TNO Working Paper Series

Working paper 2016-2

EXIOMOD 2.0: EXtended Input-Output MODel
A full description and applications

Keywords:
Input-Output model, Computable General Equilibrium model, Walrasian and Keynesian closures, energy and environmental policy modeling

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ISSN 2211-0054

TNO Working Paper Series

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EXIOMOD 2.0: EXtended Input-Output MODel
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Working Paper No. 2016-2
September, 2016

Abstract:
This document provides a full description of the new version of EXIOMOD (EXtended Input-Output MODel). "Extended" refers to the fact that EXIOMOD can extend the standard Input-Output (IO) analysis in two main directions: (1) to Computational General Equilibrium model (CGEM or CGE model) analysis, and (2) to specific topics such as environmental impacts, energy, or transport. EXIOMOD 2.0 is based on a flexible modular approach that allows for using different economic models (e.g. IO versus CGE model, Walrasian versus Keynesian closure), and for adapting the specification and refinement of the model to the subject under investigation (e.g. changing the regional and sectorial segmentation, activating specific blocks). This document also present several typical applications of EXIOMOD based on the IO and CGE models: calculation of consumption-based indicators, decomposing price and volume effects, policy scenarios to reach 2050 resource efficiency targets.

JEL codes: E12, E17, E27, E37, E47, D57, D58

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ISSN 2211-0054

Introduction

The Input-Output (IO) analysis developed by Leontief (1936) has been abundantly used in empirical economic studies. An Input-Output table provides a snapshot of relationships between different actors in an economic system, such sectors, households, government, at a given point in time. The IO analysis takes these relationships and evaluates possible impacts of various 'what-if' scenarios, with the most common application being the measurement of the economic impact of investment projects. Computable General Equilibrium models (CGEMs) are also built on IO tables, but provide a more comprehensive view of the economy, taking re-distributional and rebound effects into account. CGEMs are especially relevant as ex-ante impact assessment tools. CGEMs are capable of assessing policy proposals with broad economic and societal impact, providing insights into effects occurring in different economic sectors and in different geographical locations. When accompanied with environmental and social extensions, the estimated impacts go beyond just economy, including projected changes in emissions, material and land use and employment

In the impact assessment world the trend of the last decade was to develop a single model that will be able to answer all questions. This trend was based on a number of developments. Firstly, the global economy is becoming more and more interconnected, which rises importance of trade and multi-regional modelling. Secondly, policymakers want to have answers not just on the macro-economic level, but also understand how policies can affect very detailed sectors. The trend has also been supported by the wider data availability and better data processing techniques, which allowed the creation of a number of global multi-regional input-output databases. But the increasing size of the databases also means increasing uncertainty about specific data points and computation issues for the models. As the number on links and parameters in a model increases, its performance, in terms of efficiency and robustness, decreases exponentially.

The problem of efficiency and robustness of impact assessment models based on Input-Output databases is quite common and is being recognized now both by policy makers and scientific community. Both call for more transparent and less complex models, which is also reflected in the working used in the EU Horizon2020 calls on modelling. This paper presents a new approach towards CGE modelling, where the focus is to have a modelling tool that is flexible and capable of producing transparent and robust results. This tool is EXIOMOD 2.0. - EXtended Input-Output MODel that can extend the standard Input-Output (IO) analysis in two main directions: (1) to CGEM analysis, and (2) to specific topics such as environmental impacts, energy, or transport. EXIOMOD has been developed within the Economic Modeling Platform for sUStainability (EM-PLUS). The modeling philosophy extents to the whole EM-PLUS modeling framework. However, this paper will mainly describe the EXIOMOD tool.

Section 2 gives the background of CGEMs and extends on the need to the new approach in CGE modelling. Section 3 shows the advantages and limits of IO models and shows how CGEM analysis is an important extension of the IO approach. Section 4 presents in detail the characteristics and the structure of EXIOMOD. Sections 5 and 6 provides the results of several typical applications: calculation of consumption-based indicators, decomposing price and volume effects, policy scenarios to reach 2050 resource efficiency targets. Section 7 concludes and discusses possible extensions of the model.

1 The need for a new approach in Computable General Equilibrium models

EXIOMOD is an economic model able to measure the environmental impact of economic activities. As a multisector model, it accounts for the economic dependency between sectors. It is also a global and multi-country model with a consistent trade linking between countries at the commodity level. Based on national account data, it can provide compressive scenarios regarding the evolution of key economic variables such as GDP, value-added, turn-over, (intermediary and final) consumption, investment, employment, trade (exports and imports), public spending or taxes. Thanks to its environmental extensions, it makes the link between the economic activities of various agents (sectors, consumers) and the use of a large number of resources (energy, mineral, biomass, land, water) and negative externalities (greenhouse gases, wastes).

Compared to other existing multi-country economic models such as GTAP (Center for Global Trade Analysis - GTAP, 2014), ENV-Linkages (Chateau, Dellink, & Lanzi, 2014), GEM-E3 (Capros, Van Regemorter, Paroussos, & Karkatsoulis, 2013), E3ME (Cambridge Econometrics, 2014), GINFORS (Lutz, Meyer, & Wolter, 2010) or NEMESIS (ERASME, n.d.), EXIOMOD has several important features:

- Based on a flexible modular structure, EXIOMOD can run (and compare) several standard economic modelling approaches. Whereas Input-Output (IO) analysis concentrates on the interdependence between economic sectors, general equilibrium analysis takes also into accounts price effects.
- The modular approach also allows for customizing the model setup by switching on or off specific blocks in order to adjust the level of model complexity and detail to the question under study.
- EXIOMOD can have the properties of the two main types of CGEM. Walrasian CGEMs (such GTAP, ENV-Linkages or GEM-E3) assume perfect prices flexibility whereas neo-Keynesian CGEMs (such E3ME, GINFORS or NEMESIS) assume market imperfections (e.g. involuntary unemployment) due to slow adjustment for prices and production factor and consumption. This difference may lead to major differences in the results.
- EXIOMOD uses the EXIOBASE database that covers a high level of detail on economic sectors as well as environmental extensions on emissions, resources, water and land use.

In the recent years, many efforts have been made in developing detailed multi-regional Input-Output (IO) databases that provide the basis for economic models. These databases provide a coherent framework to measure the economic relations between sectors and agents. They are also generally extended with environmental accounts in order to better understand and quantify the link between resource use and economic activity (Tukker & Dietzenbacher, 2013). World IO databases include the GTAP database (www.gtap.agecon.purdue.edu, Peters, Andrew, & Lennox, 2011), WIOD (www.wiod.org, Dietzenbacher, Los, Stehrer, Timmer, & de Vries, 2013; Timmer, Erumban, Francois, & Genty, 2012) or EXIOBASE (www.exiobase.eu, Wood et al., 2015; Tukker et al., 2009). At the country level, efforts have also been made in disaggregating national IO database in several regions in order to better account for regional heterogeneity and to study the dependence of economic activities across regions. Examples of these regional database include RHOMOLO database for the European Union (Brandsma, Kancs, Monfort, & Rillaers, 2015), Transnational Interregional Input-Output Table for China, Japan and

Korea developed by IDE-JETRO[1] and the US Regional Input-Output Modeling System (RIMS II)[2] developed the U.S. Department of Commerce.

These IO databases have two key applications. First, they can be used to perform standard IO analysis (Miller & Blair, 1985) and therefore to answer to the following type of questions: What is the economic impact of developing a particular sector (in terms of employment, value-added, investment, etc.)? Will domestic or foreign producers benefit the most? Which other economic sectors will benefit from it? With the inclusion of environmental extensions, IO tables can also be used to derive and compare various indicators of resource use: e.g. consumption-based versus production-based indicators (Davis & Caldeira, 2010). A second common application for IO databases is the development of Computational General Equilibrium Model (CGEM) able to cover most regions of the world economy. Examples of these models include GTAP (Center for Global Trade Analysis - GTAP, 2014), E3ME (Cambridge Econometrics, 2014), GINFORS (Lutz, Meyer, & Wolter, 2010) and NEMESIS (ERASME, n.d.)[3].

CGEMs are used to simulate the economic impact of various policies (in particular, fiscal policies) but also structural changes such as technological change, changes in economic behaviors or external shocks (e.g. decrease in the productivity of certain production factors such as land due to climate change, decrease of the availability of water). CGEMs have been subject to several criticisms (André, Cardenete, & Romero, 2010; Grassini, 2007). The choice of the model specification is arbitrary because of the difficulty to conduct statistical or empirical validation. An important issue for the analyze of results obtained with a multi-sector and/or multi-region CGEM is the abundance of linkages and effects which are difficult to separate from one to another. Because of the general equilibrium framework the direction of causalities is by definition non-identifiable. Moreover, the results heavily depend on many assumptions such as the level of elasticity, closing rule, underlying data for the sector disaggregation. To some extent, CGEMs have become too complex to answer specific questions which are paradoxically embedded in the model. For instance, whereas CGEMs use IO database, the complexity of their production and consumption structure makes it difficult to isolate input-output from general equilibrium effects.

These difficulties call for the use of a simpler analysis or at least for a more modular approach where the level of complexity and detail can be adapted to the question under investigation. This paper presents a new modeling tool that goes in this direction. This tool is an EXtended Input-Output MODel (EXIOMOD). “Extended” in the sense that it can extend the standard IO analysis (1) to different type CGEM (Walrasian versus Keynesian closures), and (2) to specific topics such as environmental impacts, energy, or transport. More precisely, it can distinguish different key effects embodied in CGEM which can greatly help the interpretation of the results.

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[1] http://www.ide.go.jp/English/Data/Io/index.html

[2] http://bea.gov/regional/rims/

[3] E3ME, GINFORS and NEMESIS are often not seen as CGEM in particular by their authors. One argument is that they are econometric models and that they include non-market clearing wage and price setting. As we shall see later, we interpret these features as a particular type of closure of a CGEM: the Keynesian closure.

CGEM's results and therefore price effects widely depend on the closure used. In the literature two types of closure are generally used. The Walrasian closure assumes that perfect price flexibility ensures the instantaneous equilibrium between supply and demand. On the contrary, the Keynesian closure assumes that demand defines supply whereas price and quantities are rigid and adjust slowly to the optimal level. Examples of CGEM using the Walrasian closure are ENV-Linkages (Chateau, Dellink, & Lanzi, 2014) from OECD, GEM-E3 (Capros, Van Regemorter, Paroussos, & Karkatsoulis, 2013), GTAP, whereas the Keynesian closure is used in econometric models such as E3ME, GINFORS or NEMESIS. Since these closures can have a huge impact on the dynamic and long term properties of the model, EXIOMOD 2.0 can be run with alternative Walrasian and Keynesian closures.

2 From Input-Output to Computable General Equilibrium model

The Input-Output (IO) analysis developed by Leontief (1936) has been abundantly used in empirical economic studies. Based on national account data, it can measure the economic dependence between activities and regions (for an overview see Miller & Blair, 1985). A common application is the measurement of the economic impact of a given activity or the implementation of investment projects. The approach can be used to derive standard economic indicators such as employment, value-added, investment, etc. With environmental extensions, IO model can also be used to measure the environmental impact of economic activities in terms of resource use (energy, mineral, water, land) and negative externalities (gas emissions).

IO models have the advantage to account for indirect effects via the impact of one sector to another. Formally, an IO model can be derived by defining the supply-use equilibrium:

$$Y = AY + C + I \tag{1}$$

Where $Y = Y_a$, $C = C_a$ and $I = I_a$ are respectively the vectors of production, final consumption and investment. For simplicity and without loss of generality, we assume that each activity a produces only one commodity. AY is the matrix of intermediary consumption. $A = (\alpha_{a',a})$ is the matrix of technical coefficients where $\alpha_{a',a}$ are the Leontief technical coefficients, that is the share of product a' into the production of activity a. $\mathbb{I}$ being the identity matrix, production can be expressed as a function of final demand (final consumption plus investment):

$$Y = [\mathbb{I} - A]^{-1}(C + I) \tag{2}$$

The Leontief matrix $[\mathbb{I} - A]^{-1}$ gives the multiplier of intermediary consumption: because of the technical link between activities, the increase in production is higher than the increase in final demand.

Although IO models are very useful to capture the dependence between sectors, they neglect important economic effects. First, they do not taken into account other important multipliers. Because final demand (final consumption and investment) are assumed as exogenous, the multipliers of investments and of final consumption are generally not considered. In reality an increase in production requires a higher level of capital and therefore a higher level of investment. This is can be taken into account by endogenizing investment and the demand for capital:

$$I_t = \Delta K_t + \delta K_{t-1} \text{ with } K = f(Y) \tag{3}$$

Where K is the capital stock, δ its depreciation rate. $f(.)$ is a function increasing with production. Standard IO analysis often omits also the multiplier final consumption. An higher production leads to a higher employment and therefore to a higher consumption level. Accounting for this multiplier requires endogenizing consumption and labor demand which leads *in fine* to a positive relation between consumption and production, $C = f(Y)$.

Although it is technically possible to endogenize investment and final consumption within an IO framework, this is rarely done in practice for several reasons. It requires using dynamic IO analysis which raises dynamic stability issue known as dual stability theorem (Jorgenson, 1960). With all the multipliers, an increase in final demand can lead to large effects on production and eventually to unstable (explosive) solution. It can also lead to economic inconsistency with for instance a negative unemployment rate. These results point out an important limit of IO models: they do not account for limits on supply or demand. In particular, the limit on production imposed by the availability of production factors is not taken into account. By concentrating on relation in volumes between economic variables, IO models omit prices, and therefore price effects which are however crucial in economics. Because of the absence of prices, there is no substitution between production factors, consumption goods, foreign and domestic production, which makes all the input coefficients constant. In economics, price effects are also important because they act as a regulator in case of disequilibrium between supply and demand. Prices are at the center of mechanisms allowing the economy to stay within the limits of production factors. Accounting for price effects requires extending the IO model into a CGEM by endogenizing final demand and prices. The 2.0 version of EXIOMOD has been especially designed to run and compare both approaches.

3 EXIOMOD 2.0

EXIOMOD's name stands for EXtended Input-Output MODel. "Extended" refers to the fact that EXIOMOD can extend the standard Input-Output (IO) analysis in two main directions: (1) to CGEM analysis, and (2) to specific topics such as environmental impacts, energy, or transport. Whereas EXIOMOD 1.0 was a standard CGEM with a Walrasian closure, EXIOMOD 2.0 is based on a modular approach specifically designed to conduct both IO analysis and CGEM simulation. With this modular approach and depending on the subject under investigation, the modeler can easily change the regional and sectorial segmentation as well as the level of complexity regarding the specification of the model by switching on or off specific blocks.

The main objective of this modular approach is to overcome several criticisms formulated to standard CGEMs (André et al., 2010; Grassini, 2007), as discussed in the introduction. EXIOMOD can distinguish different key effects embodied in CGEM which can greatly help the interpretation of the results. In particular, it can separate volume and price effects. As we shall see, the volume effects are directly derived from the IO analysis whereas price effects come from the general equilibrium framework. Moreover, EXIOMOD can isolate direct and indirect volume effects by distinguishing different types of multipliers: multipliers of intermediaries, investments and consumption.

The current version of EXIOMOD uses the detailed Multi-regional Environmentally Extended Supply and Use (SU) / Input Output (IO) database EXIOBASE (www.exiobase.eu, Wood et al., 2015; Tukker et al., 2009). This database has been developed by harmonizing and increasing the sectorial disaggregation of national SU and IO tables for a large number of countries, estimating emissions and resource extractions by industry, trade linking countries per type of commodities. Moreover, it includes a physical (in addition to the monetary) representation for each material and resource use per sector and country in the form of environmental extensions. Using the full potential of this database, EXIOMOD can divide the global economy into 163 industry sectors per region (see Figure 3.1) and into 43 countries representing around 90% of the world GDP and five Rest of World regions (see Figure 3.2). The model includes a representation of 31 types GHG and non-GHG emissions, different types of waste, land use and use of material resources (see Table 4.1). The list of countries and sectors/commodities is provided in Section 10 (Appendix B: List of regions and sectors).

