PBL Netherlands Environmental Assessment Agency

EUROPEAN ECONOMIC MODELLING SYSTEM (EU-EMS):

NEW SPATIAL CGE MODEL FOR EUROPE WITH GLOBAL DIMENSION

Background Report

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1 Introduction

EU-EMS is a dynamic spatial general equilibrium model build by PBL Netherlands Environmental Assessment Agency that includes the representation of 62 countries of the world and one Rest of the world region. The model database has detailed regional dimensionality for EU28 countries and includes them as consisting of 276 NUTS2 regions. Sectoral and geographical dimensions of the model are flexible and can be adjusted to the needs of specific policy or research question. The model has modular structure and can be run (for now) in the following formulations:

- Leontief MRIO
- MRIO price-model
- Simple MRIO based SCGE model
- Standard recursive-dynamic international-trade CGE model with KLEM production functions
- New Economic Geography SCGE model

The model is used for policy impact assessment and provides sector-, region- and time-specific model-based support to Dutch and EU policy makers on structural reforms, growth, innovation, human capital and infrastructure policies. The current version of EU-EMS covers 276 NUTS2 regions of the EU28 Member States and each regional economy is disaggregated into 63 NACE Rev. 2 economic sectors. Goods and services are consumed by households, government and firms, and are produced in markets that can be perfectly or imperfectly competitive. Spatial interactions between regions are captured through trade of goods and services (which is subject to trade costs), factor mobility and knowledge spill-overs. This makes EU-EMS particularly well suited for analysing policies related to human capital, transport infrastructure, R&I and innovation. The model includes New Economic Geography (NEG) features such as monopolistic competition, increasing returns to scale and migration.

EU-EMS could be used not only for the ex-ante impact assessment but also for ex-post impact assessment, other policy simulations and comparison between the policy scenarios. EU-EMS incorporates the following important features:

- linking regions within a New Economic Geography (NEG) framework;
- having inter-temporal dynamic features with endogenous growth engines;
- including detailed public sector interventions;
- incorporating a multi-level governance system.

Modern impact assessment tool should be capable of assessing the impact of a particular policy measure or a combination of policy measure on all three dimensions of sustainability. Spatial economic-transport model level combines those three and allows for the following types of model outputs that are calculated at NUTS2 level:

- Social effects: includes the representation of three education levels and households grouped into five income classes. One can trace the effects of specific policy on income redistribution and allocation of negative impacts of local pollutants between various income groups. Effect of employment and unemployment by three education types can be evaluated.

- Economic effects: the model captures both direct and indirect (wide-economic and rebound) effects of policy measures. It assesses policy impacts on GDP, consumption,

production, investment etc. The spatial model allows for calculation of detailed sectoral impacts at the level of NACE economic sectors.

- Environmental effects: the model includes representation of all GHG and non-GHG emissions, different types of waste, land use and use of material resources.

2 General structure of the model

Each European country in EU-EMS consists of several NUTS regions, which are connected by interregional trade flows of goods and services as well as interregional migration flows. Trade takes place between the regions of the same country as well as between the regions of two different countries. The pattern of interregional trade flows depends upon the preferences of consumers for buying goods from particular destinations and upon the prices of goods and associated transportation costs.

Transportation costs in EU-EMS differ by type of good and depend upon the distance between the regions of origin and destination. The larger this distance is the higher the transportation costs. Interregional migration in EU-EMS takes place only within the same country in the present version of the model. This is justified by the quality and availability of the data on international migration. Net immigration flow to each region of EU-EMS depends upon the relative difference between the real wages in the region and the country average. It also depends upon the relative difference between the rate of unemployment in the region and the country average. Regions with higher real wages and lower unemployment rates will have higher net immigration.

Each NUTS 2 region in EU-EMS includes various economic agents: several types of households, production sectors, regional and federal government. Households in EU-EMS are differentiated by five income classes which makes it possible to capture their specific consumption patterns and savings behaviour. Households with higher incomes consume more luxury goods and have higher savings.

Production sectors in EU-EMS are differentiated according to Eurostat classification and include 23 different types of production sectors. Each sector produces only one type of good or service. Service sectors in EU-EMS include both market and public sectors. Production sectors use various inputs in order to produce their output. These inputs are used in accordance with sectorspecific production technology and include labour, machinery, buildings, other goods and services.

Labour in EU-EMS is differentiated in three levels of education. Production sectors use workers with these different skills and some sectors such as high-tech or research and development use a higher proportion of highly-educated labour as compared to sectors such as agriculture and mining. Wages are sector-specific and vary according to educational levels. They are determined by a negotiation process between the firms and trade unions and depend on labour productivity and on the bargaining power of trade unions. This makes it possible to capture differences in the institutional arrangements across EU countries.

Workers can become unemployed in EU-EMS and unemployment rates can vary between education levels. The level of unemployment depends upon the situation of the labour market and in particular upon the mismatch between the available unemployed labour and posted vacancies. The unemployed get unemployment benefits from the government.

Production and consumption in EU-EMS are associated with air pollution and generation of waste water and solid waste. EU-EMS includes all main types of greenhouse gas (GHG) and non-greenhouse gas (non-GHG) emissions and the associated damage valued in monetary terms. Waste can be treated differently in EU-EMS including deposit into land and water,

incineration and recovery. Waste water can be cleaned and used again in the process of water production.

EU-EMS is a dynamic model and allows for the analysis of each period of the simulation time horizon. This horizon is currently set at 2050 but it can be extended to longer time periods. For each year of the time horizon, EU-EMS calculates a set of various economic, social and environmental indicators. The economic growth rate in EU-EMS depends positively on investments in R&D and education. By investing in R&D and education each region is able to catch up faster with the technological leader region and better adopt its technologies.

Time periods in EU-EMS are linked by savings and investments. By the end of each time period, households, firms and government in the model save a certain amount of money. This money goes to the investment bank, distributing it as investments between the production sectors of the various regions. The allocation decisions of the investment bank sectors depend on the sector's financial profitability.

EU-EMS is built upon the framework of Spatial CGE (SCGE) modelling and incorporates the representation of NUTS 2 regions. Within the SCGE framework the regions are connected by trade in goods and services, relocation of factors and economic activity and income flows. The trading of goods between regions is costly, as it is necessary to pay for the services of the national transport sector. This implies positive transportation costs. Transportation costs in EU-EMS are both good-specific and differentiated between the origin and destination regions.

The greater the distance between the regions, the higher the transportation costs. ECP includes several important categories of expenditure associated with investments in road and rail transport infrastructure, and leads to a reduction in freight transportation costs. In EU-EMS, econometric analyses are used to model the link between transport infrastructure investments and transportation costs. The global congestion curve – linking the average travel time of each region with its capacity measured in terms of kilometres of road and rail and its transportation flows measured in terms of population – is estimated by using cross-section data from the ESPON database at NUTS 3 level. Travel time is calculated through regressions taking into account the kilometres of road, kilometres of rail, kilometres of road divided by population and kilometres of rail divided by population. The data of country-specific costs of building additional kilometres of road and transport network are obtained from international transportation statistics.

Freight transportation costs are made up of fixed and variable costs. Only variable costs can be influenced by travel time savings. Travel time savings reduce the use of fuel, and hence make transportation cheaper. However, as fixed costs of freight transport constitute the largest part of costs, they are not significantly affected by the changes in travel time. Data from the TRANSTOOLS model on fixed and variable costs of transportation are used in order to calculate the relative changes in freight transportation costs used in EU-EMS simulations. To derive the relative changes, the new costs are divided by old costs. Interregional and intra-regional freight transportation costs are fixed exogenously in EU-EMS. In order to simulate the effect of the improvement in transport infrastructure these costs are multiplied with the calculated relative changes in transportation costs.

Change in interregional transportation costs in EU-EMS leads to changes in trade flows between regions and has a direct influence upon the regional distribution of production and consumption. The overall decrease in transportation costs makes final goods cheaper, and increases their demand and their production.

