to 56) to better fit with the sectoral modules representation. In particular, the sectors Fish, Beverage, Fertilizer were added after discussions with the Agriculture module. The Services were disaggregated to include Trade, Hotels and restaurants, Education, Health since the Buildings module provides information on the energy consumption in these sectors. Similarly, the Appliances sector was created to account for the purchase of appliances computed in the Buildings module. Finally, Exiobase has a more detailed representation of waste management than GTAP, which allowed to include a Biogas sector.*

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 follow the sectoral modules, namely Agriculture, Transport, Industry, Services, and Electricity supply.

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 (see Deliverable 6.3, Pashaei Kamali et al. 2018). Consequently, two types of workers have been included in the model, namely the skilled and unskilled workers, defined following the International standard classification of education (ISCED):[5]

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

> ***Methodology update (with respect to Deliverable 6.1):***
>
> *Although mentioned as a possibility in Deliverable 6.1, the skills heterogeneity inclusion was confirmed following the WP6 stakeholder workshop.*

[5] 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 2.

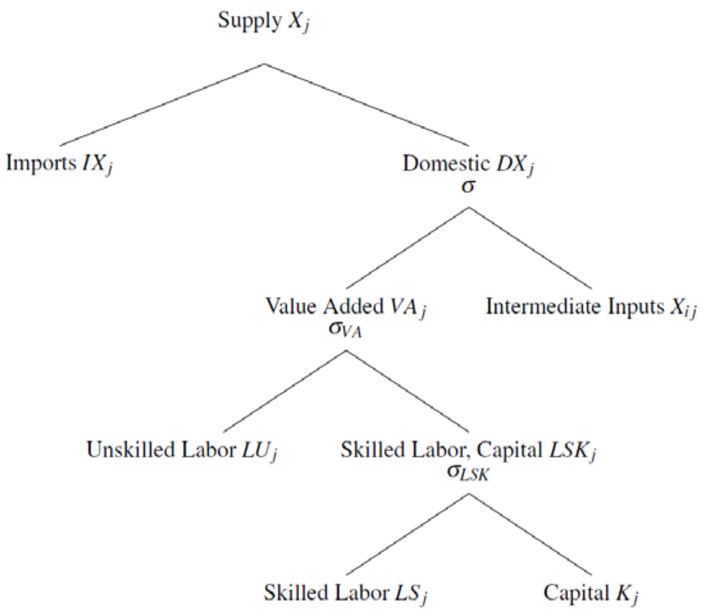

Figure 2 - Firms' production function

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, obtained from the reference Input-Output tables (see Deliverable 6.6).

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 modified 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 4.3.4.

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 4.3.4.

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

$$\min \quad w_{LU} LU_j + w_{LS} LS_j + r_K K_j + \sum_i p_i X_{ij}$$

$$\text{s.t.} \quad DX_j = \overline{DX}_j \left[\theta_{VA\,j} \left(\frac{VA_j}{\overline{VA}_j} \right)^{\rho} + \sum_i \theta_{X\,ij} \left(\frac{X_{ij}}{\overline{X}_{ij}} \right)^{\rho} \right]^{1/\rho}$$

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

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

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). The prices are normalised to unity in the reference scenario.

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

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

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

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

Methodology update (with respect to Deliverable 6.1):

In the preliminary methodology, the idea was to use an IO analysis. This method is a special case of the model defined above, where all elasticities of substitution are equal to zero. Hence, in IO analysis, the demand of intermediate inputs (e.g. labour) are independent of the relative prices (see above equations, $\sigma = \sigma_{VA} = \sigma_{LSK} = 0$). In other words, IO analysis fails to account for substitution effects and the ratio of labour with respect to the production is fixed.

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.[6] 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 4.3.4.

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

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

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

[6] 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.

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).

Methodology update (with respect to Deliverable 6.1):

In IO analysis, there is no representation of households' behaviour and thus no trade-off between consumption and leisure. Hence, IO analysis fails to account for income effects and does not model the supply of labour by households. This could create inconsistencies. For instance, there could exist a scenario where the number of workers computed thanks to employment factors is greater than the active population. Indeed, in IO analysis, there is no constraint on the labour available. By contrast, in the model defined above, labour is a scarce resource. If the labour demand increases, then the wages will adjust accordingly and also increase. Thus, labour becomes relatively more expensive than other intermediate inputs, and firms will for example substitute labour with capital. The economic constraints are respected.