Figure 3.1: Sector coverage of the EXIOBASE database

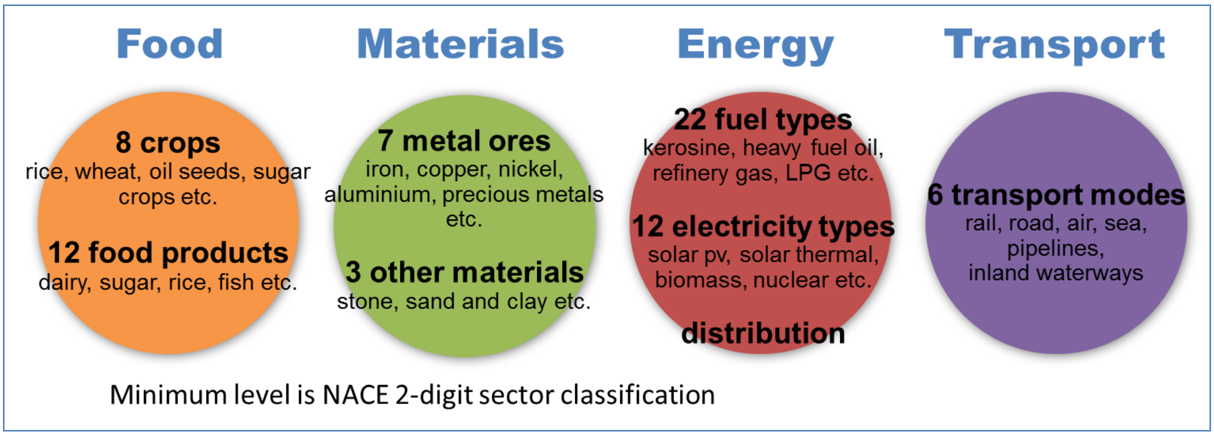

Figure 3.2: Map of country and region coverage of the EXIOBASE database

Representation of the 43 individual countries

Representation of five rest of the world regions

Table 3.1: Environmental indicators covered in the EXIOBASE v3 database

Indicator	Level of detail	Examples
Emissions in kg	31 GHG and non GHG emissions	• CO_2 • CH_4 • NH_3
Land use in ha	12 types of agricultural land use	• Arable land used for rice • Arable land used for wheat • Arable land used for sugar crops
Resource use in kg	165 types of crops	• Soybeans • Almonds • Cocoa beans
	8 types of non-metallic minerals	• Slate • Gravel and sand • Salt
	9 types of fossil fuels	• Anthracite • Peat • Crude oil
	10 types of metals	• Iron • Copper • Lead
Water use in Mm^3	• Consumption green • Consumption blue • Withdrawal blue	

With these features, EXIOMOD is particularly well suited to evaluate the impact of policies related to (energy and non-energy) resource use at the macroeconomic and sector levels:

- Environmental extensions allows for measuring the impact of various economic activities on the use of a large variety of resources.
- The sectorial trade linking allows for analyzing the impact of national consumption pattern on the economy and on the resource use in other countries. This feature is particularly convenient to confront production based and consumption based indicators of resource footprint per country.

- The modular approach allows for separating direct and indirect effects, and in particular rebound effects.

As an illustration, Sections 3 and 4 give typical applications with the IO and CGE model. Whereas all the equations of the EXIOMOD are provided in Section 11 (Appendix C: Equations of EXIOMOD), this section provides the main characteristic of each model.

3.1 Organization of the code

The EXIOMOD model's code is written in GAMS (General Algebraic Modeling System). This is one of the most common programming languages used for CGE models. The model is formulated a mixed complimentary problem (MCP) and is solved using CONOPT solver. EXIOMOD does not make use of the MPSGE subsystem developed for general equilibrium analysis. Although a code written in MPSGE is more compact and usually less error-prone in the initial stage of model development, we believe that the original GAMS language provides much more control over the model and flexibility for using different functional forms and closure rules.

We have devised a number general principles to be applied in the model coding, the principles are gives in Section 9 (Appendix A: Modelling philosophy behind EM-PLUS). Following these principles, the model is developed and applied in a transparent, flexible and robust manner. The code structure is based on a modular approach, where different modules can be switched on or off depending on a question under investigation. Our rationale behind structuring the model in modules is that it provides a well-defined structure of the code and facilitates collaborative development of the model. In the case of EXIOMOD, modularity means that a large model code is split into rather compact thematic blocks of code, such as producer, demand (consumer), trade and closure, see Figure 4.3 for a graphic representation. Each module is required for a CGEM, but a modeler is free to choose a different variant of each module, e.g. Walrasian or Keynsian closure. In some cases a modeler can even decide to try different variants of the same module and compare the results.

In a general equilibrium framework producers and consumers in all the regions are interconnected. In EXIOMOD, the connection channels between the modules are well defined and should be the same for different variants of the same module. Figure 4.4 gives an example of how the Production module, version capital-labour nest, is connected to the Demand, Trade and Closure model. There are four variables that are defined by the Production module, but also appear in the other modules: demand for the factors of production, demand for the intermediate products, output on industry level and output on product level. The exact same variables should be the connections in case a different version of the Production module, for example with capital-labour-energy nest, is used. This provides a modeler with flexibility to mix and match different versions of the preprogrammed modules without worrying about their compatibility.

The code can be summarized in the following steps:

- Step 1: Configuration of the model – which versions of the modules to use.
- Step 2: Reading of (multi-regional) supply/use or input/output data. At the current stage EXIOMOD is calibrated on EXIOBOSE, but other versions of the data can be used, e.g. WIOD or OECD data. Single-country version of the model is also an option.

- Step 3: Define the level of product/industry and region aggregation, as well as corresponding elasticity values.
- Step 4: Load all the modules of the model.
- Step 5: Simulation setup, model solve statement and processing of simulation results.
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Figure 4.3: Overview of the EXIOMOD code

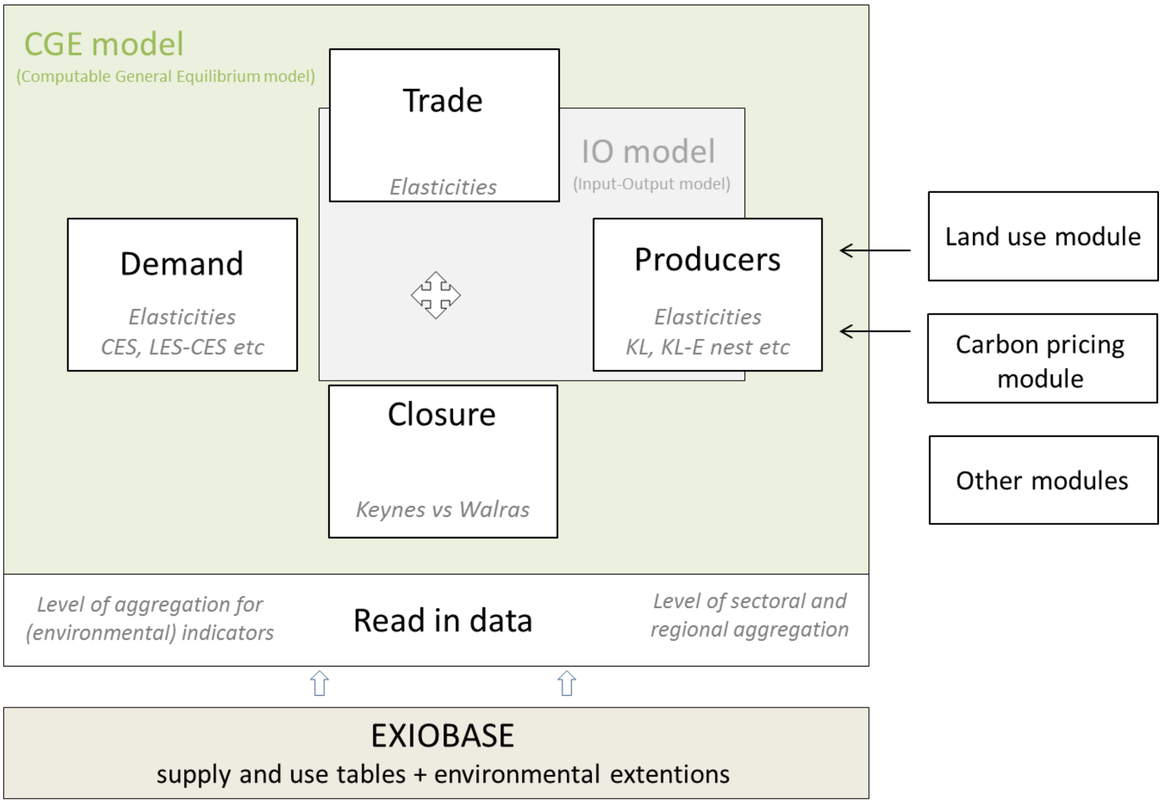
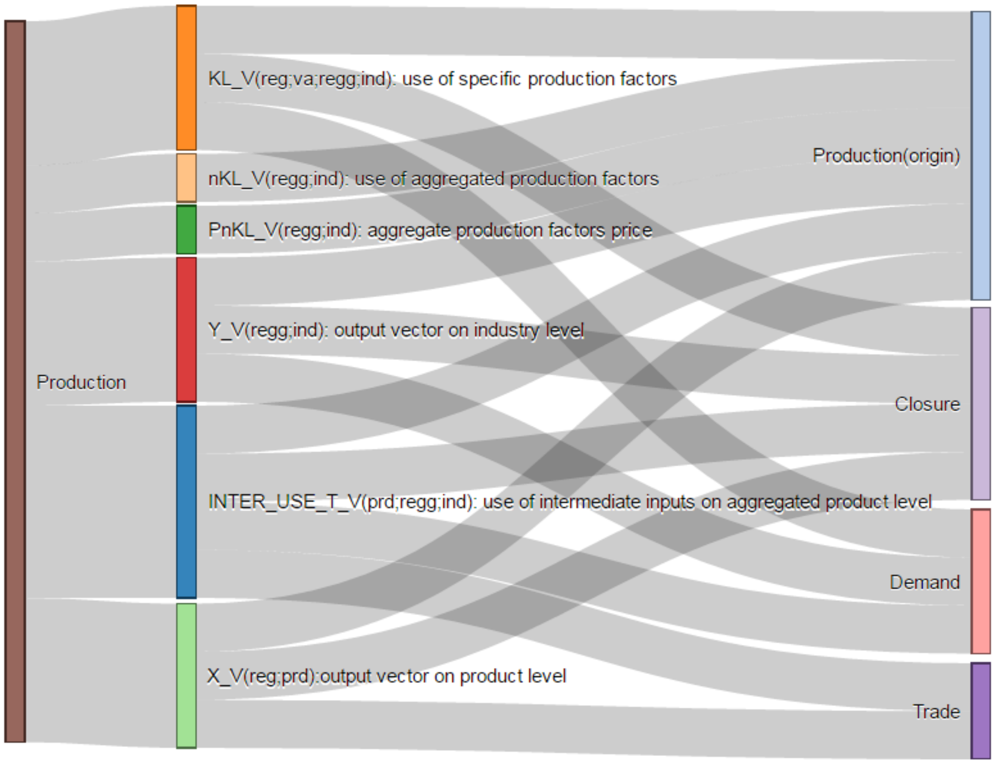
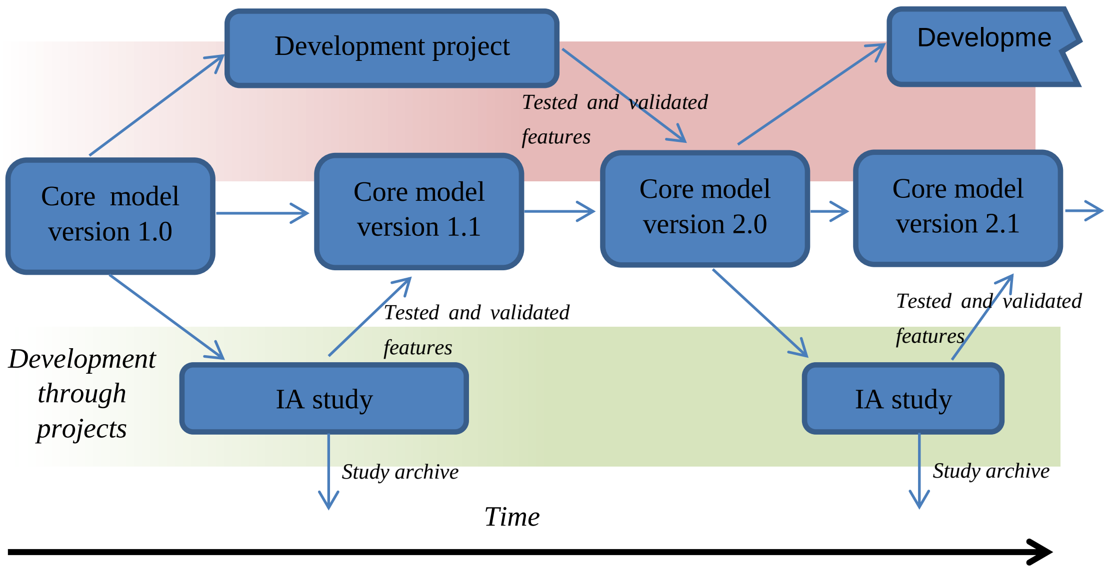


Figure 4.4: Linkages between the production (capital-labour nest version) and other blocks of the model



The model is constantly being developed further in ongoing projects. By following the modelling principles, the process of model development happens in a structured way and follows appropriate version management. This allows for reliability of the model and allows for parallel modelling developments and applications. The process of model development is visualized in the figure below. The core model of EXIOMOD is always separate from the impact assessment (IA) study but can be called and used by the study application. In parallel there can be model developments, which after testing and validation is transferred into the core model.

Figuur 4.5 Schematic overview of the process of model development on the core model and flexible modules



3.2 The Input-Output model

The IO model can be seen as a subset of equations of the CGE model. Here we are considering a standard demand-driven Leontief type of IO model, as described in Section 2. Such a model would include some selected equations from the production and trade modules. In practice, due to existing linkages with the demand and closure modules of EXIOMOD, the variables for prices and final demand volumes that appear in the IO model need to be fixed exogenously. This ensures that the system of equations is square and can be solved.

EXIOBASE contains the economic data in the form of supply and use tables. For the IO analysis, they should be converted into a symmetric IO table. We follow the approach devised by Eurostat (Eurostat, 2008) for derivation of product-by-product IO tables[4]. There are two approaches: one is based on the *product-technology* assumption and the second one is based on the *industry-technology* assumption. The *product-technology* approach assumes that the supply of commodity c by activity a ($Y_{c,a}$) is a fixed share of the aggregate production of the activity a (Y_a). In other words the ratio $Y_{c,a}/Y_a$ is fixed. It gives a representation of the production of activities in terms of by-products. For instance, increasing the production of oil by refinery leads to an increase the production of plastic, because the plastic is a by-product of petrol. The industry-technology approach assumes that the supply of commodity c by activity a ($Y_{c,a}$) is a fixed share of the aggregate production of the commodity c (Y_c). In other words the ratio $Y_{c,a}/Y_c$ is fixed. The commodities produced by an activity is driven by the aggregate demand of the commodity and not by by-products considerations.

Although both of the approaches are standard practices and are based on valid assumptions, the product-technology assumption has a number of limitations. Firstly, it does not guarantee that the resulting IO table has no negative transactions, and in case negative transactions appear they can only be corrected manually. Secondly, it requires that the starting SU tables are square, meaning that the number of products is the same as the number of industries. Thirdly, the representation of production in terms of by-products tend to concern very specific cases. In many cases, an activity produces several commodities that are not by-products of each other but because there is a demand for it. Therefore, it is recommended to use the industry-technology assumption, which is also consistent with the production structure used in the CGE version of EXIOMOD.

3.3 The Computable General Equilibrium model

As explained in Section 2, the IO model provides useful information on the quantities but has the disadvantage of leaving price effect aside. The CGE model can be activated to overcome this limit. EXIOMOD is then used as a CGEM. A CGEM takes into account the interaction and feedbacks between supply and demand as schematized in Figure 4.6. Demand (consumption, investment, exports) defines supply (domestic production and imports). Supply defines in return demand through the incomes generated by the production factors (labor, capital, energy, material, land, etc.).

[4] Input-output tables, in contrast to supply and use tables, are by definition symmetric tables, meaning that the dimensions use for row and columns should be the same. IO tables can be of two types: (1) product-by-product, when the industry dimension of SU tables is eliminated, or (2) industry-by-industry, when the product dimension is eliminated.

The notion of “general equilibrium” relates to a state where supply is equal to demand in all markets. In the literature, there are two main approaches to ensure this state. In Walrasian models, the equilibrium force is the price system. Perfect flexibility of prices and quantities (production factors, consumption, etc.) ensures the instantaneous equilibrium between supply and demand. When an exogenous shock decreases the supply of a commodity, its price tends to go up, thereby stimulating additional supply and depressing demand, until supply and demand are equal again. Arrow & Debreu (1954) demonstrate the conditions under which such an equilibrium exists[5]. This equilibrium mechanism does not only operate on the product markets. Depending on the closures retained (e.g. Shoven & Whalley, 1994), it may also apply on the production factors markets (labour, capital), on the saving market (savings equal investments) and on the foreign exchange markets (imports equal exports). Walrasian type of CGEM are static: after a shock a new equilibrium (system of prices and quantities) is found within the period of simulation[6].

The second approach is the closure retained in Neo-Keynesian models. In these models, prices do not clear the markets and market “imperfections” (e.g. involuntary unemployment) are taken into account. In coherence with empirical evidence, they assume that prices and quantities are rigid in the short run and that they adjust slowly over time toward their optimal level. The general equilibrium is achieved by assuming that demand determines supply. In the short and medium run, there can be situations of disequilibrium between notional (optimal) supply and the actual supply and of underutilization of the production capacity (in particular involuntary unemployment). Compared to the Walrasian CGEM, Neo-Keynesian CGEM are dynamic and therefore better suited to analyze medium term phenomena and the transition to the long run. Econometric models such as such as E3ME, GINFORS or NEMESIS or Dynamic Stochastic General Equilibrium (DSGE) model (e.g. Smets & Wouters, 2003) are typical examples of this type of models. EXIOMOD can be run under Walrasian and Keynesian closure. Following the approach of the THREEME model (Callonnec, Landa, Malliet, Reynès, & Yeddir-Tamsamani, 2013), adjustment parameters are calibrated based on values found in the econometric literature.

The standard version of EXIOMOD is characterized by certain key underlying hypotheses as summarized below. They are based on the EPPA model from MIT and could be considered as quite standard (Paltsev et al., 2005). These hypotheses can be adjusted in accordance with the requirements of a given project.