The specification of growth in EU-EMS is based on the semi endogenous growth models of economic growth and catch-up that are widely used in the literature in a leader-follower context of economic development. In this framework, productivity growth is generated through own innovations, knowledge spillovers and technology adoption (catching-up). The sector and region-specific productivity growth depends on an exogenous region-specific parameter and

on the TFP level relative to the technological frontier and region's absorptive capacity. The absorptive capacity is modelled as a function of human capital, R&D expenditure and sectoral specialisation (represented by location quotient and the Krugman specialisation index).

The stock of human capital for each regional and education level does not only depend on the time spent by households on education. It also depends positively upon the investments in education by households and national and regional government. The stock of human capital is equal to the human capital stock in the previous time period minus the amount of retired people plus the newly generated human capital. The amount of newly generated human capital depends upon the amount of time and money invested by households and government in human capital. Education and training normally requires several years to be completed, which results in a delayed effect of investments in human capital. In the case of higher education, for example, investments made 2-3 years ago will impact upon the stock of human capital only now. The same is true of other types of human capital investments. Each type of human capital investment has its own specific time lag with which it affects the stock of human capital. An increase in human capital leads to an increase in the capacity of a region to absorb new knowledge (implement new technological developments) and results in a higher level of TFP via the TFP equation. Additional expenditure on R&D has a direct impact upon sector-specific TFP through the TFP equation. Increase in TFP of regional production sectors leads in general to an increase in production, decrease in imports, and lower prices of final consumption goods.

The New Economic Geography (NEG) approach, emerged in the early 1990s and has gained much attraction for its arguments on centralizing and decentralizing forces in the geographic economic space, which could lead to convergence or divergence of regional incomes. In the NEG literature, initiated by the seminal papers of Krugman (1991) and Krugman/Venables (1995), the idea of agglomeration economics, as suggested by Marshall´s externalities (Marshall 1920), and of cumulative causation, as initially proposed by Myrdal (1957), is revived. The central concepts of this theory are aggregate economies of scale, the home market effect and the existence of trade costs. As to the first, economic activity tends to concentrate in large-scale agglomerations not only because of internal returns to scale of the firm´s production, but also because of externalities which produce external returns to scale.

Producer contacts, and those to intermediary goods producers and customers, labour market pooling, and spill-over effects produce these externalities. As to the second, in the spatial context, economic activity will initially locate close to the place of market demand (home market effect). Together with the third central element, transport costs, agglomeration advantages and the home market effect can produce centralizing forces in the stage of modest economic integration. Only if transport costs, or market barriers, are sufficiently reduced, will a dispersion of economic activities set in.

Each region in the model is endowed with a certain level of labor, housing stock and natural resources. Labor/human capital stock in a region depends on its initial level in a chosen year and develops further according to human capital depreciation rate and new investments made by households and government. Human capital is differentiated between three types according to education level (low, medium and high).

Each region differs by its endowment of land available for agriculture and housing stock used by the households. Endowment of agricultural land determined the regional possibilities for agricultural production. Housing stock per capita enters as an additional factor into the households' utility function and influences the households' decision to migrate to a certain region. Restriction on the available housing stock represents a 'congestion' effect in the model and limits the incentives of households to move to a particular region.

Regions differ by the type of production sectors which dominate overall production activities in the region. Some specialize in traditional sectors like agriculture, whereas others specialize in modern sectors such as finance and industry. Those sectors are characterized by different level of agglomeration and its importance. Traditional sectors do not experience any

agglomeration effects whereas modern sectors do and that allows some sectors to grow faster than the other ones. The prototype model will incorporate the regional difference in sectoral specialization and hence the difference of agglomeration economies between the regions.

Since the NEG approach will be used in our model system the regional agglomeration structure is one of the main determinants of regional economic growth. In particular, the urban structure within each region will play an important role as a regional specific variable in the model. This variable will be able to account for the fact that a region at NUTS3 level can be a combination of on or more main agglomerations with a hinterland of smaller cities, or in fact can be a city itself, like Bremen or Hamburg. Data on population and land use at the urban level are available from GIS database (for example from Corine database) and are translated into an agglomeration variable for each region in the model.

Passenger transport in the model is represented explicitly, they arise as an integral part of the spatial economic activities and can be differentiated according to the following types of tip purposes:

- Commuting: modelled as a result of search and matching process on the regional labour market using Pissaridies' matching function. Time spend on commuting is deducted for the total labour supply.

- Leisure trips: modelled as a part of the demand function of the households using Linear Expenditure System, the demand for leisure trips depends on available income and belongs to luxury type of consumption that reduces with the decrease in income.

- Shopping trips: the number of these trips is linked to the overall consumption of goods and services and depends upon the exogenous assumptions about the amount of goods and services purchases online in each model scenario.

- Business trips: the number of business trips is related to the inter-regional trade in services, increase in these trade leads to increase in the number of business trips.

3 Description of the model database

The overall objective behind the creation of the EU-EMS model database is to develop and implement a methodology for estimating a system of regional supply and use tables that are connected with interregional trade. The methodology should be complemented with an implementation in a GAMS computer program and an application of the adjustment of the data to the EU-EMS model format. The outcome is a full dataset on inter-regional trade flows for EU-28 of the year 2013 and be made available in a format that can be directly applied to the EU-EMS model. The data should be consistent with the national accounts in a supply and use format.

Figure below represent the main steps in the construction of the Multi-Regional Input-Output (MRIO) table for EU28 at NUTS2 level of regional details. The first two steps of the analysis include updating the existing Eurostat Supply and Use tables in NACE Rev2 classification to the year 2013 and creating trade-linked country-level Supply and Use tables for EU28 and the rest of the world. The trade flows should include both trade flows of goods and services. The present document describes the first two steps towards the construction of the consistent inter-regional MRIO table for EU28.

