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Contents

1 Introduction

Within this study a multi-sector, multi-regional Computable General Equilibrium (CGE) model named GEM-E3-CH is developed based on the blueprints of the large scale applied CGE model GEM-E3 (**https://e3modelling.com/modelling-tools/gem-e3/**). The orientation of the model will be on the socio-economic assessment of energy and climate policies with a particular focus on the impacts related to GDP, sectoral production, welfare and employment. This report is split into four main sections: Section 2 gives a general presentation of the model, Section 3 focuses on the data and input requirements of the model. Section 4 presents the algebraic formulation of the model and Section 5 presents a proposal for link the energy system model STEM with GEM-E3. In this respect this document serves as a methodological and technical guide of the GEM-E3-CH model and its integration with sectoral models providing all the necessary information. The guide presents the theoretical foundations on which the model is built, and it provides the mathematical formulations for all the equations included in the model.

2 Theoretical foundations, general presentation, and policy analysis application

The GEM-E3-CH model is a CGE model specific to Switzerland which includes the interactions of the country with the rest of the world. The model covers the whole world aggregated in 5 countries/regions (Table 1) where Switzerland is represented individually. The other regions are grouped into: China, USA, EU27+UK, and the rest of the world group of countries. The model is multi-sectoral recursive dynamic CGE model driven by accumulation of capital and equipment which provides details on the macro-economy and its interactions with the environment and the energy system. It covers individually 53 activities including the detailed representation of the power generation technologies (Table 2). It is written in structural form and can be used for the comparative analysis of alternative policy scenarios and the provision of insights on the distributional effects of long-term structural adjustments. In all simulation alternatives the model ensures that the economic system is always in general equilibrium. It extends beyond the static comparison of alternative policies. Finally, it s a dynamic model, in the sense that projections change over time. Its properties are manifested through stock-flow relationships, technical progress, capital accumulation and agents' (myopic) expectations.

The GEM-E3-CH model is written entirely in GAMS. The implementation of the model is split in two stages:

1. **Calibration**: At this stage the calculation of the model parameters is carried out so that the model replicates a single year (base year) data.
2. **Scenario quantification**: This stage entails model implementation that quantifies a reference and/or a counterfactual scenario.

The GEM-E3-CH model is built in modules enabling the user to choose between different closure options and market institutional regimes the choice of which rests with the modeler and the policies under consideration. The model includes projections of full Input-Output (IO) tables for Switzerland and other regions included in GEM-E3-CH, national accounts, employment, balance of payments, public finance and revenues, household consumption, energy use and supply, GHG emissions and atmospheric pollutants. The GEM-E3-CH environment module includes all GHGs (CO_2, CH_4, N_2O, HFC, PFC and SF_6) to be able to provide a consistent analysis of climate change policies.

Table 1: Country-Regional aggregation of the GEM-E3-CH model

Abbr.	Country/ Region
CHE	Switzerland
EU27	EU27+UK
CHN	China
USA	USA
ROW	Rest of the World

Table 2: Sectoral aggregation of the GEM-E3-CH model

Agriculture		**Industries**		**Industries**	
AGR01	Agriculture	IND01	Basic Metals	IND21	Equipment for wind power technology
Energy		IND02	Fabricated Metal products	IND22	Equipment for PV panels
ENE01	Coal	IND03	Chemical Products	IND23	Equipment for CCS power technology
ENE02	Crude Oil	IND04	Basic pharmaceutical products	IND24	CO2 Capture
ENE03	Oil	IND05	Rubber and plastic products	**Power Generation**	
ENE04	Gas	IND06	Paper products, publishing	PGT01	Coal fired
ENE05	Power Supply	IND07	Non-metallic minerals	PGT02	Oil fired
ENE06	Biomass Solid	IND08	Computer, electronic and optical products	PGT03	Gas fired
ENE07	Biofuels	IND09	Electrical equipment	PGT04	Nuclear
ENE08	Hydrogen	IND10	Machinery and equipment	PGT05	Biomass
ENE09	Clean Gas	IND11	Transport equipment (excl. EV)	PGT06	Hydro electric
Transport		IND12	Other Equipment Goods	PGT07	Wind
TRA01	Warehousing	IND13	Food, beverages, and tobacco	PGT08	PV
TRA02	Air transport	IND14	Textiles	PGT09	Geothermal
TRA03	Land transport	IND15	Wood products	PGT10	CCS coal
TRA04	Water transport	IND16	Construction	PGT11	CCS Gas
Services		IND17	Batteries	PGT12	CCS Bio
SRV01	Market Services	IND18	EV Transport Equipment		
SRV02	Non-Market Services	IND19	Advanced Electric Appliances		
SRV03	R&D	IND20	Advanced Heating and Cooking Appliances		

3 Data sources, structure, and manipulation

The development of the GEM-E3-CH model requires substantial data inputs from a range of data sources. Data requirements of the GEM-E3-CH model include: detailed Social Accounting Matrices (SAM) for every country/region, detailed bilateral trade, investment and consumption matrices, data on energy balances, emissions and pollutants, demographic and labour market data, fiscal data (like tax rates) and other macroeconomic data (like interest rates and consumer price indices).

For the construction of the GEM-E3-CH database two main sources of IO tables have been used, namely: the Swiss Statistical office datasets[1] and the Global Trade Analysis Project (GTAP)[2] database. The latest version of the GTAP database v11 covers the whole world aggregated into 65 activities, 160 countries at the years, 2004, 2007, 2011, 2014 and 2017. The Swiss Statistical Office provides IO tables for Switzerland and distinguishes between 56 activity types. Swiss Statistical Office alone cannot support the calibration of a global model, thus further IO data from the GTAP model have been used.

The choice of the base year on which the model is calibrated depends on the data availability. Calibration of the model is based on the most recent year for which a fully detailed dataset is available. The most recent data available on the GTAP database and the latest Swiss Statistical Office tables that can be used in GEM-E3-CH model regard year 2017.

The calibration of the GEM-E3-CH model makes use of the GTAP database the SAM for Switzerland for 2017 is constructed. The GTAP ensures a consistent framework for the economic transactions of all countries and sectors used in the GEM-E3-CH model. The economic structure of the Swiss economy (i.e., IO table) resulted from the use of the GTAP database is compared with the structure of the latest available data retrieved by the Swiss Statistical Office. This comparison allows to identify a change in the economic structure and the model parameters that reflect the economic structure are updated in the running period of the model (i.e. in 2020) based not only if a different between the two databases identified but also if the economic structure is changed over time.

The calibration of dynamic relationships (like stock-flow for capital stock and investment or for financial transactions) requires data which extend beyond one single year. The IO tables for Switzerland and for the other world regions have been constructed based on the available data on the GTAP database.

The elasticities used in the GEM-E3-CH model are extracted from the literature and in some cases are extracted from the GTAP database. For macroeconomic data the Swiss Statistical Office database for Switzerland and the World Bank database for non-EU countries have been used respectively. Data covers GDP, population, tax rates, unemployment, labour force, inflation (yearly change on Consumer Price Index) and interest rates. Capital stock data are also obtained from Swiss Statistical Office for the Switzerland economy and from GTAP for the rest of other world regions. Real interest rate in GEM-E3-CH has been computed as for each region as the difference between the nominal interest rate (the yield on a 10-year government bond) minus the yearly inflation rate.

Data used for Switzerland have been made compatible with GEM-E3-CH requirements. To achieve the GEM-E3-CH level of sectoral detail the SAM for Switzerland has been split in the GEM-E3-CH sectoral disaggregation. Energy sector has been split in electricity supply and power generation sectors by fuel type, equipment sectors include also clean energy technology sectors (see Table 2).

3.1 Input Requirements

Constructing a consistent database for an economy-wide multi regional and multi sectoral model is a difficult task as a significant number of accounts (in most cases from different sources) are required to be integrated into the accounting framework and balance out. This section presents the key data requirements of the GEM-E3-CH model. For the base year (usually the most recent year for which a

[1] https://www.bfs.admin.ch/bfs/en/home/statistics/catalogues-databases/data.html

[2] See: https://www.gtap.agecon.purdue.edu/databases/v11/

complete set of data is available), the key data required are presented in **Error! Reference source not f ound.**.

Table 3: Data Requirements for the GEM-E3-CH model

Type of Data	Description	Source
Symmetric Input Output table	IOT 2017 compatible with the revision of the national accounts (August 2022).	**https://www.bfs.admin.ch/bfs/en/home/statistics/national-economy/input-output.assetdetail.23506821.html**
Gross domestic product: production approach	Production account and the gross domestic product as well as their variation, since 1995.	**https://www.bfs.admin.ch/bfs/en/home/statistics/national-economy/national-accounts.assetdetail.23184111.html**
Households disposable income	Disposable income and savings of households.	**https://www.bfs.admin.ch/bfs/en/home/statistics/national-economy/national-accounts.assetdetail.23184134.html**
Wages and Salaries	Compensation of employees by industry	**https://www.bfs.admin.ch/bfs/en/home/statistics/national-economy/national-accounts/production.assetdetail.23184204.html**
Production per economic activity	Industries production account (59 industries)	**https://www.bfs.admin.ch/bfs/en/home/statistics/national-economy/national-accounts/production.assetdetail.23184153.html**
Household consumption purpose	This dataset presents the annual figures for the households' final national consumption expenditure by purpose of consumption, since 1995.	**https://www.bfs.admin.ch/bfs/en/home/statistics/national-economy/national-accounts/investment-consumption-expendidure.assetdetail.27065128.html**
Government expenditures	Expenditure of general government by function (COFOG)	**https://www.bfs.admin.ch/bfs/en/home/statistics/national-economy/national-accounts/general-government.assetdetail.23908134.html**
Investment by economic activity	Gross fixed capital formation since 1995	**https://www.bfs.admin.ch/bfs/en/home/statistics/national-economy/national-accounts/investment-consumption-expendidure.assetdetail.23184237.html**
Investment in construction by category of building	This dataset presents the annual figures for the investment in construction and its variation by category of building, since 1995.	**https://www.bfs.admin.ch/bfs/en/home/statistics/national-economy/national-accounts/investment-consumption-expendidure.assetdetail.23184239.html**
Investment matrix	This dataset presents the annual figures for the investment in equipment and its percentage change by classification of assets, since 1995.	**https://www.bfs.admin.ch/bfs/en/home/statistics/national-economy/national-accounts/investment-consumption-expendidure.assetdetail.23184238.html**
Exports (countries)	Exports by trading partners (countries)	**https://www.bfs.admin.ch/bfs/en/home/statistics/industry-services/foreign-trade/balance-import-export.assetdetail.22745743.html**

Imports (countries)	Imports by trading partners (countries)	**https://www.bfs.admin.ch/bfs/en/home/statistics/industry-services/foreign-trade/balance-import-export.assetdetail.22745757.html**
Foreign Trade	Exports and imports by economic activity	**https://www.bfs.admin.ch/bfs/en/home/statistics/industry-services/foreign-trade/balance-import-export.assetdetail.22745751.html**
Employment	Full-time job equivalent per sector	**https://www.bfs.admin.ch/bfs/en/home/statistics/industry-services/businesses-employment.assetdetail.24305953.html**
Population	Key population figures, 1950-2021	**https://www.bfs.admin.ch/bfs/en/home/statistics/population.assetdetail.23328853.html**
GHG Emissions	GHG Emissions by type, 1990 - 2021	**https://www.bafu.admin.ch/dam/bafu/en/dokumente/klima/fachinfo-daten/THG_Inventar_Daten.xlsx.download.xlsx/Evolution_GHG_since_1990_2023-04.xlsx**
Energy prices	Prices by energy type for final consumption	**https://opendata.swiss/en/dataset/energiedashboard-ch-energiepreise**

Technoeconomic data regarding the levelized cost of the power generation technologies, energy volumes will be harmonized with the STEM energy model. These data had to be adjusted in order to be consistent with the model nomenclature. In addition to the above data, the model requires additional input regarding elasticities (substitution elasticities, income elasticities, price elasticities, trade elasticities). Elasticities are either directly estimated for the model dimensions or extracted from the literature. In the next subsections the key data tabular arrangements required for the GEM-E3-CH model are presented.

3.1.1 The GEM-E3-CH SAM

A SAM is a square matrix of monetary flows that describes all transactions taking place between the economic agents of an economy for a determined year. The number of transactors constitutes the dimension of the square matrix. By convention, columns represent expenditures while rows represent receipts. A schematic representation of the GEM-E3-CH SAM is shown in **Error! Reference source not found.**.

The construction, harmonization of the SAM is the starting point of the model building work. In the base year, by definition, the balance of flows in the SAM is satisfied in both constant and current currency.

Figure 1: GEM-E3-CH SAM

	01………… ………….n	Total intermediate demand	Labour	Capital	Total	Household consumption incl. NPISHs)	Public consumption	Firms	Investments	Change in Stocks	Exports	Total final demand	Total Demand
01 n	IO	[8]				[9] HC	[10] GC		[11] INV	[12] STV	[13] EXP	[14]=[9]+[10]+[11]+[12]+[13]	[15]=[14]+[8]
Total intermediate inputs	[1]												
Operating surplus	KA										FFASE		
Wages and Salaries	LA										FFASE		
Social security contribution	SS												
Total Value Added	[2]												
Total supply at basic prices	[3]=[1]+[2]												
Households			FSEFA: labour income	FSEFA: income from operating surplus		FSESE	FSESE: (i.e. social benefits, pension)	FSESE			FSESE		
Firms				FSEFA: income from operating surplus		FSESE	FSESE	FSESE			FSESE		
VAT	TX_VAT*(vat_base)												
Subsidies	TX_SUB*(sub_base)							FGRS					
Direct taxes						FGRS: (i.e. income from direct taxation)		FGRS			FGRS		
Social security contributions						FGRS							
Indirect taxes	TX_IT*(it_base)					FGRS					FGRS		
Duties	TX_DUT*(dut_base)												
Environmental taxes	TX_ENV*(env_base)												
Government - Firms				FGRF		FGRS		FGRS			FGRS		
Government - Rest of the World											FGRS		
Total taxes	[4]												
Total supply at producer prices	[5]=[4]+[3]												
Imports	[6] IMP		FSEFA	FSEFA		FSESE	FSESE	FSESE					
Savings						SAVE	SAVE	SAVE			SAVE		
Total supply	[7]=[5]+[6]												

Demand = Supply [7] = [15]

FSESE: Transactions from sector to sector
FSEFA: Transactions from factors to sector
FGRF: Government ownerhsip of firms
FGRS: Transactions of government with the other economic agents

The balance is conceived as the equality between the sum by row and the sum by column. In addition, a SAM ensures the fulfillment of the Walras law in the base year, since by construction the algebraic sum of surplus or deficits of agents is equal to zero. The GEM-E3-CH SAM represents flows between production sectors, production factors and economic agents. The production sectors produce an equal number of distinct goods (or services), as in an Input-Output table.

Production factors include, in the SAM, only primary factors, namely labour and capital. The economic agents, namely households, firms, government and the foreign sector, are owners of primary factors, so they receive income from labour and capital rewarding.

In addition, there exist transactions between the agents, in the form of taxes, subsidies and transfers. The agents distribute their income between consumption and investment and form final domestic demand. The foreign sector also makes transactions separately with each sector. These transactions represent imports (as a row) and exports (as a column) of goods and services. The difference between income and spending (on consumption and investment) by an economic agent determines its surplus or deficit.

3.1.2 Household Consumption & Consumption matrix

Household final consumption expenditure mainly represents the traditional consumer spending. It includes, however, imputed rent for the provision of owner-occupied housing services, income in kind and consumption of own production. In GEM-E3-CH the household sector is consolidated with the non-profit institutions serving households (NPISH) sector. Although these institutions form a distinct sector in the European system of account, detailed figures that allow a separate identification of that sector are not yet available. Household consumption is built up from the detailed information available from the Swiss Statistical Office[3].

There are two approaches in analyzing the components of household consumption. The first is a commodity breakdown into types of good and service. The second approach is a purpose classification and, for this, an internationally agreed standard, the Classification of Individual Consumption by Purpose (COICOP), is used. COICOP groups together consumption according to the purpose of its use.

In GEM-E3-CH a mechanism that combines these two approaches is needed: this is the consumption matrix. The consumption matrix translates the demand per consumer category into deliveries by branch. An example of the consumption matrix is given in Table 4.

[3] https://www.bfs.admin.ch/bfs/en/home/statistics/national-economy/national-accounts/investment-consumption expenditure.assetdetail.27065128.html

Table 4: Consumption Matrix in coefficient form for Switzerland

	Food beverages and tobacco	Clothing and footwear	Housing and water charges	Fuels and power	Household equipment and operation (excl. heating and	Heating and cooking appliances	Medical care and health	Purchase of vehicles	Operation of vehicles	Transport services	Communication	Recreational services	Miscellaneous goods and services	Education
AGR01	8.7	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.1	0.0
ENE01				0.0										
ENE02				0.0										
ENE03				8.0					15.0					
ENE04				3.4										
ENE05				22.2					0.0					
ENE06				0.0										
ENE07									0.1					
ENE08				0.0					0.0					
ENE09				0.0										
IND01	0.0	0.0	0.0	0.0	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
IND02	0.0	1.2	0.0	0.1	1.7	1.7	0.0	0.0	0.2	0.0	0.0	0.0	0.3	0.0
IND03	0.1	0.0	0.1	0.1	1.1	0.0	0.4	0.0	0.7	0.0	0.0	0.1	0.6	0.0
IND04	0.0	0.0	0.0	0.0	0.0	0.0	7.6	0.0	0.0	0.0	0.0	0.1	0.0	0.0
IND05	0.0	1.1	0.0	0.0	1.0	0.0	0.5	0.0	1.2	0.0	0.0	0.0	0.1	0.0
IND06	0.3	1.3	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.0
IND07	0.0	0.0	0.1	0.0	0.5	1.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0
IND08	0.0	0.0	0.0	0.0	5.7	0.0	0.8	0.0	1.8	0.0	2.3	0.0	0.5	0.0
IND09	0.0	0.0	0.0	0.0	1.2	22.7	0.0	0.0	0.6	0.0	0.0	0.0	0.1	0.0
IND10	0.0	0.0	0.0	0.0	0.3	2.1	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0
IND11	0.0	0.0	0.0	0.0	0.3	0.0	0.3	38.5	3.1	0.0	0.0	0.0	0.1	0.0
IND12	0.0	3.3	0.0	0.0	8.4	0.0	13.6	0.0	0.0	0.0	0.1	0.7	3.2	0.0
IND13	75.0	0.0	0.0	0.0	1.1	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0
IND14	0.0	1.3	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0
IND15	0.0	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
IND16	0.0	0.0	3.1	0.0	2.3	23.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
IND18								1.0						
IND19					0.0									
IND20						0.0								
TRA01	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	2.8	0.0	0.0	0.1	0.0	0.0
TRA02	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	49.6	0.0	0.1	0.0	0.1
TRA03	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	35.6	0.0	8.4	0.0	0.1
TRA04										13.0				
SRV01	15.9	91.8	96.5	66.3	74.5	48.5	71.9	60.2	73.8	1.8	97.5	89.7	94.0	88.5
SRV02	0.0	0.0	0.0	0.0	0.0	0.0	5.0	0.1	0.2	0.0	0.0	0.1	0.3	9.2
SRV03														2.1

3.1.3 Investment Matrix

The investment matrix translates the demand of investment goods by the branches into deliveries by branches. The matrix is usually constructed using the following sets of information: i) investment by firm, ii) gross fixed capital formation, iii) explicit investment requirements by economic activity (extracted from dedicated studies). It is rare that investment matrices are available. The usual approach for the computation of the matrix is to use the information available on investment by branch and by product and then apply a RAS procedure (Stone (1962), Stone and Brown (1962), and Bacharach (1970), see here) to balance the matrix.

