EUCALC

Explore sustainable European futures

Documentation on the GEMINI-E3 module and interface and on the way the library is generated

D6.1

April/2017

EUCALC

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	6
Document Title	Documentation on the GEMINI-E3 module and interface and on the way the library is generated
Main authors	Boris Thurm, Lucas Spierenburg and Marc Vielle
Partner in charge	EPFL
Contributing partners	Luis Costa
Release date	30.04.2018
Distribution	*Public*

Short Description
This deliverable details the methodology to compute socio-economic impacts of different transitions toward sustainable societies within the EUCalc project. It explains how bottom-up inputs from other Work Packages are integrated in a top-down macroeconomic model in WP6. The methods to assess employment impacts are described as an example.

Quality check	
Name of reviewer	**Date**
Farahnaz Pashaei Kamali	20.04.2018
Wusheng Yu and Francesco Clora	18.04.2018

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This deliverable contains original unpublished work except where clearly indicated otherwise.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

Table of Contents

List of Tables

List of Figures

EUCALC

List of abbreviations

AUT	Austria
BAU	Business As Usual
BEL	Belgium
BGR	Bulgaria
CES	Constant Elasticity of Substitution
CHE	Switzerland
COICOP	Classification of Individual Consumption According to Purpose
CYP	Cyprus
CES	Constant Elasticity of Substitution
CGE	Computable General Equilibrium
CZE	Czech Republic
DEU	Germany
DNK	Denmark
EU	European Union
EU28	European Union 28 countries
EUCalc	European Calculator project
ESP	Spain
EST	Estonia
FIN	Finland
FRA	France
FTE	Full Time Equivalent
GBR	United Kingdom
GDP	Gross Domestic Product
GTAP	Global Trade Analysis Project
GRC	Greece
HRV	Croatia
HUN	Hungary
IO	Input-Output
IRL	Ireland
ITA	Italy
LCOE	Levelized Cost of Electricity
LFS	Labour Force Survey
LTU	Lithuania
LUX	Luxemburg

LVA	Latvia
MLT	Malta
MS	Member State
NLD	Netherlands
POL	Poland
PRT	Portugal
ROU	Romania
SVK	Slovakia
SVN	Slovenia
SWE	Sweden
ROW	Rest Of the World
WP	Working package

1 Executive Summary

This deliverable details the methodology to compute employment impacts of different transitions toward sustainable societies within the European Calculator project (EUCalc).

More specifically, the report describes the methods used in WP6 to: (a) construct a representation of the economy that is consistent with the needs of the project, (b) simulate a baseline socio-economic scenario, (c) reconcile this baseline with the user's scenario, and (d) compute the socio-economic impacts of the user's scenario, with employment effects as an example. The report also presents the databases used to calibrate our model and how these databases are harmonized.

To represent the economic structure of a country, we use an Input-Output framework that is harmonized and complemented by runs from GEMINI-E3 for the forecasted period. The Input-Output tables are linked with bottom-up sectoral inputs given by other WPs. Within this framework we are able to compute the impacts on employment resulting from different decarbonisation pathways such as dietary changes, modal split in transportation, development of renewable electricity generation, etc. The employment impacts are computed at industrial levels within an industrial classification that describes 39 sectors.

This methodology has already been implemented and tested for Germany and we show how it can be generalized for the 28 other European countries (including Switzerland). We also show that our methodology can be extended to other socioeconomic dimensions such as: employment by skills, employment by gender, value added.

Finally, we propose some ways to improve our methodology by adding new features within the GEMINI-E3 model regarding labour supply.

2 Introduction

There are numerous pathways to reach a same reduction of greenhouse gases emissions. One possibility is to promote renewables in the electricity mix. Another is to focus on energy efficiency in buildings. Alternatively, people could decrease their meat consumption or favour trains over planes. In a not so distant future, electric-vehicles could replace fuel engines. 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.[1] 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, renovation and insulation of buildings, etc. Then, the model computes several environmental and socio-economic indicators, providing information on greenhouse gases emissions, energy consumption, land, water and material uses, health, employment, etc. The objective is to highlight the trade-offs between the different pathways.

The socio-economic impacts are studied in Work Package (WP) 6, using inputs from Lifestyles (WP1), Building and Transport (WP2), Production and Manufacturing (WP3), Land, Water and Biodiversity (WP4), Electricity and Fossil Fuels (WP5) and Transboundary Effects and Trade (WP7). This deliverable describes the methods used in WP6 to: (a) construct a representation of the EU28 and Switzerland economy that is consistent with the needs of the project, (b) simulate a baseline socio-economic scenario, (c) reconcile this baseline with the user's scenario, and (d) compute the socio-economic impacts of the user's scenario, with employment indicators as an example.

To represent the economic structure of a country, we use Input-Output (IO) tables, which were pioneered by the work of Leontief (1951).[2] For each country, IO tables provide a simplified representation of the economy, linking the demand of a product to its supply. Since it would be impossible to include every existing product, they are aggregated into industrial sectors. In EUCalc, the industrial sectors are chosen in accordance with the needs of the project. For each of these sectors, IO tables describe the household demand, the public and private investments, the domestic production, the exports and the imports. Moreover, they detail how a good is produced. For instance, the production of vegetables requires inputs such as labour, electricity, fuel, water, or fertilizers. IO tables describe the quantity needed (in monetary unit) of inputs to produce a good. In this deliverable, we will first show how the IO tables for each country are obtained in the reference year (2011), and then how they are constructed until 2050.

---

[1] More information on the project is available at: http://www.european-calculator.eu/

[2] Wassily Leontief won the Nobel Memorial Prize in Economic Sciences in 1973 for his contributions on input-output analysis.

In order to simulate the state of the economy from 2011[3] to 2050, we need a baseline. A baseline is a reference socio-economic scenario, sometimes called Business-as-usual (BAU), which covers the whole studied period. We use the word "baseline" instead of "reference" to avoid the confusion with the reference year, i.e. the first year of the study. In EUCalc, WP7 designed baseline projections of population and GDP in Deliverable 7.1 (Yu and Clora, 2018). Using these projections, we simulate the evolution of the economy in EU28 and Switzerland until 2050 using the model GEMINI-E3. From this simulation, we can extract baseline IO tables for each country between 2015 and 2050.

By acting on levers, users of the calculator will design their own pathway to 2050. This scenario will differ from the BAU. For example, the demand of meat could decrease or the electricity mix could consist of more renewables. These changes will affect the production structure in the economy. To reconcile the user's scenario with the baseline, we modify the baseline IO tables, using inputs from the other WPs. Hence, we obtain IO tables that are consistent with the user's scenario, allowing us to study the socio-economic impacts of this scenario.

The rest of the deliverable is structured as follows. In Section 3, we present the representation of the economy and the construction of reference IO tables. In section 4, we describe the GEMINI-E3 model. In section 5, we present the main baseline assumptions and we explain how we reconstruct baseline IO tables from 2015 to 2050. In section 6, we detail how we reproduce the user's scenario by modifying the baseline IO tables and we discuss how employment impacts are calculated. Finally, we conclude in section 7.

---

[3] In EUCalc, the reference year is 2015. In our model, the reference year is 2011, because the most recent (and consistent across countries studied) IO tables were released for that year.

3 Representation of the economy

The economic structure of a country is represented using Input-Output (IO) tables. In this section, we first discuss the industrial sectors used in WP6. Then, we describe how IO tables were constructed for the reference year, i.e. 2011.

3.1 Industrial sectors

The industrial classification should respect a few constraints. First, data should be available to construct IO tables in a reference year 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 other WPs. 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 39 sectors (see Table 1). To calibrate the model, we use the *GTAP 9 – Power database* (Peters, 2016). This database provides data for all countries considered with an appropriate industrial disaggregation. Moreover, WP7 on Trade will also use the GTAP database.[4]

The industrial sectors were chosen in coordination with the others WPs. In particular:

- Agriculture is disaggregated between *Crops & Vegetables* (#1) and *Animal Products* (#2), in accordance with WP1 on Lifestyles and WP4 on Land, Water and Biodiversity. In WP1, users can define, among others, the evolution of food and meat consumption. Then WP4 looks at the supply of agricultural products. Even though the list of agriculture products in WPs 1 and 4 is more detailed (see Deliverable 1.3, Costa et al., 2018), the lever on food demand considers the aggregate demand of all meat products. Moreover, the main environmental impacts are associated with the consumption of meat products. This justifies the choice of separating between *Crops & Vegetables* and *Animal Products*. Similarly, we include two processed food sectors, one for *Processed Crops & Vegetables* (#34) and the other for *Processed Animal Food* (#33). In addition, the *Forestry* (#3) sector accounts for the use of wood, studied in WP4.
- Energy consumed is disaggregated between *Coal* (#4), *Crude Oil* (#5), *Petroleum products* (#6), *Gas* (#7), *Electricity* (#9) and hot water and district heating (#21). The consumption of each of these energy sources is calculated per sector: Buildings (WP2), Transport (WP2), Industry (WP3), and Agriculture (WP4).
- Electricity supply is disaggregated between its transmission and distribution (#9) and 11 production sectors (#10 to 20). WP5 models electricity supply, with the following sources: Nuclear, Fossil fuel (excluding gas), Gas, Wind, Solar, Bioenergy, and Other renewables. Our disaggregation is more detailed, distinguishing between sources and regimes of production (Base Load vs Peak Load), because we follow the GTAP 9 – Power database classification.