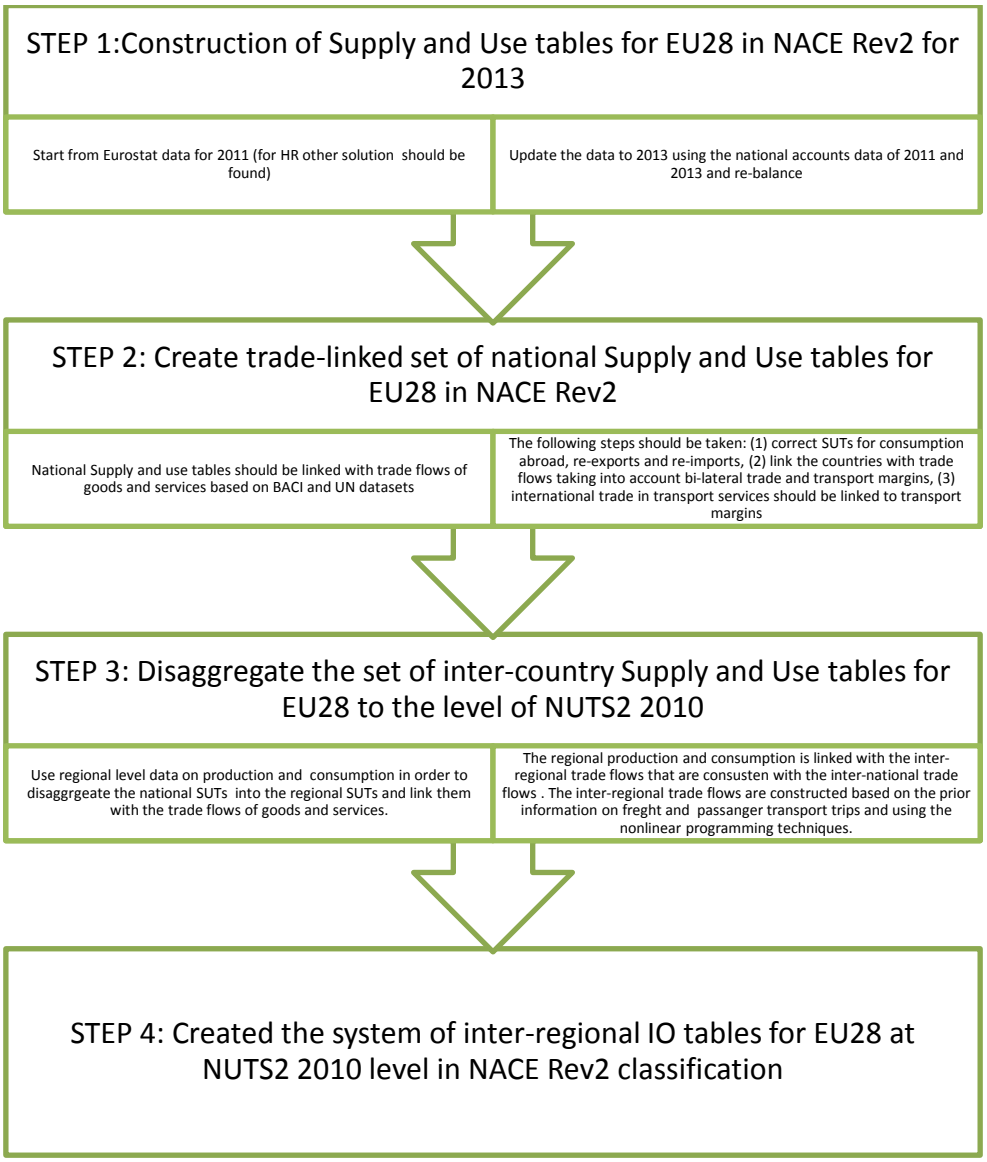


Figure 1 Data flows for the creation of the EU-EMS model database

Main data sources for EU28

Main data sources for the construction of trade-linked Supply and Use tables that cover EU28 countries separately as well as the rest of the world include:

1. Data on Supply and Use tables (SUTs) or Input-Output tables (IOs) of the countries
2. National accounts data that is used to update SUTs and IOs to the year 2013
3. International trade data for both goods and services

Table 1 below gives an overview of the available data sources that are used for the construction of the national level trade-linked Supply and Use tables. Data on Supply and Use tables and national accounts comes from Eurostat and OECD publicly accessible databases. International trade data comes from BACI database of CEPII and UN trade in services database. Access to BACI database requires subscription to UN COMTRADE as it is based on this data.

Supply and Use tables for EU28 countries in NACE Rev2 are available for different years and should be all updated to 2013 using the time-series data from national accounts. The SUTs are linked with the international trade flows based on the trade patters from BACI and UN trade in services databases.

Table 1: Overview of the data sources and their short description

Data source	Availability	Sectoral/commodity details	Geographical details	Notes
Eurostat National SUTs	2008-2011	NACE Rev2	EU27 (no HR)	2013 data is only available for 3 countries No data for Croatia
Eurostat national accounts annual data (main GDP categories)	2000-2015	SNA categories	EU28	
Eurostat national accounts annual data (detailed sectoral split)	2000-2013	90 NACE Rev2 economic sectors	EU28	Some of the sectors are the aggregates of the sub-sectors
BACI international reconciled bi-lateral commodity trade dataset	2008-2014	HS07	232 countries of the world	Represents the reconciled version of UN COMTRADE dataset prepared by CEPII for DG Trade Trade flows are represented in volumes and in values
STAN database national IO tables	1995-2011	34 sectors/commodities	Croatia and other 63 countries of the world including rest of the world	There is also inter-country IO tables available from OECD that link all countries with trade of goods and services
UN trade in services database	2000-2014	184 types of EBOPS Items (types of services)	260 countries of the world	This database is not reconciled and has relatively a lot missing values

Data used for non-European countries

Supply and use tables for non-European countries come from the OECD world-wide Input-Output database for 2011. These SUTs are constructed on the basis of IO tables and hence have diagonal supply.

The development of the OECDs input-output database started over a decade ago and is currently undergoing a new update. Over the years, the database has been used in a number of analytical applications both within and outside the OECD. Two major applications within the OECD concerned the analysis of the diffusion of embodied technology and, more

recently, the measurement of carbon dioxide emissions embodied in the international trade of goods. The latest update is being conducted as part of an OECD project looking at global value chains.

The process of compiling the database begins with requests to national statistical institutes (NSIs) to provide data in accordance with a harmonised industry structure based on the International Standard Industrial Classification of all Economic Activities (ISIC). ISIC Revision 3 provides the basis for the 2006 edition as was the case for the 2002 edition (the 1995 edition was compiled on the basis of ISIC Revision 2). However in order to minimise compliance costs, and to maximise co-operation, the requests stipulate that this pro-forma is not a pre-requisite, and that any relevant data (input-output and/or supply-use tables) at the most detailed and practicable level are welcomed in any (detailed) format. A number of countries do not produce input-output tables but do produce supply-use tables which can be easily converted into input-output tables using some standard assumptions.

The sectoral classification chosen by OECD for its input-output database is different from NACE Rev2 and includes 34 economic sectors presented in the table below. This sectoral classification has quite some similarities with NACE Rev2.1 classification of Eurostat.

Table 2 List of the sectors/commodities used in OECD Input-Output database

1	TTL_C01T05: Agriculture, hunting, forestry and fishing
2	TTL_C10T14: Mining and quarrying
3	TTL_C15T16: Food products, beverages and tobacco
4	TTL_C17T19: Textiles, textile products, leather and footwear
5	TTL_C20: Wood and products of wood and cork
6	TTL_C21T22: Pulp, paper, paper products, printing and publishing
7	TTL_C23: Coke, refined petroleum products and nuclear fuel
8	TTL_C24: Chemicals and chemical products
9	TTL_C25: Rubber and plastics products
10	TTL_C26: Other non-metallic mineral products
11	TTL_C27: Basic metals
12	TTL_C28: Fabricated metal products
13	TTL_C29: Machinery and equipment, nec
14	TTL_C30T33X: Computer, Electronic and optical equipment
15	TTL_C31: Electrical machinery and apparatus, nec
16	TTL_C34: Motor vehicles, trailers and semi-trailers
17	TTL_C35: Other transport equipment
18	TTL_C36T37: Manufacturing nec; recycling
19	TTL_C40T41: Electricity, gas and water supply
20	TTL_C45: Construction
21	TTL_C50T52: Wholesale and retail trade; repairs
22	TTL_C55: Hotels and restaurants
23	TTL_C60T63: Transport and storage
24	TTL_C64: Post and telecommunications
25	TTL_C65T67: Financial intermediation
26	TTL_C70: Real estate activities
27	TTL_C71: Renting of machinery and equipment
28	TTL_C72: Computer and related activities
29	TTL_C73T74: R&D and other business activities
30	TTL_C75: Public administration and defence; compulsory social security
31	TTL_C80: Education
32	TTL_C85: Health and social work
33	TTL_C90T93: Other community, social and personal services
34	TTL_C95: Private households with employed persons

The OECD input-output database covers the whole world and includes the data on 62 separate countries (all EU28 member states are presented as well) and one aggregated rest of the world region.

Besides the data on input-output tables for various countries of the world and the rest of the world region, OECD provides the time-series data for the aggregated elements of the national accounts of 42 of the countries presented in its input-output database.

Regional data

For the regionalization of the national level Supply and Use tables we have made use of the available data from Eurostat and other publicly available data sources. The used data sources are presented in Table 1 below. In case of Eurostat data for SBS we have to fill in the gaps for some regions and sectors.