For the decomposition of power generation investments to deliveries of capital goods, a number of sources are used, including the most recent data on power plants cost-structure published by EIA (Energy Information Agency of the US) and engineering information regarding the power plants equipment. Table 5 provides an illustration for the power generation technologies investments[4] matrix in coefficient form.

Table 5: Illustrative investment matrix for power generation technologies: Contribution (%) of industries delivering the capital goods to total investments

	Coal fired	Oil fired	Gas fired	Nuclear	Biomass	Hydro	Wind	PV	CCS coal	CCS Gas	Geothermal	CCS Bio
	PGT01	PGT02	PGT03	PGT04	PGT05	PGT06	PGT07	PGT08	PGT10	PGT11	PGT09	PGT12
Construction	22.7%	22.7%	16.8%	27.8%	22.7%	64.8%	25.0%	35.7%	22.7%	16.8%	22.7%	22.7%
Equipment Goods	55.7%	55.7%	60.9%	40.1%	57.0%	19.1%	54.8%	57.4%	55.7%	60.9%	55.7%	55.7%
Services	21.5%	21.5%	22.3%	32.1%	20.3%	16.0%	20.2%	6.9%	21.5%	22.3%	21.5%	21.5%
	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Source: EIA, author's calculations

3.1.4 Trade

Exports in GEM-E3-CH are valued at f.o.b (free on board) prices while for imports a different convention is applied. This is the 'cost-insurance-freight' (c.i.f.) price – that of a good delivered at the frontier of the importing country before payment of any duties or taxes on imports.

Regarding foreign trade data, the GEM-E3-CH model requires detailed bilateral trade matrices for all commodities included in the model. These statistics are available from the COMEXT and GTAP databases, which also include bilateral duties and transportation costs.

3.2 Calibration

In GEM-E3-CH the calibration module is written as a separate model and has a recursive structure. Calibration uses single year (base-year) data which correspond to monetary terms for which appropriate price indices are chosen to compute the corresponding volumes (quantities). Data for the year previous to the base year are required to give values to those variables that are lagged in the model. The calibration procedure is defined in such a manner that the model reproduces exactly the observed statistics of the base year. The GEM-E3-CH model calibration makes use of the latest data available in GTAP for Switzerland, corresponding to year 2017. These data are combined with Swiss Statistical Office data available for 2017 and then the model is re-calibrated for 2020 by updating the model parameters (i.e., share parameters) that represent the structure of the Swiss economy.

A first step in the calibration of the GEM-E3-CH model is the definition of elasticities that determine all coefficients that do not correspond to directly observable variables. GEM-E3-CH uses values of elasticities from the literature or guess-estimated when no econometric estimates are available. The sets of elasticities used in the model are demand function elasticities following the Armington assumption (see Armington 1969) (substitutability of domestic/imported goods and across imported goods, by

[4] The data are drawn from the EIA report (2020) "Capital Cost and Performance Characteristic Estimates for Utility Scale Electric Power Generating Technologies" and the IRENA report "Renewable Power Generation Costs in 2019".

country of origin), elasticities of substitution in production (substitution among production factors) and consumer preferences (price or income elasticities in households demand for commodities)[5].

4 Mathematical model formulation

GEM-E3-CH model considers several economic agents and develops with the latter being its core building blocks. The economic agents who are individually represented in the GEM-E3-CH model are:

- Firms
- Household
- Government
- External sector

GEM-E3-CH model also considers the detailed representation of the GHG emissions while it makes provisions for links with sectoral models. The model formulation takes into consideration the micro-theory on agents' behaviour and the macroeconomic relationships and flows between them. The following sections provide the mathematical formulation of the model with detailed presentation of economic agents' behaviour.

4.1 Firms

Domestic activity in GEM-E3-CH is defined by branch. **Error! Reference source not found.** presents t he GEM-E3-CH main sectors and the activities matched to the latter. Table 7 presents the GEM-E3-CH subsectors used in different production nesting schemes. Every GEM-E3-CH activity produces a single good which is differentiated from any other good in the economy.

Table 6: GEM-E3-CH mapping of sectors to activities

Acronym	Description	GEM-E3-CH activities
prdf	Default sectors	Agriculture, Coal, Gas, Basic metals, Fabricated Metal products, Chemical Products, Basic pharmaceutical products, Rubber and plastic products, Paper products, publishing, Non-metallic minerals, Computer, electronic and optical products, Electrical equipment, Machinery and equipment, Transport equipment (excluding EV), Other Equipment Goods, Food, beverages and tobacco, Textiles, Wood products, Construction, Warehousing and support activities, Air transport, Land transport, Water transport, Market Services, Non Market Services, R&D, Biomass Solid, Biofuels, Batteries, EV Transport Equipment, Advanced Electric Appliances, Advanced Heating and Cooking Appliances, Equipment for wind power technology, Equipment for PV panels, Equipment for CCS power technology, Hydrogen, Clean Gas, CO2 Capture

[5] See Annex-I for elasticities used in GEM-E3-CH

prfele	Energy sectors	Coal, Oil, Gas, Power Supply, Biomass Solid, Biofuels, Hydrogen, Clean Gas
prtec	Power generation technologies	Coal fired, Oil fired, Gas fired, Nuclear, Biomass, Hydro electric, Wind, PV, Geothermal, CCS coal, CCS Gas, CCS Bio

Table 7: GEM-E3-CH mapping of subsectors to activities

Acronym	**Description**	**GEM-E3-CH activities**
prmane	Sectors included in the material bundle of default and resource sectors	Agriculture, Crude Oil, Basic metals, Fabricated Metal products, Chemical Products, Basic pharmaceutical products, Rubber and plastic products, Paper products, publishing, Non-metallic minerals, Computer, electronic and optical products, Electrical equipment, Machinery and equipment, , Transport equipment (excluding EV), Other Equipment Goods, Food, beverages and tobacco, Textiles, Wood products, Construction, Warehousing and support activities, Air transport, Land transport, Water transport, Market Services, Non Market Services, R&D, Batteries, EV Transport Equipment, Advanced Electric Appliances, Advanced Heating and Cooking Appliances, Equipment for wind power technology, Equipment for PV panels, Equipment for CCS power technology, CO2 Capture
prma	Sectors included in the material bundle of refinery sectors	Agriculture, Basic metals, Fabricated Metal products, Chemical Products, Basic pharmaceutical products, Rubber and plastic products, Paper products, publishing, Non-metallic minerals, Computer, electronic and optical products, Electrical equipment, Machinery and equipment, Transport equipment (excluding EV), Other Equipment Goods, Food, beverages and tobacco, Textiles, Wood products, Construction, Warehousing and support activities, Air transport, Land transport, Water transport, Market Services, Non Market Services, R&D, Batteries, EV Transport Equipment, Advanced Electric Appliances, Advanced Heating and Cooking Appliances, Equipment for wind power technology, Equipment for PV panels, Equipment for CCS power technology, CO2 Capture
prfuel	Fuels sectors	Coal, Oil, Gas, Biomass Solid, Biofuels, Hydrogen, Clean Gas
prrs	Sectors with natural resources as main inputs	Crude Oil
prref	Refineries	Oil
pr_ele	Power supply	Power supply
prtec	Power generation technologies	Coal fired, Oil fired, Gas fired, Nuclear, Biomass, Hydro electric, Wind, PV, Geothermal, CCS coal, CCS Gas, CCS Bio

Firms adopt an optimization behaviour, and they operate under a perfect competition regime. A nested multi-factor CES production function is used. The different nests are presented in the next subsections. Firms' choice regards the optimum level of factor inputs (including capital, labour by skill, energy, intermediate inputs and reserves). The model identifies a number of *i* firms, *j* intermediate inputs, *s* labour skills, one type of land (optional) and capital. To facilitate readability, the description below refers to a one-level production function; the expansion to multi-level (nested) production is considered straightforward.

Firms that operate in perfectly competitive sectors decide upon production factor inputs such as to minimise their production costs. Each production factor is paid at its marginal product and firms' unit cost prices[6] are set to exactly cover the production costs (capital payment inclusive), hence not allowing for non-normal profits. It is assumed that each firm produces a single good which is differentiated from any other good produced. Firms' output, factor demands and associated unit costs are presented below. Each firm uses a constant elasticity of substitution (CES) production technology, operates under perfect competition, and demands production inputs in order to minimise its production cost. The nesting of the CES production function depends on the substitution possibilities that characterise the production technology of each firm.

The cost minimisation objective function of the firm is:

$$\min \mathrm{Cost}_{\mathrm{i,r,t}} = \sum_f QF_{f,i,r,t} \cdot PQF_{f,i,r,t} \tag{1}$$

Subject to the production technology of firms:

$$Q_{i,r,t} = \bar{Q}_{i,r} \cdot \frac{\mathrm{tfp}_{i,r,t}}{\overline{tfp}_{i,r}} \cdot \left(\sum_f \theta_{f,i,r,t} \cdot \left(\frac{QF_{f,i,r,t}}{\overline{QF}_{f,i,r}} \right)^{\rho} \right)^{\frac{1}{\rho}} \tag{2}$$

The respective derived demands for production factors (capital, labour, materials/intermediate inputs) are given by:

$$PQ_{i,r,t} = \overline{PQ}_{i,r} \cdot \frac{\overline{tfp}_{i,r}}{\mathrm{tfp}_{i,r,t}} \cdot \left(\sum_f \theta_{f,i,r,t} \cdot \left(\frac{PQF_{f,i,r,t}}{\overline{PQF}_{f,i,r}} \right)^{1-\sigma} \right)^{\frac{1}{1-\sigma}} \tag{3}$$

$$QF_{i,f,r,t} = \overline{QF}_{i,f,r} \cdot \frac{Q_{i,r,t}}{\bar{Q}_{i,r}} \cdot \left(\frac{\overline{PQF}_{f,i,r}}{\overline{PQ}_{i,r}} \cdot \frac{PQ_{i,r,t}}{PQF_{f,i,r,t}} \right)^{\sigma} \cdot \left(\frac{\mathrm{tfp}_{i,r,t}}{\overline{tfp}_{i,r}} \right)^{\sigma-1} \tag{4}$$

where

i: sector, r: region, t: time, *f*: production factor (capital, labour, land, intermediate inputs)

$Q_{i,r,t}$:	production in volume for activity i
$\bar{Q}_{i,r}$:	production in volume for activity i (base year)
$QF_{f,i,r,t}$:	amount of production factor f used in production in year *t*
$\overline{QF}_{f,i,r}$:	amount of production factor f used in production (base year).

[6] Firms' unit costs depend on the unit cost of factor inputs and on TFP. The representation of TFP is discussed in detail in the next section.

$PQF_{f,i,r,t}$: unit cost of factor f.
$\overline{PQF}_{f,i,r}$: unit cost of factor f (base year).
$PQ_{i,r,t}$: unit cost of production for activity i.
$\overline{PQ}_{i,r}$: unit cost of production for activity i (base year).
$\theta_{f,i,r,t}$: share parameter (to calibrate to base year values)
ρ: elasticity $\left(\rho = \frac{\sigma-1}{\sigma}\right)$
σ: elasticity of substitution between production factors
$\mathrm{tfp}_{i,r,t}$: total factor productivity
$\overline{tfp}_{i,r}$: total factor productivity at base year $(= 1)$

This production technology applies to all firms apart from the power generation supply where a Leontief production function is used (zero substitution possibilities). This representation is activated only if the model is to be linked with a bottom-up energy system model like STEM, otherwise a flexible functional form should be used to allow for technology shift/substitution.

Production functions in GEM-E3-CH exhibit a nested separability scheme, involving capital (K), labour (L), energy (E) and materials (M). The activities differ in their production nesting structure. The nesting scheme differentiates among the default non-energy sectors, the sectors with natural resources inputs (coal, crude oil and natural gas extraction), electricity supply, power producing technologies and refineries. The nesting scheme differentiates among the sectors so as to take into account the specific features of each activity and to capture the different substitution possibilities that characterize each production sector. Below are presented the nesting structure and algebraic formulation of the different activities included in the model.

We use two different bundles in labour, the “Skilled labour”, that contains the occupations technicians, clerks and managers), and the “Unskilled labour” that contains the occupations unskilled workers and shop service workers.

For the remainder of the text, we use the following symbols for variables’ subscripts:

- *pr, br,* (interchangeably) for activity sector
- *er, cr, cs* (interchangeably) for countries
- *t* for time
- *gvb* for government revenues and expenses categories
- *ghga* for GHG emissions categories
- *fn* for consumption by purpose categories
- *itrn* for transport margin categories
- *fa* for production factor
- *se, sr* (interchangeably) for institutional sector, i.e. households (*h*), firms (*f*), government (*g*), and world (*w*)
- *sk_type* for different occupation

4.1.1 Electricity supply sector

The nesting scheme for the electricity supply sector is presented in Figure . This sector regards the electricity generation and distribution.

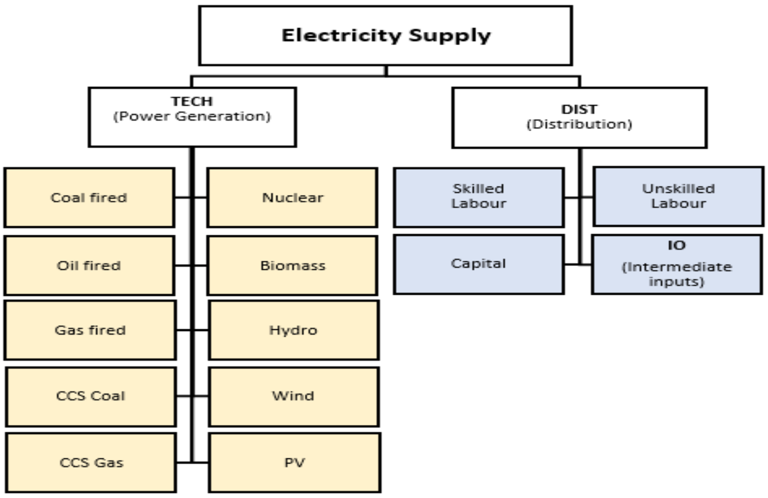
The model provides two options in calculating the power mix:

i) endogenous least cost calculation based on the firms' optimisation presented below

ii) calibration to exogenous power mix shares (in this option it is the share parameters of the production function that are calibrated to the exogenous market shares). Data on market shares can be obtained from energy balance statistics and energy focused models with detailed representation of the different power generation technologies. The shares of each technology in power generation in the base year are introduced from energy balance statistics. Some of the potential technologies that may develop in the future are not used in the base year. Hence in the model calibration provision should be made so as to introduce artificially small shares even for the non-existing technologies in order to allow for the possibility of their penetration in the future.

In the GEM-E3-CH model the second option is followed and a soft-link approach with the STEM energy model is followed (see Section 5).

Figure 2: Nesting of the GEM-E3-CH model – Electricity supply



The nesting scheme develops as follows:

1st level:	Electricity Supply (XD) is split into power producing technologies bundle (*TECH*) and transmission and distribution bundle (*DIST*)

$A\_XD = \textbf{LEONTIEF}(A\_TECH, A\_DIST)$

2nd level:	TECH is split into power generation technologies in the same nest (*IO*) DIST is spit into capital, skilled and unskilled labour and intermediate input materials (*IO*).

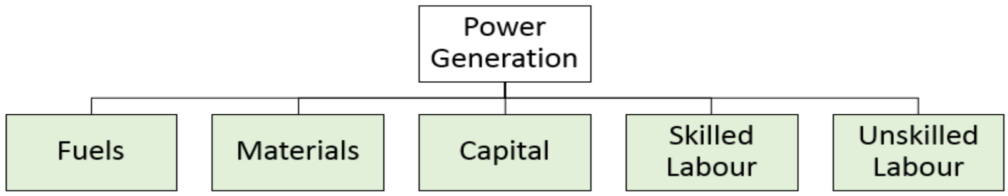
$A\_TECH = \textbf{LEONTIEF}(A\_XD_{prtec})$ or $A\_TECH = \textbf{WEIBULL}(A\_XD_{prtec})$ with exogenous or endogenous power mix shares, respectively

$A\_DIST \ = \textbf{LEONTIEF}(A\_KAV, A\_LAV, A\_IO_{pr})$

4.1.2 Power producing technologies

The nesting scheme for power producing technologies is presented in Figure .