4.3.3 Market clearing

Assuming perfect competition 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 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 Description of parameters

The only (but crucial) parameters in the model are the elasticities of substitutions. The values used are detailed in the following tables. These values are adapted from the literature. Once the Employment module is fully integrated with the rest of the model, a sensitivity analysis will be performed to test the influence of each parameter on the model results.

Table 3 - Elasticities of substitution values

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

Table 4 – 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

4.4 Interaction with other modules

4.4.1 Inputs

The employment module receives inputs from all sectoral modules (e.g. Lifestyle, 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.

4.4.1.1 Lifestyle

In the Lifestyle 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. For a complete description of the Lifestyle module, please refer to Deliverable 8.3 (Costa et al., 2018).

The first input variables received from the Lifestyle 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 Lifestyle module aggregates 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 Lifestyle module also provides the household consumption of paper (for sanitary purposes, printing, etc.). Finally, the Lifestyle 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 5 – 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 and District Heating

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. These levers are detailed in Deliverable 2.5 (Kockat et al., 2019).

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, while the construction of network infrastructure for district heating (i.e. pipes) are calculated in the District Heating module (described in Deliverable 2.6, Codina Gironès et al., 2018). 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, dryers, computers, phones and TV.

Table 6 – 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_capex_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. A detailed description of the Transport module is available in Deliverable 2.2 (Taylor et al., 2018).

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 7 – 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_capex_LDV/2W_tech [MEUR]	Household purchases of new vehicles	(Transport Machinery; Household)
tra_capex_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 (see Deliverable 3.2, Warmuth et al., 2019).

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 domestic production lever (the “BAU” setting of which is calibrated using values from the Trade and transboundary module) allows to derive the domestic production share with respect to the final demand. The Employment module uses this information to compute the net import in the industrial sectors.

Table 8 – 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_capex_sector [MEUR]	Investment in new technologies in a given sector	(Sector, Investment)
ind_import_sector [-]	Domestic production share in a given sector	(Net Import; Sector)

4.4.1.5 CCUS

The Carbon Capture Use and Storage (CCUS) module receives the carbon captured in the industry and energy sectors. The carbon is then either stored or used, i.e. processed into useful products such as synthetic natural gas. The CCUS module is described in Deliverable 3.3 (Li et al., 2019).

The CCUS module computes the cost of storage and use, depending on the technology involved. This information is sent to the Employment module and corresponds to investment either in Construction (for carbon storage) or in Gas (for carbon use).

Table 9 – Inputs from CCUS module

Variable [unit]	Description	Link with employment module
ccu_capex_sector [MEUR]	Investment in new technologies in a given sector	(Sector, Investment)

4.4.1.6 Agriculture

The Agriculture module not only 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 and 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. A detailed description of the Agriculture is available in Deliverables 4.1 (input data, levers definition) and 8.4 (calculation logic) (Baudry et al., 2019a,b).

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 domestic production lever allows to derive the domestic production share. 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 will be considered for implementation. These include:

- 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 10 – 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)
agr_import_sector [-]	Domestic production share in a given sector	(Import; Sector)

4.4.1.7 Electricity and Storage

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 in the Storage module 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 Electricity and Storage modules are described in Deliverables 5.1 and 8.5 (Gyalai-Korpos et al., 2019a,b).

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 and Storage modules, 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 11 – Inputs from Electricity module

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

4.4.1.8 Other modules

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

- The Water module could provide the water consumption of households and of agriculture, industry and power production sectors;
- The Land Use and Forestry module could provide the domestic production and net import of wood products;
- The Mineral modules could provide the demand and net import of minerals;

- The Oil refinery modules could provide the net import of fossil fuels;
- 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

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 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.

The methodology for each of these steps is presented herein. The integration of the equations in the modelling framework is described in Deliverable 8.7.

4.5.1 Indicators of transition

The first step consists of 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, the construction of infrastructure for carbon storage, 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. Thus, the Employment module uses as inputs the same input variables as defined in section 4.4, but whose values correspond to the reference scenario. The reproduction of the reference scenario in the calculator, and the associated input data for the Employment module, is discussed in Deliverable 6.6.