---

[4] More precisely, WP7 will use the *GTAP-E Data Base*, which contains the same data without the disaggregation of the electricity sector.

- The consumption of water is studied for each sector (WPs 2 to 4). Hence, we include a *Water* (#22) sector.
- Since WP2 on Buildings looks at the construction and renovation of buildings, we include a sector *Construction* (#23).
- Transport is disaggregated between *Land Rail Transport* (#24), *Land Road Transport* (#25), *Water Transport* (#26) and *Air Transport* (#27) to be consistent with WP2 which studies the evolution of passenger and freight transport by road, rail, and air. Moreover, WP2 also analyses the production of new vehicles and transport infrastructure. Thus we include a *Transport machinery* (#37) sector.
- The consumption of materials is tackled in WP3 and WP4. We keep a representation close to theirs by including *Iron and Steel* (#28)*, Chemicals* (#29)*, Non-ferrous metal* (#30)*, Non-metallic minerals* (#31)*, Paper* (#32) *and Timber* (#36)*.

This list might evolve to include features developed in latter stages of the project. Indeed, a key goal of EUCalc is to involve stakeholders throughout the project. Experts' consultation workshops are regularly conducted to obtain feedbacks. Based on experts' inputs, the model is updated and improved.

EUCALC

Table 1 – Industrial classification in Employment Module

EUCalc WP6 Sectors		GTAP 9 Correspondence[5]
01	Crops and Vegetables	1, 2, 3, 4, 5, 6, 7, 8
02	Animal Products	9, 10, 11, 12, 14
03	Forestry	13
04	Coal	15
05	Crude Oil	16
06	Petroleum Products	32
07	Gas	17
08	Mining	18
09	Electricity Transmission and Distribution	43
10	Nuclear Base Load	43
11	Coal Base Load	43
12	Gas Base Load	43
13	Wind Base Load	43
14	Hydro Base Load	43
15	Oil Base Load	43
16	Other Base Load	43
17	Gas Peak	43
18	Hydro Peak	43
19	Oil Peak	43
20	Solar Peak	43
21	Gas, Hot Water and Steam	44
22	Water	45
23	Construction	46
24	Land Transport: Rail	48
25	Land Transport: Road	48
26	Water Transport	49
27	Air Transport	50
28	Iron and Steel	35
29	Chemicals	33
30	Non-ferrous metal	36, 37
31	Non-metallic minerals	34
32	Paper, Pulp, Printing	31
33	Processed Animal Food	19, 20, 22
34	Processed Crops and Vegetables, Beverages	21, 23, 24, 25, 26
35	Textile and Leather	27, 28, 29
36	Timber	30
37	Transport Machinery	38, 39
38	Other Industrial	40, 41, 42
39	Services	47, 51, 52, 53, 54, 55, 56, 57

---

[5] Description of GTAP 9 Sectors:
https://www.gtap.agecon.purdue.edu/databases/v9/v9_sectors.asp

3.2 Construction of 2011 IO Tables

The *GTAP 9 – Power database* (Peters, 2016) provides data for the reference year 2011 for all the selected sectors and studied countries. The correspondence between WP6 representation and GTAP sectors is shown in Table 1. However, to be consistent with others WPs, we need to adjust the GTAP data in two industry branches: electricity and transport.

3.2.1 Electricity sectors

The *GTAP 9 – Power database* disaggregates electricity between *Electricity Transmission and Distribution* (#9) and 11 sectors related to electricity production (#10 to 20). But the electricity production sectors also include part of the transmission. In EUCalc, *Electricity Transmission and Distribution* corresponds to the electricity consumed in each sector (WPs 2 to 4) while the production is associated with the electricity supply studied in WP5. Consequently, we modify the original GTAP 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). For example, the cell corresponding to column 1 and row 22 is the water consumption (sector #22) of the *Crops and Vegetables* sector (#1). Since we consider that sectors 10 to 20 are only related to electricity production, the inputs of electricity should only come from *Electricity Transmission and Distribution* (#9). Thus, for each sector (column), we sum the electricity consumed (sectors #9 to 20) into *Electricity Transmission and Distribution* (#9). We proceed similarly for the electricity consumption of households and government. The column *Electricity Transmission and Distribution* (#9) describes the inputs needed to produce electricity. Hence, the electricity mix is represented in this column by the inputs in electricity production (rows #10 to 20). We modify the cells corresponding to the electricity mix (column #9, rows #10 to 20) 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.

3.2.2 Transport sectors

In the *GTAP 9 – Power database*, Land Transport is aggregated into one sector. However, in the WP2 on Transport, there is a distinction between transportation by road and by rail. Such a disaggregation exists in the Exiobase database[6] (Tukker et al., 2009). Thus, we use the Exiobase to disaggregate the original Land Transport sector in GTAP into Road and Rail. To do so, we assume that the share of Road and Rail in the economy did not change between the reference year of Exiobase 2 data (2007) and GTAP data (2011). First, we compute the shares of Road and Rail in Exiobase for each of our sectors. Then, we split the GTAP Road transport according to these shares. Finally, we balance the IO table using a RAS algorithm (Lecomber, 1975), so that the supply equals the demand in all sectors. As a result, we obtain reference IO tables for all the EU28 countries

---

[6] https://www.exiobase.eu/

and Switzerland in 2011, with an industrial classification consistent with others WPs.

4 The GEMINI-E3 Model

In this section, we introduce the GEMINI-E3 model, which we used to simulate the evolution of the economy until 2050.

4.1 Core model

GEMINI-E3 is a worldwide multi-country, multi-sector, computable general equilibrium (CGE) model. A CGE model describes the behaviour of households, government and firms to analyse the evolution of the economy in the long-run. It is called general equilibrium because this class of model represents the whole economy, covering the interactions between different sectors (in opposition with partial equilibrium that analyses a peculiar sector). Moreover, the word "equilibrium" refers to the assumption that all market "clears", i.e. the demand of a product is equal to its supply.[7]

GEMINI-E3 has been specifically designed to assess energy and climate change policies. The model is detailed in Bernard and Vielle (2008). GEMINI-E3 has been extensively used for deriving total costs and benefits of various energy and climate policies. It 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 (MS) and Switzerland are described separately. The rest of the World is aggregated in one region called ROW.

Table 2 – 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

The industrial classification used in this study is presented in Table 2. The huge 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

---

[7] A good description of CGE models is available in Böhringer et al. (2003).

with the one in Table 1. Nonetheless, the two representations are consistent and closely related. In Section 5, we explain how we reconcile GEMINI-E3 simulations with the rest of the model.

Modelling of international trade is based on the Armington assumption (Armington 1969): a domestically produced good is not equivalent to the same good produced by a foreign industry. GEMINI-E3 incorporates a global constraint of foreign trade balance (zero or exogenous deficit) for each region. The government collects taxes and distributes the resulting revenues to households and firms through transfers and subsidies. Wage is chosen as a numeraire in each region. The model is recursive dynamic, with backward looking (adaptive) expectations.