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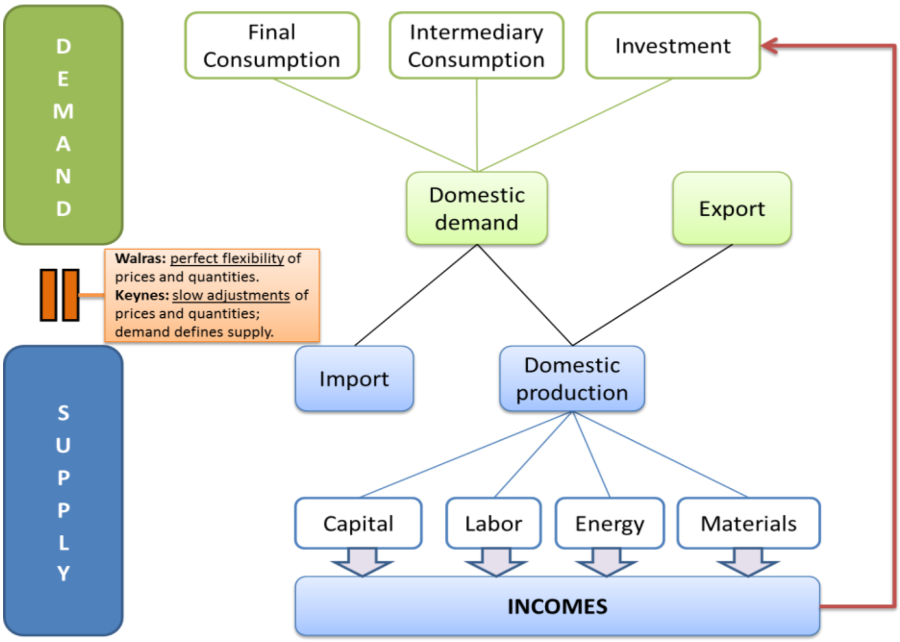
5 They demonstrate that the Walrasian equilibrium is a Nash (1950, 1953) equilibrium if agents are perfectly rational, if they do not commit anticipation errors, if the production functions do not show increasing returns to scale, and if the utility functions satisfy the standard properties of continuity, non-saturation and strict convexity of their isoquants. Additional more technical properties are also required (see e.g. Hahn, 1982).

6 Some CGE models introduce a recursive dynamic where the past savings define next year capital stocks. This type of dynamics is not included in the base version of EXIOMOD, but it can be added for a specific project. EXIOMOD instead uses a more advanced Keynesian version of dynamic closure.

Figure 4.6: Architecture of a CGEM

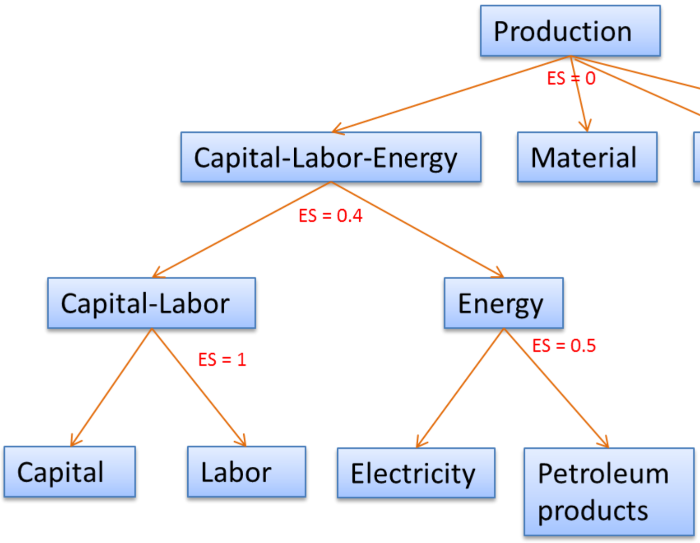


3.3.1 Production technology

The production technology, which can be adapted depending on the subject under study, is modeled as a nested Constant Elasticity of Substitution (CES) function. The nesting structure allows for introducing different substitution possibilities between different groups of inputs. Figure 4.6 illustrates the nesting structure as setup in the default version of the model, the same version as applied in Section 5 of this document. At the first level, we assume that material (non-energy intermediaries), land and water are perfectly complementary to the aggregate capital, labor, energy, that is the Elasticity of Substitution (ES) is equal to zero. At the second level, energy can be substituted to the aggregate input capital-labor with an ES equal to 0.4. At the third level, the ES between labor and capital is equal to one (Cobb-Douglas function) and the ES between energy types is equal to 0.5.

Due to the modular and flexible structure of the model, the production function can be adjusted for each specific study. Firstly, the structure of the nests can be modified, in case one wants to explore specific technologies in detail. Secondly, the values of ES can be changed, including a sensitivity analysis for different values of elasticities.

Figure 4.7: Illustration of production structure in EXIOMOD, as in application in section 5



3.3.2 Household's utility

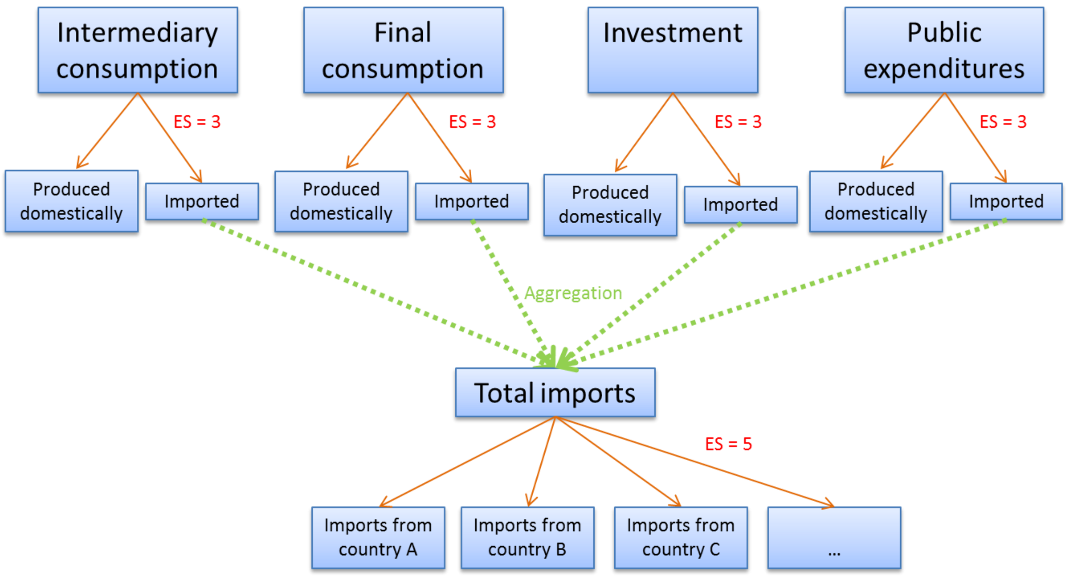
In the application of Section 5, the household's utility is specified as a LES-CES function (Linear Expenditure System - Constant Elasticity of Substitution) allowing to differentiate between necessity and luxury products. This function defines a subsistence level for each good consumed which lead to an elasticity between consumption and revenue lower than one. For instance for food we have a high subsistence level, whereas for other products consumption is more sensitive to the level of income. We assume that the subsistence levels for consumption of products grows at the same rate as population. The subsistence level for energy products is divided by the improvement in energy efficiency. The subsistence levels are based on the GTAP values as used in the study by Lejour et al. (2006). Including all households expenditures, the subsistence level of consumption corresponds to 33 percent of the base year consumption, but this level jumps to 80 percent for agricultural products. Above this minimum level of consumption, substitution between good is possible depending on the price, with an ES equal to one.

3.3.3 Trade

The trade structure is schematized in . Per type of use (e.g. final, intermediate consumption), a good can either be imported or produced domestically. For simplicity, we assume that the ES is equal to five for each use except for the following commodities: energy, water, construction (ES = 0.5). This means that energy, water and construction are less flexible for changing trade partners compared to the other products. In a second step, all imported products per use are aggregated to calculate the total level of imports. In a third level, imports can be supplied by different countries. We assume a CES function characterized by possibilities of substitutions between regions of origin (with ES = 5). The ES value might seem somewhat high, however it is within the range discussed in the literature (e.g., McDaniel & Balistreri, 2003). Moreover, the high value reflects the observations in the literature that the long-term value of the parameter is relatively high, meaning that trade partners are more flexible in the long-term.

As in the case with production functions, the structure of the model allows to explore different values of ES for the trade. In case a range of elasticities seems plausible, sensitivity analysis can be performed.

Figure 4.8: Illustration of trade structure in EXIOMOD, as in application in section 5



<u>Note:</u> these ES are set to 0.3 in the upper level and 0.5 in the lower level for the commodities electricity and water.

3.3.4 Closure

In the terminology of CGEMs the so-called 'closure rules' are used to define, on one hand, where we draw the border between endogenous and exogenous parameters of the model and, on the other hand, what assumption we make about the markets for endogenous parameters. The closure rules are meant to bring the behavior of separate agents of the model into a closed general equilibrium system, technically speaking in a system where the number of unknown variables is equal to the number of equations. The choice of the closure could have a great impact on the model results and should always be explicitly stated and explained.

The Production, Demand and Trade modules are defining parameters of EXIOMOD based on the preferences of corresponding agents, but the question of finding the prices that would bring the markets into balance is left to the Closure module. There is a number of markets to be defined by the closure rule and each market can have several modelling options. Below we provide the list of markets and options that are already considered in EXIOMOD 2.0. We constantly develop this list further in response to requirements of our projects. The modular approach ensures that different combinations of the assumptions can be modeled, depending on the question under study.

1. Labour market: full employment vs. involuntary unemployment.
2. Prices: immediate adjustment to the optimal level vs. sticky prices.
3. Capital market: static exogenous capital stock with capital mobility across sectors vs. dynamic endogenous capital with investment decisions on sector level.
4. Rest of the world (regions with not modelled behavior): fixed current account.

3.3.5 Environmental extensions

EXIOMOD relates the resource use to the economic activity in several ways. CO2 emissions are directly related to the level of consumption of the energy commodities responsible for the emission. Water consumption of economic activities is related to the level of production. For households, it is related to the water consumption (purchased from the water sector). Materials (such as metal, non-metallic minerals, etc.) are related to the production of the mining sector responsible of the extraction.

The environmental extensions of EXIOMOD can be used in a number of ways. Firstly, once a new level of economic activity has been simulated, they can be used to determine the new level of environmental effects. In this case the level of environmental effects is defined outside of the model and is implemented as a post-processing step. Secondly, they can be used to model pollution permits markets, e.g. carbon permits, or land markets. In this case environmental extensions are made endogenous by adding corresponding market rules equations to the closure of the model.

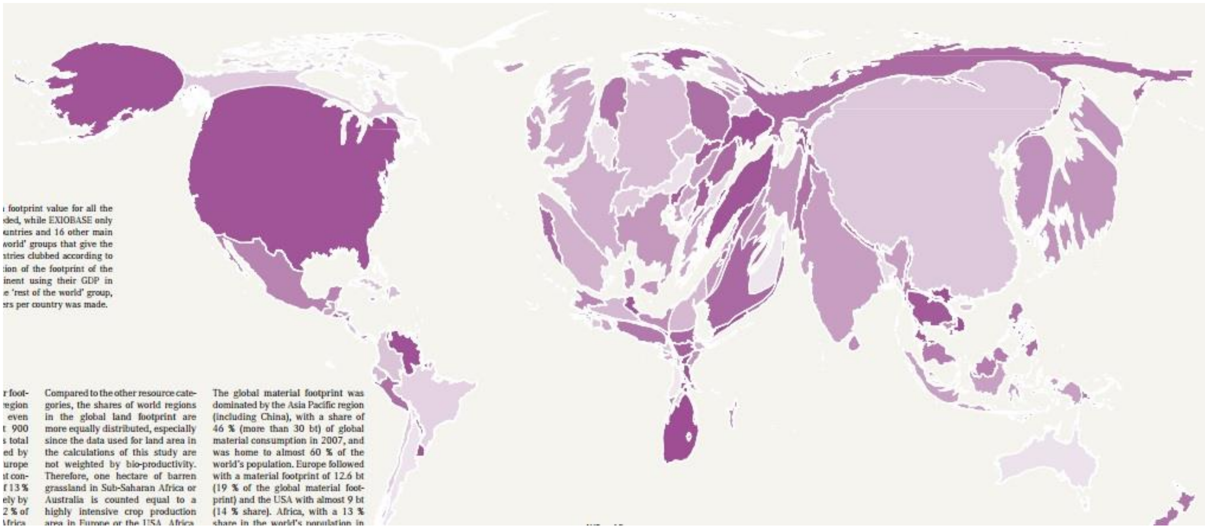
4 Applications of the Input-Output model

4.1 Calculation of consumption-based indicators

The overuse of resources calls for the calculation of consumption-based indicators. Each good consumed embodies natural resources. IO analysis can be used to measure it and answer the following important question: what is the carbon or resource content of a specific good consumed in a specific country? This question is crucial. The use of a resource should be attributed to the one who consumes it, not to the one who produces it. It was one element in the center of the negotiation around CO2 emission between advanced and developing countries during the COP 21 (2015 United Nations Climate Change Conference).

Using this criteria, the ranking regarding resilient countries may change as illustrated in the figure below. The figure presents the world map where the size of the country represents the size of its resource footprint. The footprints were calculated using EXIOBASE v2 within the CREEA project (www.creea.eu) which is the same input-output method and database as used in EXIOMOD. With our IO model we are able to produce the same results.

Figure 5.1: World map of resource footprints by country

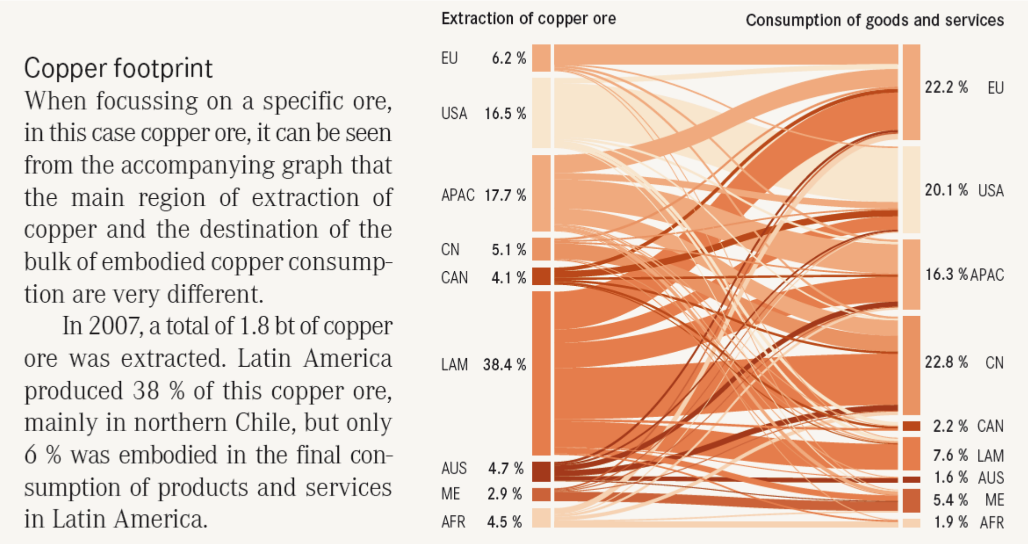


Source: CREEA Booklet, see Tukker et al. (2014)

The full chain from extraction of ores in one country is traced to the final consumption of embodied ores in other countries, in order to estimate footprints. An global multi-regional and environmentally extended input-output table, such as the EXIOBASE database, contains the relevant information for this calculation. EXIOBASE covers for each final product and consuming country (1) direct inputs and indirect inputs (i.e. the inputs used to produce the direct inputs); (2) the country of origin for each of the direct and indirect inputs; (3) the associated resource extraction for the each input and country of origin.

Very detailed footprints can be estimated using the EXIOBASE database as it has one of the most detailed products and environmental extensions that are currently available from input-output tables. In the most detailed set-up, footprints can be estimated by 49 regions (44 countries and five rest of the world regions), by 200 products and by various environmental indicators. The environmental indicators are available as an extension to the input-output tables and are listed in Table 3.1. For each of these indicators, footprints can be estimated. An example of such detailed footprint for copper is shown in Figure 5.2.