Figure 3: Nesting of the GEM-E3-CH model-Power producing technologies



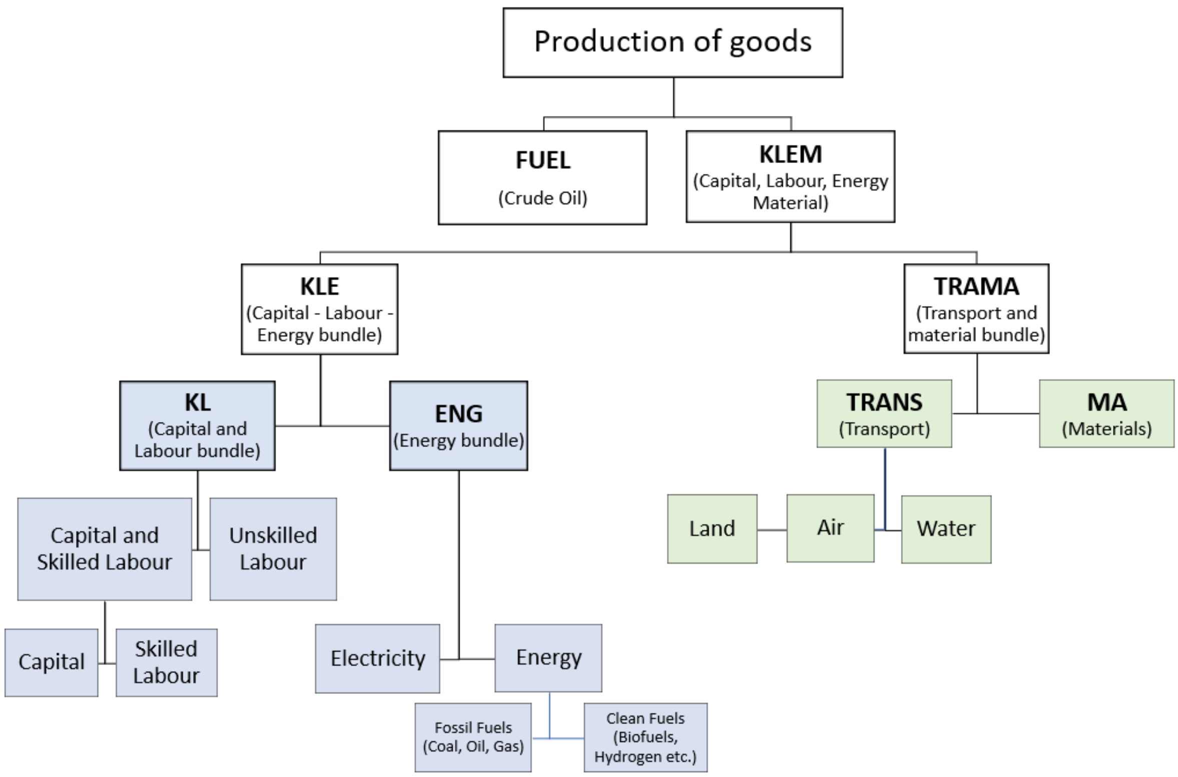
Power generation technologies exhibit a one level production function that includes capital, skilled and unskilled labour, materials and fuels.

$A\_XD = \mathbf{LEONTIEF}(A\_KAV, A\_LAV, A\_IO)$

4.1.3 Refineries

Figure presents the nesting scheme of the refineries sector. The nesting structure is similar to the default sectors with a change at the top level of the nest where the two aggregates are now *KLEM* and fuels (*FUEL*).

Figure 4: Nesting of the GEM-E3-CH model – Refineries



The nesting scheme develops as follows:

1st level:	Production of goods (XD) is split into capital, labour, energy and material bundle (*KLEM*) and fuels (*IO*)

$$XD = a\_xd_0 \cdot \left(d^{klem} \cdot \left(\frac{A\_KLEM}{a\_klem_0}\right)^{\rho} + d^{io} \cdot \left(\frac{A\_IO_{Crude\_Oil}}{a\_io_0}\right)^{\rho} + d^{io} \cdot \left(\frac{A\_IO_{Gas}}{a\_io_0}\right)^{\rho} \right)^{\frac{1}{\rho}}$$

2nd level:	KLEM is split into capital, labour and energy bundle (*KLE*) and transport and material bundle (*TRAMA*)

$A\_KLEM = \mathbf{CES}(A\_KLE, A\_TRAMA)$

3rd level:	KLE is split into capital and labour bundle (*KL*) and energy bundle (*ENG*) TRAMA is split into transport (TRANS) and materials bundle (*MA*)

$A\_KLE = \mathbf{CES}(A\_KL, A\_ENG)$
$A\_TRAMA = \mathbf{LEONTIEF}(A\_TRANS, A\_MA)$

4th level:	KL is split into capital and skilled labour bundle (KLSKLD) and unskilled labour ENG is split into fuels energy bundle (EN) and electricity (ELE) TRANS is split into land transport (TRALAND), water transport (TRAWATER) and air transport (TRAAIR) MA is split into intermediate inputs materials (IO)

$A\_KL = \mathbf{CES}(A\_KLSKLD, A\_LAV\_UNSKLD)$
$A\_ENG = \mathbf{CES}(A\_EN, A\_ELE)$
$A\_TRANS = \mathbf{CES}(A\_TRALAND, A\_TRAWATER, A\_TRAAIR)$
$A\_MA = \mathbf{CES}(A\_IO_{prma})$

5th level:	KLSKLD is split into capital and skilled labour EN is split into fuels energy intermediate inputs (IO) ELE is equal to electricity intermediate inputs (IO)

$A\_KLSKLD = \mathbf{CES}(A\_KAV, A\_LAV\_SKLD)$
$A\_EN = \mathbf{CES}(A\_IO_{prfuel})$
$A\_ELE = A\_IO_{prele}$

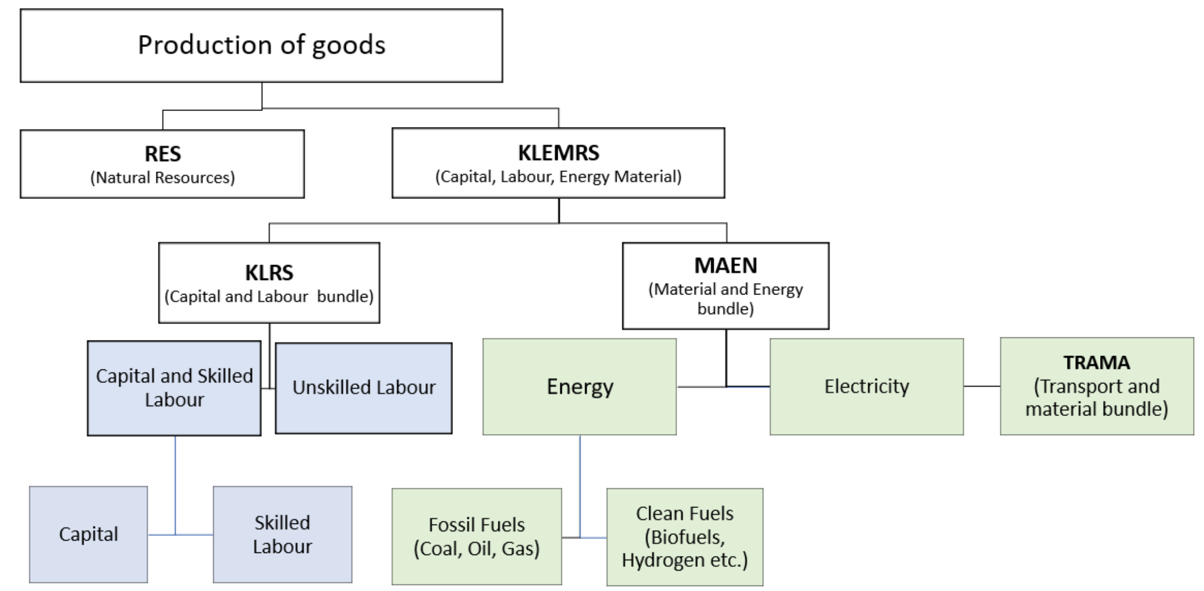
6th level:	TRALAND is equal to land transport intermediate input (IO) TRAAIR is equal to air transport intermediate input (IO) TRAWATER is equal to water transport intermediate input (IO)

$A\_TRALAND = A\_IO_{land}$
$A\_TRAAIR = A\_IO_{air}$
$A\_TRAWATER = A\_IO_{water}$

4.1.4 Resource sectors

The nesting scheme for the resource sectors in presented in Figure .

Figure 5: Nesting of GEM-E3-CH model – Resource sectors



The nesting scheme develops as follows:

1st level:	Production of Goods (XD) is split into capital, labour, energy and material bundle (*KLEMRS*) and resources (*RES*)

$$A\_XD = a\_xd_0 \cdot \left(d^{klem} \cdot \left(\frac{A\_KLEMRS}{a\_klemrs_0}\right)^{\rho} + d^{res} \cdot \left(\frac{A\_RES}{a\_res_0}\right)^{\rho}\right)^{\frac{1}{\rho}}$$

2nd level:	KLEMRS is split into capital and labour bundle (*KLRS*) and material and energy bundle (*MAEN*) RES is equal to resources

$A\_KLEM = \mathbf{CES}(A\_KLRS, A\_MAEN)$
$A\_RES = \text{Resources}$

3rd level:	KLRS is split into capital and skilled labour bundle (KLRSSKLD) and unskilled labour MAEN is split into fuels energy bundle (EN), electricity (ELE) and transport – material bundle (TRAMA)

$A\_KLRS = \mathbf{CES}(A\_KLRSSKLD, A\_LAV\_UNSKLD)$
$A\_MAEN = \mathbf{CES}(A\_EN, A\_ELE, A\_TRAMA)$

4th level:	KLRSSKLD is split into capital and skilled labour EN is split into fuels energy intermediate inputs (IO) ELE is equal to electricity intermediate inputs (IO) TRAMA is split into transport (TRANS) and materials bundle (*MA*)

$A\_KLRSSKLD = \mathbf{CES}(A\_KAV, A\_LAV\_SKLD)$
$A\_EN = \mathbf{CES}(A\_IO_{prfuel})$
$A\_ELE = A\_IO_{prele}$
$A\_TRAMA = \mathbf{LEONTIEF}(A\_TRANS, A\_MA)$

5th level:	TRANS is split into land transport (TRALAND), water transport (TRAWATER) and air transport (TRAAIR) MA is split into intermediate inputs materials (IO)

$A\_TRANS = \mathbf{CES}(A\_TRALAND, A\_TRAWATER, A\_TRAAIR)$
$A\_MA = \mathbf{CES}(A\_IO_{prmane})$

6th level:	TRALAND is equal to land transport intermediate input (IO) TRAAIR is equal to air transport intermediate input (IO) TRAWATER is equal to water transport intermediate input (IO)

$A\_TRALAND = A\_IO_{land}$

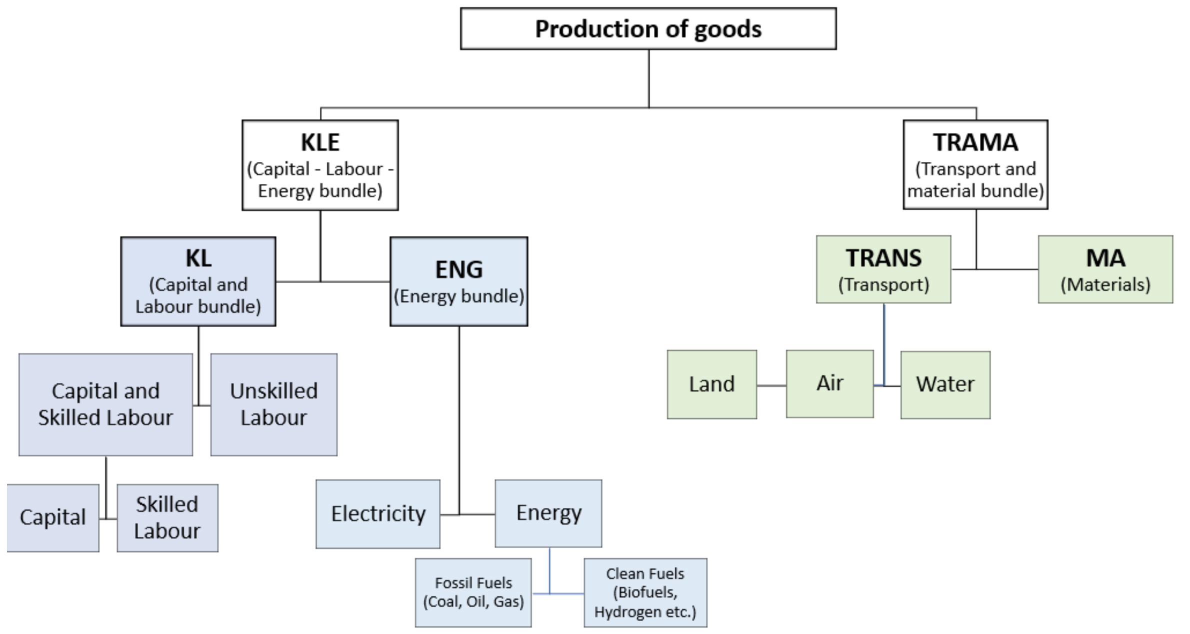
$A\_TRAAIR = A\_IO_{air}$

$$A\_TRAWATER = A\_IO_{water}$$

4.1.5 Default sectors

The nesting scheme for the default non-energy sectors is presented in Figure .

Figure 6: Nesting of GEM-E3-CH default sectors



The nesting scheme develops as follows:

1st level:	Production of Goods (XD) is split into capital, labour, energy bundle (*KLE*) and transport and materials bundle (*TRAMA*)

$$A\_XD = a\_xd_0 \cdot \left(d^{kle} \cdot \left(\frac{A\_KLE}{a\_kle_0}\right)^{\rho} + d^{trama} \cdot \left(\frac{A\_TRAMA}{a\_trama_0}\right)^{\rho} \right)^{\frac{1}{\rho}}$$

where: d: share parameter and ρ: substitution elasticity parameter

2nd level:	KLE is split into capital and labour bundle (*KL*) and energy bundle (*ENG*) TRAMA is split into transport (TRANS) and materials bundle (*MA*)

$A\_KLE = \mathbf{CES}(A\_KL, A\_ENG)$

$A\_TRAMA = \mathbf{LEONTIEF}(A\_TRANS, A\_MA)$

3rd level:	KL is split into capital and skilled labour bundle (KLSKLD) and unskilled labour ENG is split into fuels energy bundle (EN) and electricity (ELE) TRANS is split into land transport (TRALAND), water transport (TRAWATER) and air transport (TRAAIR) MA is split into intermediate inputs materials (IO)

$A\_KL = \mathbf{CES}(A\_KLSKLD, A\_LAV\_UNSKLD)$

$A\_ENG = \mathbf{CES}(A\_EN, A\_ELE)$

$A\_TRANS = \mathbf{CES}(A\_TRALAND, A\_TRAWATER, A\_TRAAIR)$

$A\_MA = \mathbf{CES}(A\_IO_{prmane})$

4th level:	KLSKLD is split into capital and skilled labour

	EN is split into fuels energy intermediate inputs (IO) ELE is equal to electricity intermediate inputs (IO) TRALAND is equal to land transport intermediate input (IO) TRAAIR is equal to air transport intermediate input (IO) TRAWATER is equal to water transport intermediate input (IO)

$A\_KLSKLD = \mathbf{CES}(A\_KAV, A\_LAV\_SKLD)$
$A\_EN = \mathbf{CES}(A\_IO_{prfuel})$
$A\_ELE = A\_IO_{prele}$
$A\_TRALAND = A\_IO_{land}$
$A\_TRAAIR = A\_IO_{air}$
$A\_TRAWATER = A\_IO_{water}$

4.2 Investment

GEM-E3-CH is a recursive dynamic model solved sequentially over time.

It is assumed that investment that takes place in time *t* increases the production capacity in the following period at time *t+1*. The law of motion of capital stock is given by:

$$A\_KAVC_{pr,er,t} = (1 - d_{pr,er,t})^{\Delta t} \cdot A\_KAVC_{pr,er,t-1} + \frac{1 - (1 - d_{pr,er,t})^{\Delta t}}{d_{pr,er,t}} A\_INV_{pr,er,t} \quad [5]$$

Following Hayashi (1982), the firm decides the optimal level of investment according to the rental price of capital and its replacement cost $\frac{P\_KAV_{pr,er,t}}{P\_INV_{pr,er,t} \cdot (rr_{er,t} + d_{pr,er,t})}$. It is also assumed that the firms always replace the depreciated capital ($d_{pr,er,t}\ A\_KAV^*_{pr,er,t}$). Therefore, the investment function becomes:

$$A\_INV_{pr,er,t} = A\_KAV^*_{pr,er,t} \cdot a0_{pr,er,t} \left[\left(\frac{P\_KAV_{pr,er,t}}{P\_INV_{pr,er,t} \cdot (rr_{er,t} + d_{pr,er,t})} \right)^{a1_{pr,er,t} \cdot sinv_{pr,er,t}} \cdot (1 + stgr_{pr,er,t}) - 1 + d_{pr,er,t} \right] \quad [6]$$

where:

$A\_KAVC_{pr,er,t}$: capital stock of firms

$A\_KAV^*_{pr,er,t}$ the optimal level of capital

$d_{pr,er,t}$: depreciation rate

$A\_INV_{pr,er,t}$: investment of firms in volume

$P\_KAV_{pr,er,t}$: the user cost of capital

$P\_INV_{pr,er,t}$: the price of investment

$stgr_{pr,er,t}$: the exogenously specified expected growth rate of the sector

rr: interest rate

$a0_{pr,er,t}$: scale parameter in investment function

$a1_{pr,er,t}$: the speed of adjustment parameter

$sinv_{pr,er,t}$: elasticity parameter

Firm's investment is translated into demand for investment goods which are produced from the rest of the sectors of the economy through an investment matrix of constant coefficients $tinvpv_{pr,br}$:

$$A\_INVP_{pr,br,er,t} = tinvpv_{pr,br,er,t} \cdot \frac{p\_inv0_{br.er}}{p\_invp0_{pr.er}} \cdot A\_INV_{pr,er,t} \quad [7]$$

where:

$tinvpv_{pr,br,er,t}$: share of each firm in delivery of investment

$A\_INVP_{pr,br,er,t}$: deliveries for investment by activity

p_inv0: Base year price of Investment (unit cost of investment for the firm)

p_invp0: Base year price of investment product

4.3 Household

For each region/country in the GEM-E3-CH model there exists a representative household that maximizes its utility function subject to its budget constraint. Its budget is derived from: i) labour supply, ii) dividends from firm's ownership iii) transfers from other institutional sectors.