Figure 1 represents the structure of the production sectors in the model. Production technologies are described through nested Constant Elasticity of Substitution (CES) functions.[8] First, demand (which includes final demand and intermediate consumption) is separated between Imports and Domestic production using the Armington assumption. Then, we assume that Domestic production required four aggregated and substitutable inputs: Energy, Materials, Labour and Capital. For Energy, we distinguish two levels of substitution, 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).
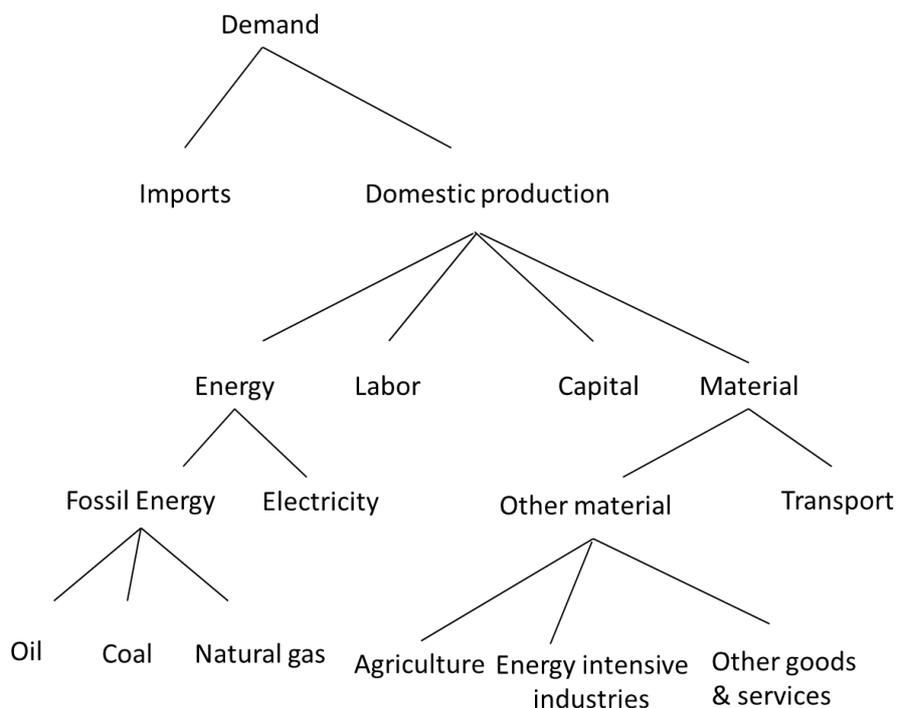
Figure 1 - Nested CES structure of the production

---

[8] See Arrow et al. (1961) and McFadden (1963) for discussions of CES production functions.

Finally, the representative household maximizes a nested CES utility function (see

Figure 2). 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.
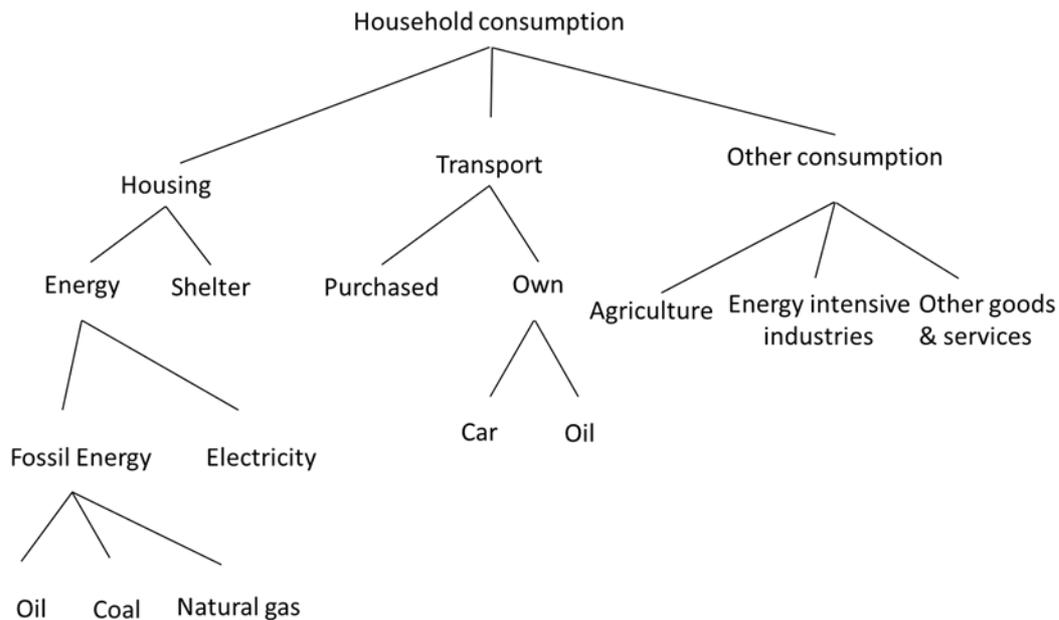
Figure 2 - Nested CES structure of household consumption

4.2 Labour in GEMINI-E3

In the current version of GEMINI-E3, labour supply is exogenous and linked to the active population, i.e. the population in age of working. To better suit with EUCalc needs, we could implement several improvements, described below by order of complexity.[9]

Note that GEMINI-E3 is used to forecast baseline IO tables (see Section 5), and not to directly assess the socio-economic impacts of decarbonisation pathways (see Section 6). Thus, upgrading the current version of the model is not mandatory for the success of the project, but could be an interesting value-added. This will be discussed with the project's partners.

4.2.1 Leisure

An endogenous labour supply means that households can decide on the number of hours they work depending on the wage. Simply put, they face a trade-off: working more is dissatisfying (utility loss), but increases households' revenue,

---

[9] A review of labour-markets modelling techniques in CGE is available in Boeters and Savard (2011).

and in turn consumption (utility gain). In other words, if wages are low, households have no incentives to work, but at the same time they should work more to maintain their consumption level.

The easiest way to model this choice is to introduce leisure in the households' utility function. This feature is common in macroeconomics theory (e.g. Becker, 1967; Lucas & Rapping, 1969; King et al., 1988) and in CGE models (e.g. Böhringer et al., 2005; Boeters & van Leeuwen 2010; Capros et al., 2013).[10] In

Figure 2, this means that there is an upper level in the nested CES, to represent the substitution between aggregate consumption and leisure. As a drawback, adding leisure would require to add a new set of parameters in the model, namely the elasticities of substitution between consumption and leisure for each country.

4.2.2 Heterogeneity in skills

People are not affected in the same way by energy and sustainable transitions depending on their education levels, i.e. their skills. Indeed, some industries have a higher demand in skilled than in unskilled labour. For instance, in Germany in 2011, the agriculture and construction sectors employ mainly unskilled workers while the services sector requires more skilled workers. There are also important disparities in the electricity production sectors (see Figure 3).
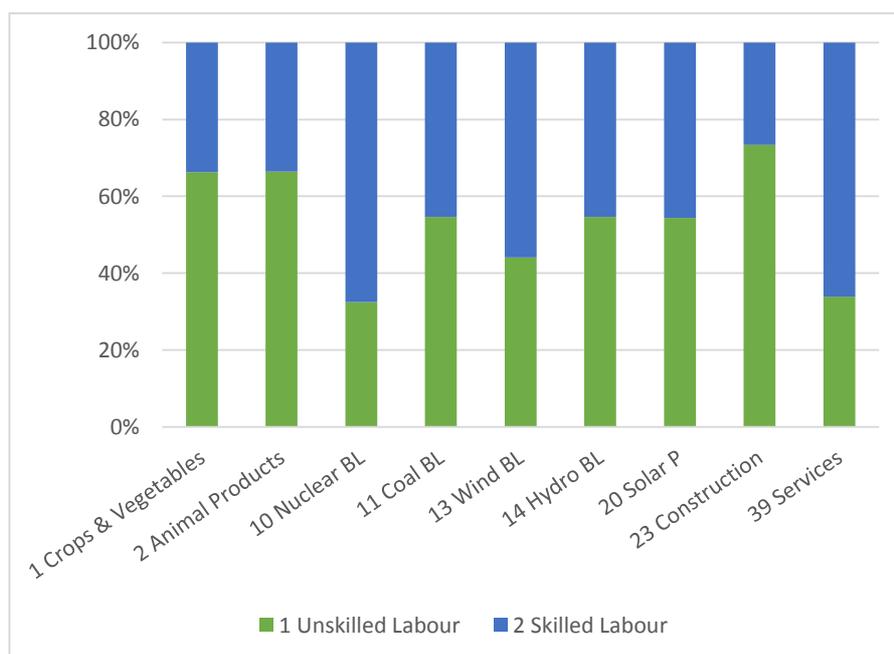
Figure 3 - Repartition of Labour Value Added between unskilled and skilled labour for selected industrial sector in Germany in 2011 (Data: GTAP-9 Power database; Figure with all sectors available in the Appendix)

We could introduce skills heterogeneity in GEMINI-E3, separating sectoral labour demand between unskilled and skilled labour demand. To do so, a possibility would be to proceed as in Böhringer et al. (2005). In this setup, the production structure represented in Figure 1 is modified. Instead of substituting between Energy, Material, Labour and Capital, domestic firms substitute between Energy,

---

[10] See Boyer and Smith (2001) for a review and a discussion of the historical development of labour economics.