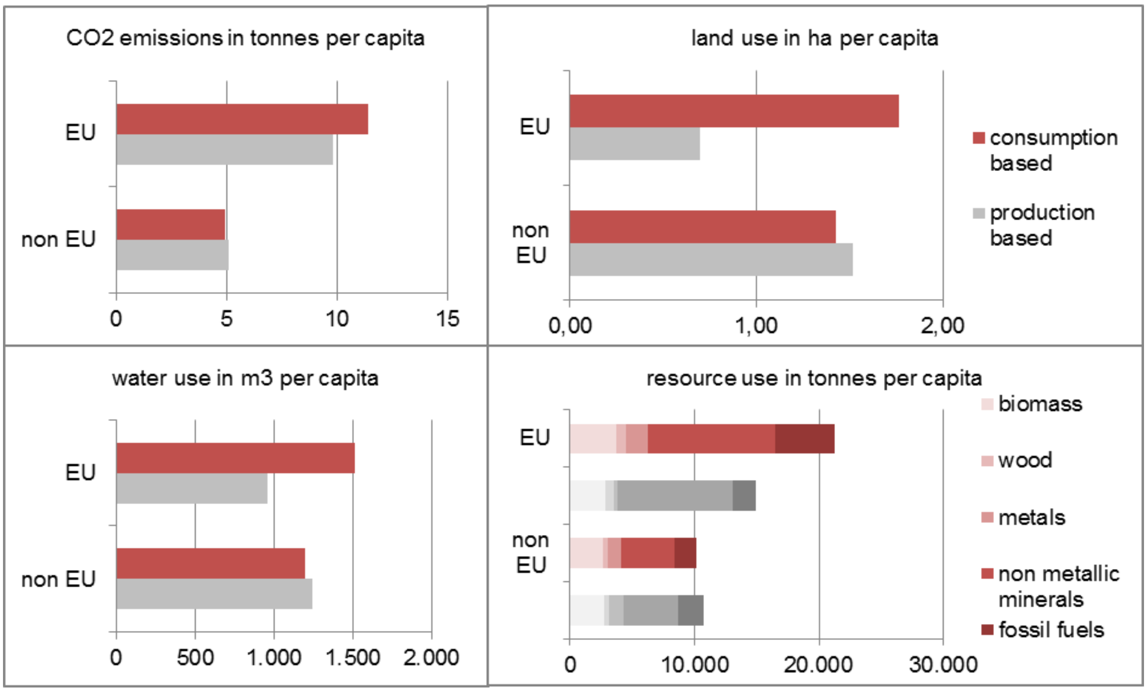
Figure 5.2: Extraction of copper ore by region and consumption of embodied copper in goods and services by region



Source: CREEA Booklet, see Tukker et al. (2014)

The same database and methods from the CREEA Booklet are used in the EXIOMOD modeling framework. Some EXIOMOD results are shown below on consumption based (footprint) and production based indicators for emissions, land, water and resource use. In the figure we see that there is a huge difference between the actual land use in the EU Member States compared to the land use footprint. The land use footprint per capita is two and half times larger as the actual land use per capita in the EU. Most of the required land to produce the agricultural products for the final consumption in the EU, is situated in non EU regions. The metal footprint per capita is even four and a half times more than the actual metal extraction in the EU. Similar trends can be seen for CO2 emissions, water use and other resource use.

Figure 5.3: Consumption based (footprint) and production based indicators on CO2 emission (tonnes/cap), land use (ha/cap), water use (m3/cap) and resources (tonnes/cap) for the EU and non EU region



5 Applications of the Computable General Equilibrium model

5.1 Decomposing price and volume effects

By using the modular approach of EXIOMOD 2.0, we can easily decompose results of a CGEM policy simulation into volume effects, i.e. with fixed prices in the input-output setup, and general equilibrium, or price, effects. This type of analysis helps a researcher to get a better understanding of policy assumptions used in a simulation and to make a decision whether the current version of the model captures all the necessary effects. In this section we provide an example of such a decomposition for a policy simulation regarding a change in the electricity production mix: development of renewable energy sources to replace fossil resources. Policy makers would typically be interested in the effect of such a policy on employment, production and on the environment.

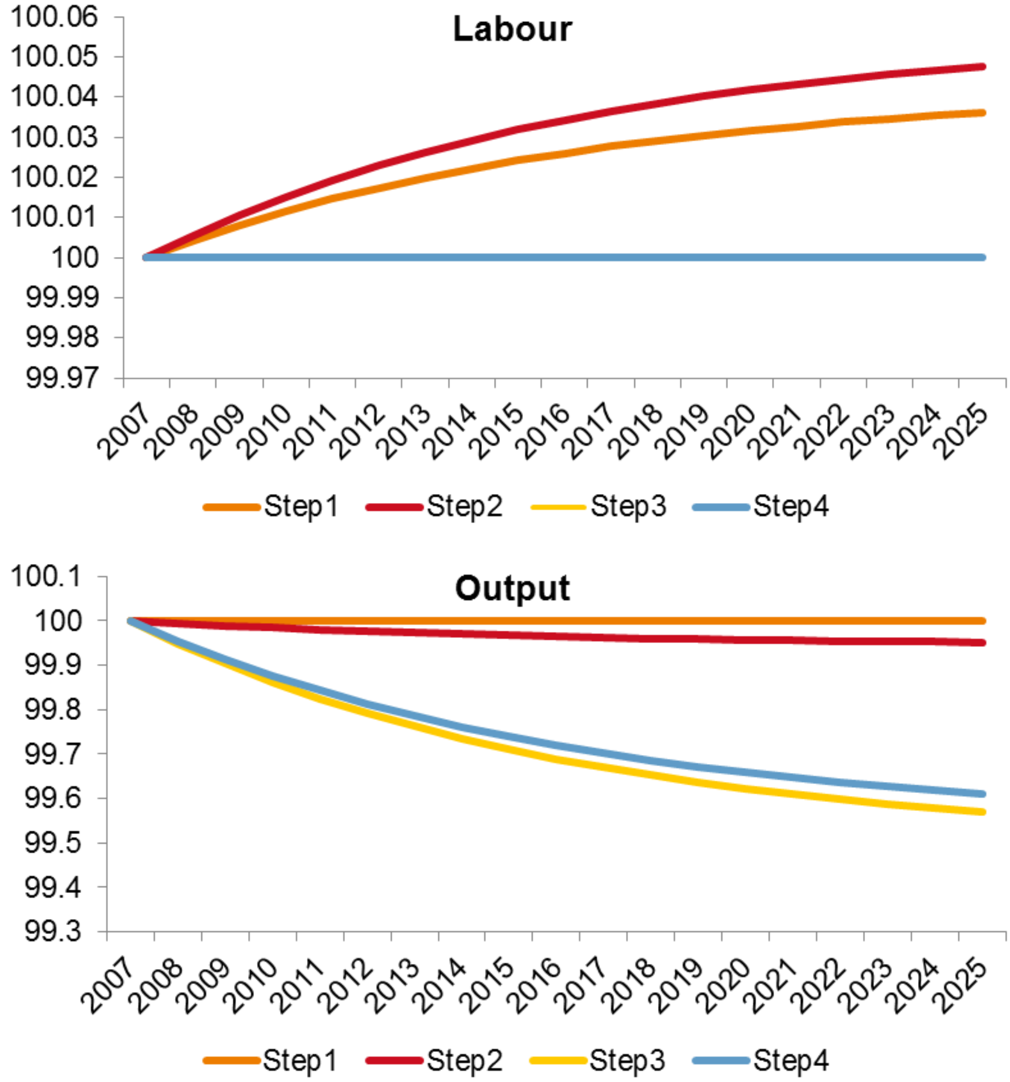
In the results presented below we compare two alternative visions of the future for EU-27 as a whole: (1) the shares of electricity generated by different technologies remain the same as today (baseline); (2) the share of renewable electricity gradually increases from nearly 0% to 55% by 2025 and the share of fossil-based electricity is gradually reduces from 65% to 10%, the share of nuclear power stays constant. The decomposition is done in the following 4 steps:

- Step 1: only direct effect of changing the electricity shares.
- Step 2: Step 1 + effects of changes in the intermediate demand (IO effect).
- Step 3: Step 2 + domestic price and income effects.
- Step 4: Step 3 + international price effects (full general equilibrium effect).

Figure 6.1 shows the decomposition results for the level of employment and output. The results are shown in comparison to the baseline scenario where the level of the baseline scenario has been normalized to 100. On Step 1, we see yet no effect on the output level because the direct effect implies only changes in the production shares of the electricity sectors, but not in the level of overall economic activity. But at the same time, the effect on employment is positive in Step 1, which is explained by a higher labor intensity of renewable electricity sectors, compared to fossil electricity. At the same time, renewable electricity is less intensive in terms of intermediate inputs, especially primary energy inputs, which leads to the negative IO effect on output level in Step 2. Although seemingly counterintuitive in the Step 2 result output decreases while employment increases, has a logical explanation. It comes from the difference in the input structures of renewable and fossil electricity sectors: the main suppliers of renewable technologies (manufactures and services) are more labor intensive than the main suppliers of fossil technologies (mining). This becomes clearly visible though our IO analysis.

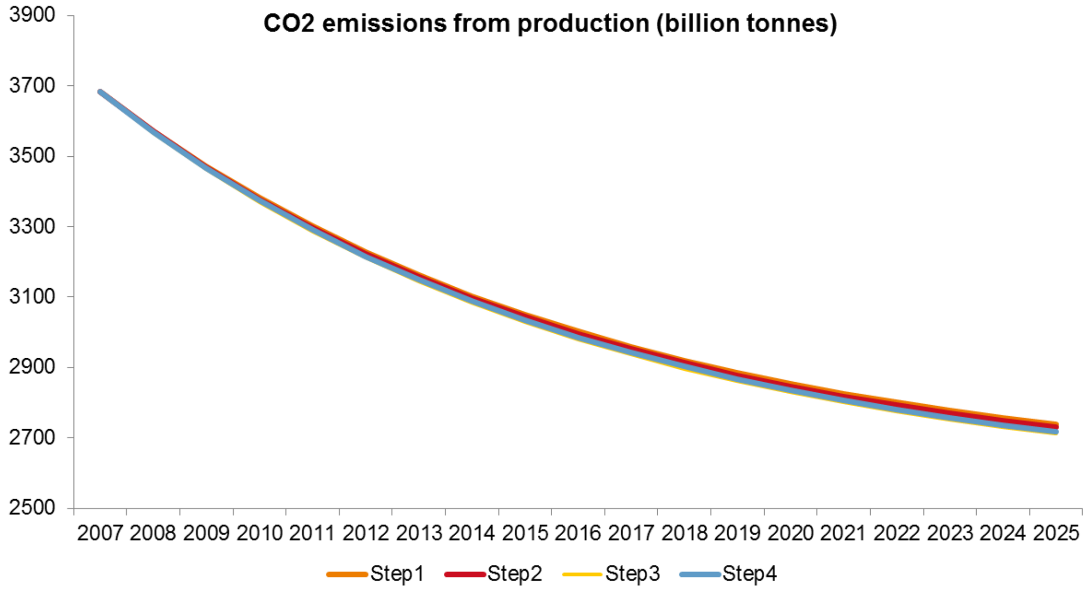
In Step 3 and 4, we include market clearing conditions for all markets. In the version of the model used in this exercise, we have assumed that the labor market always clears, without any unemployment. This explains the drop of employment to the baseline levels. The drop in employment leads to the simultaneous reduction in the level of output that can be produced. Compared to the baseline case, the output has reduced because the increased share of renewable electricity increased the labor intensity of the economy, but the number of available labor force stayed the same. On Step 4 the output bounces back a bit due to addition of international trade effects, which allows to find a more optimal distribution of production factors between sectors.

Figure 6.1: Changes in the of level employment and output (total for EU-27) compared to the baseline scenario decomposed into 4 steps, baseline scenario is normalized to 100



As shown in Figure 6.2 the trends for carbon dioxide emissions are almost identical for all the 4 steps, meaning that performing only the analysis of direct effects can give already a pretty complete picture of the policy effect in terms of CO2 emissions. This also means that indirect effects such a rebound effects are relatively small here.

Figure 6.2: Development of CO2 emissions in EU-27 in the policy scenario decomposed into 4 steps



From the presented exercise on decomposition of CGE effects into several steps, a number of conclusions can be drawn. Firstly, the version of the model with the full clearance of the labor market is probably not suitable for analysis of this type of policy, especially if the question of employment is one of the central ones. The input-output block alone can give an idea about the employment effects, but the effect is probably over-estimated since it neglects possible tension on the labor market. A Keynesian closure, that accounts for involuntary unemployment would probably give an intermediate result between the Walras closure and the IO case. Secondly, the effect on CO2 emissions can be estimated using a very simple version with only direct effects, without losing too much precision. It should be noted that this conclusion cannot be easily extended to other environmental effects without some additional trial model runs.

5.2 Policy scenarios to reach 2050 resource efficiency targets

This section describes an application of the EXIOMOD model in combination with the EXIOBASE database. The illustrative application is based on the work done by TNO in the FP7 project POLFREE. A policy mix aimed at reaching resource efficiency targets by 2050 is implemented in different compositions of intensity for each policy scenario. The economic and environmental effects of the policy scenarios are then compared to a baseline scenario.

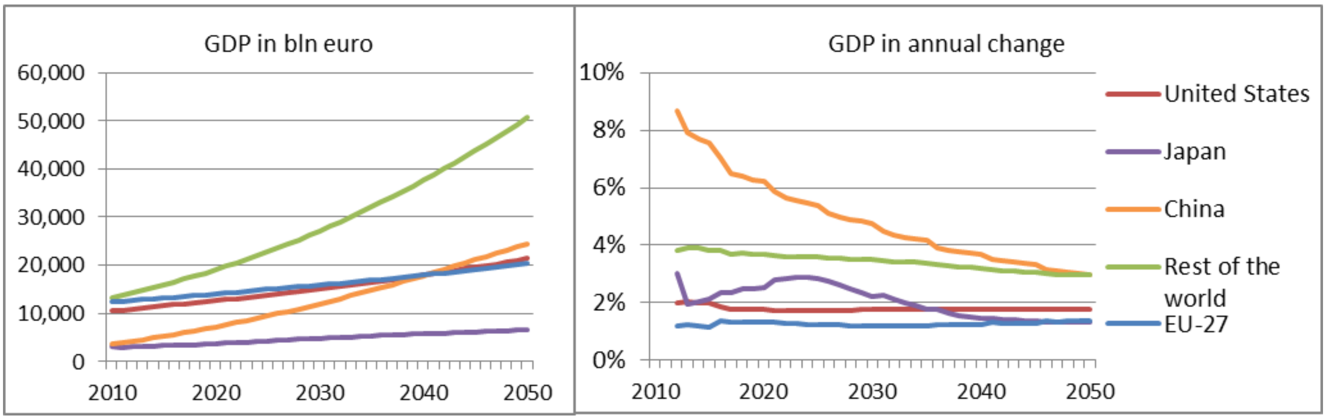
The baseline scenario assumes no additional policy interventions but incorporates exogenous projections of technical progress related to both capital-labour productivity and resource efficiency (energy and materials). The first policy scenario is called “Global cooperation” and assumes global implementation of the policy mix. Scenario 2 “EU goes ahead” assumes that only the EU-27 implements the policy mix while the rest of the world will follow the baseline trajectory.

A number of policy measures are included in the policy mix aimed at energy, transport, built environment, food, materials and recycling. These include market based instruments (such as carbon tax and public transport subsidies), regulatory instruments (such as recycling quota and eco-design standards) as well as educational instruments (such as information program on food waste). More details can be found in the POLFREE report on scenario interpretation (see Deliverable 3.7b available on www.polfree.eu).

The combination of the EXIOMOD model and the EXIOBASE database enables the modeling of the linkages between the economy and environment. In EXIOMOD we could easily switch on modules that are important for this study. We differentiated between necessity and luxury goods for final consumption and enabled investments in energy efficient technologies for the industry. Other modules in the model were kept in its standard form as accepted by the literature.

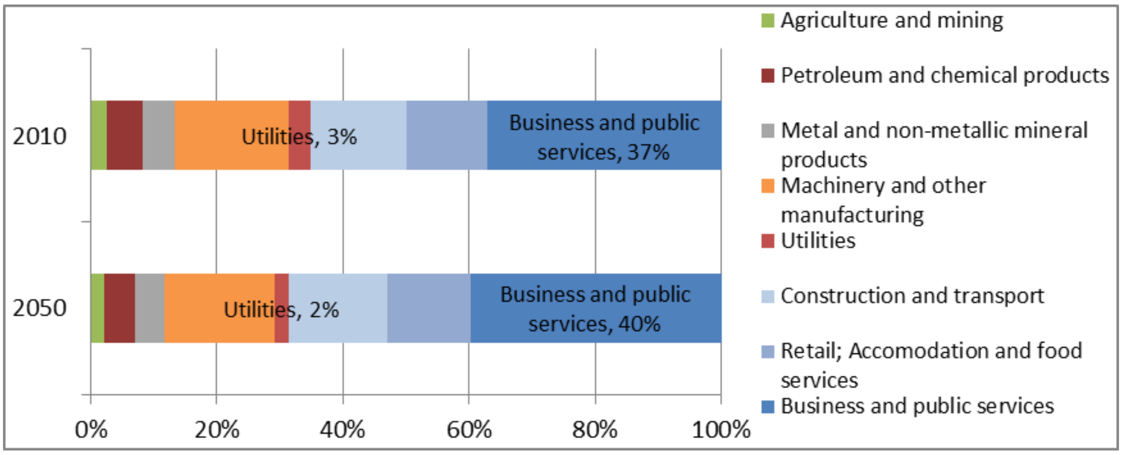
Baseline scenario
The baseline scenario shows how the world will look by 2050 based on historical trends. Figure 6.3 shows the GDP projections for the main world regions. The developing regions are expected to grow faster compared to developed regions and can even overtake them (e.g. China). These baseline values are based on exogenous projections of productivity, population and technical improvement of resource efficiency. We use economic growth projections from the CEPII EconMap v2.2 database (Fouré et al., 2012; Fouré et al., 2013).