Table 1: Overview of the available data sources at NUTS2 level for EU28

Data source	Availability	Sectoral/commodity details	Geographical details	Notes
Eurostat regional accounts – GDP, households' incomes, employment and wages	2000-2013	14 NACE Rev2 sectors (cover the whole economy)	NUTS1 2010 and NUTS2 2010 regions of EU28 + NO + CH + IS + MK + TR	Some of the sectors are the aggregates of the sub-sectors
Eurostat SBS – employment and wages	2000-2011	100 NACE Rev2 sectors (cover industry and private services)	NUTS1 2010 and NUTS2 2010 regions of EU27 (no HR) + NO	Some of the sectors are the aggregates of the sub-sectors
ETIS-Plus database (freight and passenger transport flows by mode)	2000 and 2010	Freight flows in NST2 classification (52 types of goods) Passenger trips by 7 transport modes, 4 trips lengths, differentiated between business, private, vacation and commuting International trade in values and in volumes	NUTS1 2006, NUTS2 2006 and NUTS3 2006 regions of EU28 (in total for 235 countries of the world by sub-national regions of these countries)	This database has been constructed for DG MOVE and is used as the baseline database of the TRANSTOOLS model Freight flows between the regions are represented in volumes

Data from regional accounts consists of the information on wages and employment by NACE Rev2 economic sectors according to the classification presented in Table 2. This sectoral level of details is not very detailed but covers the whole of the economy. Regional accounts data does not have any missing values and hence is fully complete.

Table 2 Sectoral classification of the regional accounts data at NUTS2 level

A	Agriculture, forestry and fishing
B-E	**Industry (except construction)**
C	Manufacturing
F	Construction
G-J	**Wholesale and retail trade; transport; accommodation and food service activities; information and communication**

G-I	Wholesale and retail trade, transport, accomodation and food service activities
J	Information and communication
K-N	**Financial and insurance activities; real estate activities; professional, scientific and technical activities; administrative and support service a...**
K	Financial and insurance activities
L	Real estate activities
M_N	Professional, scientific and technical activities; administrative and support service activities
O-U	**Public administration and defence; compulsory social security; education; human health and social work activities; arts, entertainment and recreati...**
O-Q	Public administration, defence, education, human health and social work activities
R-U	Arts, entertainment and recreation; other service activities; activities of household and extra-territorial organizations and bodies

Another set of sectoral data at the NURS2 regional level provided by Eurostat is the Structural Business Statistics (SBS) dataset. This dataset provides much more sectoral details at NACE Rev2 classification for the private part of the economic sectors and includes information on both wages and employment. The level of sectoral details is presented at Table 3. The SBS dataset has some missing values for some regions and sectors that we have imputed using the data on regions with similar levels of GDP per capita. The share of missing values in the SBS dataset is less than 1% of all observations.

In order to be able to regionalize the 65 NACE Rev2 sectors of the Supply and Use tables we have chosen to combine the data from SBS and regional accounts. SBS data is used for the regionalization of private economic sectors and regional accounts dataset is used for regionalization of agriculture, forestry and fishery as well as public economic sectors.

Table 3 Sectoral details of the Structural Business Statistics data from EuroStat

B	**Mining and quarrying**	C23	Manufacture of other non-metallic mineral products	F42	Civil engineering	G473	Retail sale of automotive fuel in specialised stores	J61	Telecommunications
B05	Mining of coal and lignite	C24	Manufacture of basic metals	F43	Specialised construction activities	G474	Retail sale of information and communication equipment in specialised stores	J62	Computer programming, consultancy and related activities
B06	Extraction of crude petroleum and natural gas	C25	Manufacture of fabricated metal products, except machinery and equipment	**G**	**Wholesale and retail trade; repair of motor vehicles and motorcycles**	G475	Retail sale of other household equipment in specialised stores	J63	Information service activities
B07	Mining of metal ores	C26	Manufacture of computer, electronic and optical products	**G45**	**Wholesale and retail trade and repair of motor vehicles and motorcycles**	G476	Retail sale of cultural and recreation goods in specialised stores	**L**	**Real estate activities**
B08	Other mining and quarrying	C27	Manufacture of electrical equipment	G451	Sale of motor vehicles	G477	Retail sale of other goods in specialised stores	L68	Real estate activities
B09	Mining support service activities	C28	Manufacture of machinery and equipment n.e.c.	G452	Maintenance and repair of motor vehicles	G478	Retail sale via stalls and markets	**M**	**Professional, scientific and technical activities**
C	**Manufacturing**	C29	Manufacture of motor vehicles, trailers and semi-trailers	G453	Sale of motor vehicle parts and accessories	G479	Retail trade not in stores, stalls or markets	M69	Legal and accounting activities
C10	Manufacture of food products	C30	Manufacture of other transport equipment	G454	Sale, maintenance and repair of motorcycles and related parts and accessories	**H**	**Transportation and storage**	M70	Activities of head offices; management consultancy activities
C11	Manufacture of beverages	C31	Manufacture of furniture	**G46**	**Wholesale trade, except of motor vehicles and motorcycles**	H49	Land transport and transport via pipelines	M71	Architectural and engineering activities; technical testing and analysis
C12	Manufacture of tobacco products	C32	Other manufacturing	G461	Wholesale on a fee or contract basis	H50	Water transport	M72	Scientific research and development
C13	Manufacture of textiles	C33	Repair and installation of machinery and equipment	G462	Wholesale of agricultural raw materials and live animals	H51	Air transport	M73	Advertising and market research
C14	Manufacture of wearing apparel	**D**	**Electricity, gas, steam and air conditioning supply**	G463	Wholesale of food, beverages and tobacco	H52	Warehousing and support activities for transportation	M74	Other professional, scientific and technical activities
C15	Manufacture of leather and related products	D35	Electricity, gas, steam and air conditioning supply	G464	Wholesale of household goods	H53	Postal and courier activities	M75	Veterinary activities

C16	Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials	**E**	**Water supply; sewerage, waste management and remediation activities**	G465	Wholesale of information and communication equipment	**I**	**Accommodation and food service activities**	**N**	**Administrative and support service activities**
C17	Manufacture of paper and paper products	E36	Water collection, treatment and supply	G466	Wholesale of other machinery, equipment and supplies	I55	Accommodation	N77	Rental and leasing activities
C18	Printing and reproduction of recorded media	E37	Sewerage	G467	Other specialised wholesale	I56	Food and beverage service activities	N78	Employment activities
C19	Manufacture of coke and refined petroleum products	E38	Waste collection, treatment and disposal activities; materials recovery	G469	Non-specialised wholesale trade	**J**	**Information and communication**	N79	Travel agency, tour operator reservation service and related activities
C20	Manufacture of chemicals and chemical products	E39	Remediation activities and other waste management services	**G47**	**Retail trade, except of motor vehicles and motorcycles**	J58	Publishing activities	N80	Security and investigation activities
C21	Manufacture of basic pharmaceutical products and pharmaceutical preparations	**F**	**Construction**	G471	Retail sale in non-specialised stores	J59	Motion picture, video and television programme production, sound recording and music publishing activities	N81	Services to buildings and landscape activities
C22	Manufacture of rubber and plastic products	F41	Construction of buildings	G472	Retail sale of food, beverages and tobacco in specialised stores	J60	Programming and broadcasting activities	N82	Office administrative, office support and other business support activities

4 Further extension of the model

MONROE Horizon2020 project (see www.monroeproject.eu)aims at developing a modelling toolkit and an interactive online tool that would allow a broad range of stakeholders such as European and national governments, academia, regional and local bodies to quantitatively evaluate the impacts of their specific research and innovation (R&I) policies and programmes. The toolkit will assess medium and long-term impacts of R&I policies and programmes on economic growth, job creation, competitiveness, social inequality and sustainability at various geographical levels ranging from world-wide to European, country and regional levels and for various economic sectors. Using innovative modelling methodologies and online visualisation techniques the developed modelling toolkit and an interactive online tool will encourage collaboration between different societal actors in the process of co-creation for sustainable R&I driven economic growth.