Material and Value Added. The Value Added is a composite of unskilled labour, skilled labour and capital. At the second node, domestic firms substitute between unskilled labour and a composite of skilled labour and capital (see Figure 4). According to Böhringer et al. (2005), this structure best represents empirical evidence, showing that unskilled labour is a good substitute to both skilled labour and capital whereas skilled labour and capital are relatively bad substitutes.
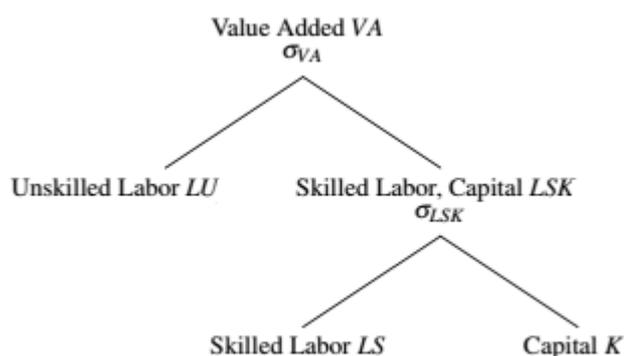
Figure 4 - Nested CES structure with skills differentiation

4.2.3 Involuntary unemployment

When the labour supply is determined by the trade-off between consumption and leisure (section 4.2.1), the labour market is competitive. This means that unemployment is voluntary: households decide not to work more because their income is sufficient. Of course, this is a simplified way to model the reality. But if the focus is to analyse the impacts on unemployment, then it is imperative to model involuntary unemployment. There are several possibilities to do so:[11]

- 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). This approach has been implemented for instance by Capros et al. (2013).
- Search and matching: this approach was developed by Diamond, Mortensen and Pissarides (Diamond, 1981, 1982; Mortensen & Pissarides, 1994).[12] 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. Böhringer et al. (2005) or Boeters & van Leeuwen (2010) have successfully implemented this approach.

We are currently exploring which method is more suited for EU28 countries and Switzerland. The choice to implement or not this extension will also depend on the availability of the data for the calibration of the model.

---

[11] See for instance Pissarides (1998) or Sørensen (1999) on how to implement involuntary unemployment in a macroeconomic model. In their papers, they analyse labour tax effects depending on the structure of unemployment and wages.

[12] Peter A. Diamond, Dale T. Mortensen and Christopher A. Pissarides were awarded the Nobel Memorial Prize in Economic Sciences in 2010 for their analysis of markets with search frictions.

4.2.4 Labour mobility across member states

Since in GEMINI-E3, the supply depends on the country population, which is exogenous, European workers will not migrate to another member states seeking better job opportunities. An alternative would be to let (a share of) workers decide endogenously on the country they wish to work in. Such a feature has been implemented in some macroeconomics model (e.g. Brandsma et al., 2014; House et al., 2018).

However, there are several challenges associated with this implementation. It first requires to model skills heterogeneity and involuntary unemployment as described above. Indeed, job opportunities depend on unemployment and differ between skills levels. The willingness to migrate also varies between skill levels. Next, it is important to distinguish between economic migration (better wages and job position, unemployment) and migration for other motives (e.g. quality of life, family reasons, etc.). The attractiveness of each country depends not only on its economic health but also on its social conditions and on environmental factors. For instance, the country's climate plays a role, which raises numerous uncertainties because of climate change. Furthermore, households from different countries will find another country more or less attractive due to language and cultural barriers. For example, moving to Germany might be easier for Austrian than for Spanish. Moreover, the population scenario used to calibrate the model already takes into account migration. Thus, there is a risk of double counting. Finally, it is not sufficient to restrict the analysis to EU28 and Switzerland since migration also occurs with the rest of the world.

Consequently, modelling labour mobility is highly complex and is associated with many assumptions and uncertainties. It requires extensive data and is sensitive to the choice of parameters. For these reasons, and because GEMINI-E3 is not directly use to assess socio-economic impacts in EUCalc (see Section 6), implementing labour mobility was not identified as a priority for the project.

5 Forecasting baseline IO tables

In section 3, we detailed how we construct IO tables for the reference year 2011 using the GTAP database. But the interface that computes socio-economic impacts within EUCalc needs to consider not only the reference year but also forthcoming periods. This requires updating the IO tables in order to take into account:

1. The economic growth;
2. The change in production factors (labour, capital);
3. The change in input-output coefficients.

We propose in this section a methodology that uses the runs of GEMINI-E3 in order to adjust IO tables taking into account the evolution of the economic structure.

5.1 The baseline scenario

We build a BAU scenario on the period 2011–2050 with yearly timesteps using GEMINI-E3. This baseline scenario was elaborated in coordination with WP7 (Yu and Clora, 2018). It relies on the following assumptions.

5.1.1 Demographic assumptions

Assumptions on population are based on the recent joint work of the Economic Policy Committee and the European Commission (DG ECFIN) published in 2015 (European Commission, 2015). In this projection, the EU population is projected to reach 526 million in 2050, an increase of almost 5% from 2013.

The report is used to calibrate the labour force in the GEMINI-E3 model. Labour force is equal to the labour force for the age group 20-64 corresponding to the Table III.1.29 of the report. This labour force per country is shown in Table 3.

Table 3 - Labour force 20-64 (thousands)

	2013	**2020**	**2030**	**2040**	**2050**
AUT	4'150	4'308	4'249	4'282	4'255
BEL	4'897	5'223	5'463	5'821	6'115
BGR	3'313	3'121	2'783	2'462	2'180
CYP	438	459	453	468	484
CZE	5'186	5'049	4'949	4'799	4'667
DEU	40'594	39'573	36'143	33'855	32'018
DNK	2'649	2'749	2'787	2'789	2'896
ESP	22'825	22'599	21'604	20'034	19'111
EST	649	607	553	517	475
FIN	2'528	2'523	2'525	2'605	2'632
FRA	29'137	29'400	29'885	30'067	30'816
GRC	4'827	4'858	4'537	4'086	3'652
HUN	4'341	4'574	4'548	4'236	3'956
IRL	2'059	1'957	1'883	1'869	1'859
ITA	24'493	25'619	25'599	24'715	24'466
LTU	1'426	1'227	890	780	758
LUX	256	302	363	420	462
LVA	987	888	727	655	603
MLT	181	192	201	205	201
NLD	8'210	8'228	8'032	7'764	7'733
POL	18'149	17'613	16'539	15'585	13'791
PRT	4'954	4'776	4'473	3'974	3'548
ROU	8'560	8'225	7'548	6'734	6'247
SVN	981	984	925	880	836
SVK	2'687	2'608	2'429	2'208	1'930
SWE	4'783	4'972	5'244	5'580	5'919
GBR	30'317	31'280	31'815	33'198	34'423
EU28	**233'577**	**233'914**	**227'147**	**220'590**	**216'034**

5.1.2 Economic growth

The assumptions on the economic growth are derived from the GDP growth used by the PRIMES model in its EU Reference Scenario 2016 (European Commission 2016). This economic growth is consistent with the demographic scenario given in section 5.1.1. GDP growths per country are presented in Table 4.

Table 4 – Annual GDP growth rate in percentage

	2015-2020	**2020-2030**	**2030-2040**	**2040-2050**
AUT	1.6%	1.5%	1.6%	1.5%
BEL	1.4%	1.5%	2.1%	2.0%
BGR	2.3%	1.6%	1.4%	0.9%
CYP	0.9%	1.5%	2.8%	2.3%
CZE	1.9%	1.8%	1.7%	1.5%
DEU	1.3%	0.9%	0.8%	1.0%
DNK	2.2%	1.9%	1.7%	1.9%
ESP	1.7%	1.8%	1.5%	1.0%
EST	2.2%	1.8%	1.6%	1.0%
FIN	0.9%	1.3%	1.8%	1.6%
FRA	1.4%	1.4%	1.7%	1.8%
GRC	-0.9%	0.8%	1.8%	1.0%
HRV	1.4%	1.2%	2.0%	1.7%
HUN	1.8%	2.2%	1.5%	1.3%
IRL	2.5%	1.7%	1.7%	1.5%
ITA	1.0%	1.2%	1.5%	1.5%
LTU	2.7%	0.7%	0.7%	1.4%
LUX	2.9%	2.7%	3.0%	2.5%
LVA	3.1%	1.4%	1.5%	1.1%
MLT	2.7%	2.3%	1.8%	1.6%
NLD	1.4%	1.0%	1.3%	1.5%
POL	2.9%	2.4%	1.5%	0.9%
PRT	1.1%	1.5%	1.0%	0.8%
ROU	2.5%	1.8%	1.4%	1.5%
SVK	3.1%	2.8%	1.4%	0.7%
SVN	1.4%	1.6%	1.4%	1.2%
SWE	2.1%	2.1%	2.2%	2.1%
GBR	1.6%	1.3%	2.0%	1.9%
CHE	1.5%	1.3%	1.2%	0.9%
ROW	3.0%	4.0%	3.7%	3.5%
World	**2.6%**	**3.5%**	**3.3%**	**3.2%**

