PROJECT N. 037033

EXIOPOL

A NEW ENVIRONMENTAL ACCOUNTING FRAMEWORK USING EXTERNALITY DATA AND INPUT-OUTPUT TOOLS FOR POLICY ANALYSIS

OUTLINE ON INTERFACE TO ECONOMY-WIDE AND BOTTOM-UP SECTORAL MODELS

Report of the EXIOPOL project

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1 Introduction

Environmentally-extended IO tables are an important building block of a variety of socio-economic models and other tools in use for sustainability impact assessment, in particular input-output (IO) models, econometric input-output (EIO) models, and computable general equilibrium (CGE) models. Furthermore, in recent years the philosophy of "chaining together" different models in order to cover different aspects of the analytical framework has gained substantial momentum (see for instance the EU-funded projects TRANSTOOLS, SENSOR, SEAMLESS). In this sense, the IO framework can be usefully exploited as a tool to provide the economy-wide insights to complement the results of specific sectoral models.

One of the founding pillars of the EXIOPOL project is to develop a trade-linked multi-country database of supply & use and IO tables, extended with environmental and resource satellite accounts. Conversely, EXIOPOL does not have the ambition to develop new applied *models*. The objective of this Work Package is instead to ensure that the EE I-O database possess the necessary properties to be easily incorporated or linked to existing models, In other words to ensure a wide applicability of the data generated in the overall project for the European Commission with socioeconomic models and other quantitative tools.

2 Scope of the models considered

This Work Package will carry out demonstration activities for the linkage of a number of models with the EXIOPOL database. The list of models has been expanded, with respect to the original work plan as per DOW, in order to achieve a broad representation of the main types of socioeconomic models in mainstream use. These models will be:

(i) The World Trade Model (WTM), a multi-regional IO model with endogenous, bi-lateral determination of imports and exports; due to the thorough foreseen integration of the EXIOPOL database within the WTM, this task is reported separately in deliverable DIII.4.c.1

(ii) The class of CGE models that rely on the GTAP database.

(iii) The EIO model GINFORS, (**G**lobal **IN**terindustry **FOR**ecasting **S**ystem), a model specifically developed to allow for a global analysis of the economic-environmental interdependencies as a tool for concrete policy planning.

(iv) Sectoral models. They are models that provide very detailed information relative to a specific sector of the economy (typically agriculture, energy or transport) but by and large neglect the interactions with the rest of the economy. The IO framework can be utilised to expand the analysis with an estimate of the repercussions to the rest of the economy. JRC-IPTS has various models in use, for which such a linkage will be demonstrated; in particular the energy system model POLES, the agricultural model CAPRI and the transportation model TREMOVE.

3 Link with CGE models: GTAP based models

A large number of mainstream CGE models (and not only CGE models) use the GTAP (**G**lobal **T**rade **A**nalysis **P**roject) database as their main database.

The GTAP 6 database has 57 sectors defined with a focus on international trade. The sectors are pretty standard, without much resolution on services, except for a remarkable detail in the agro-food sectors. GTAP comprises 87 regions including all EU27 member states individually. For a detailed overview of GTAP 6 sectors and regions, see Dimaranan and McDougall (2006).

Trade and trade-related data include, for each region, the following trade flows:

- total exports from each sector to each other region (not resolved by sector)
- total imports to each sector from each other region (not resolved by sector)

GTAP (since the release of the GTAP-E extension of the GTAP4 database) furthermore contains some energy satellites (in physical units).

To be noted that the EXIOPOL project does not have the ambition to submit an update to the GTAP consortium. However, it can be expected that in the next future, probably already from the GTAP 7 release in 2008, a more consistent integration of EUROSTAT tables in GTAP will be achieved.

There is a specific interest for the WorldScan model which is used by DG ENTR, to analyze in more detail energy-intensive industries (similar to POLES sub-sectors: Iron & Steel, Aluminium, Pulp & Paper, Glass, Cement, Brick). A further disaggregation of the GTAP database with respect to energy-intensive industries would allow analysing the impact of energy/environmental policies on international competitiveness for the most-affected sectors in the economy. Furthermore, this interest in the disaggregation of energy-intensive sectors also exists for GTAP based models in general. This disaggregation is necessary because the sectoral classification that has been used so far shows some weaknesses. For instance, the sector “Non-ferrous metals” (NFM) of the GTAP database consists of different metals, e.g. aluminium, lead, zinc and copper, whose properties in production technologies, energy intensities and environmental performance in part vary tremendously. The same reasoning applies to other sectors, e.g. cement and glass, respectively, in the GTAP sector “Non-metallic minerals” (NMM) and pulp and paper in “Paper products, publishing” (PPP). These technological differences are not regarded in the current representation of many models. By using EXIOPOL data ZEW will attempt to overcome these weaknesses.