For example, for the electricity consumption of households:

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

Similarly, the other economic flows for which information is available are:

- 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.

4.5.2 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:

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

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

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:

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

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 Concluding remarks: lessons learned and future improvement

The Employment module computes the employment impacts for each decarbonisation pathway using a macroeconomic model specifically designed for the module. The detailed industrial classification chosen allows for a close interface with the EUCalc sectoral modules. It also enables to provide information on which economic sectors are more affected by a transition toward a low-carbon economy. The inclusion of skill heterogeneity provides information on which population groups are more vulnerable. The scope and questions addressed by the module were defined in the WP6 stakeholders' consultation workshop.

The Employment module has several advantages with respect to existing model and studies looking at the impacts on employment of energy transition. First, it has a larger flexibility since each user can define her own decarbonisation pathway. Second, it has a larger scope. The model, for example, enables to visualize the effects on employment of lifestyles changes, while those are often overlooked in the literature. Finally, thanks to the coupling with the sectoral modules, the Employment module has accessed to detailed sectoral information. A standard macroeconomic model cannot have the in-depth sectoral representation achieved by the EUCalc modular approach.

In addition to its contribution to the scientific literature, the Employment module offers an important methodological contribution for future calculators by trying to reconcile macroeconomic theory with the engineering-based calculator approach. Simplifying assumptions allow fast computation time and a closer interface with sectoral modules. Despite these advancements, many improvements could be implemented in future versions of the calculator.

Firstly, 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. Implementing involuntary unemployment would thus require a more detailed analysis of each country and additional data to properly calibrate the model.

Second, no levers are designed in the current version of the module. 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.[7] However, the definition of ambition levels for levers in the Employment module would be subjective and their calibration could be challenging. Therefore, the implementation of these levers is left for future calculators.

[7] 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”.

6 References

Baudry G., Raffray, M., Bouchet, A., Price, J., Forstenhaeusler, N., Mwabonje, O., Woods, J. 2019a. Deliverable 4.1: Land, land use, minerals, water and biodiversity input spreadsheets for calculator model – Public deliverable of the EUCalc project

Baudry G., Raffray, M., Bouchet, A., Price, J., Forstenhaeusler, N., Mwabonje, O., Woods, J. 2019b. Deliverable 8.4: Integration of the resource's modules "Land allocation, biodiversity impact & forestry", "Water scarcity" and "minerals" modules – Public deliverable of the EUCalc project

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

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*.

Codina Gironès, V., Li, X., and Maréchal, F. 2019. Deliverable 2.6: Data and model for the integration of district heating – Public deliverable of the EUCalc project

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

Costa, L., Forstenhäusler, N., Warren, R., Price, J. 2018. Deliverable 8.3: Integration of the Lifestyle and Climate modules – 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*.

Gyalai-Korpos, M., Hegyfalvi, C., and Zsiborács, H. 2019a. Deliverable 5.1: Energy supply module documentation – Public deliverable of the EUCalc project

Gyalai-Korpos, M., Hegyfalvi, C., Zsiborács, H., and Detzky, G. 2019b. Deliverable 8.5: Storage requirements module – Public deliverable of the EUCalc project

Kockat, J., Wallerand, A. S., Jankovic, I., Wang, X. 2019. Deliverable 2.5: Identification of levers and levels for the building stock – Public deliverable of the EUCalc project

Li, X., Wallerand, A. S., and Codina Gironès, V. 2019. Deliverable 3.3: Carbon Capture Use and Storage module – Public deliverable of the EUCalc project

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

Perrier, Q., and Quirion, P. 2018. How shifting investment towards low-carbon sectors impacts employment: three determinants under scrutiny. *Energy Economics*, 75, pp.464-483.

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.

Taylor, E., Cornet, M., Pestiaux, J., and Vermeulen, P. 2018. Deliverable 2.2: Identification of levers and levels of ambition for passenger & freight transport in Europe – Public deliverable of the EUCalc project

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.

Warmuth, H., Pfefferer, B., and Auer, M. 2019. Deliverable 3.2: Energy intensive industry demand – Public deliverable of the EUCalc project

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