Figure 6.3: GDP in bln euro and annual change by region in the baseline scenario, 2010-2050



Another important driver of how the world will look by 2050 is the sectoral composition. Figure 6.4 shows the sectoral output in the EU-27 in 2010 and 2050. We see that the share of resource intensive sectors will decrease while the labour intensive sectors will increase. This is caused by the consumption function where additional income is spent more on luxury products (e.g. services) rather than on basic goods (e.g. food). The share of business and public services is expected to grow substantially from 37 percent to 40 percent. On the other hand the share of resource intensive sectors such as petroleum (from six to five percent) and utilities (from three to two percent) will decline. These sectoral trends are driven by the LES-CES demand structure with income elasticities differentiated by sector. EXIOMOD bases its CES-LES income elasticities on the Worldscan and GTAP model (Lejour et al., 2006).

Figure 6.4: Output by sector in the EU-27 in shares in the baseline scenario, 2010 and 2050



The environmental extensions of the EXIOBASE database allow for modelling various environmental indicators. The figure below shows the results on CO2 emissions for the EU-27 and the world. The EU target of 40% reduction of CO2 emissions by 2030 compared 1990 levels is reached but the EU target of 80% reduction by 2050 is not. The global target of 12,000 Mt should be reached to follow the two degree pathway according to the Shell LENS scenarios (Royal Dutch Shell, 2013). However, the gap with the global 2050 target is significant and even becomes larger over time. CO2 emissions are driven by the endogenous sectoral composition as well as assumptions on energy productivity and carbon intensity. Assumptions on energy and carbon efficiency improvements in the future are derived from the 2013 EU reference scenario (European Commission, 2013).

Figure 6.5: CO2 emissions by region in Mt in the baseline scenario, 2010-2050

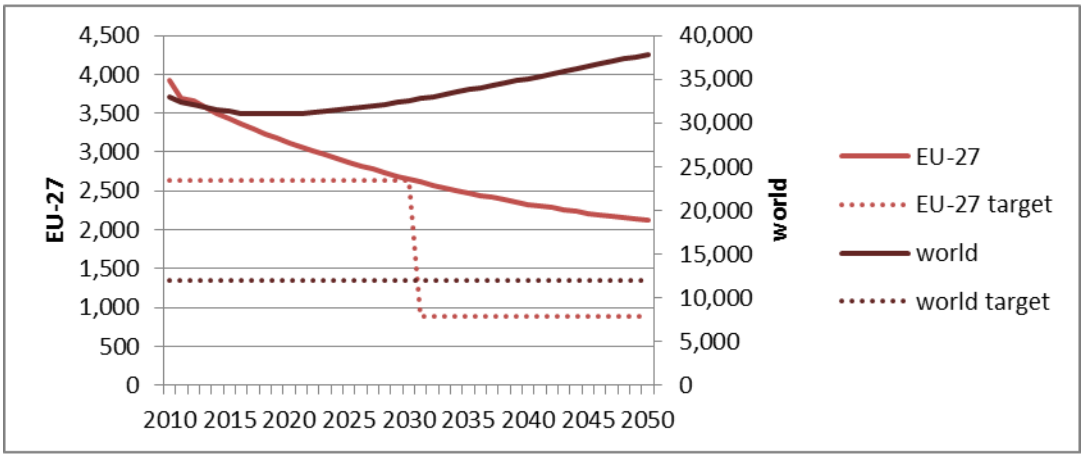
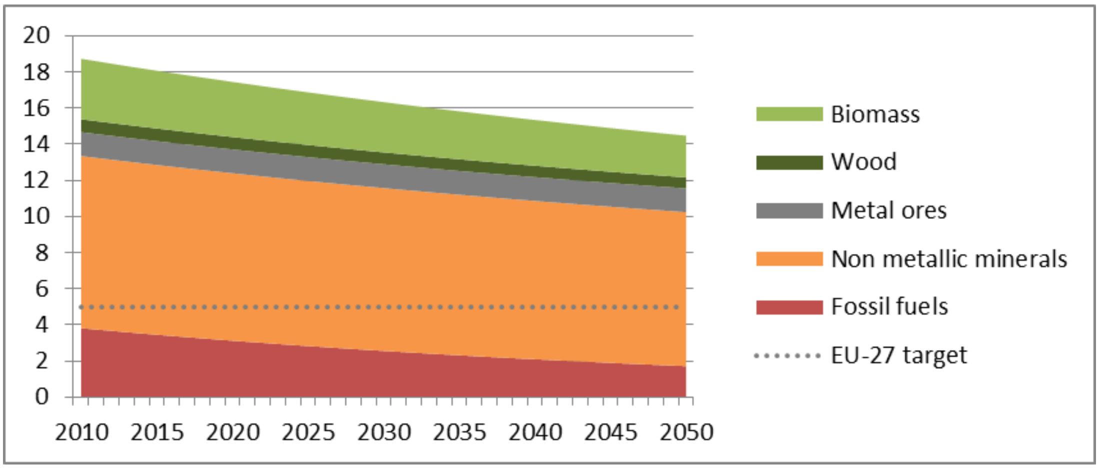


Figure 6.6 shows the raw material consumption or raw material footprint in the EU-27 in tonnes per capita. Total raw material consumption is expected to decrease from 19 tonnes per capita in the 2010 to 14 tonnes per capita in 2050. However, the 2050 EU target is five tonnes per capita.

Figure 6.6: Raw material consumption by material type in the baseline scenario, in tonnes per capita, EU-27, 2010-2050



Policy scenarios

The economic and environmental effects of implementing the policy mix at global level (Scenario 1) or at EU level (Scenario 2) are described below. The model takes into account substitution and rebound effects of policy measures. For instance a tax can make a product less attractive for consumers and therefore leads to substitution towards other products. However subsidies that improve the energy efficiency of houses can cause rebound effects by making heating per degree temperature increase cheaper.

The effect on CO2 emissions of the policies from Scenario 1 “Global cooperation” and Scenario 2 “EU goes ahead” are shown in Figure 6.7 and Figure 6.8. In the EU-27 CO2 emissions are reduced by 10% in Scenario 1 and by 5% in Scenario 2 compared to the baseline scenario by 2050. In the case of Scenario 2 with implementation in the EU only, carbon leakage occurs. This means that substitution with products from non EU regions can partly offset the CO2 savings. However, in both scenarios the CO2 savings are not sufficient to reach the 2050 target. An additional 1.5% annual improvement in (technical) efficiency is required in order to reach the target. At the global level a larger reduction in CO2 emissions is reached as shown in Figure 6.8. In Scenario 1, 18% reduction is reached and in Scenario 2 this is 13%. Nonetheless, the gap with the global target is huge and the gap is still increasing over time.

Figure 6.7: EU-27 CO2 emissions in Mt by scenario, 2010-2050

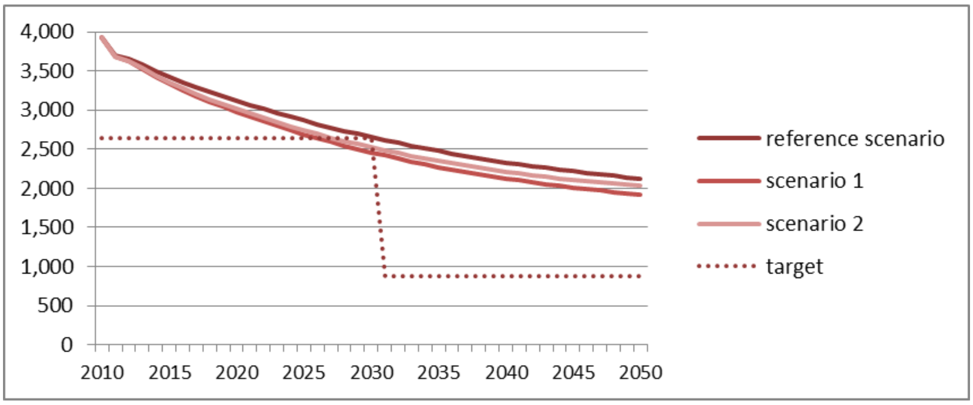
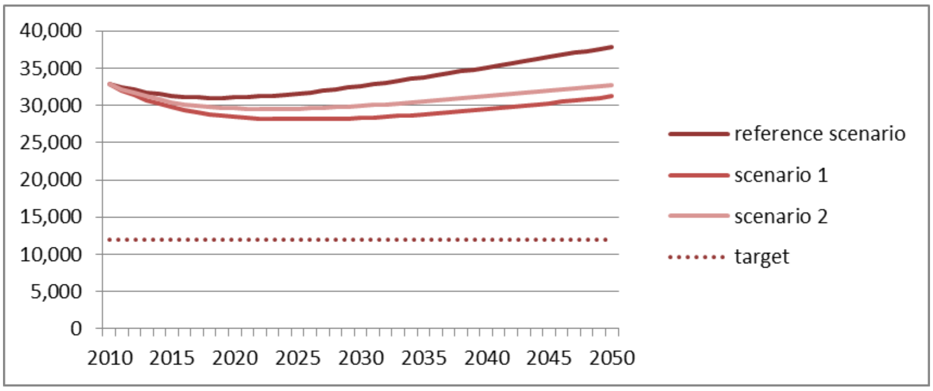


Figure 6.8: World CO2 emissions in Mt by scenario, 2010-2050



The implementation of the policy mix at the global level shows a larger reduction in raw material consumption compared to an implementation at only EU level. The effect on the material footprint are shown in Figure 6.9 for the EU and for the world. The raw material consumption amounts to nine tonnes per capita in Scenario 1 “Global cooperation” and ten tonnes per capita in Scenario 2 “EU goes ahead”. At the world level the raw material consumption amounts to six and seven tonnes per capita. The target of five tonnes per capita by 2050 is nearly reached at the global level.

Figure 6.9: EU-27 raw material consumption in tonnes per capita, 2010 and 2050

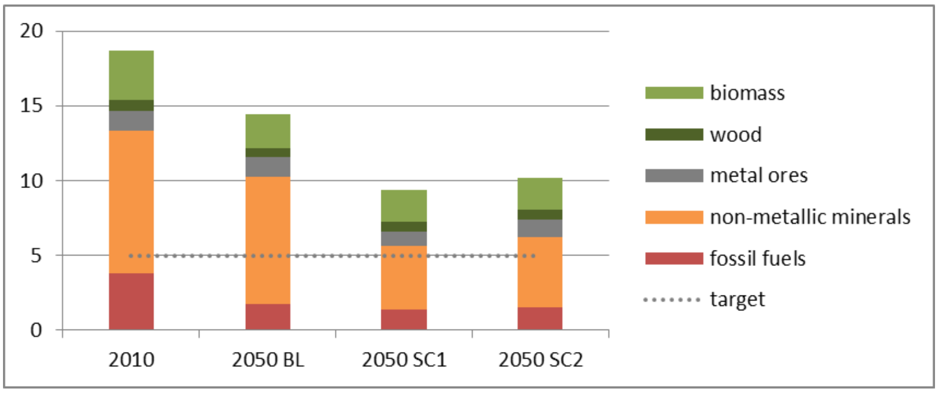
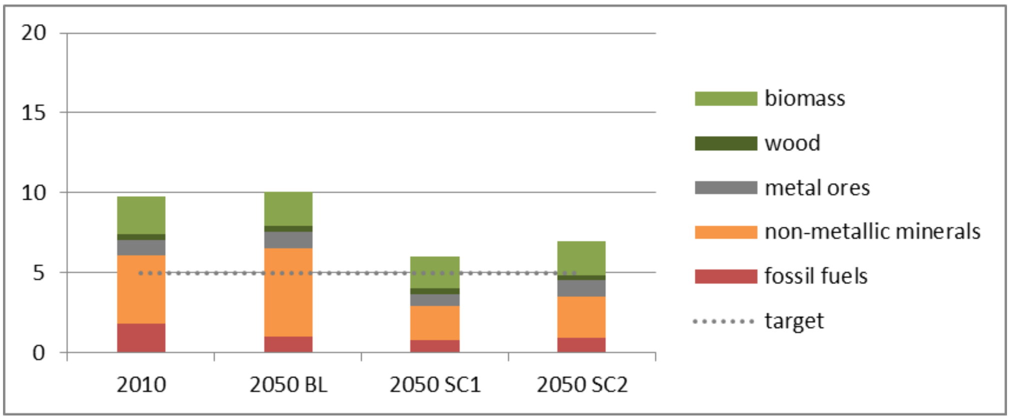


Figure 6.10: World raw material consumption in tonnes per capita, 2010 and 2050



The effects on GDP are very small but negative in both scenarios. Implementation in the EU only will not harm the EU economy. In fact, economically it is slightly better when EU goes ahead compared to global implementation. This is due to the compensating effects of tax recycling and international trade. Tax revenues are recycled as labour cost reduction and this stimulates labour intensive sectors, giving them an advantage at the international market. This will increase exports that increases economic growth. The compensating effects of trade do not occur to this extent in the case of global implementation. The GDP values are given in Figure 6.11 for the EU and Figure 6.12 for the world. GDP is 0.7 per cent lower in the EU by 2050 in Scenario 1 compared to the baseline scenario and in Scenario 2 this is 0.6 percent. The world GDP is due to the policy mix is one (resp. 0.9) percent lower by 2050 in Scenario 1 (resp. Scenario 2) compared to the baseline scenario.

Figure 6.11: EU-27 GDP in % difference compared to baseline scenario, 2010-2050

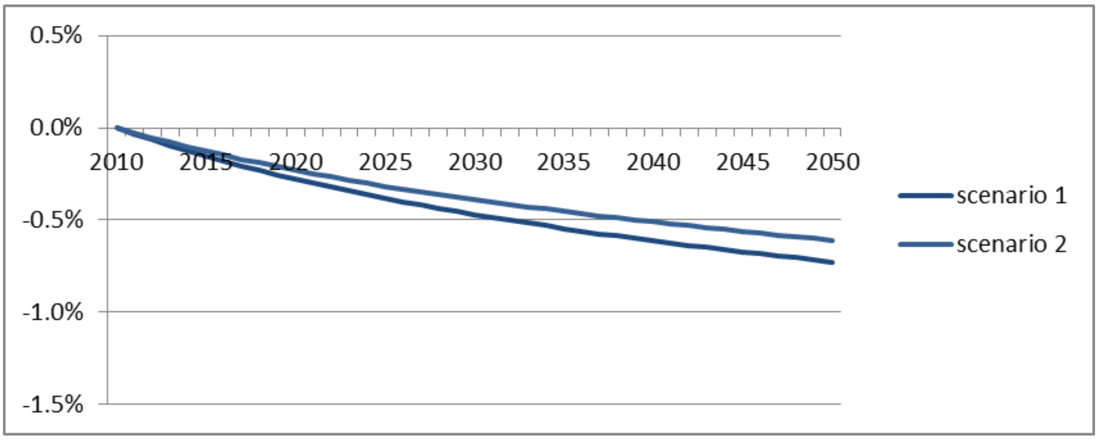
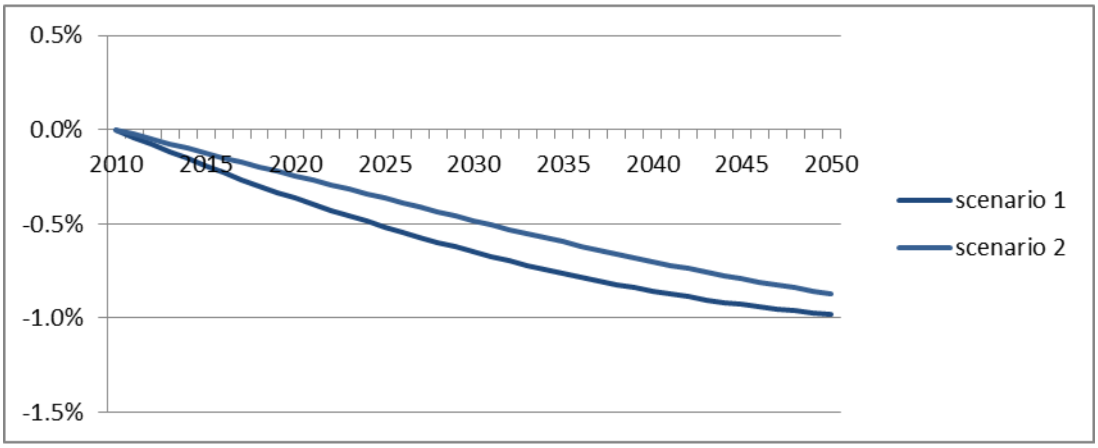


Figure 6.12: World GDP in % difference compared to baseline scenario, 2010-2050



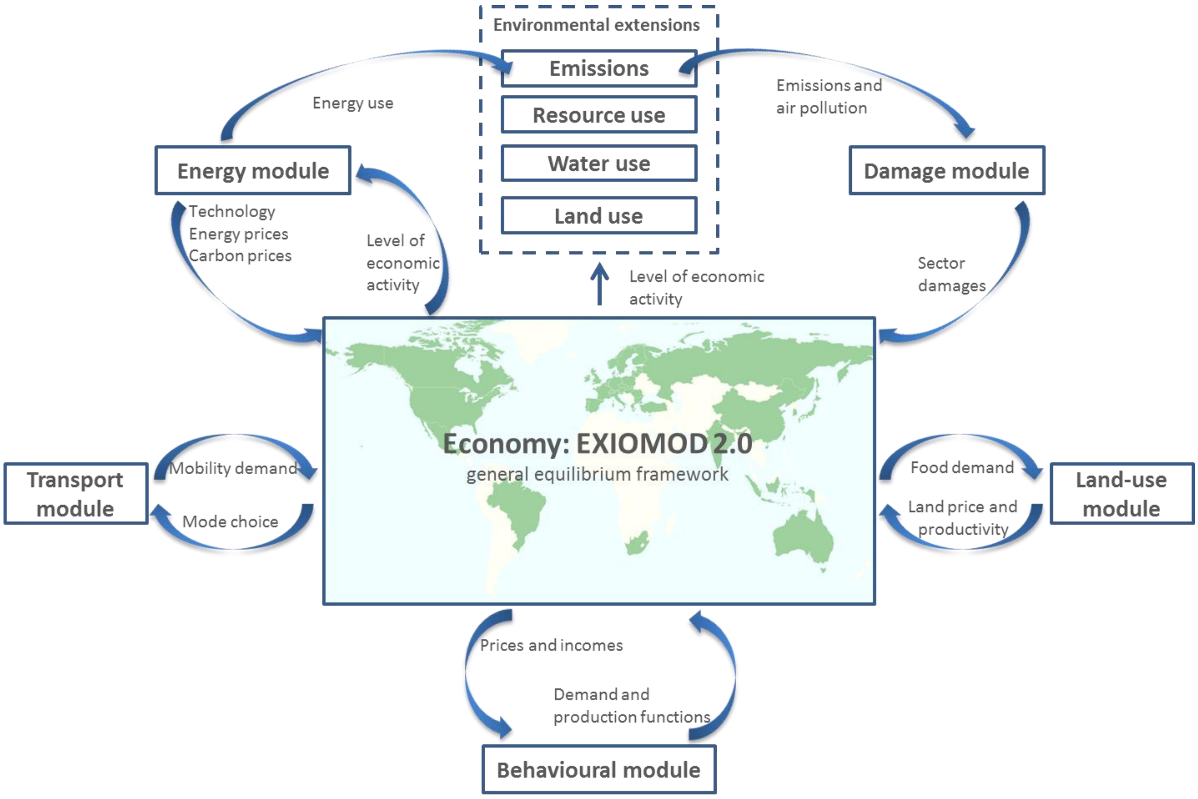
The results show that the implementation of climate and resource policy at the global level, rather than only at EU-27 level, has a higher impact on reducing emissions and resource use. This does come with a slightly higher economic cost. However the environmental benefits of implementation at the global level (five percent less CO_2 and one tonne less resources per capita) is relatively larger than the economic costs (0.1 percent less GDP).