The modelling toolkit will be used in the project to provide sound evidence for the impact of research and innovation policies as well as the impacts of research and innovation on economic growth, job creation social inequality and sustainability. Such evidence will be based on the combination of novel macroeconomic theory and general econometric analysis with the parametrisation of the developed toolkit on the basis of European, country, sector and region specific historical data.

The modelling toolkit will be based on a range of existing state-of-the-art models including a dynamic stochastic general equilibrium (DSGE) models, a macro-sectoral Computable General Equilibrium (CGE) models (GEM-E3-RD and PACE), a macro-econometric model (E3ME) and a regional-economic New Economic Geography (NEG) model (EU-EMS). The project will develop the methodologies and modelling approaches for realistic assessment of various aspects of R&I within each of these models. The project will also promote cross-fertilisation between modelling approaches to encourage best practice in the modelling of endogenous productivity.

The impacts of R&I policies in the current version of the EU-EMS model are captured via an endogenous econometrically estimated productivity that is a function of the distance to technological frontier and absorption capacity of each region measured in R&I and human capital stocks. The development of productivity in the model follows the semi-endogenous growth approach of the catch-up process of lagging sectors in particular regions.

Within MONROE the EU-EMS model will be further extended to include the inter-regional R&I spillover effects between sectors that operate via inter-regional trade flows, migration and capital investment flows. The R&I module of the model will be further extended with the explicit stochastic knowledge function, distinction between private and public R&I as well as the differentiation between the different types of R&I policies and programs.

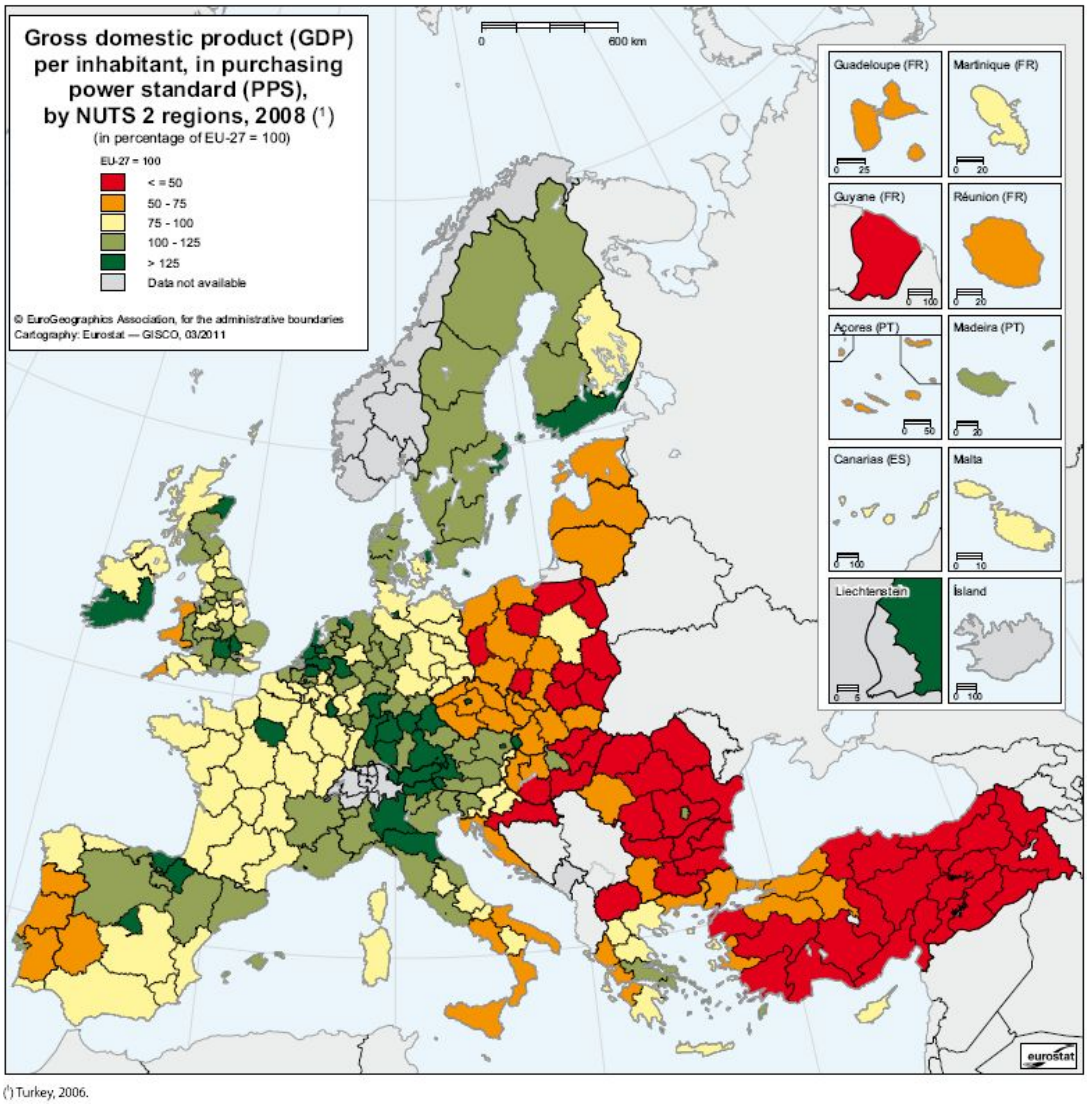
5 Technical annex

A.1 General description of the global EU-EMS CGE model

EU-EMS is a macro- and regional-economic SCGE model that divides the global economy in 62 countries, 276 NUTS2 regional of EU28 and Rest of World region with 63 industry sectors per country according to Eurostat NACE Rev 2 classification. The model is presently calibrated on the data for 2013. The model is dynamic and uses currently the period 2013-2050 as the time period for its calculations.

Table 1 Overview of countries represented in the global CGE model

AUS	Australia	ARG	Argentina
AUT	Austria	BGR	Bulgaria
BEL	Belgium	BRA	Brazil
CAN	Canada	BRN	Brunei Darussalam
CHL	Chile	CHN	China
CZE	Czech Republic	CHN.DOM	China Domestic sales only
DNK	Denmark	CHN.PRO	China Processing
EST	Estonia	CHN.NPR	China Non processing goods exporters
FIN	Finland	COL	Colombia
FRA	France	CRI	Costa Rica
DEU	Germany	CYP	Cyprus
GRC	Greece	HKG	Hong Kong SAR
HUN	Hungary	HRV	Croatia
ISL	Iceland	IDN	Indonesia
IRL	Ireland	IND	India
ISR	Israel	KHM	Cambodia
ITA	Italy	LTU	Lithuania
JPN	Japan	LVA	Latvia
KOR	Korea	MLT	Malta
LUX	Luxembourg	MYS	Malaysia
MEX	Mexico	PHL	Philippines
MEX.GMF	Mexico Global Manufacturing	ROU	Romania
MEX.NGM	Mexico Non-Global Manufacturing	RUS	Russian Federation
NLD	Netherlands	SAU	Saudi Arabia
NZL	New Zealand	SGP	Singapore
NOR	Norway	THA	Thailand
POL	Poland	TUN	Tunisia
PRT	Portugal	TWN	Chinese Taipei
SVK	Slovak Republic	VNM	Viet Nam
SVN	Slovenia	ZAF	South Africa
ESP	Spain	RoW	Rest of the world
SWE	Sweden		
CHE	Switzerland		
TUR	Turkey		
GBR	United Kingdom		
USA	United States		



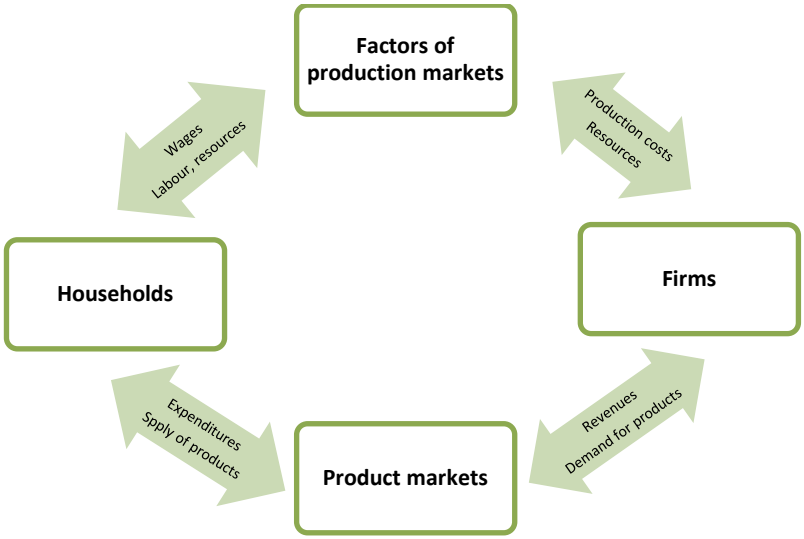
(1) Turkey, 2006.