5.1.3 Energy prices

The international energy prices are also derived from the EU Reference Scenario (European Commission 2016). Figure 5 shows these fossil fuel import prices. In 2050, the Brent price reaches 130 $2013 per barrel, the gas price is equal to 70 $2013 per barrel of oil equivalent and the coal prices stays below its 2010 level. This energy prices projection is consistent with the New Policies Scenario of the World Energy Outlook 2015 (International Energy Agency, 2015).
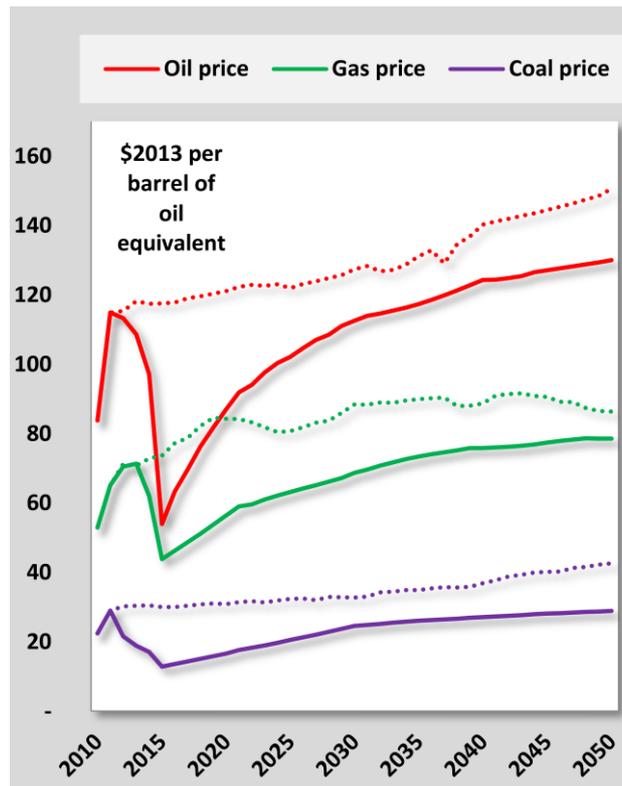
(Source: European Commission 2016)

Figure 5 – Fossil fuel imports prices[13]

5.2 Computing baseline IO Tables

We compute baseline IO tables for the following years: 2020, 2030, 2040 and 2050. The methodology consists of modifying the reference IO Table (year 2011) the following 4 steps (see Figure 6):

1. We use the reference IO tables (2011) built in section 3.2;
2.
   a. We multiply each final demand components (i.e. Households consumption, Government consumption, Investment, Exports) by the change with respect to year 2011 computed by GEMINI-E3. We do it at the aggregated level;
   b. We update the structure of the final demand components. When the classification of the reference IO tables corresponds exactly to the one used by GEMINI-E3, it is done directly. For example, electricity consumption is represented both by the IO tables and by GEMINI-E3. When it is not the case, we consider the change at the aggregated level. For example, the share of the consumption of energy intensive goods in the IO tables (i.e. sectors #28 to #32 in Table 1) is assumed to follow the share of the good *Energy intensive industry* (#07, Table 2) computed by GEMINI-E3;
   c. The intermediate consumption is adjusted to take into account variations computed by GEMINI-E3, either at the sectoral level or at

---

[13] Dotted lines represent the previous Reference Scenario.

the aggregated level depending on the concordance between the representations;

3. We also change the imports of each goods 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.
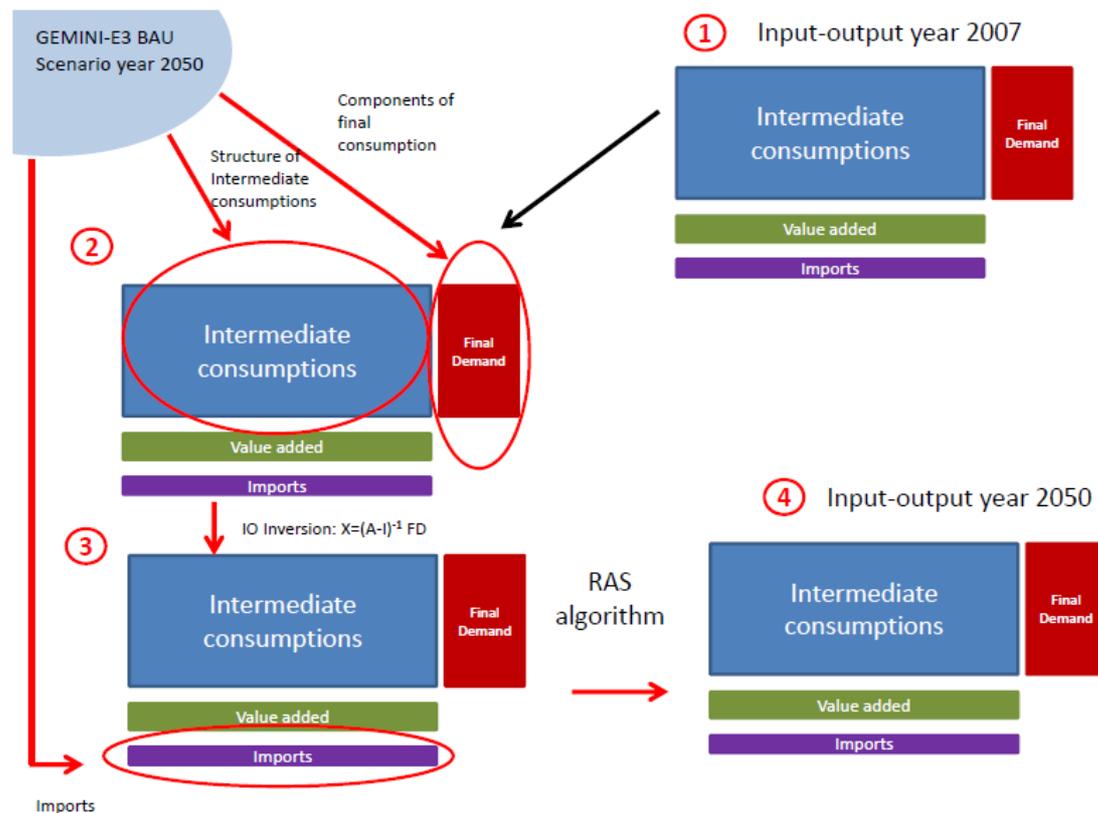
Figure 6 – Steps to compute baseline IO tables

We obtain at the end baseline IO tables for each country, which are consistent with the BAU scenario computed by GEMINI-E3, and which consider not only economic growth but also changes in the economic structure.

6 Assessing socio-economic impacts: Example of the Employment module

In EUCalc, users can design their own alternative future scenarios. They make decisions for instance on energy consumption in buildings, electricity mix, transportation mode, food habits, etc. To assess the socio-economic impacts of this alternative future, we need to reconstruct the state of the economy in the year of interest. The original plan was to reproduce users' scenario using GEMINI-E3. However, there are two main constraints preventing the use of a CGE model.

First, WPs 1 to 5 provide bottom-up sectoral inputs. Conciliating the bottom-up inputs with the top-down framework in a CGE model is a daunting task. Indeed, in EUCalc, each user of the calculator can decide on the allocation of consumption between the different products. This means that either the households' behaviour is not driven by utility maximization or that there is a distinct utility function for each scenario (and thus for each user). In the former case, users' choices are either inconsistent with the classical representation of macroeconomics models. In the latter case, we have not enough information on the shape of the utility function to model a different one for each user.

Second, important features of EUCalc are the simplicity, tractability and transparency of the model. In particular, the model should allow fast calculation (a few seconds) to be more attractive for the users. But CGE models are computationally and time-expensive. Simulations require several minutes to compute a solution. The alternative would be to simulate all possible scenario combinations in advance, and compile the results in a library. However, this option was discarded since the number of possible scenario is too high.[14]

Consequently, we designed a simpler, innovative method. The idea is to modify the baseline IO tables computed in section 5.2 using information gained from WPs 1 to 5 and from WP7.

6.1 Linking EUCalc Inputs to WP6

6.1.1 Description of the method

The main challenge is to translate bottom-up sectoral inputs from WP1 to WP5 and from WP7 to a top-down representation of the economy. We proceed in several steps:

1. We modify the baseline IO Tables to account for the difference in GDP growth rate (see subsection 6.1.2).
2. We modify the final demand of crops & vegetables, meat (WP4), energy, electricity, construction, transportation (WP2) and exports (WP7) (see subsection 6.1.3).
3. We modify the structure of intermediate consumption, especially energy demand in agriculture sectors (WP4), in materials (WP3), in transport (WP2) and in services (WP2), electricity mix (WP5), construction and

---

[14] In EUCalc, users adjust levers to design their own pathways. There are four levels for each lever of the calculator. Considering 20 levers, this gives 4^{20} scenarios for each country, i.e. more than 3×10^{13} scenarios for EU28 countries and Switzerland.

transportation (WP2) and imports (WP7). Then, the technical coefficients matrix is recalculated, by dividing each cell by the sum of the corresponding column (see subsection 6.1.4).