6 Further extensions

In this paper we have introduced a new version of Computable General Equilibrium model EXIOMOD 2.0. EXIOMOD's name stands for EXtended Input-Output MODel. "Extended" refers to the fact that it can extend the standard Input-Output (IO) analysis in two main directions: (1) to CGEM analysis, and (2) to specific topics such as environmental impacts, energy, or transport. Whereas EXIOMOD 1.0 was a standard CGEM with a Walrasian closure, EXIOMOD 2.0 is based on a modular approach specifically designed to conduct both IO analysis and CGEM simulation. EXIOMOD 2.0 introduces a new standard into the world on CGEMs, where flexibility, transparency and robustness become the key criteria of a model's relevance and applicability. This has been translated into a set of modelling principles that represent our modelling philosophy.

EXIOMOD can be used as a stand-alone model, but for some applications an integrated impact assessment can be achieved by linking EXIOMOD to models that describe the biophysical consequences of environmental pressure such as land use, climate dynamics, air quality, and emissions. This linking can also be used to better calibrate the exogenous variables of EXIOMOD such as changes in consumer behavior, production share, and technical parameters. Such linking is done in EM-PLUS, Economic Modelling PLatform for sUStainability. Figure 7.1 shows a conceptual modelling framework of EM-PLUS. Expansions and new applications of EM-PLUS will include analyzing distributional issues of environmental and resource efficiency policies with focus on climate change, impacts of local air pollutants on health, scarcity of natural resources and land use competition between food and bioenergy, renewable energy and energy efficient technologies.

Figure 7.1: The modelling framework of EM-PLUS



Our view is that the future of modelling environmental-economic-social problems requires a flexible way of coupling, depending on the research question, of the best and most relevant subsystem models. Hard linking seems promising but so far it give disappointing results: models do not have the same dimensions, same coverage; one error in one model goes into another model; long resolution time; many transaction cost (models in different modeling teams); IP issue often prevent from going beyond a "super" black-box. The explicit goal of EM-PLUS is to have a flexible modelling interface that allows combining models and databases relatively easily, depending on the research question at stake, while allowing the use of the full spatial, temporal and economic/sector details of EXIOMOD. In this, we build upon experiences as Asynchronous model coupling (e.g. Lockerby, Patronis, Borg, & Reese, 2015), next to more traditional soft linking approaches[7]. Asynchronous coupling relies on flexible combinations of tools that each run locally and individually and communicate with a central database.

EM-PLUS is currently under development, but some of the sub-models such as 'Energy' have been already used in projects. We further will analyze and evaluate to what extent the model coupling is successful and capable to better address specific stakeholder needs as compared to classical integrated assessment models.

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[7] See Millennium Assessment Reports (2005), http://www.millenniumassessment.org/en/index.html.

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Vitae

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Acknowledgements

The authors acknowledge the financial support of the European Community's Seventh Framework Programme funded project COMPLEX, funded under Grant Agreement No. 308601.

9 Appendix A: Modelling philosophy behind EM-PLUS

We have compiled the following list from various sources on software development (e.g., object-oriented, agile). We are not strictly following one of the existing approaches but rather finding a suitable mix of principles that will support long-term development of Economic Modelling Platform for Sustainability (EM-PLUS).

1. *Iterative, incremental and evolutionary development methods*: Tasks are broken into small increments, iterations, with minimal planning and do not directly involve long-term planning. This allows the project to adapt quickly to changing environment. An iteration might not add enough functionality to warrant a market release, but the goal is to have an available release (with minimal bugs) at the end of each iteration.

2. *Code vs. documentation*: Documentation should be "Just Barely Good Enough" (JBGE) - too much or comprehensive documentation would usually cause waste. Developers rarely trust detailed documentation because it's usually out of sync with code. At the same time too little documentation may also cause problems for maintenance, communication, learning and knowledge sharing.

3. *A module should be open for extension but closed for modification*: We should write our modules so that they can be extended, without requiring them to be modified. In other words, we want to be able to change what the modules do, without changing the source code of the modules.

4. *Classes that change together, belong together*: A large development project is subdivided into a large network of interrelated packages. The work to manage, test, and release those packages is non-trivial. The more packages that change in any given release, the greater the work to rebuild, test, and deploy the release.

5. *Depend in the direction of stability*: Stability is related to the amount of work required to make a change. One sure way to make a software package difficult to change, is to make lots of other software packages depend upon it. A package with lots of incoming dependencies is very stable because it requires a great deal of work to reconcile any changes with all the dependent packages. A piece of software that is designed to be stable should not depend on the piece that is designed to be flexible (not stable).

10 Appendix B: List of regions and sectors

Table 8.1: List of countries and regions in the EXIOBASE database

EU-27	Other main economies	Rest of the world
Austria	Australia	RoW Africa
Belgium	Brazil	RoW America
Bulgaria	China	RoW Asia and Pacific
Cyprus	Canada	RoW Europe
Czech Republic	India	RoW Middle East
Denmark	Indonesia	
Estonia	Japan	
Finland	Mexico	
France	Norway	
Germany	Russia	
Greece	South Africa	
Hungary	South Korea	
Ireland	Switzerland	
Italy	Taiwan	
Latvia	Turkey	
Lithuania	United States	
Luxembourg		
Malta		
Netherlands		
Poland		
Portugal		
Romania		
Slovakia		
Slovenia		
Spain		
Sweden		
United Kingdom		

Table 8.2: List of products in the EXIOBASE database

	Sector name		Sector name
1	Paddy rice	101	Cement, lime and plaster
2	Wheat	102	Ash for treatment, Re-processing of ash into clinker
3	Cereal grains nec	103	Other non-metallic mineral products
4	Vegetables, fruit, nuts	104	Basic iron and steel and of ferro-alloys and first products thereof
5	Oil seeds	105	Secondary steel for treatment, Re-processing of secondary steel
6	Sugar cane, sugar beet	106	Precious metals
7	Plant-based fibers	107	Secondary precious metals for treatment, Re-processing of secondary preciuos metals into new preciuos metals
8	Crops nec	108	Aluminium and aluminium products
9	Cattle	109	Secondary aluminium for treatment, Re-processing of secondary aluminium into new aluminium
10	Pigs	110	Lead, zinc and tin and products thereof
11	Poultry	111	Secondary lead for treatment, Re-processing of secondary lead
12	Meat animals nec	112	Copper products
13	Animal products nec	113	Secondary copper for treatment, Re-processing of secondary copper into new copper
14	Raw milk	114	Other non-ferrous metal products
15	Wool, silk-worm cocoons	115	Secondary other non-ferrous metals for treatment, Re-processing of secondary other non-ferrous metals
16	Manure (conventional treatment)	116	Foundry work services
17	Manure (biogas treatment)	117	Fabricated metal products, except machinery and equipment
18	Products of forestry, logging and related services	118	Machinery and equipment n.e.c.
19	Fish and other fishing products; services incidental of fishing (05)	119	Office machinery and computers
20	Anthracite	120	Electrical machinery and apparatus n.e.c.
21	Coking Coal	121	Radio, television and communication equipment and apparatus
22	Other Bituminous Coal	122	Medical, precision and optical instruments, watches and clocks
23	Sub-Bituminous Coal	123	Motor vehicles, trailers and semi-trailers
24	Patent Fuel	124	Other transport equipment
25	Lignite/Brown Coal	125	Furniture; other manufactured goods n.e.c.
26	BKB/Peat Briquettes	126	Secondary raw materials
27	Peat	127	Bottles for treatment, Recycling of bottles by direct reuse
28	Crude petroleum and services related to crude oil extraction, excluding surveying	128	Electricity by coal
29	Natural gas and services related to natural gas extraction, excluding surveying	129	Electricity by gas
30	Natural Gas Liquids	130	Electricity by nuclear
31	Other Hydrocarbons	131	Electricity by hydro
32	Uranium and thorium ores (12)	132	Electricity by wind
33	Iron ores	133	Electricity by petroleum and other oil derivatives
34	Copper ores and concentrates	134	Electricity by biomass and waste

	Sector name		Sector name
35	Nickel ores and concentrates	135	Electricity by solar photovoltaic
36	Aluminium ores and concentrates	136	Electricity by solar thermal
37	Precious metal ores and concentrates	137	Electricity by tide, wave, ocean
38	Lead, zinc and tin ores and concentrates	138	Electricity by Geothermal
39	Other non-ferrous metal ores and concentrates	139	Electricity nec
40	Stone	140	Transmission services of electricity
41	Sand and clay	141	Distribution and trade services of electricity
42	Chemical and fertilizer minerals, salt and other mining and quarrying products n.e.c.	142	Coke oven gas
43	Products of meat cattle	143	Blast Furnace Gas
44	Products of meat pigs	144	Oxygen Steel Furnace Gas
45	Products of meat poultry	145	Gas Works Gas
46	Meat products nec	146	Biogas
47	products of Vegetable oils and fats	147	Distribution services of gaseous fuels through mains
48	Dairy products	148	Steam and hot water supply services
49	Processed rice	149	Collected and purified water, distribution services of water
50	Sugar	150	Construction work
51	Food products nec	151	Secondary construction material for treatment, Re-processing of secondary construction material into aggregates
52	Beverages	152	Sale, maintenance, repair of motor vehicles, motor vehicles parts, motorcycles, motor cycles parts and accessoiries
53	Fish products	153	Retail trade services of motor fuel
54	Tobacco products	154	Wholesale trade and commission trade services, except of motor vehicles and motorcycles
55	Textiles	155	Retail trade services, except of motor vehicles and motorcycles; repair services of personal and household goods
56	Wearing apparel; furs	156	Hotel and restaurant services
57	Leather and leather products	157	Railway transportation services
58	Wood and products of wood and cork (except furniture); articles of straw and plaiting materials	158	Other land transportation services
59	Wood material for treatment, Re-processing of secondary wood	159	Transportation services via pipelines
60	Pulp	160	Sea and coastal water transportation services
61	Secondary paper for treatment, Re-processing of secondary paper	161	Inland water transportation services
62	Paper and paper products	162	Air transport services
63	Printed matter and recorded media	163	Supporting and auxiliary transport services; travel agency services
64	Coke Oven Coke	164	Post and telecommunication services
65	Gas Coke	165	Financial intermediation services, except insurance and pension funding services
66	Coal Tar	166	Insurance and pension funding services, except compulsory social security services
67	Motor Gasoline	167	Services auxiliary to financial intermediation
68	Aviation Gasoline	168	Real estate services

	Sector name		Sector name
69	Gasoline Type Jet Fuel	169	Renting services of machinery and equipment without operator and of personal and household goods
70	Kerosene Type Jet Fuel	170	Computer and related services
71	Kerosene	171	Research and development services
72	Gas/Diesel Oil	172	Other business services
73	Heavy Fuel Oil	173	Public administration and defence services; compulsory social security services
74	Refinery Gas	174	Education services
75	Liquefied Petroleum Gases (LPG)	175	Health and social work services
76	Refinery Feedstocks	176	Food waste for treatment: incineration
77	Ethane	177	Paper waste for treatment: incineration
78	Naphtha	178	Plastic waste for treatment: incineration
79	White Spirit & SBP	179	Inert/metal waste for treatment: incineration
80	Lubricants	180	Textiles waste for treatment: incineration
81	Bitumen	181	Wood waste for treatment: incineration
82	Paraffin Waxes	182	Oil/hazardous waste for treatment: incineration
83	Petroleum Coke	183	Food waste for treatment: biogasification and land application
84	Non-specified Petroleum Products	184	Paper waste for treatment: biogasification and land application
85	Nuclear fuel	185	Sewage sludge for treatment: biogasification and land application
86	Plastics, basic	186	Food waste for treatment: composting and land application
87	Secondary plastic for treatment, Re-processing of secondary plastic	187	Paper and wood waste for treatment: composting and land application
88	N-fertiliser	188	Food waste for treatment: waste water treatment
89	P- and other fertiliser	189	Other waste for treatment: waste water treatment
90	Chemicals nec	190	Food waste for treatment: landfill
91	Charcoal	191	Paper for treatment: landfill
92	Additives/Blending Components	192	Plastic waste for treatment: landfill
93	Biogasoline	193	Inert/metal/hazardous waste for treatment: landfill
94	Biodiesels	194	Textiles waste for treatment: landfill
95	Other Liquid Biofuels	195	Wood waste for treatment: landfill
96	Rubber and plastic products	196	Membership organisation services n.e.c.
97	Glass and glass products	197	Recreational, cultural and sporting services
98	Secondary glass for treatment, Re-processing of secondary glass	198	Other services
99	Ceramic goods	199	Private households with employed persons
100	Bricks, tiles and construction products, in baked clay	200	Extra-territorial organizations and bodies

11 Appendix C: Equations of EXIOMOD

1. **Input-output structure**

Equation 1.1: Product market balance: product output is equal to total uses, including intermediate use, household consumption, government consumption, gross fixed capital formation, stock changes and, in case of an open economy, export. Product market balance is expressed in volume. Product market balance should hold for each product produced in each region (i^o).

$$X_{i^o} = \sum_{j^d} IO_{i^o j^d} + \sum_{d} (CG_{i^o d} + CH_{i^o d} + I_{i^o d} + SV_{i^o d}) + \sum_{w} EXP_{i^o w} \qquad (1.1)$$

Equation 1.2A: Output level of products: given total amount of output per activity, output per product (i^o) is derived based on fixed output shares of each industry (j^d). Equation 1.2A corresponds to product technology assumption in input-output analysis, equation 1.2B corresponds to industry technology assumption in input-output analysis. Equation 1.2A is only suitable for input-output analysis where number of product is equal to number of industries. Equation 1.2A cannot be used in MCP setup.

$$X_{i^o} = \sum_{j^d} cpA_{i^o j^d} Y_{j^d} \qquad (1.2A)$$

Equation 1.2B: Output level of activities: given total amount of output per product, required output per activity (j^d) is derived based on fixed sales structure on each product market (i^o). Equation 1.2A corresponds to product technology assumption in input-output analysis, equation 1.2B corresponds to industry technology assumption in input-output analysis. Equation 1.2B is suitable for input-output and CGE analysis.

$$Y_{j^d} = \sum_{i^o} cpB_{i^o j^d} X_{i^o} \qquad (1.2B)$$

Equation 1.3: Demand for intermediate inputs on aggregated product level. The demand function follows Leontief form, where the relation between intermediate inputs of aggregated product (i) and output of the industry (j^d) in volume is kept constant.

$$IO_{ij^d} = io_{ij^d} Y_{j^d} \qquad (1.3)$$

Equation 1.4: Demand for domestically produced intermediate inputs. The demand function follows CES form, where demand of each industry (j^d) for each domestically produced product (i) depends linearly on the demand of the same industry for the corresponding aggregated product and with certain elasticity on relative prices of domestically produced product and aggregated imported product

$$IO^D_{ij^d} = IO_{ij^d} \phi^D_{ij^d} \left(\frac{P_{id}}{P^{IO}_{ij^d} (1 + tc^{IND}_{ij^d})} \right)^{-e^{IO\_DM}_{ij^d}} \qquad (1.4)$$