Figure 1 NUTS2 regions of EU28 and respective GDP per capita

Computable General Equilibrium (CGE) models are the type of simulation tools that use large datasets of real economic data in combination with complex computational algorithms. Such model is used to assess how the economy reacts to changes in governmental policy, technology, availability of resources and other external macro-economic factors. The global CGE model consists of: (1) the system of non-linear equations, which describes the behaviour of various economic actors and, (2) very detailed database of economic, trade, environmental and physical data. The core part of the model database is a Social Accounting Matrix (SAM), which represents in a consistent way all annual economic transactions.

A CGE model accounts for the following interaction/feedbacks: (a) between price and demand/supply quantities and, (b) between economic agents at the macro and sectorial level. Therefore, it gives the economic relations between all industry sectors via their intermediate use. In Figure 4 the circular flow of the economy is presented. It summarizes the interaction between households, firms, the factors of productions (such as labor and capital) and the product markets. The model is a dynamic, recursive over time, model, involving dynamics of capital accumulation and technology progress, stock and flow relationships and adaptive expectations.

Figure 1 Circular economic flow in the global CGE model



The model equations tend to be neo-classical in spirit, assuming cost-minimizing behaviour by producers, average-cost pricing, and household demands based on optimizing behaviour. A CGE model database consists of tables of transaction values and elasticities, i.e. dimensionless parameters that capture behavioural response. As mentioned before, the database is presented as a SAM. It covers the whole economy of a country, and distinguishes a number of sectors, commodities, primary factors and types of households.

CGE models utilize the notion of the aggregate economic agent. They represent the behaviour of the whole population group or of the whole industrial sector as the behaviour of one single aggregate agent. It is further assumed that the behaviour of each such aggregate agent is driven by certain optimization criteria such as maximization of utility or minimization of costs.
T
he global CGE model combines economic, environmental and social domains in an efficient and flexible way:

- Social effects: includes the representation of three education levels and households grouped into five income classes. One can trace the effects of specific policy on income redistribution and unemployment.

- Economic effects: the model captures both direct and indirect (wide-economic and rebound) effects of policy measures. The global CGE model allows for calculation of detailed sectoral impacts at the level of 63 economic sectors and 63 goods/services markets.

- Environmental effects: the model includes representation main GHG and non-GHG emissions, different types of waste, land use and use of material resources.

Table 2 Overview of main elements of the global CGE model per country and region

N	Element of the model	Dimension	Main outputs
1	Households	Five income quintiles	Consumption of goods and services, expenditures, incomes and savings

2	Firms	Grouped into 63 types of sectors	Outputs, value added, use of factors of production and intermediate inputs, investments and capital stock
3	Governments	Federal governments	Governmental revenues and expenditures by type including main taxes and subsidies, social transfers to households, unemployment benefits
4	Markets for factors of production	Three education levels, natural resources including land, water, materials, biomass and energy	Wages, unemployment levels, natural resource rents, return to capital, supply of and demand for factors of production
5	Markets for goods and services	63 types of goods and services	Prices of goods and services, supply of and demand for goods and services
6	International and inter-regional trade	62 countries and one Rest-of-the-World region, 276 NUTS regions, 63 types of goods and services	Trade flows of goods and services between the countries, use of international transport services
7	Savings and investments	National investment bank	Total savings, depreciation, new investments and change in sector-specific capital stock
8	Use of materials	Various physical materials	Use of materials by each of 129 production sectors and their extraction
9	Generation of emissions	Main types of GHG and non-GHG emissions	Emissions associated with energy use, emissions associated with households' consumption and emissions associated with general production process
10	Waste and recycling	Various types of waste treatment and recycling by type of material	Representation of waste treatment and recycling sectors as a part of the economy

A.2 Data and calibration

The global CGE model is implemented using country and regional level Social Accounting Matrices (SAMs) for the year 2013 that are constructed on the basis of trade-linked Supply and Use tables constructed by PBL as well as some elements of the EXIOBASE 2.0 database constructed as part of FP7 CREEA project[1] in combination with the national accounts data from UN-STAT.

Most of the behavioural parameters of the model have been calibrated using the data of SAMs under the standard assumption of unit price normalisation. The calibration formulas have been obtained by solving the final and intermediate demand equations of the model with respect to its parameters while assuming that quantities and prices are known. Elasticities of substitution of production and utility functions as well as income elasticities of commodities used for the calibration of subsistence consumption levels of the Stone-Geary utility function (its maximization results in Linear Expenditure Demand System) have been taken from the literature.

[1] See http://www.creea.eu/index.php/about

The values of these elasticities are presented at Table 3 below. The values of the elasticities of substitution of Capital-Labour-Energy-Material (KLEM) nests of the production function are based on Koesler and Schymura (2007) study that have used WIOD time series dataset for estimations using non-linear least squares technique. Armington elasticity of substitution used in the model is based on Hertel, Hummels, Ivanic and Keeney (2004). The income elasticities of commodities have been set according to the results of Jussila, Tamminen and Kinnunen (2012). The value of the Frisch parameter that is needed for the calibration of the Linear Expenditure Demand System (LES) for the households has been adopted from the Lunch et al. (1977) for the European Union and has been set to -2.07. More specific details are available from the authors upon request.

Table 3 Values of elasticities used in the global CGE model

Aggregated sectors for which values of elasticities could be found in the literature	Elasticity of substitution between capital and labor	Elasticity of substitution between capital-labor nest and energy nest	Elasticity if substitution between capital-labor-energy nest and materials nest	Armington elasticity of substitution between domestic production and imports	Elasticity of substitution between products and services from different countries	Income elasticity used for calibration of Linear Expenditure System
Agriculture, forestry and fishing	0,34	5,23	0,78	1,88	3,75	0,41
Mining and quarrying	1,28	0,54	0,27	1,88	3,75	0,41
Manufacturing of food, beverage and tobacco products	0,26	0,10	0,62	2,96	5,91	0,80
Manufacturing of textile, wood and printed products	0,32	0,38	0,63	3,57	7,14	1,29
Manufacturing of coke and petroleum products	0,31	7,86	0,31	2,10	4,20	1,29
Manufacturing of chemicals and chemical products	0,52	1,15	0,77	3,30	6,60	0,83
Manufacturing of rubber and plastic products	0,22	0,17	0,56	3,63	7,27	0,83
Manufacturing of non-metallic mineral products	0,29	0,87	0,64	1,90	3,80	0,83
Manufacturing of basic metals and metal products	0,30	0,14	0,16	3,63	7,27	0,83
Manufacturing of electronic computer, optical equipment	0,29	0,29	0,00	4,23	8,45	1,78
Manufacturing of machinery and equipment nec	0,82	0,00	0,79	3,62	7,23	1,20
Electricity	0,30	0,28	1,20	2,80	5,60	0,83