4. We obtain the sectoral output and intermediate consumptions as in a classical IO model: let X be the output vector, A the matrix of technical coefficient (i.e. AX is the intermediate demand) and D the final demand, we have:

$$X = AX + D \rightarrow X = (I - A)^{-1}D$$

where I is the identity matrix.

All these steps are summed up in Figure 7. For each country and year studied, we obtain IO Tables that are consistent with the user's scenario.
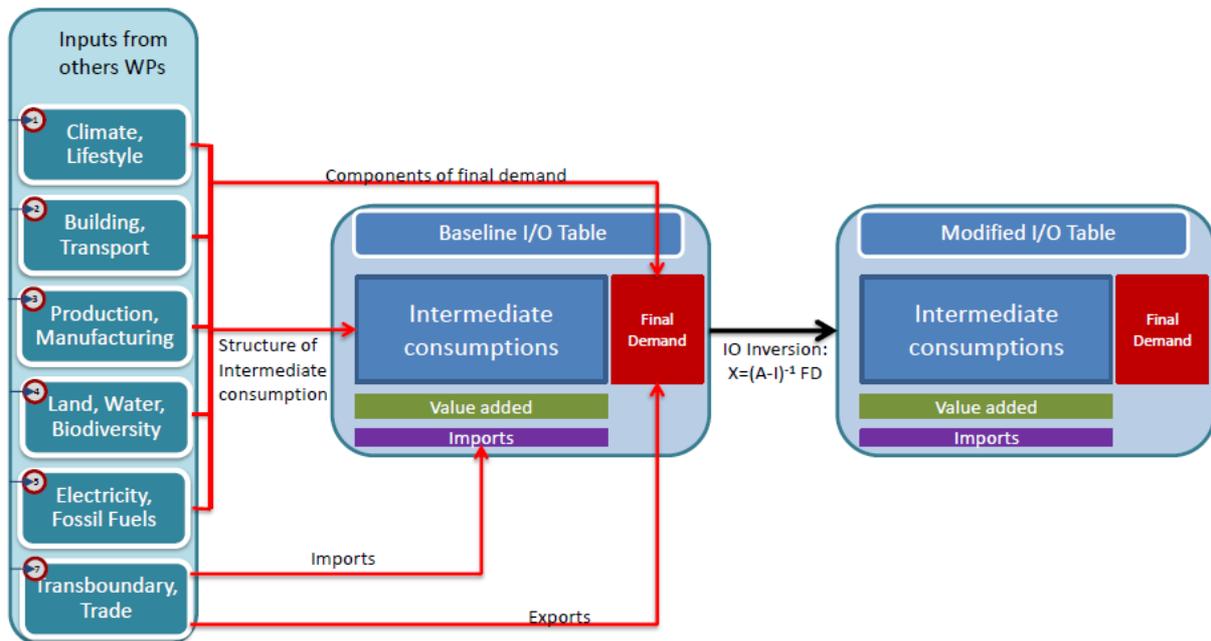
Figure 7 - Methods to reconstruct IO tables in user scenario

The inputs used from others WPs are described in Table 5 and in Figure 8. Note that this list of inputs is not definitive. Defining the interactions between WPs is an iterative and ongoing process. In the following subsections, we detail how these inputs are used to modify the baseline IO tables.

Table 5 – Inputs used from others WPs

WP	Module	Input
1	Lifestyle	Demography per country
1	Lifestyle	Household consumption of meat and crops & vegetables per country
1	Technology	LCOE and CAPEX of electricity technologies
1	Economy	Electricity, fuel, water, food, timber prices per country
1	Economy	Taxes and subsidies per product per country
2	Buildings	Electricity and fuel demand in buildings of Households per country
2	Buildings	Electricity and fuel demand in buildings in Services per country
2	Buildings	Investment in retrofit and new heating system technology per country
2	Transport	Electricity and fuel demand in transport sectors per country
2	Transport	Passenger activity in transport sectors per country
2	Transport	Freight activity in Rail and Road transport sectors per country
2	Transport	Car sales per country
2	Transport	Infrastructure expenditure per country
3	Industry	Electricity, fuel and water demand per industrial sectors/material per country
4	Agriculture	Electricity, fuel and water demand per agriculture sectors per country
4	Agriculture	Fertilizers demand of crops & vegetables and biofuel per country
4	Agriculture	Production of crops & vegetables, biofuel, meat, forestry per country
5	Electricity	Electricity mix per country
5	Electricity	Investment in power plant stocks per country
5	Oil Refinery	Electricity demand in oil refineries per country
5	Water-energy	Water demand of electricity sources per country
7	Trade	GDP growth per country
7	Trade	Imports per economic sector per country
7	Trade	Exports per economic sector per country
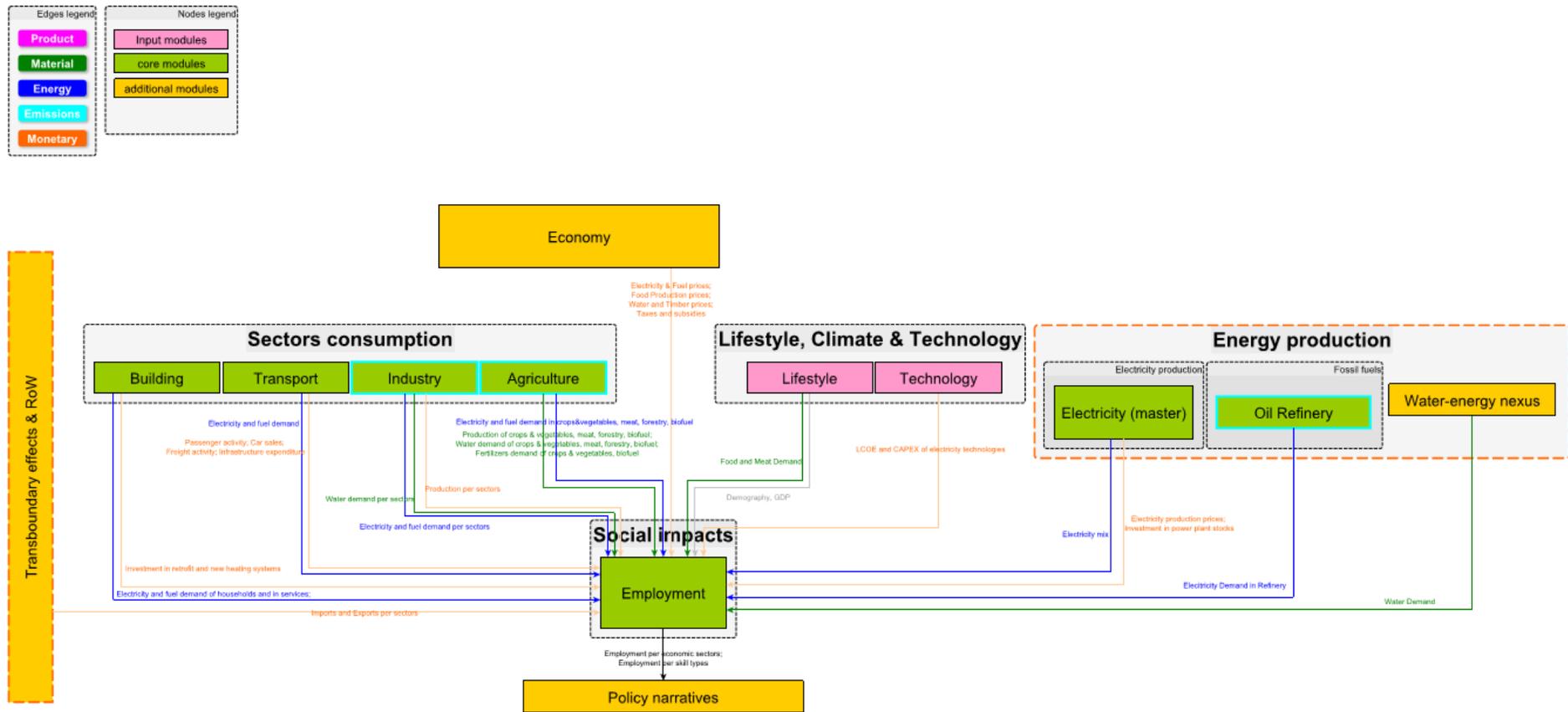
Figure 8 - Interactions between the Employment module and other EUCalc modules

6.1.2 Change in GDP

From WPs 1 and 7, we get the GDP growth. Since this growth might differ from the baseline scenario, we modify the IO Tables accordingly. To do so, we multiply the whole table by the difference between the baseline and the user scenarios. The table obtained describes the economy without any transition, i.e. the structure of the economy is the same as in the baseline, the only difference being the shock on the GDP.