Its utility function is a Linear Expenditure System (LES[7]) function:

$$U = \left(\sum_i bh_{i,r,t} \cdot ln\left(CV_{i,r,t} - CH_{i,r,t}\right) \right) \quad [8]$$

Where $CV_{i,r,t}$ is total consumption, $CH_{i,r,t}$ is the subsistence minima consumption. Total and disposable income is derived as follows:

$$M = PL \cdot L + W^{oth} \quad [9]$$
$$YDISP = M - S \quad [10]$$

where:

$PL \cdot L$: labour income

W^{oth}: non-labour income (e.g. dividends, social transfers)

S: Savings

The consumer's optimization problem is defined as:

$$max_{CV} \int_{t=0}^{\infty} e^{-stp \cdot t} U(CV) \quad [11]$$

[7] See Stone (1954)

$$s.t.\ \dot{w}(t) = YDISP(t) - PCI(t) \cdot CV(t) - PCI(t) \cdot CH(t) \quad [12]$$

where *stp* is the social time preference / subjective rate of discount. Solving the above problem, the optimal demand for total consumption is derived:

$$CV = CH + \mu \cdot \frac{bh}{PCI} \cdot (YDISP - PCI \cdot CH) \quad [13]$$

μ is a proxy to the marginal propensity to consume $\mu = \frac{stp}{r}$, and *r* is the interest rate. *bh* is the LES private consumption share parameter. Once the household decides total household consumption it needs to decide over the different consumption categories (*FN*).

GEM-E3-CH uses consumption matrices that translate consumption by purpose to specific demand for consumption by product. Hence the final household demand by product is calculated as:

$$A\_HC_{pr} = \sum_{\mathrm{fn}} tchcfv_{pr,fn} \cdot \mathrm{A\_HCFV_{fn}} \quad [14]$$

$tchcfv_{pr,fn}$: private consumption coefficients

A_HCFV_{fn}: consumption by purpose in volume

A_HC_{pr}: consumption by branch in volume

fn: production categories

4.4 Government

Government's behaviour is exogenous to the GEM-E3-CH model. Government's final demand by product ($A\_GC_{pr,er,t}$) is obtained by applying fixed coefficients ($tgcv_{pr,er,t}$) to the exogenous volume of government consumption ($gctv_{er,t}$):

$$A\_GC_{pr,er,t} = gctv_{er,t} \cdot tgcv_{pr,er,t}\ ,\ if\ swGC = 0 \quad [15]$$

$$A\_GC_{pr,er,t} = f(GDP)\ ,\ if\ swGC = 1 \quad [16]$$

$swGC$ is the switch for the endogenous/exogenous calculation of government consumption (see below for details on the switches included in the GEM-E3-CH model). In the case where $swGC$ = 1 the government consumption is a constant share of GDP.

The following equations describe all tax revenues and subsidy expenditure of the government disaggregated by government tax/revenue categories:

Government revenues from duties is the sum of bilateral duty rates for all the imported products adjusted by the price index.

$$V\_FGRB_{gvb,pr,er,t} = \sum_{cr} txduto_{pr,er,cr,t} \cdot A\_IMPO_{pr,er,cr,t} \cdot \frac{WPI_t}{WPI_0} \quad GVB\text{=duties} \quad [17]$$

Government expenditures on subsidies are subsidy costs for production, products, household energy and firms' energy, each component weighted by its respective subsidy rate — *GVB*=subsidies [18]

$$V\_FGRB_{gvb,pr,er,t} = sub\_production_{pr,er,t} \cdot \frac{WPI_t}{WPI_0} \cdot A\_XD_{pr,er,t} + sub\_products_{pr,er,t} \cdot \frac{WPI_t}{WPI_0} \cdot \left[\sum_{br} \left(A\_IO_{pr,br,er,t} + ABIOV_{pr,br,er,t} \right) + A\_GC_{pr,er,t} + A\_HC_{pr,er,t} + \sum_{br} \left(A\_INVP_{pr,br,er,t} \right) + A\_BUILD\_ENERGYSAVE\_H_{pr,er,t} \right] + \sum_{fn} txsubnrj\_HC_{pr,fn,er,t} \cdot \frac{WPI_t}{WPI_0} \cdot A\_HCFVPV_{pr,fn,er,t} + \sum_{br} txsubnrj\_Firms_{pr,br,er,t} \cdot \frac{WPI_t}{WPI_0} \cdot A\_IO_{pr,br,er,t}$$

Government revenue on indirect taxes is the sum of the respective tax rates multiplied by production, products, households' energy consumption and on firms' energy

$$V\_FGRB_{gvb,pr,er,t} = tax\_production_{pr,er,t} \cdot \frac{WPI_t}{WPI_0} \cdot A\_XD_{pr,er,t} + tax\_products_{pr,er,t} \cdot \frac{WPI_t}{WPI_0} \cdot \left[\sum_{br} \left(A\_IO_{pr,br,er,t} + ABIOV_{pr,br,er,t} \right) + A\_GC_{pr,er,t} + A\_HC_{pr,er,t} + \sum_{br} \left(A\_INVP_{pr,br,er,t} \right) + A\_BUILD\_ENERGYSAVE\_H_{pr,er,t} \right] + \sum_{fn} txitnrj\_HC_{pr,fn,er,t} \cdot \frac{WPI_t}{WPI_0} \cdot A\_HCFVPV_{pr,fn,er,t} + \sum_{br} txitnrj\_Firms_{pr,br,er,t} \cdot \frac{WPI_t}{WPI_0} \cdot A\_IO_{pr,br,er,t}$$

GVB=Indirect taxes [19]

Government revenue on value added tax

$$V\_FGRB_{gvb,pr,er,t} = txvat_{pr,er,t} \cdot \left(P\_Y_{pr,er,t} + \left(tax\_products_{pr,er,t} + sub\_products_{pr,er,t} \right) \cdot \frac{WPI_t}{WPI_0} \cdot A\_HC_{pr,er,t} \right)$$

GVB=Value added tax [20]

Government revenue on environmental taxes are taxes on firms proportional to their emissions less the endowments from unauctioned permits plus tax revenues from households' environmental tax

$$V\_FGRB_{gvb,pr,er,t} = \sum_{ghga}\left(TXENV_{ghga,pr,er,t} \cdot EMMBR_{ghga,pr,er,t}\right) - \sum_{ghga}\left(\left(1 - SHAUCTBR_{ghga,pr,er,t}\right) \cdot SALEP_{ghga,pr,er,t}\right) + \sum_{ghga,fn}\left(TXENVHDG_{ghga,fn,er,t} \cdot bech_{ghga,pr,fn,er,t} \cdot aerh_{pr,fn,er,t} \cdot eafh_{pr,fn,er,t} \cdot A\_HCFVPV_{pr,fn,er,t}\right)$$

GVB= Environmental tax [21]

where:

$txduto_{pr,er,cr,t}$: bilateral duty rate

$sub\_production_{pr,er,t}$: the subsidy rate in production

$sub\_products_{pr,er,t}$: the subsidy rate in products

$txsubnrj\_HC_{pr,fn,er,t}$: the subsidy rate related to energy for household

$txsubnrj\_Firms_{pr,br,er,t}$: the subsidy rate related to energy for firms

$tax\_production_{pr,er,t}$: the indirect tax rate in production

$tax\_products_{pr,er,t}$: the indirect tax rate in products

$txitnrj\_HC_{pr,fn,er,t}$: the energy tax rate imposed on household

$txitnrj\_Firms_{pr,br,er,t}$: the energy tax rate imposed on firms

$txvat_{pr,er,t}$: VAT rate per branch

$TXENV_{pr,er,t}$: the environmental tax for firms

$P\_Y_{pr,er,t}$: the price of domestic demand

$A\_IMPO_{pr,er,cr,t}$: imports in volume

$A\_XD_{pr,er,t}$: production in volume

$A\_IO_{pr,br,er,t}$: IO deliveries between sectors of activities

$ABIOV_{pr,br,er,t}$: deliveries of products for abatement

$A\_HC_{pr,er,t}$: the deliveries to private consumption

$A\_GC_{pr,er,t}$: deliveries to public consumption by branches

$A\_BUILD\_ENERGYSAVE\_H_{pr,er,t}$: Building materials for energy saving

$P\_INVP_{pr,er,t}$: the price of deliveries to investment

$A\_EMMBR_{ghga,pr,er,t}$: the emissions by branches

$shauctbr_{ghga,pr,er,t}$: the share of auctioned permits

$SALEP_{ghga,pr,er,t}$: the value of endowment in permits

WPI_t: the world price index

WPI_0: the world price index in the base year

$TXENVHDG_{ghga,dg,er,t}$: the environmental tax for household

$bech_{ghga,pr,fn,er,t}$: the emission factor

$aerh_{pr,fn,er,t}$: the share of energy combusted to total energy consumed

$eafh_{pr,fn,er,t}$: the emission adjustment factor

4.5 External sector

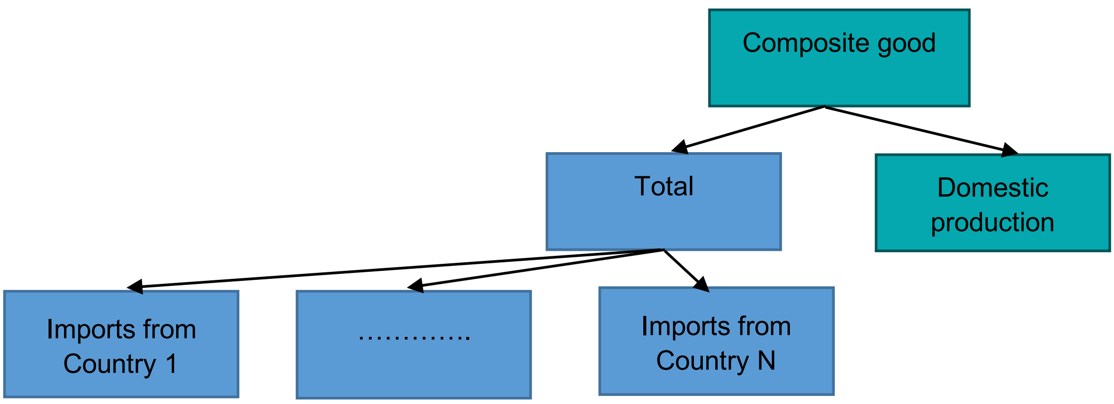
Firms and households consume a composite good that is composed of an imported part and a domestically produced part. Imported and domestically produced goods are considered as imperfect substitutes (Armington, 1969).

The supply decision of a good in the domestic economy is split in two stages:

1. At the first stage firms decide on the overall imports that they require.
2. At the second stage firms decide from which countries they will import. They split total import demand decided at stage 1 to regional/country demand.

Each country imports at the prices set by the supplying country.

Figure 1: Trade decision tree



Firms' cost minimization problem (for the Imports 1st level) is minimizing its production cost for domestic use together the cost of its imports:

$$\min C_{pr,er,t} = P\_XD_{pr,er,t} \cdot A\_XXD_{pr,er,t} + P\_IMP_{pr,er,t} \cdot A\_IMP_{pr,er,t} \qquad [22]$$

where:

$P\_XD_{pr,er,t}$: price of domestically produced good

$A\_XXD_{pr,er,t}$: production for domestic use

$P\_IMP_{pr,er,t}$: import price

$A\_IMP_{pr,er,t}$: imports

Such that the composite good is a CES function aggregate between the domestic production and the imports:

$$A\_Y_{pr,er,t} = AC_{pr,er,t} \cdot \left[\delta_{pr,er,t} \cdot A\_XXD_{pr,er,t}^{\frac{\sigma_{x_{pr,er,t}}-1}{\sigma_{x_{pr,er,t}}}} + \left(1-\delta_{pr,er,t}\right) \cdot A\_IMP_{pr,er,t}^{\frac{\sigma_{x_{pr,er,t}}-1}{\sigma_{x_{pr,er,t}}}} \right]^{\frac{\sigma_{x_{pr,er,t}}}{\sigma_{x_{pr,er,t}}-1}} \quad [23]$$

where:

$A\_Y_{pr,er,t}$: composite good

$AC_{pr,er,t}$: scale parameter in the Armington function

$\delta_{pr,er,t}$: share parameter estimated from the base year data related to the value shares of $A\_XXD_{pr,er,t}$ and $A\_IMP_{pr,er,t}$ in the demand for composite good $Y_{pr,er,t}$

σ_X: the Armington elasticity between imported and domestically produced goods

The optimal demand for domestic and imported goods is obtained by employing the Shephard's lemma (Shephard 1953).

$$A\_XXD_{pr,er,t} = \begin{cases} A\_Y_{pr,er,t} \cdot AC_{pr,er,t}^{\sigma_{x_{pr,er,t}}-1} \cdot \left(1-\delta_{pr,er,t}\right)^{\sigma_{x_{pr,er,t}}} \cdot \left(\dfrac{P\_Y_{pr,er,t}}{P\_XD_{pr,er,t}}\right)^{\sigma_{x_{pr,er,t}}} & if\ AC_{pr,er,t} \neq 0 \\ A\_Y_{pr,er,t} & if\ AC_{pr,er,t} = 0 \end{cases} \quad [24]$$

$$A\_IMPC_{pr,er,t} = A\_Y_{pr,er,t} \cdot AC_{pr,er,t}^{\sigma_{x_{pr,er,t}}-1} \cdot \delta_{pr,er,t}^{\sigma_{x,pr,er,t}} \cdot \left(\frac{P\_Y_{pr,er,t}}{P\_IMP_{pr,er,t}}\right)^{\sigma_{x_{pr,er,t}}} \quad [25]$$

where:

$A\_IMPC_{pr,er,t}$: the competitive imports by branch

$P\_Y_{pr,er,t}$: the unit cost for the composite good

$$P\_Y_{pr,er,t} = \frac{1}{AC_{pr,er,t}} \cdot \left[\delta_{pr,er,t}^{\sigma_{x,pr,er,t}} \cdot P\_IMP_{pr,er,t}^{1-\sigma_{x_{pr,er,t}}} \cdot + \left(1-\delta_{pr,er,t}\right)^{\sigma_{x_{pr,eu,t}}} \cdot P\_XD_{pr,er,t}^{1-\sigma_{x_{pr,er,t}}} \right]^{\frac{1}{1-\sigma_{x_{pr,er,t}}}} \quad if\ pr = brt \quad [26]$$

$$P\_Y_{pr,er,t} = P\_IMP_{pr,er,t} \cdot rtxd_{pr,er,t} + P\_PD_{pr,er,t} \cdot txsub_{pr,er,t} \frac{WPI_t}{WPI_0} \cdot \left(1 - rtxd_{pr,er,t}\right) \quad if\ pr = brnt \quad [27]$$

$$A\_IMP_{pr,er,t} = A\_IMPC_{pr,er,t} + A\_IMPNC_{pr,er,t} \;\; if\; pr = brt \qquad [28]$$

$$A\_IMPNC_{pr,er,t} = rtnc_{pr,er,t} \cdot A\_XD_{pr,er,t} \qquad [29]$$

$$A\_IMP_{pr,er,t} = rtxd_{pr,er,t} \cdot A\_Y_{pr,er,t} \quad if\; pr = brnt \qquad [30]$$

$$P\_IMP_{pr,er,t} = \left[\sum_{cr} beta_{pr,er,cr,t}^{sigmai_{pr,er,t}} \cdot P\_IMPO_{pr,er,cr,t}{}^{(1-sigmai_{pr,er,t})}\right]^{\left(\frac{1}{1-sigmai_{pr,er,t}}\right)} \qquad [31]$$

where:

$rtnc_{pr,er,t}$: is the share of non-competitive imports

$P\_IMP_{pr,er,t}$: price of total imports

$beta_{pr,er,cr,t}$: share parameter

$\sigma_{pr,er,t}$: the elasticity of substitution

$P\_IMPO_{pr,er,cr,t}$: import price of good *pr* for country *er* originating from country *cr*

$$P\_IMPO_{pr,cs,cr,t} = P\_PWE_{pr,cr,t} + txduto_{pr,cs,cr,t} \cdot \frac{WPI_t}{WPI_0} + \sum_{itrn}\left(cif\_vtwr_{itrn,pr,cs,t} \cdot P\_TR_{itrn,t}\right) \qquad [32]$$

where:

$P\_PWE_{pr,cr,t}$: the export price in international currency

$cif\_vtwr_{itrn,pr,cs,t}$: the demand share for transport margins

$P\_TR_{itrn,t}$: the international transport margin price

International transport services

The model represents international transport services by origin and destination and by mode of transport. The data used to model international trade are:

1. bilateral trade flows of goods and services (the representation of which in the GEM-E3-CH model is described in the previous section)
2. supply of international trade margins (i.e. freight transport services)

The parameters related to trade are:

Name	Description
VST(mg*,er)	Margin exports
VTWR(mg,pr,er,cr)	Margin usage in facilitation of flow of commodity pr from er to cr

* mg: air, land, water, Source: McDougal (2006)

The sector that supplies the international transport services (i.e. water, air and land transport) earns the difference between *c.i.f.* and *f.o.b.* ($\sum_r VST_{j,r}$, the supply of margins). The market clearance conditions for the international market services imply that the sum across all regions of service exports equals the sum of all bilateral trade flows of service inputs (usage):

$$\sum_r vst_{j,r} = \sum_{i,r,s} vtwr_{j,i,r,s} \quad [33]$$

In the GEM-E3-CH model the international transport margin price is determined by the following equation where the price of international price must be less or equal that the sum of the transport margin shares of each country multiplied by the export price over the export price in the base year:

$$P\_TR_{itrn,t} \leq \sum_{er}\left(thetavst_{itrn,er,t} \cdot \frac{P\_PWE_{pr,er,t}}{P\_PWE_{pr,er,0}}\right) \quad [34]$$

where:

thetavst$_{itrn,er,t}$: measures the share of each country in total international transport margins in the base year.

The activity level of each type of transport is defined as:

$$A\_YVST_{itrn,t} \cdot vtag_{itrn,t} \geq \sum_{br,er,cr}\left(A\_EXPO_{pr,er,cr,t} \cdot cif\_vtwr_{itrn,pr,er,cs,t}\right) \quad [35]$$

vtag$_{itrn,t}$: the output per type of transport in the international pool in the base year

Exports of transport services are given by the level of each transport type multiplied by the output per type and the share of each country in total international transport margins:

$$A\_YVTWR_{itrn,er,t} = A\_YVST_{itrn,t} \cdot vtag_{itrn,t} \cdot thetavst_{itrn,er,t} \quad [36]$$

The bilateral import price equals the export price of the exporter in case of tradable services, while in the case of merchandise sectors the bilateral import price is given by the export price plus the bilateral *cif/fob* margins.