Construction	0,31	0,06	0,71	4,23	8,45	0,83
Wholesale and retail trade and	0,14	0,48	0,79	4,23	8,45	0,83
Accommodation and food service activities	0,57	1,10	0,82	4,23	8,45	0,83
Road and rail transportation services	0,87	0,22	0,92	4,23	8,45	1,40
Sea, coastal and IWW transportation services	0,30	1,20	0,84	4,23	8,45	1,40
Other transportation, storage and communication service	0,36	0,70	0,71	4,23	8,45	1,40
Real estate, renting and business activities	0,68	0,61	1,01	4,23	8,45	1,01
Public administration, education, health and other	0,43	0,33	1,03	4,23	8,45	0,93

A.3 Production: KLEM specification

The total sales X_{ri} of tradable goods and services i in country r in the model is an Armington Constant Elasticity of Substitution (CES) composite between domestic output X_{ri}^{D} and imports X_{ri}^{M} such that

$$X_{ri} = \left[\left(\alpha_{ri}^{D} \cdot X_{ri}^{D} \right)^{\rho_i} + \left(\alpha_{ri}^{M} \cdot X_{ri}^{M} \right)^{\rho_i} \right]^{1/\rho_i} \quad (1)$$

Where α_{ri}^{D} and α_{ri}^{M} are the calibrated share parameters of the CES function and $\rho_i = \frac{\sigma_i - 1}{\sigma_i}$ with σ_i being the Armington elasticity of substitution between domestic and imported tradable goods and services. The elasticity of substitution varies between different types of goods and services depending on the available empirical estimates. In case of non-tradable the composite is equal to the domestically produced product.

Imported goods can come from various countries represented in the model and the composite imported goods and services are represented by CES composite that uses a higher Armington elasticity of substitution as compared to the upper Armington nest. We assume as in the GTAP model that the elasticity of substitution between the same type of goods and services coming from different countries is twice as large as the elasticity of substitution between domestic and aggregate imported goods and services. The aggregate imported good is calculated according to the following CES composite function

$$X_{ri}^{M} = \left[\sum_{s} \left(\alpha_{sri}^{T} X_{sri}^{T} \right)^{\rho_i^T} \right]^{1/\rho_i^T} \quad (2)$$

Where α_{sri}^{T} is the calibrated share coefficient of the CES production function, X_{sri}^{T} is the flow of trade in commodity i from country s to country r .The coefficient $\rho_i^T = \frac{\sigma_i^T - 1}{\sigma_i^T}$ where σ_i^T is the elasticity of substitution between commodities produced in different countries.
Domestic production X_{ri}^{D} is obtained using the nested-CES production technology of KLEM type, where K is the capital, L is the labour, E is the energy and M is the materials. Figure 5 represents the nests in the KLEM production function used in the model with services between used according to the fixed Leontief input coefficients in the production process. The energy in the model is differentiated between electricity and other types of energy with some substitution possibilities between them. The labour is differentiated according to three education levels according to International Labour Organisation (ILO) classification.
The domestic production is generated according to nested production CES function that is described by the following set of composite CES functions that follow the production structure from top to the bottom nest

$$X_{ri}^{D} = \left[\left(a_{ri} \cdot M_{ri} \right)^{\rho_{M,KLE}} + \left((1 - a_{ri}) \cdot KLE_{ri} \right)^{\rho_{M,KLE}} \right]^{1/\rho_{M,KLE}} \quad (3)$$

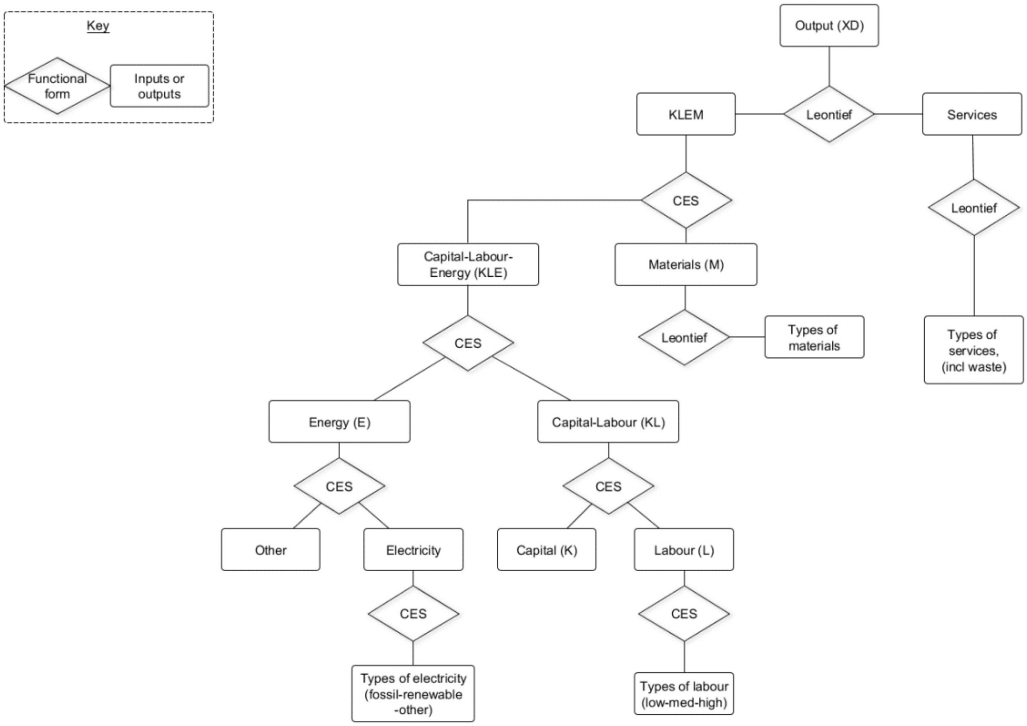
$$KLE_{ri} = \left[\left(b_{ri} \cdot E_{ri} \right)^{\rho_{E,KL}} + \left((1 - b_{ri}) \cdot KL_{ri} \right)^{\rho_{E,KL}} \right]^{1/\rho_{M,KLE}} \quad (4)$$

$$KL_{ri} = \left[\left(c_{ri} \cdot K_{ri} \right)^{\rho_{K,L}} + \left((1 - c_{ri}) \cdot L_{ri} \right)^{\rho_{K,L}} \right]^{1/\rho_{K,L}} \quad (5)$$

$$E_{ri} = \left[\left(d_{ri} \cdot E_{ri}^{NELEC} \right)^{\rho_E} + \left((1 - d_{ri}) \cdot E_{ri}^{ELEC} \right)^{\rho_E} \right]^{1/\rho_E} \quad (6)$$

$$L_{ri} = \left[\sum_{e} \left(f_{rie} L_{rie}^{ED} \right)^{\rho_L} \right]^{1/\rho_L} \quad (7)$$

Where a_{ri} , b_{ri} , c_{ri} , d_{ri} and f_{rie} are the share parameters of the corresponding production function nests and $\rho_{M,KLE}$, $\rho_{E,KL}$, $\rho_{K,L}$, ρ_E and ρ_L represent the substitution possibilities for each of the production function nests. The inputs into the production are denoted as M_{ri} input of materials, KLE_{ri} composite capital-labor-energy nest, E_{ri} energy inputs, KL_{ri} composite capital-labor nest, K_{ri} capital input, L_{ri} labor input, E_{ri}^{NELEC} input of non-electric energy, E_{ri}^{ELEC} input of electric energy and L_{rie}^{ED} inputs of labor by type of education e .
Figure 2 Structure of KLEM production functions in the model



A.4 Households' demand: A Linear Expenditure System

In the global CGE model we model the households' demand for goods and services is represented by the linear expenditure (LES) system that is derived as a solution to the Stone-Geary utility maximisation problem:

$$U_r = \prod_i \left(C_{ri} - \mu_{ri}\right)^{\gamma_{ri}} \tag{8}$$

The resulting demand system where I_r denotes households' disposable income and P_{ri} are consumer prices of goods and services that include taxes, subsidies, transport and trade margins can be written as follows