Equation 1.5: Demand for aggregated imported intermediate inputs. The demand function follows CES form, where demand of each industry (j^d) for each aggregated imported product (i) depends linearly on the demand of the same industry for the corresponding aggregated product and with certain elasticity on relative prices of aggregated imported product and domestically produced product

$$IO_{ij^d}^{M} = IO_{ij^d}\phi_{ij^d}^{M}\left(\frac{P_{id}^{M}}{P_{ij^d}^{IO}(1+tc_{ij^d}^{IND})}\right)^{-e_{ij^d}^{IO\_DM}} \quad (1.5)$$

2. **Factor demand**

Equation 2.1: Demand for aggregated production factors. The demand function follows Leontief form, where the relation between aggregated value added and output of the industry (j^d) in volume is kept constant.

$$VA_{j^d} = \alpha_{j^d}^{VA} Y_{j^d} \quad (2.1)$$

Equation 2.2: Demand for specific production factors. The demand function follows CES form, where demand of each industry (j^d) for each factor of production (f^o) depends linearly on the demand of the same industry for aggregated production factors and with certain elasticity on relative prices of specific factors of production.

$$KL_{f^o j^d} = \frac{VA_{j^d}}{fprod_{fj^d}}\alpha_{f^o j^d}\left(\frac{P_{f^o}^{KL}}{fprod_{fj^d} P_{j^d}^{VA}}\right)^{-e_{j^d}^{KL}} \quad (2.2)$$

3. **Final demand by households**

Equation 3.1: Household demand for aggregated products. The demand function follows CES form, where demand by households in each region (d) for each aggregated product (i) depends with certain elasticity on relative prices of different aggregated products. The final demand function is derived from utility optimization, but there is no market for utility and corresponding price doesn't exist, contrary to CES demand functions derived from optimization of a production function. Scaling parameter (SF_d^{FD}) is introduced in order to ensure budget constraint (see equation 10.10).

$$CH_{id} = SF_d^{CH}\theta_{id}^{CH}\left(P_{id}^{CH}(1+tc_{id}^{CH})\right)^{-e_d^{CH}} \quad (3.1)$$

Equation 3.2: Household demand for domestically produced products. The demand function follows CES form, where demand by households in each regions (d) for each domestically produced product (i) depends linearly on the demand by the same households for the corresponding aggregated product and with certain elasticity on relative prices of domestically produced products and aggregated imported product.

$$CH_{id}^{D} = CH_{id}\theta_{id}^{CH\_D}\left(\frac{P_{id}}{P_{id}^{CH}(1+tc_{id}^{CH})}\right)^{-e_{id}^{FD\_DM}} \quad (3.2)$$

Equation 3.3: Household demand for aggregated imported products. The demand function follows CES form, where demand by households in each region (d) for each aggregated imported product (i) depends linearly on the demand by the same households for the corresponding aggregated product and with certain elasticity on relative prices of aggregated imported product and domestically produced products.

$$CH_{id}^{M} = CH_{id}\theta_{id}^{CH\_M}\left(\frac{P_{id}^{M}}{P_{id}^{CH}(1+tc_{id}^{CH})}\right)^{-e_{id}^{FD\_DM}} \quad (3.3)$$

4. **Final demand by government**

EQUATION 4.1: Government demand for aggregated products. The demand function follows CES form, where demand by government in each region (d) for each aggregated product (i) depends with certain elasticity on relative prices of different aggregated products. Scaling parameter (SF^{GC}) is introduced in order to ensure budget constraint (see EQUATION 10.11).

$$CG_{id} = SF_{d}^{CG}\theta_{id}^{CG}(P_{id}^{CG}(1+tc_{id}^{CG}))^{-e_{d}^{CG}} \qquad (4.1)$$

EQUATION 4.2: Government demand for domestically produced products. The demand function follows CES form, where demand by government in each regions (d) for each domestically produced product (i) depends linearly on the demand by the same government for the corresponding aggregated product and with certain elasticity on relative prices of domestically produced products and aggregated imported product.

$$CG_{id}^{D} = CG_{id}\theta_{id}^{CG\_D}\left(\frac{P_{id}}{P_{id}^{CG}(1+tc_{id}^{CG})}\right)^{-e_{id}^{FD\_DM}} \qquad (4.2)$$

EQUATION 4.3: Government demand for aggregated imported products. The demand function follows CES form, where demand by government in each region (d) for each aggregated imported product (i) depends linearly on the demand by the same government for the corresponding aggregated product and with certain elasticity on relative prices of aggregated imported product and domestically produced products.

$$CG_{id}^{M} = CG_{id}\theta_{id}^{CG\_M}\left(\frac{P_{id}^{M}}{P_{id}^{CG}(1+tc_{id}^{CG})}\right)^{-e_{id}^{FD\_DM}} \qquad (4.3)$$

5. **Final demand by investment agent**

EQUATION 5.1: Investment agent demand for aggregated products. The demand function follows CES form, where demand by investment agent in each region (d) for each aggregated product (i) depends with certain elasticity on relative prices of different aggregated products. Scaling parameter (SF^{I}) is introduced in order to ensure budget constraint (see EQUATION 10.12).

$$I_{id} = SF_{d}^{I}\theta_{id}^{I}(P_{id}^{I}(1+tc_{id}^{I}))^{-e_{d}^{I}} \qquad (5.1)$$

EQUATION 5.2: Investment agent demand for domestically produced products. The demand function follows CES form, where demand by investment agent in each region (d) for each domestically produced product (i) depends linearly on the demand by the same investment agent for the corresponding aggregated product and with certain elasticity on relative prices of domestically produced products and aggregated imported product.

$$I_{id}^{D} = I_{id}\theta_{id}^{I\_D}\left(\frac{P_{id}}{P_{id}^{I}(1+tc_{id}^{I})}\right)^{-e_{id}^{FD\_DM}} \qquad (5.2)$$

EQUATION 5.3: Investment agent demand for aggregated imported products. The demand function follows CES form, where demand by investment agent in each region (d) for each aggregated imported product (i) depends linearly on the demand by the same investment agent for the corresponding aggregated product and with certain elasticity on relative prices of aggregated imported product and domestically produced products.

$$I_{id}^{M} = I_{id}\theta_{id}^{I\_M}\left(\frac{P_{id}^{M}}{P_{id}^{I}(1+tc_{id}^{I})}\right)^{-e_{id}^{FD\_DM}} \quad (5.3)$$

6. **Stock changes**

EQUATION 6.1: Stock changes of products. Stock changes of each product (i) produced in each region (o) supplied to each region (d) is a share of the corresponding product output. It is assumed that the stock changes are covered from income of the investment agent in the same region (d).

$$SV_{i^o d} = \theta_{i^o d}^{SV} X_{i^o} \quad (6.1)$$

7. **Inter-regional trade**

EQUATION 7.1: Total demand for aggregate products imported from modeled regions. The demand for each aggregated imported product (i) in each region (d) is a sum of the corresponding demand of industries, household, government and investment agent in this region.

$$IMP_{id} = \sum_{j} IO_{ij^d}^{M} + CH_{id}^{M} + CG_{id}^{M} + I_{id}^{M} \quad (7.1)$$

* EQUATION 7.2: Demand for aggregated import from modeled regions. The demand function follows CES form, where demand from each importing region (regg) for each product type (prd) produced in modeled regions depends linearly on the total demand for aggregated imported product in the same importing region and with certain elasticity on relative prices of the same product between rest of the world region and modeled regions.

$$IMP_{id}^{MOD} = IMP_{id}\gamma_{id}^{MOD}\left(\frac{P_{id}^{M\_MOD}}{P_{id}^{M}}\right)^{-e_{id}^{M\_ROW}} \quad (7.2)$$

* EQUATION 7.3: Demand for import from rest of the world region. The demand function follows CES form, where demand from each importing region (regg) for each product type (prd) produced in rest of the world region depends linearly on the total demand for aggregated imported product in the same importing region and with certain elasticity on relative prices of the same product between rest of the world region and modeled regions.

$$IMP_{id}^{ROW} = IMP_{id}\gamma_{id}^{ROW}\left(\frac{P_{id}^{ROW}}{P_{id}^{M}}\right)^{-e_{id}^{M\_ROW}} \quad (7.3)$$

EQUATION 7.4: Demand for bi-lateral trade transactions. The demand function follows CES form, where demand from each importing region (d) for each product type (i^o) produced in each exporting region (reg) depends linearly on the total demand for aggregated imported product (only from modeled regions) in the same importing region and with certain elasticity on relative prices of the same product types produced by different exporting regions.

$$TRADE_{i^o d} = IMP_{id}^{MOD}\gamma_{i^o d}^{TRADE}\left(\frac{P_{i^o}}{P_{id}^{M\_MOD}}\right)^{-e_{id}^{TRADE}} \quad (7.4)$$

Equation 7.5: Export supply to the rest of the world regions. Export of each product produced in each region (i^o) supplied to each rest of the world regions (w) is a share of the corresponding product output. It is assumed that the rest of the world regions are buying all the export supplied to them.

$$EXP_{i^o w} = \gamma^E_{i^o w} X_{i^o} \qquad (7.5)$$

8. **Factor and tax revenue**

Equation 8.1: Revenue from factors of production. The revenue of each specific factor (f^o) is a sum of revenues earned by the corresponding factor in each industry in each region (j^d).

$$F\_REV_{f^o} = \sum_{j^d} KL_{f^o j^d} P^{KL}_{f^o} \qquad (8.1)$$

EQUATION 8.2: Revenue from net taxes on products. The revenue in each region (o) is a sum of revenues earned from sales of products to industries (j) for intermediate use, households, government, investment agent in the same region.

$$TSP\_REV_d = \sum_{i^o}(\sum_j (IO_{i^o j^d} P^{IO}_{i^o} tc^{IND}_{ij^d}) + CH_{i^o d} P^{CH}_{i^o} tc^{CH}_{id} + CG_{i^o d} P^{CG}_{i^o} tc^{CG}_{id} + I_{i^o d} P^I_{i^o} tc^I_{id} + SV_{i^o d} P_{i^o} tc^{SV}_{id})$$
$$+ \sum_i P^{ROW} SV^{ROW}_{id} tc^{SV}_{id} \qquad (8.2)$$

Equation 8.3: Revenue from net taxes on production. The revenue from each specific tax type (o) is a sum of revenue earned from production activities of each industry in each region (j^d).

$$NTP\_REV_o = \sum_{j^d} Y_{j^d} P^Y_{j^d} tx^{IND}_{oj^d} \qquad (8.3)$$

EQUATION 8.4: Revenue from tax on export and international margins. The revenue in each region (o) is a sum of revenues earned from production activities of each industry (j^d) and from final consumers in each modeled region (o) and rest of the world region (w). The revenues from final consumers and rest of the world are not explicitly modeled and taken as exogenous values from the calibration year.

$$TIM\_REV_o = \sum_{j^d} Y_{j^d} P^Y_{j^d} tx^{TIM}_{oj^d} + \sum_d TIM^{FD}_{od} LASPEYRES_d + TIM^E_{ow} P^{ROW} \qquad (8.4)$$

9. **Final consumers budget**

EQUATION 9.1: Gross income of households. Gross income is composed of shares of factor revenues attributable to households in each region (d), and well as income transfers from other final users (u^o). At the moment income transfers is one of the exogenous variables of the model, therefore it is multiplied by a price index in order to preserve model homogeneity in prices of degree zero.

$$INC^{CH}_d = \sum_{f^o} F\_REV_{f^o} f^{DISTR\_CH}_{f^o d} \text{ with } u^d = CH^d \qquad (9.1)$$

EQUATION 9.2: Gross income of government. Gross income is composed of shares of factor revenues attributable to government in each region (d), tax revenues, as well as income transfers from other final users (u^o). At the moment income transfers is one of the exogenous variables of the model, therefore it is multiplied by a price index in order to preserve model homogeneity in prices of degree zero.

$$INC_d^{CG} = \sum_{f^o} F\_REV_{f^o} f_{f^o d}^{DISTR\_CG} + TSP\_REV_d + NTP\_REV_d + TIM\_REV_d \quad (9.2)$$

EQUATION 9.3: Gross income of investment agent. Gross income is composed of shares of factor revenues attributable to investment agent in each region (d), and well as income transfers from other final users (u^o). At the moment income transfers is one of the exogenous variables of the model, therefore it is multiplied by a price index in order to preserve model homogeneity in prices of degree zero.

$$INC_d^{I} = \sum_{f^o} F\_REV_{f^o} f_{f^o d}^{DISTR\_I} \quad (9.3)$$

Equation 9.4: Budget available for household consumption. Budget is composed of (1) gross income of households in each region (d) plus (2) net income transfers from other final users and less (3) international margin paid by household. At the moment income transfers is one of the exogenous variables of the model, therefore it is multiplied by a price index in order to preserve model homogeneity in prices of degree zero. The endogenous income transfers are income tax to the government in the same region and savings to the investment agent in the same region.

$$CBUD_d^{CH} = INC_d^{CH}$$

$$+[GTRF_d LASPEYRES_d + \sum_{u^o} TRANSFER_{u^d u^o}^{INC} LASPEYRES_d + TRANSFER_{u^d w}^{ROW} P^{ROW} + ty_d INC_d^{CH} + mps_d (INC_d^{CH}(1-ty_d))]$$

$$-[\sum_{ou} TIM_{ou^d}^{FD} LASPEYRES_d + \sum_{wu} TIM_{wu^d}^{FD\_ROW} P^{ROW} + TRANSFER_{u^o w}^{ROW} P^{ROW}]$$

with $u^d = CH^d$

with $u^o = CH^o$ (9.4)

EQUATION 9.5: Budget available for government consumption. Budget is composed of (1) gross income of government in each region (d) plus (2) household income tax revenue plus (3) net income transfers from other final users and less (4) international margin paid by government. At the moment income transfers is one of the exogenous variables of the model, therefore it is multiplied by a price index in order to preserve model homogeneity in prices of degree zero.

$$CBUD_d^{CG} = INC_d^{CG} + ty_d INC_d^{CH}$$

$$+[\sum_{u^o} TRANSFER_{u^d u^o}^{INC} LASPEYRES_d + TRANSFER_{u^d w}^{ROW} P^{ROW} - GTRF_d LASPEYRES_d - GSAV_d LASPEYRES_d]$$

$$-[\sum_{ou} TIM_{ou^d}^{FD} LASPEYRES_d + \sum_{wu} TIM_{wu^d}^{FD\_ROW} P^{ROW} + TRANSFER_{u^o w}^{ROW} P^{ROW}]$$

with $u^d = CG^d$

with $u^o = CG^o$ (9.5)

EQUATION 9.6: Budget available for gross fixed capital formation. Budget is composed of (1) gross income of investment agent in each region (d) plus (2) net income transfers from other final users less (3) expenditures on stock changes, and less (4) international margin on gross fixed capital formation and on (5) stock change. At the moment income transfers is one of the exogenous variables of the model, therefore it is multiplied by a price index in order to preserve model homogeneity in prices of degree zero. The endogenous income transfer is household savings in the same region.

$$CBUD_d^I = INC_d^I$$

$$+[mps_d (INC_d^{CH} (1-ty_d)) + GSAV_d LASPEYRES_d + \sum_{uu^o} TRANSFER_{u^d u^o}^{INC} LASPEYRES_d + TRANSFER_{u^d w}^{ROW} P^{ROW}]$$

$$-[\sum_{i^o} SV_{i^o d} P_{i^o} (1+tc_{id}^{SV}) + \sum_{i^w} SV_{i^w d}^{ROW} P_w^{ROW} (1+tc_{id}^{SV}) + \sum_{ou} TIM_{ou^d}^{FD} - \sum_{wu} TIM_{wu^d}^{FD\_ROW} P^{ROW} + TRANSFER_{u^o w}^{ROW} P^{ROW}]$$

with $u^d = I^d, S^d$

with $u^o = I^o$ (9.6)

10. **Prices**

EQUATION 10.1: Zero-profit condition. Industry output price for each industry (j) in each region (d) is defined in such a way that revenues earned from product sales less possible production net taxes are equal to the cost of intermediate inputs and factors of production, including possible product and factor taxes, plus, if modeled, excessive profit margins. Output price for one industry in one country is chosen as a numéraire (exogenous variable), so in order to keep the system square, the equation is not defined for this specific industry in this specific region.

$$Y_{j^d} P_{j^d}^Y (1 - \sum_o (tx_{oj^d}^{IND} + tx_{oj^d}^{TIM})) = \sum_{i^o} IO_{i^o j^d} P_{i^o}^{IO} (1 + tc_{ij^d}^{IND})$$

$$+\sum_{f^o} KL_{f^o j^d} P_{f^o}^{KL} + \sum_w TIM_{wj^d}^{IO\_ROW} P_w^{ROW} \quad (10.1)$$

Equation 10.2: Balance between product price and industry price. Price of each product in each region of production (i^o) is defined as a weighted average of industry prices, where weights are defined as output of the product by the corresponding industry . Price equation are only relevant for CGE model, and since only equation 1.2B is suitable for CGE model, the co-production coefficients of equation 1.2B are used.

$$P_{i^o} X_{i^o} = \sum_{j^d} P_{j^d}^Y cpB_{i^o j^d} X_{i^o} \quad (10.2)$$

Equation 10.3: Balance on production factors market. Price of each production factor (f^o) is defined in such a way that total demand for the corresponding production factor is equal to the supply of the factor less, if modeled, unemployment. Supply of production factors is one of the exogenous variables of the model.