A_IMPO$_{br,cr,cs,t}$: denotes imports of good br demanded by country cr from country cs.

Imports are a function of total imports multiplied by the share parameter and the price of imports over the price at the base year.

$$A\_IMPO_{br,cr,cs,t=}A\_IMP_{nr,cr,t} \cdot \left(beta_{br,cr,cs,t} \cdot \frac{P\_IMP_{br,cr,t}}{P\_IMPO_{br,cr,cs,t}}\right)^{\sigma_{br,cr,t}} \quad [37]$$

4.6 Institutional transfers

The institutional sectors included in the GEM-E3-CH model are:

- Households (*h*)
- Firms (*f*)
- Government (*g*)
- World (*w*)

An example of different type of transactions amongst the different agents is presented in tabular form in Table 8, where rows represent revenues and columns represent expenditures of the institutional sectors.

Table 8: Institutional sector transfers

		Expenditures			
Revenues		Household	Firms	Government	World
	Household		Dividends	Social Benefits	Remittances
	Firms			Subsidies	
	Government	Direct Taxes Social Security	Direct Taxes		
	World	Transfers abroad			

The transfers between sectors are described by the following equations in GEM-E3-CH model.

The following equation describes the dividend earnings of households from firms:

$$V\_FSESE_{se,sr,er,t} = txdividh_{er,t} \cdot \sum_{fa=CAP} V\_FSEFA_{se,fa,er,t}$$

Firms pay / households receive (*se*=*h*), (*sr*=*f*), (*fa*=*CAP*) [38]

Households' payments to the government are the sum of social security expenses "SS" and direct taxes "DT"

$$V\_FSESE_{se,sr,er,t} = V\_FGRS_{"SS","F",er,t} + V\_FGRS_{"SS",sr,er,t} + V\_FGRS_{"DT",sr,er,t}$$

Household pay / Government receive (*se*=*g*), (*sr*=*h*) [39]

Firms' payment to the government are the sum of direct taxes and dividends

$$V\_FSESE_{se,sr,er,t} = V\_FGRS_{"DT",sr,er,t} + txdividh_{er,t} \cdot \sum_{fa=CAP} V\_FSEFA_{se,sr,er,t}$$

Firms pay / Government receive (*se*=*g*), (*sr*=*f*) [40]

Government payments to households are the sum of social benefits, permits to households and property income

$$V\_FSESE_{se,sr,er,t} = Social\_Benefit_{er,t} \cdot actpt_{er,t} \cdot \frac{WPI_t}{WPI_0} + \sum_{ghga} \sum_{fn} \left(1 - SHAUCTH_{ghga,er,t}\right) \cdot SALEPH_{ghga,fn,er,t} + Property\_Income_{se,er} \cdot \frac{WPI_t}{WPI_0}$$

Government pays/ households receive (*se*=*h*), (*sr*=*g*) [41]

Government payments to abroad are the sum of the expenditure of firms and households to buy permits

$$V\_FSESE_{se,sr,er,t} = \sum_{ghga}\sum_{br} BUSAT_{ghga,br,er,t} + \sum_{po1}\sum_{lnd} BUSATH_{ghga,fn,er,t}$$

Government pays / World receives (*se*=*w*), (*sr*=*g*) [42]

Social security for households equals the sum across all products of social security rate on households less the social security given by firms for the labour value added

$$V\_FGRS_{gvs,se,er,t} = \sum_{br}\left(txhss_{br,er,t}\left(1 - txfss_{br,er,t}\right) \cdot V\_VA_{fa,br,er,t}\right)$$

Household pays social security (*gvs*=*ss*), (*se*=*h*), (*fa*=*LAB*) [43]

Social security for firms equals the social security rate on firms, multiplied by the value added for labour

$$V\_FGRS_{gvs,se,er,t} = \sum_{br}\left(txfss_{br,er,t} \cdot V\_VA_{fa,br,er,t}\right)$$

Firms pays social security (*gvs*=*ss*), (*se*=*f*), (*fa*=*LAB*) [44]

Direct taxes of the firms are the direct tax rate multiplied by the payments by factors to the firms and transfers between firms

$$V\_FGRS_{gvs,se,er,t} = txdirtaxf_{er,t} \cdot \left(\sum_{fa} V\_FSEFA_{se,fa,er,t} + \sum_{sr} V\_FSESE_{se,sr,er,t}\right)$$

Firm pays direct taxes (*gvs*=*dt*), (*se*=*f*) [45]

Direct taxes of the households are the direct tax rate multiplied by the payments by factors to households and transfers between households

$$V\_FGRS_{gvs,se,er,t} = txdirtaxh_{er,t} \cdot \left(\sum_{fa} V\_FSEFA_{se,fa,er,t} + \sum_{sr} V\_FSESE_{se,sr,er,t}\right)$$

Household pays direct taxes (*gvs*=*dt*), (*se*=*h*) [46]

where:

se, sr: institutional sectors, i.e. households (*h*), firms (*f*), government (*g*), and world (*w*).

$txdividh_{er,t}$: the rate of dividend from firms to household

$V\_FSEFA_{se,sr,er,t}$: the payments by factors to the sectors

$V\_FSESE_{se,sr,er,t}$: the transfers between sectors

$Social\_Benefit_{er,t}$: social benefits rate

$actp\_t_{er,t}$: the active population

$SHAUCTH_{po1,er,t}$: the share of auctioned permits per household

$SALEPH_{po1,lnd,er,t}$: the value of endowment of permits for households

$SALEP_{po1,er,t}$: the value of endowment of permits for firms

$BUSAT_{po1,br,er,t}$: the expenditure of firms for buying permits

$BUSATH_{po1,br,er,t}$: the expenditure of households for buying permits

$V\_FGRS_{gvs,se,er,t}$: the payments by sectors to public sector expenditure categories

$txfss_{br,er,t}$: the social security rate on firms

$txhss_{br,er,t}$: the social security rate on households

$txdirtaxf_{er,t}$: the rate of direct taxes on firms

$txdirtaxh_{er,t}$: the rate of direct taxes on household

The transfers between factors of production and the economic sectors as given in the Social Accounting Matrix (SAM) are described in the equations below. The most important of these transfers include:

The value added from the labour factor is for every skill type the sum of labour multiplied by the price of labour

$$V\_VA_{fa,pr,er,t} = \sum_{sk\_type} A\_LAV_{sk\_type,pr,er,t} \cdot P\_LAV_{sk\_type,pr,er,t}$$

Value added from labour factor (*fa=sk_type*) [47]

The value added from the capital factor is the capital multiplied by the price of capital plus the sum of the share of non-auctioned permits per household multiplied by the value of endowment of permits for firms

$$V\_VA_{fa,pr,er,t} = A\_KAV_{pr,er,t} \cdot P\_KAV_{pr,er,t} + \sum_{ghga} \left((1 - SHAUCTBR_{ghga,pr,er,t}) \right) \cdot SALEP_{ghga,pr,er,t}$$

Value added from capital factor (*fa=k*) [48]

The value added from resources factor is the volume of reserves multiplied by the price of reserves

$$V\_VA_{fa,pr,er,t} = A\_RESFV_{pr,er,t} \cdot P\_RESF_{pr,er,t}$$	Value added from resources factor (*fa=r*)	[49]

Total payments by factors is the sum of the value added of every factor

$$V\_FSEFAT_{fa,pr,er,t} = \sum_{br} V\_VA_{fa,br,er,t}$$	Total payment of factors (*fa=l, k, r*)	[50]

Factor payments to government is the tax rate for every factor multiplied by the total payment of factors

$$V\_FSEFA_{se,fa,er,t} = txfsefa_{se,fa,er,t} \cdot \sum_{br} V\_VA_{fa,br,er,t}$$	Factor payments to government (*se=g*)	[51]

where:

$V\_VA_{fa,pr.er,t}$: the value added

$A\_LAV_{sk\_type,br,er,t}$: the demand for labour

$P\_LAV_{sk\_type,br,er,t}$: the unit cost of labour

$txfsefa_{se,fa,er,t}$: the parameter indicating the share of the each agent to factor income (as calculated in base year)

$A\_KAV_{pr,er,t}$: the capital stock

$P\_KAV_{pr,er,t}$: the user cost of capital

$A\_RESFV_{pr,er,t}$: volume of reserves

$P\_RESF_{pr,er,t}$: price of reserves

$V\_FSEFAT_{fa,pr,er,t}$: the total payments by factors

$V\_FSEFA_{se,fa,pr,er,t}$: payment by factor to sectors

$SHAUCTBR_{ghga,pr,er,t}$: share of auctioned permits per household

The final consumption of the sectors of the economy is given in equations below:

Households' final consumption is the value of private consumption

$$V\_FC_{se,er,t} = V\_HCDTOT_{er,t}$$	*se=h*	[52]

Firms' final consumption is zero

$$V\_FC_{se,er,t} = 0$$ se=f [53]

Government's final consumption is the government consumption multiplied by the price of delivery to domestic consumption

$$V\_FC_{se,er,t} = \sum_{pr} P\_GC_{pr,er,t} \cdot A\_GC_{pr,er,t}$$ se=g [54]

World's final consumption is the sum of the cost for bilateral exports and exports to international transport pool

$$V\_FC_{se,er,t} = \sum_{pr} \left(P\_PWE_{pr,er,t} \cdot \sum_{eu} A\_EXPO_{pr,er,eu,t} + P\_PWE_{pr,er,t} \cdot A\_YVTWR_{pr,er,t} \right)$$ se=w [55]

where:

$V\_FC_{se,er,t}$: the consumption by sector

$V\_HCDTOT_{er,t}$: private consumption in value

$P\_PWE_{pr,er,t}$: the unit cost of exports

$A\_EXPO_{pr,er,cr,t}$: the bilateral exports in volume

$A\_YVTWR_{pr,er,t}$: the exports to international transport pool in volume

$A\_GC_{pr,er,t}$: the government consumption in volume.

$P\_GC_{pr,er,t}$: the price of delivery to domestic consumption.

The savings of each agent is determined by:

Households' savings are the difference between the disposable income and the private consumption

$$V\_SAVE_{se,er,t} = V\_YDISP_{er,t} - V\_HCDTOT_{er,t}$$ se=h [56]

Firms' savings are the sum of payments by factors firms less the firms' final consumption

se=f [57]

$$V\_SAVE_{se,er,t} = \sum_{fa} V\_FSEFA_{se,sr,er,t} + \sum_{sr} V\_FSESE_{se,sr,er,t} - V\_FC_{se,er,t} - \sum_{sr} V\_FSESE_{sr,se,er,t}$$

Government's savings are the sum of government revenues – government expenditures

$$V\_SAVE_{se,er,t} = \sum_{gv}\sum_{br} V\_FGRB_{gv,br,er,t} + \sum_{fa} V\_FSEFA_{se,sr,er,t} + \sum_{sr} V\_FSESE_{se,sr,er,t} - V\_FC_{se,er,t} - \sum_{sr} V\_FSESE_{sr,se,er,t} \qquad se=g \qquad [58]$$

$$V\_SAVE_{se,er,t} = \sum_{pr}\sum_{cr} P\_IMPO_{pr,er,cr,t} \cdot A\_IMPO_{pr,er,cr,t} + \sum_{fa} V\_FSEFA_{se,sr,er,t} - \sum_{gv=DUT}\sum_{br} V\_FGRB_{gv,br,er,t} + \sum_{sr} V\_FSESE_{se,sr,er,t} - V\_FC_{se,er,t} - \sum_{sr} V\_FSESE_{sr,se,er,t} \qquad se=w \qquad [59]$$

where:

$V\_YDISP_{er,t}$: Household's disposable income given by equation below

$$V\_YDISP_{er,t} = \sum_{fa} V\_FSEFA_{se,fa,er,t} + \sum_{er} V\_FSESE_{sr,se,er,t} - \sum_{sr} V\_FSESE_{sr,se,er,t} \qquad se=h \qquad [60]$$

$$SURPL_{se,er,t} = V\_SAVE_{se,er,t} - V\_INV_{se,er,t} \qquad [61]$$

where:

$V\_SAVE_{se,er,t}$: the savings by sector

$V\_INV_{se,er,t}$: the investments in value

4.7 Prices

Intermediate and final consumers buy the composite good A_Y at the price P_Y plus taxes. Below are reported the different price formulations included in the GEM-E3-CH model:

The value of intermediate inputs to production are the sum of indirect tax on goods, the subsidy, the trade margin rate, the transport margin rate and the price.

$$P\_IO_{pr,er,t} = tax\_products_{pr,er,t} \cdot \frac{WPI_t}{WPI_0} + sub\_products_{pr,er,t} \cdot \frac{WPI_t}{WPI_0} + trade\_m\_rate_{pr,er,t} \cdot \frac{WPI_t}{WPI_0} + trans\_m\_rate_{pr,er,t} \cdot \frac{WPI_t}{WPI_0} + P\_Y_{pr,er,t} \qquad [62]$$

The price of deliveries to private consumption are the value of intermediate inputs to production plus the tax on value added.

$$P\_HC_{pr,er,t} = (1 + txvat_{pr,er,t})\Big[P\_Y_{pr,er,t} + (tax\_products_{pr,er,t} + sub\_products_{pr,er,t} + trade\_m\_rate_{pr,er,t} + trans\_m\_rate_{pr,er,t}) \cdot \frac{WPI_t}{WPI_0}\Big] \quad [63]$$

where:

$P\_IO_{pr,er,t}$: value of intermediate inputs to production

$P\_HC_{pr,er,t}$: price of deliveries to private consumption by branch

$txvat_{pr,er,t}$: the rate of value added tax imposed on good *pr.*

$tax\_products_{pr,er,t}$: the indirect tax rate imposed on good *pr.*

$sub\_products_{pr,er,t}$: the subsidy rate imposed on good *pr.*

$trade\_m\_rate_{pr,er,t}$: the trade margin rate imposed on good *pr.*

$trans\_m\_rate_{pr,er,t}$: the trade margin rate imposed on good *pr.*

The price of delivery to public consumption and investments follows a similar structure

$$P\_GC_{pr,er,t} = (1 + txvat_{pr,er,t}) \cdot \Big[P\_Y_{pr,er,t} + (tax\_products_{pr,er,t} + sub\_products_{pr,er,t} + trade\_m\_rate_{pr,er,t} + trans\_m\_rate_{pr,er,t}) \cdot \frac{WPI_t}{WPI_0}\Big] \quad [64]$$

$$P\_INVP_{pr,er,t} = (1 + txvat_{pr,er,t}) \cdot \Big[P\_Y_{pr,er,t} + (tax\_products_{pr,er,t} + sub\_products_{pr,er,t} + trade\_m\_rate_{pr,er,t} + trans\_m\_rate_{pr,er,t}) \cdot \frac{WPI_t}{WPI_0}\Big] \quad [65]$$

where:

$P\_GC_{pr,er,t}$: price of delivery to public consumption by branch

$P\_INVP_{pr,er,t}$: price of delivery to investments by branch

The unit cost of investment by sector of destination (owner) depends on its composition in investment goods (by sector of origin). This structure is represented by a set of fixed technical coefficients $tinvpv_{pr,br,er,t}$:

$$P\_INV_{br,er,t} = P\_INV0_{br,er} \cdot \sum_{pr} \frac{P\_INVP_{pr,er,t}}{p\_invp0_{pr,er}} \cdot tinvpv_{pr,br,er,t} \quad [66]$$

The producer price is given by:

$$P\_XD_{brt,er,t} = P\_PD_{brt,er,t} + (sub\_production_{brt,er,t} + tax\_production_{brt,er,t}) \cdot \frac{WPI_t}{WPI_0} + P\_IMP_{brt,er,t} \cdot rtnc_{brt,er,t} \quad [67]$$

$$P\_PWE_{pr,er,t} = P\_PD_{pr,er,t} + (sub\_production_{pr,er,t} + tax\_production_{pr,er,t} + trade\_m\_rate\_exprt_{pr,er,t} + ttrans\_m\_rate\_exprt_{pr,er,t}) \cdot \frac{WPI_t}{WPI_0} + P\_IMP_{pr,er,t} \cdot rtnc_{pr,er,t} \quad [68]$$

where:

$P\_XD_{brt,er,t}$: the (domestic) supply price addressed to domestic demand

$P\_PWE_{pr,er,t}$: the (domestic) supply price addressed to exports

$sub\_production_{pr,er,t}$: the rate of subsidies in production

$tax\_production_{pr,er,t}$: the tax rate in production

$trade\_m\_rate\_exprt_{pr,er,t}$: the trade margin rate in exports

$trans\_m\_rate\_exprt_{pr,er,t}$: the transport margin rate in exports

4.8 Equilibrium

The market clearance equation is:

$$A\_XD_{pr,er,t} = \begin{cases} A\_XXD_{pr,er,t} + \sum_{cr} A\_EXPO_{pr,er,cr,t} & if\ pr = brt \\ A\_Y_{pr,er,t} + \sum_{eu} A\_EXPO_{pr,er,eu,t} + A\_YVTWR_{pr,er,t} - A\_IMP_{pr,er,t} & if\ pr = brnt \end{cases} \quad [69]$$

Total supply of goods (domestically produced and imported) expended to intermediate consumption, private and public consumption and investments.

$$A\_Y_{pr,er,t} = \sum_{br} (A\_IO_{pr,br,er,t,} + ABIOV_{pr,br,er,t} + A\_INVP_{pr,br,er,t}) + A\_HC_{pr,er,t} + A\_GC_{pr,er,t} + ch\_stock_{pr,er,t} + A\_TRADE\_M_{pr,er,t} + A\_TRANS\_M_{pr,er,t} + A\_BUILD\_ENERGYSAVE\_H_{pr,er,t} \quad [70]$$

where:

$ch\_stock_{pr,er,t}$: the change in stock

$A\_TRADE\_M_{pr,er,t}$: the trade margins by branch

$A\_TRANS\_M_{pr,er,t}$: the transport margins by branch

The market clearance equations for capital are:

Case 1: capital is immobile between sectors and between regions

$$A\_KAV_{pr,er,t} = A\_KAVC_{pr,er,t-1} \quad [71]$$

Case 2: mobility across sectors but not across regions

$$\sum_{pr} A\_KAV_{pr,er,t} = \sum_{pr} A\_KAVC_{pr,er,t-1} \quad [72]$$

Case 3: Full mobility across sectors and regions

$$\sum_{pr}\sum_{er} A\_KAV_{pr,er,t} = \sum_{pr}\sum_{er} A\_KAVC_{pr,er,t-1} \quad [73]$$

where:

$KAVC_{pr,er,t}$: the total amount of capital stock available, fixed within the time period.