6.1.3 Modifications of final demand

The final demand includes the consumption and the private investment of households, public investment by governments, as well as exports. In EUCalc, the user designs its own scenario of consumption and investment behaviors. Using information provided by the different modules of EUCalc, we modify the final demand of each sector to represent the user's scenario. To do so, we compute indicators of the evolution of sectoral final demand between the baseline and the user's scenario, for all sectors for which other WPs provide information. These indicators are simply the ratio of the consumption in the user's scenario divided by the consumption in the baseline scenario for each sector. Then, we multiply the cell of interest in the IO Tables by this ratio. Hence, we modify the allocation of the consumption between the different sectors in a way that is consistent with the user's scenario.

Energy mix of households: The Building module (WP2) computes the electricity and fuel demand in buildings of Households. The Transport module (WP2) computes the electricity and fuel demand of Households in their transport activity (e.g. gasoline and electricity in cars). Combining this information, we get the consumption of each energy source by the households in the year of interest in energy unit. We convert this energy consumption in monetary unit using prices, taxes and subsidies given by the Economy module (WP1). We then update the energy sectors *Coal* (#4), *Petroleum products* (#6), *Gas* (#7), *Electricity Transmission and Distribution* (#9) and *Gas, Hot Water and Steam* (#21).

Investment in retrofit and new buildings: The energy transition relies in lowering energy losses. The investment in retrofit and new buildings is given by the Building module (WP2). In the IO Tables, these expenses are included in the *Construction* sector (#23), and we modify it accordingly.

Transportation mode: Private cars are less energy efficient than public transports or bike in terms of energy spent per passenger. In EUCalc, the user can decide on the intensity of each mode of transportation: cars, buses, trains, planes, etc. The passengers' activity in railway transport, road commercial transport (public transport) and air transport is computed in the Transport module (WP2). We use this input to modify the associated sectors *Land Transport: Rail* (#24), *Land Transport: Road* (#25) and *Air Transport* (#27).

Similarly, WP2 computes the passengers' activity in private cars and the sales of new cars. The change in car use affects several sectors: *Petroleum Products* (#6) due to gasoline purchases, *Electricity Transmission and Distribution* (#9) due to the emergence of electric vehicles, *Transport Machinery* (#37) due to car purchase and spare parts, *Services* (#39) due to insurances, parking, tolls and maintenance. The gasoline and electricity consumption were already taken into account in the changes in the energy mix of households. The *Transport*

Machinery sector is modified using the indicator on new cars sales. The share of transport-related services in the *Services* sector is modified using the passenger's activity indicator, assuming that an increase in car use increases the need for insurance proportionally. To know the part of Services related to car use, we use data on household budgets from the COICOP database in Eurostat.[15]

Diet: Meat consumption is responsible for an important share of greenhouse gases emissions and natural resources use. In module Lifestyle (WP1), users can select the future food habits, i.e. the consumption of crops & vegetables and meat. Using this information, we modify the sectors *Crops and Vegetables* (#1), *Animal product* (#2), *Processed animal food* (#33) and *Processed Crops and Vegetables, Beverages* (#34).

Exports: WP7 deals with Transboundary effects and Trades. The module computes the exports for each country and economic sectors, so that we can directly use this input.

Balancing: Due to the modifications in the final demand described above, the total final demand might not be equal to the one calculated in subsection 6.1.2. Since the increase in GDP should be consistent with the increase in final demand, this creates an inconsistency. We solve it by multiplying the final demand in each sector by the ratio between the total final demand after modifications and the total final demand as calculated in section 6.1.2.

6.1.4 Change in intermediate demand

The user's scenario will lead to a change in the structure of the economy. To account for these changes, we modify the intermediate demands in order to calculate the technical coefficients, so that the structure of the economy is consistent with the user's scenario.

In an IO table, each column corresponds to the demand of one sector in intermediate inputs from the others sectors. Conversely, each row corresponds to the supply of one sector to the others sectors. As before, we use information from the different WPs to modify the cells, rows and columns associated with the inputs by using the ratio of the firms' consumption in the user's scenario divided by the firms' consumption in the baseline scenario. The energy consumption is converted into monetary unit using prices, taxes and subsidies given by the Economy module (WP1).

Energy demand in Services: The Building module (WP2) computes the electricity and fuel demand in buildings in Services. Thus, we modify the inputs in *Coal* (row #4), *Petroleum products* (row #6), *Gas* (row #7), *Electricity Transmission and Distribution* (row #9) and *Gas, Hot Water and Steam* (row #21) of the *Services* sector (column #39).

Investment in retrofit and new buildings: Using the ratio of the total investment in retrofit and new buildings in the user's scenario divided by the one in the baseline scenario, we modify the row corresponding to the *Construction*

---

[15] Description of the database: http://ec.europa.eu/eurostat/statistics-explained/index.php/Glossary:Classification_of_individual_consumption_by_purpose_(COICOP);
Dataset: http://ec.europa.eu/eurostat/web/products-datasets/product?code=nama_10_co3_p3

sector (#23). This means that we assume that each sector invests more in retrofit and new efficient buildings in a similar pattern.

Energy demand in Transports: The Transport module (WP2) computes the electricity and fuel demand in the Transport sectors. Consequently, we modify the inputs in *Coal* (row #4), *Petroleum products* (row #6), *Gas* (row #7), *Electricity Transmission and Distribution* (row #9) and *Gas, Hot Water and Steam* (row #21) of the different Transport sectors (columns #24, 25, 26 & 27).

Transportation mode: The Transport module (WP2) provides the freight activity in Rail and Road transport. Assuming that each sector follows the same variation in the transportation mode, we modify the rows corresponding to the Rail (#24) and Road (#25) Transport.

Energy and water demand of Materials: The Industry module (WP3) computes the electricity, fuel and water demands to produce materials. As before, we modify the inputs in *Coal* (row #4), *Petroleum products* (row #6), *Gas* (row #7), *Electricity Transmission and Distribution* (row #9), *Gas, Hot Water and Steam* (row #21) and *Water Supply* (row #22) of the different material sectors (columns #28 to 32).

Energy, water and material demand of Agriculture: The Agriculture module (WP4) computes the electricity, fuel and water demands in the agriculture sectors. We modify the inputs in *Coal* (row #4), *Petroleum products* (row #6), *Gas* (row #7), *Electricity Transmission and Distribution* (row #9), *Gas, Hot Water and Steam* (row #21) and *Water Supply* (row #22) of the agriculture sectors (columns #1 & 2). The Agriculture module also computes the fertilizers demand in the *Crops & Vegetables* sectors. We modify the inputs in *Chemicals* (row #29) accordingly.

Electricity mix: The Electricity module (WP5) is responsible for the electricity supply. This module computes the electricity produced by each source (in GWh), which is then converted in monetary unit using the Levelized Cost Of Electricity (LCOE) given by the Technology module (WP1). In addition, WP5 computes the new capacity installed (in GW), which we convert in monetary unit using technology Capital Expenditure (CAPEX) obtained from the Technology module (WP1). Combining these information, we modify the demand of the *Electricity Transmission and Distribution* sector (column #9) in the various Electricity production sources (rows #10 to 20).

Imports: The Trades module (WP7) computes the imports for each country and economic sectors, and we can directly use this input, by modifying the row corresponding to Imports in the Input-Output table.

Balancing: Due to the modifications, the IO tables are not balanced anymore, i.e. the demand of a product is not equal to its supply. To balance the table, we first calculate the new matrix of technical coefficients by dividing each cell by the sum the associated column. Then, we can calculate the sectoral output and intermediate demand as detailed in step 4 in subsection 6.1.1.

For each country and year of interest, we obtain balanced IO tables that are consistent with the user's scenario.

EUCALC

6.2 Employment assessment

The IO tables computed in section 6.1 provide information on the state of the economy along the user's pathway. They can be used to assess various socio-economic impacts. As an example, we explain here how to assess impacts on employment, using the method of employment factors. The employment factors link the output of a sector to the labour demand.

First, we need data on employment per sectors in the reference year (2011) for EU28 countries and Switzerland. We use the Labour Force Survey (LFS) in the Eurostat database.[16] The LFS provides data on the number of people employed per activity branches, per educational level and per gender. Since the classification of activity branches in the LFS is not exactly the same as in the GTAP database, we need to reconcile the two sets of data using concordance tables.[17] As a result we obtain the number of people employed per economic sectors for each country in 2011.

Then, we calculate the employment factors for each country in 2011, by dividing the sectoral employment by the sectoral output. When studying future time period, we need to adjust the employment factors to account for productivity changes. Indeed, if productivity increases, less people are needed to produce the same output. Thus, we multiply the sectoral employment factors by the sectoral change in productivity, computed by GEMINI-E3.

Finally, the number of people employed in each sector is calculated by multiplying the sectoral output (obtained from IO tables) by the associated employment factor.