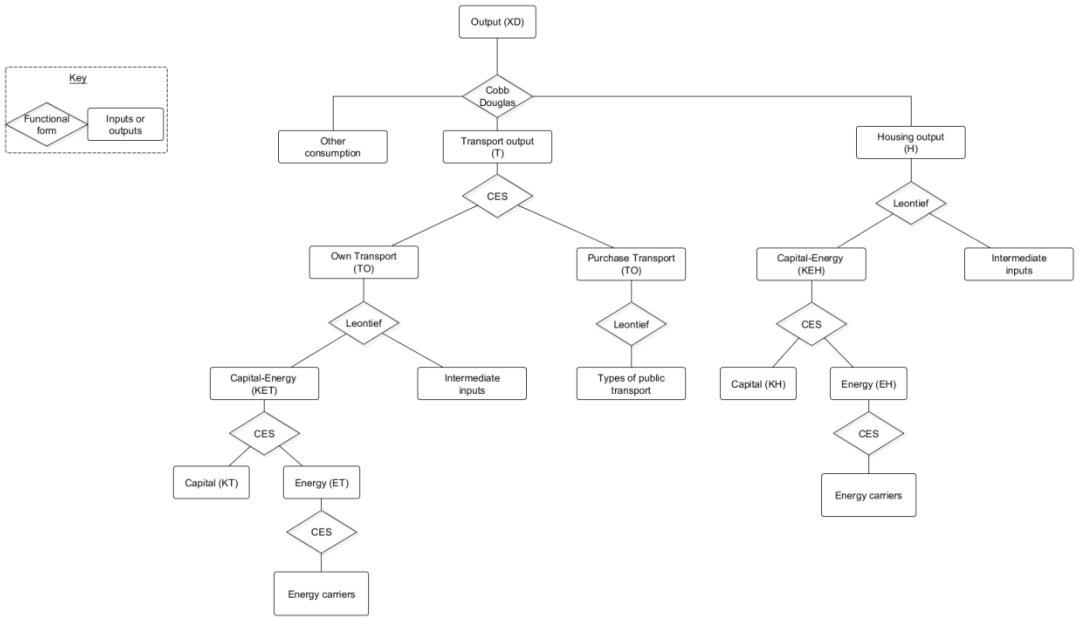
$$C_{ri} = \mu_{ri} + \gamma_{ri} \cdot \frac{1}{P_{ri}} \cdot \left(I_r - \sum_j \mu_{rj} \cdot P_{rj} \right) \tag{9}$$

Households always consume a certain minimum level of each good and services where this level reflects the necessity (or price elasticity) of the good or service. Necessities such as food have low price elasticity and hence higher minimum level of consumption.
The disposable income of the households consist of wages, return to capital, social transfers from the government minus the income taxes and households' savings.

A.5 Households' demand: own production of transport and housing services

One of the important goals of the global CGE model is to include a correct representation not only of the energy use by the firms but also by the households. In many existing CGE models the households demand is modelled using ether Cobb-Douglas or Stone-Geary utility functions. These functions however cannot capture the impacts of technological progress or energy efficiency changes in the personal housing and transportation of the households. The later effects can be captured as in case of the sectorial production functions with the use of nested CES functions. In order to make use of this powerful tool for the representation of energy use and hence emissions related to the households activities we introduce two dummy services into the model: own transportation and own housing services of the households. These two

dummy services are produced using nested CES production functions that are very similar to the one used for usual economic sectors. Increase in the capital stocks of own transport and own housing sectors due to for example buying new type of the car or investing in insolation of the house lead through substitution effects to lower use of the energy by the households.
In case of the production of own transport the households have to first choose the combination of public and private transport (by car), after that they have to choose between the use of capital and energy where energy includes mostly gasoline. Own production of housing also requires the use of capital stock and energy, where the energy inputs mostly consist of gas and coal.
By changing the parameters of the own transport production function including for example productivity of the energy nest, elasticity of substitution between capital and energy as well as share parameters of the CES functions one can simulate the impacts of changes in transportation technologies on both energy and non-energy consumption of the households.
Figure 3 Structure of own production of transport and housing services by the households



A.6 Government and macroeconomic closure rule

The government collects production, consumptions and income taxes. The tax revenue is further used to pay social transfers and buy goods and services for public consumption. The governmental savings can be either endogenous or exogenous in the model depending on the type of simulation and the type of chosen macro-economic closure.

A.7 Equilibrium

Market equilibrium in the economy results in equalisation of both monetary values and quantities of supply and demand. Market equilibrium results in equilibrium prices that represent in case of CGE models the solution to the system of nonlinear equations that include both intermediate and final demand equations as well as accounting constraints that calculate households' and government incomes, savings and investments as well as trade balance. CGE model represent a closed economic system meaning that nothing appears from nowhere or disappears into nowhere in it. This feature of the CGE model constitutes the core of the Walrasian equilibrium and ensures that even if one excludes any single equation of the model it will still hold. This is the property of CGE models called Walras law that tells us that in the closed economic system if n-1 markets are in equilibrium the last n^{th} market will also be in equilibrium.
In our global CGE model the static equilibrium is described by the set of commodity and factor prices, total outputs, final demands of households and government, investments, savings and

net transfers from abroad such that (1) markets for goods and services clear, (2) total investments are equal to total savings, (3) total households consumption is equal to their disposable income minus savings, (4) total governmental consumption is equal to its net tax revenues minus transfers to households minus savings, (5) total revenue of each economic sector is equal to its total production costs and (6) difference between imports and exports is equal to the net transfers from abroad.

A.8 Recursive dynamics and accumulation of capital

The global CGE model runs for the period 2007-2050 in a recursive dynamic way. This means that each time period one solves the model to find its static equilibrium while having the sectoral capital stocks fixed exogenously in the model. The capital stocks evolve according to the dynamic rule presented below, where the capital stock in period t is equal to the capital stock in period t-1 minus the depreciation plus the new investments into the capital stock

$$K_{tri} = K_{t-1ri}(1-\delta_i) + I_{tri}\,. \tag{10}$$

At the end of each period there is a pool of savings S_r available for investments into additional capital stocks of the sectors. This pool of savings comes from households, firms and foreign investors.

The sector investments I_{tri} are derives as a share of the total savings in the economy according to the discrete choice formula

$$I_{tri} = \frac{ST_{t-1r} B_{ri} K_{t-1ri} e^{\vartheta \cdot WKR_{t-1ri}}}{\sum_j B_{rj} K_{t-1rj} e^{\vartheta \cdot WKR_{t-1rj}}}\,. \tag{11}$$

with

$$WKR_{t-1ri} = \frac{r_{t-1ri}}{PI_{t-1r}} \cdot (g_r + \delta_{ri})\,. \tag{12}$$

Where WKR_{t-1ri} denotes the capital remuneration rate, g_r the steady-state growth rate, B_{ri} the calibrated gravity attraction parameter and ϑ the speed of investment adjustments.

A.9 Emissions and resource use

Each economic activity both production and final consumption is associated with emissions and use of resources such as materials, water and land. For modelling of production related emissions we differentiate them between combustion and other emissions. The first type of emissions is related directly to the use of fuels whereas the second type is related to the production process as a whole. The modelling of emissions in the model follows the same principle: combustion emissions are linked to the use of fuels via exogenously determined energy emissions coefficients, whereas non-combustion emissions are related to the total level of the sectorial output via another set of exogenously fixed emissions coefficients. The use of materials measured in tonnes are linked directly to the intermediate inputs of the corresponding types of materials via the tonnes to values ratios of the base year 2007. The use of land and water is directly linked to the total output of each economic sector based on the base year ratios between values of the sectorial outputs and use of land and water in physical units.