Depending on the capital mobility choice, through the switch parameter $swonkm(stime)$ (i.e. 0 for no mobility, 1 for mobility between sectors), the dual price of the capital *is computed:* as $P\_KNOKM_{pr,er,t}$ and $P\_KNAKM_{pr,er,t}$, respectively.

$$P\_KAV_{pr,er,t} = \begin{cases} P\_KNOKM_{pr,er,t} & if\ SWONK = 0 \\ anakm_{pr,er,t} \cdot P\_KNAKM_{pr,er,t} & if\ SWONK = 1 \end{cases} \quad [74]$$

where:

$anakm_{pr,er,t}$ is a calibrated parameter.

4.9 Labour market

The GEM-E3-CH model allows for involuntary unemployment using a labour supply curve where wages are inversely related to unemployment. The labour supply function is calibrated to a wage elasticity of -0.1 documented in several empirical studies (see McCelland and Mok, 2012). The wage function for skilled and unskilled labour is:

$$P\_WRMEAN_{sk\_type,er,t} = \frac{P\_PCI}{\overline{\overline{P\_PCI}}} \cdot \left(a_{sk\_type} + \frac{b_{sk\_type}}{RT\_UNRT_{sk\_type} - edelta_{sk\_type}}\right)^{sigmawage_{sk\_type}} \quad [75]$$

where:

$P\_WRMEAN_{sk\_type,er,t}$: the wage rate of labour by occupation

$a_{sk\_type,er,t}$: the unemployment benefit/minimum wage by occupation

$RT\_UNRT_{sk\_type,er,t}$: the unemployment rate by occupation

$edelta_{sk\_type,er,t}$: the natural rate of unemployment by occupation

$sigmawage_{sk\_type,er,t}$: calibrated parameter in the wage curve by occupation

The following equations serve to compute the unemployment rate while the equilibrium conditions in the labour market serve to compute the wage rate, which is the average nominal wage rate used to derive the labour cost by occupation $P\_LAV_{sk\_type,er,t}$.

$$RT\_UNRT_{sk\_type,er,t} = 1 - \frac{\sum_{pr} A\_LAV_{sk\_type,pr,er,t}}{A\_POPV_{sk\_type,er,t}} \quad [76]$$

$$A\_POPV_{sk\_type,er,t} = TotLabFrc_{sk\_type,er,t} \quad [77]$$

where:

$RT\_UNRT_{sk\_type,er,t}$: the unemployment rate by occupation

$A\_POPV_{sk\_type,er,t}$: the labour supply by occupation

$TotLabFrc_{sk\_type,er,t}$: is the total labour force by occupation measured in million hours. The unit cost of labour is computed according to the average wage rate derived from the equilibrium of the labour market.

$XLNUM_{sk\_type,er,t}$ is used in order to ensure that the computation of $tl_{sk\_type,pr,er,t}$ is consistent with the unit cost of labour of sectors both in the baseline and the scenario.

$$XLNUM_{sk\_type,er,t} = \frac{\sum_{pr} A\_LAV_{sk\_type,pr,er,t}}{\sum_{pr}(A\_LAV_{sk\_type,pr,er,t} \cdot tl_{sk\_type,pr,er,t})} \quad [78]$$

$$P\_LAV_{sk\_type,er,t} = \frac{tl_{sk\_type,pr,er,t} \cdot P\_WRMEAN_{sk\_type,er,t} \cdot XLNUM_{sk\_type,er,t}}{(1 - txfss_{sk\_type,pr,er,t})} \quad [79]$$

where:

$P\_LAV_{sk\_type,pr,er,t}$: the unit cost of labour by occupation

$tl_{sk\_type,pr,er,t}$: the relative wage rate of labour by occupation

$P\_WRMEAN_{sk\_type,er,t}$: the wage rate of labour by occupation

$txfss_{sk\_type,pr,er,t}$: the employers social security rate by occupation

$XLNUM_{sk\_type,er,t}$: the adjustment in the average wage rate based on the labour mobility and the allocation between sectors

4.10 Environment

The GEM-E3-CH environment module includes all GHGs (CO_2, CH_4, N_2O, HFC, PFC and SF_6) to be able to provide a consistent analysis of climate change policies. A GHG reduction policy can be implemented either through the imposition of an exogenous tax or through the introduction of an emission reduction constraint.

From a technical point of view the introduction of an exogenous carbon tax requires:

i) the activation of the appropriate switches - *swtxexobr(ghga,br,er,an)* for firms or/and *swtxexoh(ghga,fn,er,an)* for households (see below for switches included in GEM-E3-CH)

ii) the assignment of the desired level of carbon tax to the *txem(ghga,br,er,an)* parameter for firms and to *txemhdg(ghga,dg,er,an)* for households.

In the case where an emission reduction target needs to be introduced the following are required:

i) switch activation*: swclubbr(ghga,br,er,cc,an)* for firms or/and *swclubh(ghga,dg,er,cc,an)* for households.

ii) set of the desired target (i.e. imposing an GHG emission cap) in the *supperfeu(ghga,cc,an)* parameter.

The imposition of an exogenous carbon tax or of an emission reduction target (where a carbon price that clears the emission permit market is calculated endogenously) increases the user cost of GHG emitting activities. GHG emissions of each sector (see [80]) are calculated either based on energy consumption (energy related emissions) or based on production level (process related emissions). In the households' sector only CO_2 energy related emissions have been modelled (see [81]).

$$A\_EMMBR_{ghga,br,er,t} = \begin{cases} \sum_{prfuel} bec_{ghga,prfuel,br,er,t} \cdot aer_{prfuel,br,er,t} \cdot eaf_{prfuel,br,er,t} \cdot (1 - Transport\_IntUse_{br,er}) \cdot A\_IO_{prfuel,br,er,t} & if\ ghga = poem \\ (1 - AAtot_{ghga,br,er,t}) \cdot mec_{ghga,br,er,t} \cdot (1 - Transport\_IntUse_{br,er}) \cdot A\_XD_{br,er,t} & if\ ghga = poghg \end{cases} \quad [80]$$

where:

$bec_{ghga,prfuel,br,er,t}$: emission factor for energy related GHG in the branch level

$aer_{prfuel,br,er,t}$: share of energy consumption with emissions in the branch level

$eaf_{prfuel,br,er,t}$: emission adjustment factor in the branch level

$A\_IO_{prfuel,br,er,t}$: intermediate demand of fuels in the branch level

$AAtot_{ghga,br,er,t}$: degree of abatement in the branch level

$mec_{ghga,br,er,t}$: emission factor for process related GHG

$A\_XD_{br,er,t}$: domestic production

The parameter $Transport\_IntUse_{br,er}$ is used to account for international aviation and bunker emissions.

$$A\_EMMHLND_{ghga,br,er,t} = \sum_{prfuel} bech_{ghga,prfuel,lnd,er,t} \cdot aerh_{prfuel,br,er,t} \cdot A\_HCFVPV_{prfuel,lnd,er,t} \quad [81]$$

where:

$bech_{ghga,prfuel,br,er,t}$: emission factor for energy related GHG in households

$aerh_{prfuel,br,er,t}$: share of energy consumption with emissions in households

$A\_HCFVPV_{prfuel,lnd,er,t}$: household energy demand in the consumption matrix

The respective equation for the total demand of emission permits (firms and household) is given below:

$$DEMPEREU_{ghga,cc,t} = \sum_{er,br} \left(A\_EMMBR_{ghga,br,er,t} \cdot swclubbr_{ghga,br,er,cc,t}\right) + \sum_{er,fn} \left(A\_EMMHLND_{ghga,fn,er,t} \cdot swclubh_{ghga,fn,er,cc,t}\right) \quad [82]$$

where:

$swclubbr_{ghga,br,er,cc,t}$: switch for permit market participation for sectors

$swclubh_{ghga,fn,er,cc,t}$: switch for permit market participation for households

The market clearance of the emission permit market results in $P\_PCLUBAG_{cc,t}$ or else in the price of emission permits. The equations below describe the market clearance.

$$\sum_{ghg} supperfeu_{ghg,cc,t} \geq \sum_{ghg} DEMPEREU_{ghg,cc,t}$$ dual variable $P\_PCLUBAG_{cc,t}$ [83]

with:

$$P\_PCLUB_{ghg,cc,t} = P\_PCLUBAG_{cc,t} \quad [84]$$

where:
$supperfeu_{ghga,cc,t}$: supply of permits (user defined)

In the GEM-E3-CH the exogenous carbon tax (see [86], [88]) or the endogenous carbon price (see [85], [87]) have been assigned in the *TXENV(ghga,br,er,an)* variable for firms and in the *TXENVHDG(ghga,dg,er,an)* for households.

$$TXENV_{ghga,br,er,t} = \sum_{cc} P\_PCLUB_{ghga,cc,t} \cdot swclubbr_{ghga,br,er,cc,t} \quad [85]$$

$$TXENV_{ghga,br,er,t} = txem_{ghga,br,er,t} \cdot swtxexobr_{ghga,br,er,t} \quad [86]$$

$$TXENVHDG_{ghga,dg,er,t} = \sum_{cc} P\_PCLUB_{ghga,cc,t} \cdot swclubh_{ghga,dg,er,cc,t} \quad [87]$$

$$TXENVHDG_{ghga,dg,er,t} = txemhdg_{ghga,dg,er,t} \cdot swtxexoh_{ghga,dg,er,t} \quad [88]$$

The price signal in firms and households to abate emissions has been modelled differently in energy related (CO_2) and in process related (CO_2, CH_4, N_2O, HFC, PFC and SF_6) emissions.

In the energy related emissions, the carbon tax or the carbon price is added in the unit cost of energy which are used in firm's production [89] or in household's consumption [90].

$$P\_ENPR_{prfuel,br,er,t} = P\_IO_{prfuel,br,er,t} + \sum_{poem} \begin{matrix} TXENV_{poem,br,er,t} \cdot bec_{ghga,prfuel,br,er,t} \cdot \\ aer_{prfuel,br,er,t} \cdot eaf_{prfuel,br,er,t} \end{matrix} \quad [89]$$

$$P\_HCFV_{fn,er,t} = \sum_{pr} thcfv_{pr,fn,er,t} \cdot P\_HC_{pr,er,t} + \sum\nolimits_{poem,prfuel} \begin{matrix} TXENVDG_{poem,fn,er,t} \cdot bech_{poem,prfuel,fn,er,t} \cdot \\ aerh_{prfuel,fn,er,t} \cdot A\_HCFVPV_{prfuel,fn,er,t} \end{matrix} \Big/ A\_HCFV_{fn,er,t} \quad [90]$$

where:

$P\_ENPR_{prfuel,br,er,t}$: the unit cost of energy including abatement cost in the branch level

$P\_IO_{prfuel,br,er,t}$: the unit cost of energy excluding abatement cost in the branch level

$P\_HCFV_{lnd,er,t}$: the unit cost of consumption by purpose including abatement cost in households

$P\_HC_{pr,er,t}$: the unit cost of consumption goods excluding abatement cost in households

$A\_HCFVPV_{pruel,fn,er,t}$: the household energy demand for consumption by purpose (consumption matrix)

$A\_HCFV_{fn,er,t}$: the household demand for goods (consumption by purpose)

In the process related emissions, the carbon tax or the carbon price is added to the unit cost of production [91].

$$\begin{aligned} P\_PD_{br,er,t} = {} & P\_PDBSR_{br,er,t} - PSALE_{br,er,t} \\ & + \sum_{poabx} \Big(TXENV_{poghg,br,er,t} \cdot \left(1 - AAtot_{poghg,br,er,t}\right) + AAincr_{poghg,br,er,t} \\ & \cdot \sum\nolimits_{pr} tabcost_{poghg,pr,er,t} \cdot P\_IO_{pr,er,t} \cdot CABAVV_{poghg,br,er,t} \Big) \cdot mec_{poghg,br,er,t} \end{aligned} \quad [91]$$

where:

$P\_PDBSR_{br,er,t}$: the cost of production deriving from the firm's production function,

$PSALE_{br,er,t}$: the value of free permit endowment per unit of production,

$tabcost_{poghg,pr,er,t}$: is the share of energy component (combustible) of intermediate input,

$CABAVV_{poghg.br,er,t}$: the unit cost of abatement in process related emissions.

In the GEM-E3-CH, firms and households decide the level of GHG emissions abatement, AAincr(poghg,br,er,an), endogenously. For CO_2 energy related emissions the model provides a sufficiently large number of endogenous abatement options (i.e. fuel substitution, change in power mix, adoption of advanced and energy efficient technologies etc.) whereas for each process related GHG emissions abatement options are introduced in a reduced form (exogenously estimated marginal abatement cost curves).

The optimum level of abatement for a firm of process related GHG emissions is at the point where the marginal cost of reducing one tonne of CO_2 eq. equals the carbon tax/price.

$$MCGHG_{poghg,br,er,t} \leq TXENV_{poghg,br,er,t} \quad [92]$$

where:

$\mathrm{MCGHG}_{\mathrm{poghg,br,er,t}}$: the marginal abatement cost of process related greenhouse gas emissions.

The cost function which is used to determine the marginal abatement cost [93] is: $f(AA) = mac1 \cdot (e^{AA} - AA - 1)$.

$$MCGHG_{poghg,br,er,t} = \frac{WPI_t}{WPI_0} \cdot mac1_{er,poghg,br,an} \cdot (e^{AA_{poghg,br,er,an}} - 1) \quad [93]$$

where:

$\mathrm{mac1}_{\mathrm{er,poghg,br,t}}$: is a marginal abatement cost coefficient for process related GHG emissions

The unit cost of abatement which take into account the abatement option possibilities is given by the equation below.

$$CABAVV_{poghg,br,er,t} = \frac{WPI_t}{WPI_0} \cdot mac1_{er,poghg,br,t} \cdot \frac{\left(e^{AA_{poghg,br,er,t}} - AA_{poghg,br,er,t} - 1\right)}{\sum_{pr} tabcost_{poghg,pr,er,t} \cdot P\_IO_{pr,er,t}} \quad [94]$$

Demand for intermediate inputs to meet abatement purposes, $ABIOV_{pr,br,er,t}$ in the case of firms, is added directly to domestic demand for goods $A\_Y_{pr,er,t}$.

$$ABIOV_{pr,br,er,t} = \sum_{poghg} \left(tabcost_{poghg,pr,er,t} \cdot CABAVV_{poghg,br,er,t} \cdot AAincr_{poghg,br,er,t} \cdot mec_{poghg,br,er,t} \cdot A\_XD_{br,er,t}\right) \quad [95]$$

$$AAincr_{poghg,br,er,t} = AA_{poghg,br,er,t} - AAtot_{poghg,br,er,t-1} \cdot \left(1 - AAdepr_{poghg,t}\right)^{\Delta t} \quad [96]$$

$$AAtot_{poghg,br,er,t} = AAincr_{poghg,br,er,t} + AAtot_{poghg,br,er,t-1} \cdot \left(1 - AAdepr_{poghg,t}\right)^{\Delta t} \quad [97]$$

where:

$AAincr_{poghg,br,er,t}$: the incremental degree of abatement in the branch level

$AAdepr_{poghg,br,er,t}$: the depreciation of the abatement in the branch level

$AAtot_{poghg,br,er,t}$: the degree of abatement in the branch level

4.11 Macroeconomic closure

Each sector (firms, households, government, world) has savings that are used to finance investments. At the global level total savings should be equal to total investments.

$$\sum_{se,r} V\_SAVE_{se,r,t} = \sum_{se,r} V\_INV_{se,r,t}$$

This equation determines a global interest rate, set so as to equalise global investment with global surpluses. In particular, the dual variable of this equation, the $rltlrword_t$, is used to increase/decrease the household consumption and thus decrease/increase the household saving so as the equation to be met.

4.12 Switches

Several GEM-E3-CH modules come with alternative features and assumptions. The choice of which of the latter will be included in the model is left to the modeler and depends on the policies under study. Indicative are the environmental module (alternative options include the introduction of exogenous carbon tax, introduction of emission reduction targets, etc.) and the budget balancing mechanisms available in GEM-E3-CH (these include endogenous determination of interest rates, setting of constant budget deficit/surplus as share of GDP, etc.). The GEM-E3-CH model is fitted with switch parameters which enable the activation of specific equations in the model linked to the different modules and modelling assumptions. Equations are activated if the switch parameter linked to each equation takes the respective value (i.e., 1). In contrast the equations are deactivated and do not enter the model if the switches linked to the latter take the value of zero (0). Table 9 summarizes the switches found in the GEM-E3-CH model and the associated model option.

Table 9: Switch parameters and related features in GEM-E3-CH model

"switch" parameter	Description
Environmental Switches	
SWTXEXOBR(ghga,br,er,t)	Introduction of exogenous carbon tax (txem) on firms, for selective pollutants (ghga), in activities (br), countries (er) and time (t).
SWTXEXOH(ghga,fn,er,t)	Introduction of exogenous carbon tax (TXEMHDG) on households, for selective pollutants (ghga), in consumption categories (fn), countries (er) and time (t).
SWCLUBBR(ghga,br,er,cct,t)	Introduction of an emission reduction target on a branch level (br) for the region (er) which belong on the club (cct) for selective pollutants (ghga), in activities (br), countries (er) and time (t).
SWCLUBH(ghga,fn,er,cct,t)	Introduction of an emission reduction target on households for the region (er) which belong on the club (cct), for selective pollutants (ghga), in consumption categories (fn), countries (er) and time (t).