6.3 Limitations

The IO tables and employment factors methodology have several limitations. First, there are no prices in this model. Thus, the labour demand only depends on the output and not on the wages level. In reality, if wages increase, firms could decrease their labour demand by substituting with others production inputs, such as capital. For example, they could replace workers with machines. These substitution effects are modelled in a CGE framework but not in an IO model with employment factors. Second, the labour supply (discussed in section 4.2) is not modelled, i.e. there is no link between the labour demand and the labour supply. Consequently, there is no restriction on the labour level: firms can hire as many workers as they need.

The answer to these limitations would be to use a CGE model, but as explained at the beginning of section 6, it is not possible to properly represent users' scenarios in a CGE framework. On the other hand, the IO analysis enables to do so in a simple, transparent and fast model. Weighting the advantages and drawbacks of each method (summed up in Table 6), the IO analysis is more in line with the EUCalc project needs. Indeed, the goal of the project is to design a tractable, transparent and user-driven model, in order to increase communication and public-awareness about decarbonisation pathways.

---

[16] Description of the Labour Force Survey and dataset :
http://ec.europa.eu/eurostat/web/microdata/european-union-labour-force-survey
[17] Concordance between GTAP and standard United Nations classifications :
https://www.gtap.agecon.purdue.edu/databases/contribute/concordinfo.asp

Table 6 - Advantages and Drawbacks of IO Analysis vs CGE model

	IO analysis	**CGE model**
Advantages	+ Represents users' scenarios in a consistent way + Limited computation time + Simple and transparent	+ Include substitutions and price effects + Can model labour supply + Suited for long-run analysis
Drawbacks	- No substitution and prices - Labour supply not represented - Not suited for large economic transition	- Inconsistent with users scenarios - Computationally expensive - "black-box": not transparent to non-expert

The IO analysis actually provides a good first order approximation of the impacts on employment but only in the case of small economic transition. Since this might be an issue in scenarios with large deviations from the baseline, we are currently testing a new method in between CGE and IO models to combine the advantages of the two approaches (Thurm & Vielle, 2017).

7 Concluding remarks

In this deliverable, we discussed how WP6 will analyse socio-economic impacts of sustainable pathways through the use of IO tables and the CGE model GEMINI-E3. We first elaborated a representation of the economy in accordance with the project needs and we described the construction of reference IO tables, in 2011. Then, we detailed how the economic baseline is modelled using GEMINI-E3 and how baseline IO tables are computed from GEMINI-E3 simulations. Finally, we linked the inputs from others WPs to WP6, with the objective to reconcile the user's scenario with our IO model. As a result, we obtain IO tables that are consistent with the user's pathway.

The IO tables provide a description of the economy for EU28 countries and Switzerland in the year of interest. Using these tables, it is possible to compute various socio-economic indicators as shown in the example on employment. Some possibilities include:

- Employment by skills
- Employment by gender
- Value added

However, the socio-economic indicators are not yet selected. The choice will be made thanks to an ongoing stakeholder's consultation process. Following an online survey, a workshop was conducting in Delft on December 1st, 2017. The objective was to analyse what important socio-economic issues should be included in EUCalc. Involving stakeholders in the design of the model is a key part of the project in order to increase transparency and communication. This process and the socio-economic indicators selected will be discussed in Deliverable D6.3 "Expert consultation workshop on identification of key socio-economic parameters".

8 References

Aguiar, A., Narayanan, B. & 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

Arrow, K. J., Chenery, H. B., Minhas, B. S., & Solow, R. M. 1961. Capital-labor substitution and economic efficiency. *The Review of Economics and Statistics*, 225-250.

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

Becker, G.S., 1965. A Theory of the Allocation of Time. *The economic journal*, pp.493-517.

Bernard, A., 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., & 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., Rutherford, T. F., & Wiegard, W. 2003. Computable general equilibrium analysis: Opening a black box. ZEW Discussion Papers 03-56.

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

Boeters, S. and van Leeuwen, N., 2010. *A labour market extension for WorldScan; modelling labour supply, wage bargaining and unemployment in a CGE framework* (No. 201). CPB Netherlands Bureau for Economic Policy Analysis.

Boeters, S., and Savard, L. 2011. The labour market in CGE models.

Boyer, G.R. and Smith, R.S., 2001. The development of the neoclassical tradition in labor economics. *ILR Review*, *54*(2), pp.199-223.

Brandsma, A., Kancs, D. A., & Persyn, D. 2014. Modelling migration and regional labour markets: an application of the new economic geography model RHOMOLO. *Journal of Economic Integration*, 372-406.

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 EU-calculator 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 2015, The 2015 Ageing Report Economic and budgetary projections for the 28 EU Member States, *European Economy 3*.

European Commission 2016, EU Reference Scenario 2016, Energy, Transport and GHG Emissions trends to 2050.

Gonseth, C., Thalmann, P., & 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.

House, C. L., Proebsting, C., & Tesar, L. L. 2018. The Benefits of Labor Mobility in a Currency Union. Working paper.

International Energy Agency 2015, World Energy Outlook 2015, OECD/IEA.

King, R.G., Plosser, C.I. and Rebelo, S.T., 1988. Production, growth and business cycles: I. The basic neoclassical model. *Journal of monetary Economics*, *21*(2-3), pp.195-232.

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.

Leontief, W.W., 1951. Input-output economics. *Scientific American*, *185*(4), pp.15-21.

Lucas Jr, R.E. and Rapping, L.A., 1969. Real wages, employment, and inflation. *Journal of political economy*, *77*(5), pp.721-754.

McFadden, D. (1963). Constant elasticity of substitution production functions. *The Review of Economic Studies*, 30(2), 73-83.

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.

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.

Sørensen, P.B., 1999. Optimal tax progressivity in imperfect labour markets. *Labour economics*, *6*(3), pp.435-452.

Thurm, B. and Vielle, M. 2017. Employment impacts of decarbonizing the economy: An alternative method between I-O analysis and CGE modelling. Green Jobs Assessment Institutions Network (GAIN), 3rd International Conference: Just Transition, Geneva, Switzerland, December 6-7, 2017

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.

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

9 Appendix

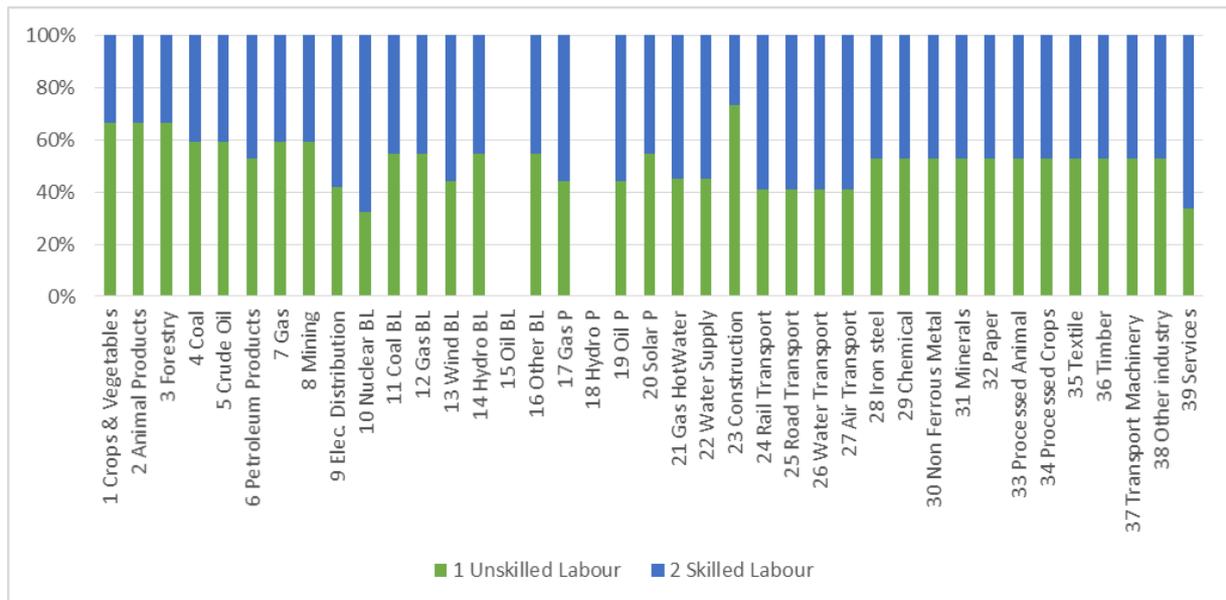## 9.1 Labour skills heterogeneity

Figure 9 - Repartition of Labour Value Added between unskilled and skilled labour per industrial sector in Germany in 2011 (Data: GTAP-9 Power database)[18]

---

[18] There is no domestic production of *Oil Base Load* (#15) and *Hydro Peak* (#18) in Germany, and thus no employment