$$KLS_{f^o} = \sum_{j^d} KL_{f^o j^d} \quad (10.3)$$

Equation 10.4: Balance between specific production factors price and aggregate production factors price. The aggregate price is different in each industry in each region (j^d) and is a weighted average of the price of specific production factors, where weights are defined as demand by the industry for corresponding production factors.

$$P_{j^d}^{VA} VA_{j^d} = \sum_{f^o} P_{f^o}^{KL} KL_{f^o j^d} \quad (10.4)$$

Equation 10.5: Balance between specific product price and aggregate product price for intermediate use. The aggregate price is different for each aggregated product (i) in each industry in each region (j^d) and is a weighted average of the price of domestically produced product and the aggregate import price, where weights are defined as corresponding demands for intermediate use.

$$P_{ij^d}^{IO} IO_{ij^d} = P_{id} IO_{ij^d}^{D} + P_{id}^{M} IO_{ij^d}^{M} \quad (10.5)$$

Equation 10.6: EQUATION 10.6: Balance between specific product price and aggregate product price for household consumption. The aggregate price is different for each aggregated product (i) demanded by households in each region (d) and is a weighted average of the price of domestically produced product and the aggregate import price, where weights are defined as corresponding household demands.

$$P_{id}^{CH} CH_{id} = P_{id} CH_{id}^{D} + P_{id}^{M} CH_{id}^{M} \quad (10.6)$$

EQUATION 10.7: Balance between specific product price and aggregate product price for government consumption. The aggregate price is different for each aggregated product (i) demanded by government in each region (d) and is a weighted average of the price of domestically produced product and the aggregate import price, where weights are defined as corresponding government demands.

$$P_{id}^{CG} CG_{id} = P_{id} CG_{id}^{D} + P_{id}^{M} CG_{id}^{M} \quad (10.7)$$

EQUATION 10.8: Balance between specific product price and aggregate product price for gross fixed capital formation. The aggregate price is different for each aggregated product (i) demanded by investment agent in each region (d) and is a weighted average of the price of domestically produced product and the aggregate import price, where weights are defined as corresponding gross fixed capital formation demands.

$$P_{id}^{I} I_{id} = P_{id} I_{id}^{D} + P_{id}^{M} I_{id}^{M} \quad (10.8)$$

EQUATION 10.9: Balance between total aggregated imported price and the price of rest of the world and modeled regions. The aggregate price is different for each product (i) in each importing region (d) and is a weighted average of the price of rest of the world and of the aggregated price of import from modeled regions, where weights are defined as corresponding demands for import from rest of the world and modeled regions.

$$P_{id}^{M} IMP_{id} = P_{id}^{M\_MOD} IMP_{id}^{MOD} + P^{ROW} IMP_{id}^{ROW} \quad (10.9)$$

EQUATION 10.10: Balance between specific imported product price and aggregated imported product price. The aggregate price is different for each product (i^o) in each importing region (d) and is a weighted average of specific product prices of exporting regions, where weights are defined as bi-lateral trade flows between the importing regions and the corresponding exporting regions.

$$P_{id}^{M\_MOD} IMP_{id}^{MOD} = \sum_{o} TRADE_{i^o d} P_{i^o}$$

Equation 10.10: Budget constraint of households. The equation ensures that the total budget available for household consumption is spent on purchase of products. The equation defines scaling parameter of households, see also explanation for EQUATION 3.1.

$$CBUD_d^{CH} = \sum_{i^o} CH_{i^o d} P_{i^o} (1 + tc_{id}^{CH}) + \sum_{i^w} CH_{i^w d}^{ROW} P_w^{ROW} (1 + tc_{id}^{CH}) \quad (10.10)$$

EQUATION 10.11: Budget constraint of government. The equation ensures that the total budget available for government consumption is spent on purchase of products. The equation defines scaling parameter of government.

$$CBUD_d^{CG} = \sum_{i^o} CG_{i^o d} P_{i^o} (1 + tc_{id}^{CG}) + \sum_{i^w} CG_{i^w d}^{ROW} P_w^{ROW} (1 + tc_{id}^{CG}) \quad (10.11)$$

EQUATION 10.12: Budget constraint of investment agent. The equation ensures that the total budget available for gross fixed capital formation is spent on purchase of products. The equation defines scaling parameter of investment agent.

$$CBUD_d^{I} = \sum_{i^o} I_{i^o d} P_{i^o} (1 + tc_{id}^{I}) + \sum_{i^w} I_{i^w d}^{ROW} P_w^{ROW} (1 + tc_{id}^{I}) \quad (10.12)$$

EQUATION 10.13: Budget constraint of investment agent. The equation ensures that the total budget available for gross fixed capital formation is spent on purchase of products. The equation defines scaling parameter of investment agent.

$$CBUD_d^{I} = \sum_{i} I_{id} P_{id}^{I} (1 + tc_{id}^{I}) \quad (10.13)$$

EQUATION 10.14: Balance of payments. Expenditures of rest of the world region on exports and income transfers are equal to the region's receipts from its imports. The balance is regulated by the price that intermediate and final users are paying for the products imported from rest of the world region.

$$\sum_{i^o} EXP_{i^o w} P_{i^o} + \sum_{o} TIM_{ow}^{E} P^{ROW} =$$

$$P^{ROW} \left[\sum_{id} IMP_{id}^{ROW} + \sum_{id} SV_{id}^{ROW} + \sum_{j^d} TIM_{wj^d}^{IO\_ROW} + \sum_{u^d} TIM_{wu^d}^{FD\_ROW} + \sum_{u^d} TRANSFERS_{u^d W}^{ROW} \right]$$

(10.14)

EQUATION 10.15: Laspeyres price index for households. The price index is calculated separately for each region (d).

$$LASPEYRES_d = \frac{\sum_{i^o} CH_{i^o d}^{0} P_{i^o} (1 + tc_{i^o d}^{CH})}{\sum_{i^o} CH_{i^o d}^{0} P_{i^o}^{0} (1 + tc_{i^o d}^{CH\,0})} \quad (10.15)$$

Indices

f	factor input categories
i	commodities
j	industries
o, d	modelled regions (origin/supply or destination/use regions)
u	final user categories (households CH, government CG, investment agent I and stock changes S)
w	rest of the world (RoW) regions

Endogenous variables

$CBUD_d^{CG}$	budget available for government consumption, by destination region
$CBUD_d^{CH}$	budget available for household consumption, by destination region
$CBUD_d^{I}$	budget available for gross fixed capital formation, by destination region
CG_{id}	government consumption on aggregated product level, by product and destination region
CG_{i^od}	government consumption of products on the most detailed level, by product and origin and destination region
CG_{id}^{D}	government consumption of domestically produced products, by product and destination region
$CG_{i^od}^{D}$	government consumption of domestically produced products, by product and origin and destination region, where origin and destination region are equal
CG_{id}^{M}	government consumption of aggregated product imported from modeled regions, by product and destination region
CH_{id}	household consumption on aggregated product level, by product and destination region
CH_{i^od}	household consumption of products on the most detailed level, by product and origin and destination region
CH_{id}^{D}	household consumption of domestically produced products, by product and destination region
$CH_{i^od}^{D}$	household consumption of domestically produced products, by product and origin and destination region, where origin and destination region are equal
CH_{id}^{M}	household consumption of aggregated product imported from modeled regions, by product and destination region
EXP_{i^o}	exports to the RoW, by product and origin region
EXP_{i^ow}	exports to the RoW, by product and origin and destination region
$F\_REV_{f^o}$	revenue from factors of production, by factor input category and origin region
$GTRF_d$	government social transfers, by destination region

I_{id}	gross fixed capital formation on aggregated product level, by product and destination region
$I_{i^o d}$	gross fixed capital formation of products on the most detailed level, by product and origin and destination region
I_{id}^{D}	gross fixed capital formation of domestically produced products, by product and destination region
$I_{i^o d}^{D}$	gross fixed capital formation of domestically produced products, by product and origin and destination region, where origin and destination region are equal
I_{id}^{M}	gross fixed capital formation of aggregated product imported from modeled regions, by product and destination region
IMP_{id}	total use of aggregated imported products, by product and destination region
IMP_{id}^{MOD}	total use of aggregated imported products from modeled regions, by product and destination region
IMP_{id}^{ROW}	total use of aggregated imported products from RoW regions, by product and destination region
INC_{d}^{CG}	gross income of government, by destination region
INC_{d}^{CH}	gross income of households, by destination region
INC_{d}^{I}	gross income of investment agent, by destination region
IO_{ij^d}	use of intermediate inputs, by product and industry and destination region (volume)
$IO_{i^o j^d}$	use of intermediate inputs, by product and industry and origin and destination region (volume)
$IO_{ij^d}^{D}$	use of domestically produced intermediate inputs, by product and industry and destination region
$IO_{ij^d}^{M}$	intermediate use of imported intermediate inputs, by product and industry and destination region (volume)
$KL_{f^o j^d}$	use of production factors, by factor input category and industry and origin and destination region
$LASPEYRES_{d}$	Laspeyres price index for household consumption, by destination region
$LASPEYRES_{o}$	Laspeyres price index for household consumption, by origin region
NTP_REV_{o}	revenue from net tax on production, by origin region
P_{i^o}	basic product price, by product and origin region
P_{id}	basic product price, by product and destination region
P_{id}^{CG}	aggregate product price for government consumption, by product and destination region

P_{id}^{CH}	aggregate product price for household consumption, by product and destination region
P_{id}^{I}	aggregate product price for gross fixed capital formation, by product and destination region
$P_{ij^d}^{IO}$	aggregate product price for intermediate use, by product and industry and destination region
$P_{f^o}^{KL}$	production factor price, by production factor and origin region
P_{id}^{M}	aggregate imported product price, by product and destination region
$P_{id}^{M\_MOD}$	imported product price from modeled regions, by product and destination region
$P_{id}^{M\_ROW}$	imported product price from RoW regions, by product and destination region
P^{ROW}	price of imports from the RoW, by RoW region
$P_{j^d}^{VA}$	aggregate production factors price, by industry and destination region
$P_{j^d}^{Y}$	industry output price, by industry and destination region
$SV_{i^o d}$	stock changes of products on the most detailed level, by product and origin and destination region
SF_d^{CG}	scale parameter for government consumption, by destination region
SF_d^{CH}	scale parameter for household consumption, by destination region
SF_d^{I}	scale parameter for gross fixed capital formation, by destination region
TIM_REV_o	revenue from tax on export and international margins, by origin region
$TRADE_{i^o d}$	bi-lateral trade flows, by product and origin and destination region (volume)
TSP_REV_d	revenue from net tax on products, by destination region
VA_{j^d}	use of aggregated production factors, by industry and destination region
X_{i^o}	output vector on product level, by product and origin country (volume)
Y_{j^d}	output vector on industry level, by industry and destination region (volume)

Exogenous variables

$CG_{i^w d}^{ROW}$ government consumption of products imported from the RoW regions, by product and origin and destination region

$CH_{i^o d}^{0}$ household consumption of products on the most detailed level in the base year, by product and origin and destination region

$CH_{i^w d}^{ROW}$ household consumption of products imported from the RoW regions, by product and origin and destination region

$cpA_{i^o j^d}$ co-production coefficients with mix per industry (product technology), by product and industry and origin and destination region

$cpB_{i^o j^d}$ co-production coefficients with mix per product (industry technology), by product and industry and origin and destination region

e_{d}^{CG} substitution elasticity between products for government final use, by destination region

e_{d}^{CH} substitution elasticity between products for household final use, by destination region

e_{d}^{I} substitution elasticity between products for capital formation final use, by destination region

$e_{id}^{FD\_DM}$ substitution elasticity between domestic and imported final use for all categories, by product and destination region

$e_{ij^d}^{IO\_DM}$ substitution elasticity between domestic and imported intermediate use, by product and industry and destination region

$e_{j^d}^{KL}$ substitution elasticity between capital and labour, by industry and destination region

$e_{id}^{M\_ROW}$ substitution elasticity between imports from RoW and aggregated import from modeled regions, by product and destination region

$e_{id}^{M\_TRADE}$ substitution elasticity between imports from different modeled regions, by product and destination region

$f_{f^o d}^{DISTR\_CG}$ distribution shares of factor income to budgets of final demand by origin and destination region and factor input (shares in value), by factor input category and origin and destination region

$f_{f^o d}^{DISTR\_CH}$ distribution shares of factor income to household budget (shares in value), by factor input category and origin and destination region

$f_{f^o d}^{DISTR\_I}$ distribution shares of factor income to gross fixed capital formation budget (shares in value), by factor input category and origin and destination region

$I_{i^w d}^{ROW}$ gross fixed capital formation of products imported from the RoW regions, by product and origin and destination region

io_{ij^d} technical input coefficients for intermediate inputs (relation in volume), by product and industry and destination region

$GSAV_{d}$ government savings, by destination region

KLS_{f^o}	supply of production factors by origin region and factor input, by factor input category and origin region
mps_d	marginal propensity to save of households, by destination region
$P^0_{i^o}$	basic product price in the base year, by product and origin region
TIM^E_{ow}	taxes and international margins paid by RoW over exported products to the RoW, by origin and destination region
TIM^{FD}_{od}	taxes and international margins paid over imported products for all final users, by origin and destination region
$TIM^{FD}_{ou^d}$	taxes and international margins paid over imported products for each final use category, by final user category and origin and destination region
$TIM^{FD\_ROW}_{wu^d}$	taxes and international margins paid over products imported from RoW for each final use category, by final user category and origin and destination region
$TIM^{IO\_ROW}_{wj^d}$	taxes and international margins paid over intermediate products imported from RoW for each industry, by industry origin and destination region
SV^{ROW}_{id}	stock changes of products imported from the RoW, by product and origin and destination region
tc^{CG}_{id}	tax and subsidies on products rates for government consumption (relation in value), by product and destination region
tc^{CH}_{id}	tax and subsidies on products rates for household consumption (relation in value) , by product and destination region
$tc^{CH0}_{i^o d}$	tax and subsidies on products rates for household consumption in the base year (relation in value) , by product and destination region
tc^{I}_{id}	tax and subsidies on products rates for gross fixed capital formation (relation in value) , by product and destination region
$tc^{IND}_{ij^d}$	taxes and subsidies on products rates for industries (relation in value), by product and industry and destination region
tc^{SV}_{id}	tax and subsidies on products rates for stock changes (relation in value) , by product and destination region
ty_d	household income tax rate, by destination region
$TRANSFER^{INC}_{u^o u^d}$	income transfers by origin and destination region and final user category
$TRANSFER^{INC}_{u^d u^o}$	income transfers, by final user category and destination and origin region
$TRANSFER^{ROW}_{u^d w}$	income transfers from the RoW regions, by final user category and destination and RoW region
$TRANSFER^{ROW}_{u^o w}$	income transfers to the RoW regions, by final user category and origin and destination region
$tx^{IND}_{oj^d}$	net taxes on production rates (relation to value), by industry and origin and destination region
$tx^{TIM}_{oj^d}$	rates of net taxes on exports and rates of international margins (relation in value), by industry and origin and destination region

Parameters

$\alpha_{f^o j^d}$ relative share parameter for factors of production within the aggregated nest (relation in volume), by factor input category and industry and origin and destination region

$\alpha_{j^d}^{VA}$ technical input coefficients for aggregated factors of production (relation in volume), by industry and destination region

$fprod_{fj^d}$ parameter on productivity on individual factors in the nest of aggregated factors of production

γ_{id}^{MOD} relative share parameter for imports originating from one of the modeled regions (relation in volume), by product and origin and destination region

γ_{id}^{ROW} relative share parameter for imports originating from RoW region (relation in volume), by product and origin and destination region

$\gamma_{i^o d}^{TRADE}$ relative share parameter for origin region of import (relation in volume), by product and origin and destination region

$\gamma_{i^o w}^{E}$ share coefficients for export (relation in volume), by product and origin and destination region

$\phi_{ij^d}^{D}$ relative share parameter for intermediate use of domestic products (relation in volume), by product and industry and destination region

$\phi_{ij^d}^{M}$ relative share parameter for intermediate use of imported products (relation in volume), by product and industry and destination region

θ_{id}^{CG} relative share parameter of government consumption on product level in total government demand (relation in volume), by product and destination region

$\theta_{id}^{CG\_D}$ relative share parameter for government consumption of domestic products (relation in volume), by product and destination region

$\theta_{id}^{CG\_M}$ relative share parameter for government consumption of products imported from modeled regions (relation in volume), by product and destination region

θ_{id}^{CH} relative share parameter of government consumption on product level in total household demand (relation in volume), by product and destination region

$\theta_{id}^{CH\_D}$ relative share parameter for household consumption of domestic products (relation in volume), by product and destination region

$\theta_{id}^{CH\_M}$ relative share parameter for household consumption of products imported from modeled regions (relation in volume), by product and destination region

θ_{id}^{I} relative share parameter of government consumption on product level in total household demand (relation in volume), by product and destination region

$\theta_{id}^{I\_D}$ relative share parameter for household consumption of domestic products (relation in volume), by product and destination region

θ_{id}^{I-M} relative share parameter for household consumption of products imported from modeled regions (relation in volume), by product and destination region

$\theta_{i^o d}^{SV}$ share coefficients for stock changes in products produced in the modeled regions (relation in volume), by product and origin and destination region