SWONPOR(ghga,pr,er,t)	Introduction of allocation of emission permits with grandfathering (free allowances) on firms for selective pollutants (ghga), in activities (br), countries (er) and time (t).
SWONPORH(ghga,fn,er,t)	Introduction of allocation of emission permits with grandfathering (free allowances) on households for selective pollutants (ghga), in consumption categories (fn), countries (er) and time (t).
SWPRIMALLOC(ghga,br,er,t)	Introduction of the method to be used to allocate the emissions permits with grandfathering (free allowances) on firms for selective pollutants (ghga), in activities (br), countries (er) and time (t).
SWPRIMALLOCH(ghga,fn,er,t)	Introduction of the method to be used to allocate the emissions permits with grandfathering (free allowances) on households for selective pollutants (ghga), in consumption categories (fn), countries (er) and time (t).
SWUPR(pr,er,t)	Enables the use of revenues from free emission permits. If zero then revenues from free permits reduce the unit cost of production of each branch (pr), country (er) and time (t) else if one increase the firms' capital income.
Budget balancing Instruments	
SWONCA(er,t)	Interest rate endogenously estimated so as the current account deficit/surplus as a percentage of GDP, expressed in current prices, remains unchanged in all scenarios. In that way, the country is not allowed to increase its borrowing in order to comply with the environmental policy.
SWONCAEU(er,t)	Interest rate endogenously estimated so as the current account deficit/surplus as a percentage of GDP, expressed in current prices, for the EU zone remains unchanged in all scenarios.
recscheme(recopt,er,t)	Activation of a constraint to keep the government's deficit/surplus as a percentage of GDP unchanged in all scenarios. This option can be used for recycling to the economy the extra government revenues e.g. from permit sales in case of auctioning. The user selects the share of participation of each recycling option in order to meet the Government Budget target. A mix of four different options can be selected: • the dual variable (TAX_REC_HT) is used as a lumb sum transfer which increase the household income. • the dual variable (TAX_REC_SS) is used as a rate which reduce social security contributions. • the dual variable (TAX_REC_IT) is used as a tax which reduce the general taxation. • the dual variable (TAX_REC_PS) is used as a subsidy which reduce the unit cost of production.

SWGC(er,t)	Activation of endogenous/exogenous calculation of government consumption. If “0” the government consumption is equal to the exogenous parameter gctv(er,stime). If “1” the government consumption is a constant share of GDP.
Other switches	
SWOKM(er,t)	Introduction of capital mobility choice in capital market. If “0” there is no capital mobility. If “1” there is a full capital within country across sectors.
SWXDIOTEC	Activation of endogenous/exogenous calculation of power mix share. If “0” power mix shares are set exogenously by the user. If “1” power mix shares are calculated endogenously through a Weibull function.

5 Link of GEM-E3-CH with the STEM Energy Model

The GEM-E3-CH model can be linked with the STEM energy model in the following main sectors/topics:

- Power
- Residential
- Energy mix (transport, commercial, industry)
- Subsidies

STEM Energy Model considers a more detailed representation of energy system, and its’ results can be used as input for GEM-E3-CH model. GEM-E3-CH model receives key information from STEM regarding the transformation of the energy system (i.e., investments, energy efficiency expenditures, energy mix, subsidies) and quantifies the macroeconomic impacts in the economy.

5.1 Input from STEM Energy Model

The main input required by the STEM model is presented in the table below:

Table 10: List of parameters provided by the STEM Energy Model

Parameter	Description
TER-FEC	Final energy consumption in Agriculture and Commercial sector
IND-FEC	Final energy consumption in Industrial sector (Food, Paper, Chemicals, Cement and other industries)
RSD-FEC	Final energy consumption in Residential sector
TRN-FEC	Final energy consumption in Transport sector by type of vehicle
TRN-Expenditures	Purchases of vehicles in the Transport sector
RSD-Efficiency-Expenditures	Energy efficiency expenditures in Residential sector
IND-Efficiency-Expenditures	Energy efficiency expenditures in Industrial sector

POW_STEM_%scen_name%**PG** POW_STEM_%scen_name%**INV**	Power mix and investment by power generation technology in the respective scenario.

5.2 Power Generation

In GEM-E3 the parameter related to the power generation mix of Switzerland is given by:

$$dio_{prtec,pr\_ele,r,t} = \frac{POW\_STEM\_Baseline_{PG,prtec,t}}{\sum_{prtecc,} POW\_STEM\_Baseline_{PG,prtecc,t}} \quad [98]$$

where dio: the shares parameter for the power generation and $POW\_STEM\_Baseline_{PG,prtec,t}$: the generation for Electricity and Heat in TJ from STEM. Similarly, in the scenario the corresponding $POW\_STEM\_SCEN_{PG,prtec,t}$ is used to compute the dio shares.

The associated investments for the power generation technologies are computed in $POW\_STEM\_Baseline_{inv,prtec,t}$ for the reference scenario and the $POW\_STEM\_SCEN_{inv,prtec,t}$ in the scenario and are assigned to $exoPG\_INVMW_{prtec,r,t}$. The $sw\_PGINV_{prtec,r,t}$ should be activated for exogenous investments in power generation technologies.

$$exoPG\_INVMW_{prtec,r,t} = POW\_STEM\_Baseline_{inv,pow,prtec,t} \quad [99]$$

where $exoPG\_INVMW_{prtec,r,t}$: the exogenous investments in GEM-E3-CH model by power generation technology and $POW\_STEM\_Baseline_{inv,pow,prtec,t}$: Investments per power generation technology in thousands of euro from STEM.

5.3 Energy mix

Based on the final energy consumption from the STEM Energy Model the value shares for energy products are computed. These value shares are used to change the corresponding shares in the CES nesting scheme. The model parameters that correspond to the value share of electricity is the $theta\_dele$, for the non-electricity energy products the $theta\_de$ and by energy product the $theta\_depr$. For each sector the corresponding final energy consumption shares are computed from the STEM Energy Model and assigned to the corresponding model parameter.

For Agricultural Sector,

$$theta\_dele_{agr,t} = FEC\_Shares\_TERFEC_{dele,agr,t}$$

$$theta\_de_{agr,t} = FEC\_Shares\_TERFEC_{de,agr,t}$$

$$theta\_depr_{prfuel,agr,t} = \frac{FEC\_Shares\_TERFEC_{prfuel,agr,t}}{\sum_{brfuel} FEC\_Shares\_TERFEC_{brfuel,agr,t}}$$

where

$theta\_dele_{agr,t}$: Value share of electricity to total energy

$theta\_de_{agr,t}$: Value share of total non-electricity energy products to total energy

$theta\_depr_{prfuel,agr,t}$: Value share of non-electricity energy products to total non-electricity energy products.

$FEC\_Shares\_TERFEC_{dele,agr,t}$: Value shares in Final Energy Consumption as computed from STEM in the reference scenario for the agriculture and commercial sectors.

In the scenario the $SCEN\_FEC\_Shares\_TERFEC_{dele,agr,t}$ is used: Value shares in Final Energy Consumption as computed from STEM.

Similarly, for Commercial Sector,

$$theta\_dele_{comm,t} = FEC\_Shares\_TERFEC_{dele,comm,t}$$

$$theta\_de_{comm,t} = FEC\_Shares\_TERFEC_{de,comm,t}$$

$$theta\_depr_{prfuel,comm,t} = \frac{FEC\_Shares\_TERFEC_{prfuel,comm,t}}{\sum_{brfuel} FEC\_Shares\_TERFEC_{brfuel,comm,t}}$$

where

$FEC\_Shares\_Commercial_{dele,comm,t}$: Value shares in Final Energy Consumption as computed from STEM in the reference scenario.

In the scenario the $SCEN\_FEC\_Shares\_Commercial_{dele,comm,t}$ is used: Value shares in Final Energy Consumption as computed from STEM.

For Industry Sector,

$$theta\_dele_{ind,t} = FEC\_Shares\_Industry_{dele,ind,t}$$

$$theta\_de_{ind,t} = FEC\_Shares\_Industry_{de,ind,t}$$

$$theta\_depr_{prfuel,ind,t} = \frac{FEC\_Shares\_Industry_{prfuel,ind,t}}{\sum_{brfuel} FEC\_Shares\_Industry_{brfuel,ind,t}}$$

where

$FEC\_Shares\_Industry_{dele,ind,t}$: Value shares in Final Energy Consumption as computed from STEM in the reference scenario.

In the scenario the $SCEN\_FEC\_Shares\_Industry_{dele,ind,t}$ is used: Value shares in Final Energy Consumption as computed from STEM.

For Transport Sector,

$$theta\_dele_{tra,t} = FEC\_Shares\_Transport_{dele,tra,t}$$

$$theta\_de_{tra,t} = FEC\_Shares\_Transport_{de,tra,t}$$

$$theta\_depr_{prfuel,tra,t} = \frac{FEC\_Shares\_Transport_{prfuel,tra,t}}{\sum_{brfuel} FEC\_Shares\_Transport_{brfuel,tra,t}}$$

where

$FEC\_Shares\_Transport_{dele,tra,t}$: Value shares in Final Energy Consumption as computed from STEM in the reference scenario.

In the scenario the $SCEN\_FEC\_Shares\_Transport_{dele,tra,t}$ is used: Value shares in Final Energy Consumption as computed from STEM.

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7 Annex I: Elasticities

7.1 Elasticity of substitution between Crude Oil Reserves & KLEM bundle

This elasticity is zero for the refineries.

7.2 Elasticity of substitution between KLE and MA

	CHN	USA	CHE	EU27	ROW
AGR01	0.2	0.2	0.2	0.2	0.2
ENE01	0.2	0.2	0.2	0.2	0.2
ENE02	0.2	0.2	0.2	0.2	0.2
ENE03	0.2	0.2	0.2	0.2	0.2
ENE04	0.2	0.2	0.2	0.2	0.2
ENE05	0.2	0.2	0.2	0.2	0.2
ENE06	0.2	0.2	0.2	0.2	0.2
ENE07	0.2	0.2	0.2	0.2	0.2
ENE08	0.2	0.2	0.2	0.2	0.2
ENE09	0.2	0.2	0.2	0.2	0.2
IND01	0.2	0.2	0.2	0.2	0.2
IND02	0.2	0.2	0.2	0.2	0.2
IND03	0.2	0.2	0.2	0.2	0.2
IND04	0.2	0.2	0.2	0.2	0.2
IND05	0.2	0.2	0.2	0.2	0.2
IND06	0.2	0.2	0.2	0.2	0.2
IND07	0.2	0.2	0.2	0.2	0.2
IND08	0.2	0.2	0.2	0.2	0.2
IND09	0.2	0.2	0.2	0.2	0.2
IND10	0.2	0.2	0.2	0.2	0.2
IND11	0.2	0.2	0.2	0.2	0.2
IND12	0.2	0.2	0.2	0.2	0.2
IND13	0.2	0.2	0.2	0.2	0.2
IND14	0.2	0.2	0.2	0.2	0.2
IND15	0.2	0.2	0.2	0.2	0.2
IND16	0.2	0.2	0.2	0.2	0.2
IND17	0.2	0.2	0.2	0.2	0.2
IND18	0.2	0.2	0.2	0.2	0.2
IND19	0.2	0.2	0.2	0.2	0.2
IND20	0.2	0.2	0.2	0.2	0.2
IND21	0.2	0.2	0.2	0.2	0.2
IND22	0.2	0.2	0.2	0.2	0.2
IND23	0.2	0.2	0.2	0.2	0.2
IND24	0.2	0.2	0.2	0.2	0.2
TRA01	0.2	0.2	0.2	0.2	0.2

TRA02	0.2	0.2	0.2	0.2	0.2
TRA03	0.2	0.2	0.2	0.2	0.2
TRA04	0.2	0.2	0.2	0.2	0.2
SRV01	0.2	0.2	0.2	0.2	0.2
SRV02	0.2	0.2	0.2	0.2	0.2
SRV03	0.2	0.2	0.2	0.2	0.2

7.3 Elasticity of substitution between KL and ENG

	CHN	USA	CHE	EU27	ROW
AGR01	0.25	0.25	0.25	0.25	0.25
ENE01	0.25	0.25	0.25	0.25	0.25
ENE02	0.25	0.25	0.25	0.25	0.25
ENE03	0.25	0.25	0.25	0.25	0.25
ENE04	0.25	0.25	0.25	0.25	0.25
ENE05	0.25	0.25	0.25	0.25	0.25
ENE06	0.25	0.25	0.25	0.25	0.25
ENE07	0.25	0.25	0.25	0.25	0.25
ENE08	0.25	0.25	0.25	0.25	0.25
ENE09	0.25	0.25	0.25	0.25	0.25
IND01	0.25	0.25	0.25	0.25	0.25
IND02	0.25	0.25	0.25	0.25	0.25
IND03	0.25	0.25	0.25	0.25	0.25
IND04	0.25	0.25	0.25	0.25	0.25
IND05	0.25	0.25	0.25	0.25	0.25
IND06	0.25	0.25	0.25	0.25	0.25
IND07	0.25	0.25	0.25	0.25	0.25
IND08	0.25	0.25	0.25	0.25	0.25
IND09	0.25	0.25	0.25	0.25	0.25
IND10	0.25	0.25	0.25	0.25	0.25
IND11	0.25	0.25	0.25	0.25	0.25
IND12	0.25	0.25	0.25	0.25	0.25
IND13	0.25	0.25	0.25	0.25	0.25
IND14	0.25	0.25	0.25	0.25	0.25
IND15	0.25	0.25	0.25	0.25	0.25
IND16	0.25	0.25	0.25	0.25	0.25
IND17	0.25	0.25	0.25	0.25	0.25
IND18	0.25	0.25	0.25	0.25	0.25
IND19	0.25	0.25	0.25	0.25	0.25
IND20	0.25	0.25	0.25	0.25	0.25
IND21	0.25	0.25	0.25	0.25	0.25
IND22	0.25	0.25	0.25	0.25	0.25

IND23	0.25	0.25	0.25	0.25	0.25
IND24	0.25	0.25	0.25	0.25	0.25
TRA01	0.25	0.25	0.25	0.25	0.25
TRA02	0.25	0.25	0.25	0.25	0.25
TRA03	0.25	0.25	0.25	0.25	0.25
TRA04	0.25	0.25	0.25	0.25	0.25
SRV01	0.25	0.25	0.25	0.25	0.25
SRV02	0.25	0.25	0.25	0.25	0.25
SRV03	0.25	0.25	0.25	0.25	0.25

7.4 Elasticity of substitution between intermediate goods

	CHN	USA	CHE	EU27	ROW
AGR01	0.25	0.25	0.25	0.25	0.25
ENE01	0.25	0.25	0.25	0.25	0.25
ENE02	0.25	0.25	0.25	0.25	0.25
ENE03	0.25	0.25	0.25	0.25	0.25
ENE04	0.25	0.25	0.25	0.25	0.25
ENE05	0.25	0.25	0.25	0.25	0.25
ENE06	0.25	0.25	0.25	0.25	0.25
ENE07	0.25	0.25	0.25	0.25	0.25
ENE08	0.25	0.25	0.25	0.25	0.25
ENE09	0.25	0.25	0.25	0.25	0.25
IND01	0.25	0.25	0.25	0.25	0.25
IND02	0.25	0.25	0.25	0.25	0.25
IND03	0.25	0.25	0.25	0.25	0.25
IND04	0.25	0.25	0.25	0.25	0.25
IND05	0.25	0.25	0.25	0.25	0.25
IND06	0.25	0.25	0.25	0.25	0.25
IND07	0.25	0.25	0.25	0.25	0.25
IND08	0.25	0.25	0.25	0.25	0.25
IND09	0.25	0.25	0.25	0.25	0.25
IND10	0.25	0.25	0.25	0.25	0.25
IND11	0.25	0.25	0.25	0.25	0.25
IND12	0.25	0.25	0.25	0.25	0.25
IND13	0.25	0.25	0.25	0.25	0.25
IND14	0.25	0.25	0.25	0.25	0.25
IND15	0.25	0.25	0.25	0.25	0.25
IND16	0.25	0.25	0.25	0.25	0.25
IND17	0.25	0.25	0.25	0.25	0.25
IND18	0.25	0.25	0.25	0.25	0.25
IND19	0.25	0.25	0.25	0.25	0.25

IND20	0.25	0.25	0.25	0.25	0.25
IND21	0.25	0.25	0.25	0.25	0.25
IND22	0.25	0.25	0.25	0.25	0.25
IND23	0.25	0.25	0.25	0.25	0.25
IND24	0.25	0.25	0.25	0.25	0.25
TRA01	0.25	0.25	0.25	0.25	0.25
TRA02	0.25	0.25	0.25	0.25	0.25
TRA03	0.25	0.25	0.25	0.25	0.25
TRA04	0.25	0.25	0.25	0.25	0.25
SRV01	0.25	0.25	0.25	0.25	0.25
SRV02	0.25	0.25	0.25	0.25	0.25
SRV03	0.25	0.25	0.25	0.25	0.25

7.5 Elasticity of substitution between (Capital and Skilled) with Unskilled Labour

	CHN	USA	CHE	EU27	ROW
AGR01	0.235	0.235	0.235	0.235	0.235
ENE01	0.200	0.200	0.200	0.200	0.200
ENE02	0.200	0.200	0.200	0.200	0.200
ENE03	1.260	1.260	1.260	1.260	1.260
ENE04	1.260	1.260	1.260	1.260	1.260
ENE05	1.260	1.260	1.260	1.260	1.260
ENE06	0.200	0.200	0.200	0.200	0.200
ENE07	1.260	1.260	1.260	1.260	1.260
ENE08	1.260	1.260	1.260	1.260	1.260
ENE09	1.260	1.260	1.260	1.260	1.260
IND01	1.260	1.260	1.260	1.260	1.260
IND02	1.260	1.260	1.260	1.260	1.260
IND03	1.260	1.260	1.260	1.260	1.260
IND04	1.260	1.260	1.260	1.260	1.260
IND05	1.260	1.260	1.260	1.260	1.260
IND06	1.260	1.260	1.260	1.260	1.260
IND07	0.730	0.730	0.730	0.730	0.730
IND08	1.260	1.260	1.260	1.260	1.260
IND09	1.260	1.260	1.260	1.260	1.260
IND10	1.260	1.260	1.260	1.260	1.260
IND11	1.260	1.260	1.260	1.260	1.260
IND12	1.260	1.260	1.260	1.260	1.260
IND13	1.120	1.120	1.120	1.120	1.120
IND14	1.260	1.260	1.260	1.260	1.260
IND15	1.260	1.260	1.260	1.260	1.260
IND16	1.400	1.400	1.400	1.400	1.400

IND17	1.260	1.260	1.260	1.260	1.260
IND18	1.260	1.260	1.260	1.260	1.260
IND19	1.260	1.260	1.260	1.260	1.260
IND20	1.260	1.260	1.260	1.260	1.260
IND21	1.260	1.260	1.260	1.260	1.260
IND22	1.260	1.260	1.260	1.260	1.260
IND23	1.260	1.260	1.260	1.260	1.260
IND24	1.260	1.260	1.260	1.260	1.260
TRA01	1.680	1.680	1.680	1.680	1.680
TRA02	1.680	1.680	1.680	1.680	1.680
TRA03	1.680	1.680	1.680	1.680	1.680
TRA04	1.680	1.680	1.680	1.680	1.680
SRV01	1.260	1.260	1.260	1.260	1.260
SRV02	1.260	1.260	1.260	1.260	1.260
SRV03	1.260	1.260	1.260	1.260	1.260

7.6 Elasticity of substitution between energy products and electricity

	CHN	USA	CHE	EU27	ROW
AGR01	0.9	0.9	0.9	0.9	0.9
ENE01	0.9	0.9	0.9	0.9	0.9
ENE02	0.9	0.9	0.9	0.9	0.9
ENE03	0.9	0.9	0.9	0.9	0.9
ENE04	0.9	0.9	0.9	0.9	0.9
ENE05	0.9	0.9	0.9	0.9	0.9
ENE06	0.9	0.9	0.9	0.9	0.9
ENE07	0.9	0.9	0.9	0.9	0.9
ENE08	0.9	0.9	0.9	0.9	0.9
ENE09	0.9	0.9	0.9	0.9	0.9
IND01	0.9	0.9	0.9	0.9	0.9
IND02	0.9	0.9	0.9	0.9	0.9
IND03	0.9	0.9	0.9	0.9	0.9
IND04	0.9	0.9	0.9	0.9	0.9
IND05	0.9	0.9	0.9	0.9	0.9
IND06	0.9	0.9	0.9	0.9	0.9
IND07	0.9	0.9	0.9	0.9	0.9
IND08	0.9	0.9	0.9	0.9	0.9
IND09	0.9	0.9	0.9	0.9	0.9
IND10	0.9	0.9	0.9	0.9	0.9
IND11	0.9	0.9	0.9	0.9	0.9
IND12	0.9	0.9	0.9	0.9	0.9
IND13	0.9	0.9	0.9	0.9	0.9

IND14	0.9	0.9	0.9	0.9	0.9
IND15	0.9	0.9	0.9	0.9	0.9
IND16	0.9	0.9	0.9	0.9	0.9
IND17	0.9	0.9	0.9	0.9	0.9
IND18	0.9	0.9	0.9	0.9	0.9
IND19	0.9	0.9	0.9	0.9	0.9
IND20	0.9	0.9	0.9	0.9	0.9
IND21	0.9	0.9	0.9	0.9	0.9
IND22	0.9	0.9	0.9	0.9	0.9
IND23	0.9	0.9	0.9	0.9	0.9
IND24	0.9	0.9	0.9	0.9	0.9
TRA01	0.9	0.9	0.9	0.9	0.9
TRA02	0.9	0.9	0.9	0.9	0.9
TRA03	0.9	0.9	0.9	0.9	0.9
TRA04	0.9	0.9	0.9	0.9	0.9
SRV01	0.9	0.9	0.9	0.9	0.9
SRV02	0.9	0.9	0.9	0.9	0.9
SRV03	0.9	0.9	0.9	0.9	0.9

7.7 Elasticity of substitution between energy products

	CHN	USA	CHE	EU27	ROW
AGR01	0.9	0.9	0.9	0.9	0.9
ENE01	0.9	0.9	0.9	0.9	0.9
ENE02	0.9	0.9	0.9	0.9	0.9
ENE03	0.9	0.9	0.9	0.9	0.9
ENE04	0.9	0.9	0.9	0.9	0.9
ENE05	0.9	0.9	0.9	0.9	0.9
ENE06	0.9	0.9	0.9	0.9	0.9
ENE07	0.9	0.9	0.9	0.9	0.9
ENE08	0.9	0.9	0.9	0.9	0.9
ENE09	0.9	0.9	0.9	0.9	0.9
IND01	0.9	0.9	0.9	0.9	0.9
IND02	0.9	0.9	0.9	0.9	0.9
IND03	0.9	0.9	0.9	0.9	0.9
IND04	0.9	0.9	0.9	0.9	0.9
IND05	0.9	0.9	0.9	0.9	0.9
IND06	0.9	0.9	0.9	0.9	0.9
IND07	0.9	0.9	0.9	0.9	0.9
IND08	0.9	0.9	0.9	0.9	0.9
IND09	0.9	0.9	0.9	0.9	0.9
IND10	0.9	0.9	0.9	0.9	0.9

IND11	0.9	0.9	0.9	0.9	0.9
IND12	0.9	0.9	0.9	0.9	0.9
IND13	0.9	0.9	0.9	0.9	0.9
IND14	0.9	0.9	0.9	0.9	0.9
IND15	0.9	0.9	0.9	0.9	0.9
IND16	0.9	0.9	0.9	0.9	0.9
IND17	0.9	0.9	0.9	0.9	0.9
IND18	0.9	0.9	0.9	0.9	0.9
IND19	0.9	0.9	0.9	0.9	0.9
IND20	0.9	0.9	0.9	0.9	0.9
IND21	0.9	0.9	0.9	0.9	0.9
IND22	0.9	0.9	0.9	0.9	0.9
IND23	0.9	0.9	0.9	0.9	0.9
IND24	0.9	0.9	0.9	0.9	0.9
TRA01	0.9	0.9	0.9	0.9	0.9
TRA02	0.9	0.9	0.9	0.9	0.9
TRA03	0.9	0.9	0.9	0.9	0.9
TRA04	0.9	0.9	0.9	0.9	0.9
SRV01	0.9	0.9	0.9	0.9	0.9
SRV02	0.9	0.9	0.9	0.9	0.9
SRV03	0.9	0.9	0.9	0.9	0.9

7.8 Elasticity of substitution between Capital and Skilled Labour

	CHN	USA	CHE	EU27	ROW
AGR01	0.25	0.25	0.25	0.25	0.25
ENE01	0.21	0.21	0.21	0.21	0.21
ENE02	0.21	0.21	0.21	0.21	0.21
ENE03	1.32	1.32	1.32	1.32	1.32
ENE04	1.32	1.32	1.32	1.32	1.32
ENE05	1.32	1.32	1.32	1.32	1.32
ENE06	0.21	0.21	0.21	0.21	0.21
ENE07	1.32	1.32	1.32	1.32	1.32
ENE08	1.32	1.32	1.32	1.32	1.32
ENE09	1.32	1.32	1.32	1.32	1.32
IND01	1.32	1.32	1.32	1.32	1.32
IND02	1.32	1.32	1.32	1.32	1.32
IND03	1.32	1.32	1.32	1.32	1.32
IND04	1.32	1.32	1.32	1.32	1.32
IND05	1.32	1.32	1.32	1.32	1.32
IND06	1.32	1.32	1.32	1.32	1.32
IND07	0.77	0.77	0.77	0.77	0.77

IND08	1.32	1.32	1.32	1.32	1.32
IND09	1.32	1.32	1.32	1.32	1.32
IND10	1.32	1.32	1.32	1.32	1.32
IND11	1.32	1.32	1.32	1.32	1.32
IND12	1.32	1.32	1.32	1.32	1.32
IND13	1.18	1.18	1.18	1.18	1.18
IND14	1.32	1.32	1.32	1.32	1.32
IND15	1.32	1.32	1.32	1.32	1.32
IND16	1.47	1.47	1.47	1.47	1.47
IND17	1.32	1.32	1.32	1.32	1.32
IND18	1.32	1.32	1.32	1.32	1.32
IND19	1.32	1.32	1.32	1.32	1.32
IND20	1.32	1.32	1.32	1.32	1.32
IND21	1.32	1.32	1.32	1.32	1.32
IND22	1.32	1.32	1.32	1.32	1.32
IND23	1.32	1.32	1.32	1.32	1.32
IND24	1.32	1.32	1.32	1.32	1.32
TRA01	1.76	1.76	1.76	1.76	1.76
TRA02	1.76	1.76	1.76	1.76	1.76
TRA03	1.76	1.76	1.76	1.76	1.76
TRA04	1.76	1.76	1.76	1.76	1.76
SRV01	1.32	1.32	1.32	1.32	1.32
SRV02	1.32	1.32	1.32	1.32	1.32
SRV03	1.32	1.32	1.32	1.32	1.32

7.9 Elasticity of substitution for investment

	CHN	USA	CHE	EU27	ROW
AGR01	0.5	0.5	0.5	0.5	0.5
ENE01	0.5	0.5	0.5	0.5	0.5
ENE02	0.5	0.5	0.5	0.5	0.5
ENE03	0.5	0.5	0.5	0.5	0.5
ENE04	0.5	0.5	0.5	0.5	0.5
ENE05	0.5	0.5	0.5	0.5	0.5
ENE06	0.5	0.5	0.5	0.5	0.5
ENE07	0.5	0.5	0.5	0.5	0.5
ENE08	0.5	0.5	0.5	0.5	0.5
ENE09	0.5	0.5	0.5	0.5	0.5
IND01	0.5	0.5	0.5	0.5	0.5
IND02	0.5	0.5	0.5	0.5	0.5
IND03	0.5	0.5	0.5	0.5	0.5
IND04	0.5	0.5	0.5	0.5	0.5

IND05	0.5	0.5	0.5	0.5	0.5
IND06	0.5	0.5	0.5	0.5	0.5
IND07	0.5	0.5	0.5	0.5	0.5
IND08	0.5	0.5	0.5	0.5	0.5
IND09	0.5	0.5	0.5	0.5	0.5
IND10	0.5	0.5	0.5	0.5	0.5
IND11	0.5	0.5	0.5	0.5	0.5
IND12	0.5	0.5	0.5	0.5	0.5
IND13	0.5	0.5	0.5	0.5	0.5
IND14	0.5	0.5	0.5	0.5	0.5
IND15	0.5	0.5	0.5	0.5	0.5
IND16	0.5	0.5	0.5	0.5	0.5
IND17	0.5	0.5	0.5	0.5	0.5
IND18	0.5	0.5	0.5	0.5	0.5
IND19	0.5	0.5	0.5	0.5	0.5
IND20	0.5	0.5	0.5	0.5	0.5
IND21	0.5	0.5	0.5	0.5	0.5
IND22	0.5	0.5	0.5	0.5	0.5
IND23	0.5	0.5	0.5	0.5	0.5
IND24	0.5	0.5	0.5	0.5	0.5
TRA01	0.5	0.5	0.5	0.5	0.5
TRA02	0.5	0.5	0.5	0.5	0.5
TRA03	0.5	0.5	0.5	0.5	0.5
TRA04	0.5	0.5	0.5	0.5	0.5
SRV01	0.5	0.5	0.5	0.5	0.5
SRV02	0.5	0.5	0.5	0.5	0.5
SRV03	0.5	0.5	0.5	0.5	0.5
PGT01	0.5	0.5	0.5	0.5	0.5
PGT02	0.5	0.5	0.5	0.5	0.5
PGT03	0.5	0.5	0.5	0.5	0.5
PGT04	0.5	0.5	0.5	0.5	0.5
PGT05	0.5	0.5	0.5	0.5	0.5
PGT06	0.5	0.5	0.5	0.5	0.5
PGT07	0.5	0.5	0.5	0.5	0.5
PGT08	0.5	0.5	0.5	0.5	0.5
PGT09	0.5	0.5	0.5	0.5	0.5
PGT10	0.5	0.5	0.5	0.5	0.5
PGT11	0.5	0.5	0.5	0.5	0.5
PGT12	0.5	0.5	0.5	0.5	0.5

7.10 Elasticity of substitution between MAEN and KL in production of resource sector

	CHN	USA	CHE	EU27	ROW
ENE02	0.2	0.2	0.2	0.2	0.2

7.11 Elasticity of substitution between int goods in production of resource sector

	CHN	USA	CHE	EU27	ROW
ENE02	0.25	0.25	0.25	0.25	0.25

7.12 Elasticity of substitution between K and L in production the resource sector

	CHN	USA	CHE	EU27	ROW
ENE02	0.2	0.2	0.2	0.2	0.2

7.13 Substitution elasticity in Armington between domestic and imports

	CHN	USA	CHE	EU27	ROW
AGR01	3.03	3.03	3.03	3.03	3.03
ENE01	1.05	1.05	1.05	1.05	1.05
ENE02	1.05	1.05	1.05	1.05	1.05
ENE03	1.05	1.05	1.05	1.05	1.05
ENE04	1.05	1.05	1.05	1.05	1.05
ENE05	2.80	2.80	2.80	2.80	2.80
ENE06	2.50	2.50	2.50	2.50	2.50
ENE07	1.05	1.05	1.05	1.05	1.05
ENE08	1.05	1.05	1.05	1.05	1.05
ENE09	1.05	1.05	1.05	1.05	1.05
IND01	4.20	4.20	4.20	4.20	4.20
IND02	3.75	3.75	3.75	3.75	3.75
IND03	3.30	3.30	3.30	3.30	3.30
IND04	3.30	3.30	3.30	3.30	3.30
IND05	3.30	3.30	3.30	3.30	3.30
IND06	2.95	2.95	2.95	2.95	2.95
IND07	1.90	1.90	1.90	1.90	1.90
IND08	4.40	4.40	4.40	4.40	4.40
IND09	4.40	4.40	4.40	4.40	4.40
IND10	4.05	4.05	4.05	4.05	4.05
IND11	3.55	3.55	3.55	3.55	3.55
IND12	3.75	3.75	3.75	3.75	3.75
IND13	2.96	2.96	2.96	2.96	2.96
IND14	3.83	3.83	3.83	3.83	3.83

IND15	3.40	3.40	3.40	3.40	3.40
IND16	1.90	1.90	1.90	1.90	1.90
IND17	4.40	4.40	4.40	4.40	4.40
IND18	3.55	3.55	3.55	3.55	3.55
IND19	3.75	3.75	3.75	3.75	3.75
IND20	3.75	3.75	3.75	3.75	3.75
IND21	4.05	4.05	4.05	4.05	4.05
IND22	4.05	4.05	4.05	4.05	4.05
IND23	3.75	3.75	3.75	3.75	3.75
IND24	3.75	3.75	3.75	3.75	3.75
TRA01	1.90	1.90	1.90	1.90	1.90
TRA02	1.90	1.90	1.90	1.90	1.90
TRA03	1.90	1.90	1.90	1.90	1.90
TRA04	1.90	1.90	1.90	1.90	1.90
SRV01	2.08	2.08	2.08	2.08	2.08
SRV02	1.90	1.90	1.90	1.90	1.90
SRV03	1.90	1.90	1.90	1.90	1.90

7.14 Substitution elasticity in Armington among countries

	CHN	USA	CHE	EU27	ROW
AGR01	6.07	6.07	6.07	6.07	6.07
ENE01	2.10	2.10	2.10	2.10	2.10
ENE02	2.10	2.10	2.10	2.10	2.10
ENE03	2.10	2.10	2.10	2.10	2.10
ENE04	2.10	2.10	2.10	2.10	2.10
ENE05	5.60	5.60	5.60	5.60	5.60
ENE06	5.00	5.00	5.00	5.00	5.00
ENE07	2.10	2.10	2.10	2.10	2.10
ENE08	2.10	2.10	2.10	2.10	2.10
ENE09	2.10	2.10	2.10	2.10	2.10
IND01	8.40	8.40	8.40	8.40	8.40
IND02	7.50	7.50	7.50	7.50	7.50
IND03	6.60	6.60	6.60	6.60	6.60
IND04	6.60	6.60	6.60	6.60	6.60
IND05	6.60	6.60	6.60	6.60	6.60
IND06	5.90	5.90	5.90	5.90	5.90
IND07	3.80	3.80	3.80	3.80	3.80
IND08	8.80	8.80	8.80	8.80	8.80
IND09	8.80	8.80	8.80	8.80	8.80
IND10	8.10	8.10	8.10	8.10	8.10
IND11	7.10	7.10	7.10	7.10	7.10

IND12	7.50	7.50	7.50	7.50	7.50
IND13	5.91	5.91	5.91	5.91	5.91
IND14	7.67	7.67	7.67	7.67	7.67
IND15	6.80	6.80	6.80	6.80	6.80
IND16	3.80	3.80	3.80	3.80	3.80
IND17	8.80	8.80	8.80	8.80	8.80
IND18	7.10	7.10	7.10	7.10	7.10
IND19	7.50	7.50	7.50	7.50	7.50
IND20	7.50	7.50	7.50	7.50	7.50
IND21	8.10	8.10	8.10	8.10	8.10
IND22	8.10	8.10	8.10	8.10	8.10
IND23	7.50	7.50	7.50	7.50	7.50
IND24	7.50	7.50	7.50	7.50	7.50
TRA01	3.80	3.80	3.80	3.80	3.80
TRA02	3.80	3.80	3.80	3.80	3.80
TRA03	3.80	3.80	3.80	3.80	3.80
TRA04	3.80	3.80	3.80	3.80	3.80
SRV01	4.16	4.16	4.16	4.16	4.16
SRV02	3.80	3.80	3.80	3.80	3.80
SRV03	3.80	3.80	3.80	3.80	3.80

7.15 Income Elasticities

	CHN	USA	CHE	EU27	ROW
01	0.73	0.48	0.57	0.48	0.73
02	0.97	0.96	0.97	0.96	0.97
03	1.07	1.06	1.06	1.06	1.07
04	0.40	0.10	0.30	0.10	0.40
05	1.05	1.05	1.05	1.05	1.05
06	0.63	0.10	0.90	0.10	0.63
07	1.40	1.23	1.26	1.23	1.40
08	0.81	0.81	0.81	0.81	0.81
09	0.93	0.93	0.93	0.93	0.93
10	1.53	1.13	1.14	1.13	1.53
11	1.15	0.86	0.88	0.86	1.15
12	1.65	1.28	1.32	1.28	1.65
13	1.64	1.23	1.26	1.23	1.64
14	1.28	0.91	0.92	0.91	1.28