In order to carry out the sectoral disaggregation a variety of information will be needed. These encompass data on the production share of the subsectors in the respective aggregate sectors, data on production costs, output prices, international trade performance, taxes, emission shares of relevant pollutants, and, in particular, information about total consumption and demand structure. Regarding the last point, data on final consumption as well as the structure of intermediate consumption by industries are necessary.

EXIOPOL data could thus be of particular help for data availability of final consumption and the structure of intermediate demand by industries. This is a crucial and sophisticated part of the disaggregation procedure since other data sources often lack these informations. Furthermore, alternative IO based sources which could be used, e.g. the EIPRO database, see Tukker et al. (2006), do not distinguish between countries. Instead, the EIPRO database developed a framework for the EU25 aggregate which is founded on US production technologies.

The advantage of the EXIOPOL database is twofold. First, the coverage of countries included individually in the EXIOPOL regional classification according to Tukker et al. (2008) matches GTAP regions almost exactly. Nearly each individual country considered in EXIOPOL is a region in GTAP 6. There is only one exception for the case of Norway: in GTAP it is part of the region "Rest of EFTA" (XEF). Nonetheless, since the other members of that region, Iceland and Liechtenstein, are very small in relation to Norway, this fact should not cause enormous difficulties and could be easily transformed. Furthermore, important emerging economies, like China, India, Brazil and Mexico, are included individually. This circumstance is significant given, among other things, the huge amount of future emissions generated in these countries. In this manner it will be possible to perform a country-specific sectoral disaggregation with the help of EXIOPOL data which would not be feasible with previously available data.

Second, the EXIOPOL project entails a rich database of environmental extensions with the necessary sectoral detail, especially with regard to energy-intensive industries. The database contains 131 industries whereas GTAP 6 only includes 57 industries. Thus, EXIOPOL can contribute strongly to the disaggregation of sectors. Given the political interest in the analysis of energy-intensive sectors, the structuring is relatively straightforward. An overview of possible sectors that could be split out of the GTAP 6 database is given in Table 1.

Table 1: Concordance between GTAP 6 and EXIOPOL sectors of energy-intensive industries

GTAP 6 sector	EXIOPOL sector
Minerals nec (18 – OMN)	Mining of uranium and thorium ores (22)
	Mining of iron ores (23)
	Mining of copper ores and concentrates (24)
	Mining of nickel ores and concentrates (25)
	Mining of aluminium ores and concentrates (26)
	Mining of precious metal ores and concentrates (27)
	Mining of lead, zinc and tin ores and concentrates (28)
	Mining of other non-ferrous metal ores and concentrates (29)
	Quarrying of stone (30)
	Quarrying of sand and clay (31)
	Mining of chemical and fertilizer minerals, production of salt, other mining and quarrying nec (32)

Paper products, publishing (31 – PPP)	Manufacture of pulp, paper and paper products (49)
	Publishing, printing and reproduction of recorded media (50)
Petroleum, coal products (32 – P_C)	Manufacture of coke oven products (51)
	Manufacture of motor spirit (gasoline) (52)
	Manufacture of kerosene, including kerosene type jet fuel (53)
	Manufacture of gas oils (54)
	Manufacture of fuel oils nec (55)
	Manufacture of petroleum gases and other gaseous hydrocarbons, except natural gas (56)
	Manufacture of other petroleum products (57)
	Processing of nuclear fuel (58)
Chemical, rubber, plastic products (33 – CRP)	Manufacture of chemicals and chemical products (59)
	Manufacture of rubber and plastic products (60)
Mineral products nec (34 – NMM)	Manufacture of glass and glass products (61)
	Manufacture of ceramic goods (62)
	Manufacture of bricks, tiles and construction products, in baked clay (63)
	Manufacture of cement, lime and plaster (64)
	Manufacture of other non-metallic mineral products nec (65)
Ferrous metals (35 – I_S)	Manufacture of basic iron and steel and of ferro-alloys and first products thereof (66)
Metals nec (36 – NFM)	Precious metals production (67)
	Aluminium production (68)
	Lead, zinc and tin production (69)
	Copper production (70)
	Other non-ferrous metal production (71)
Ferrous metals (35 – I_S)	Casting of metals (72)
Metals nec (36 – NFM)	
Metal products (37 – FMP)	Manufacture of fabricated metal products, except machinery and equipment (73)
Machinery and equipment nec (41 – OME)	Manufacture of machinery and equipment nec (74)
	Manufacture of electrical machinery and apparatus nec (76)
	Manufacture of medical, precision and optical instruments, watches and clocks (78)

Manufactures nec (42 – OMF)	Manufacture of furniture; manufacturing nec (81)
	Recycling of metal waste and crap (82)
	Recycling of non-metal waste and crap (83)
Electricity (43 – ELY)	Production of electricity by coal (84)
	Production of electricity by gas (85)
	Production of electricity by nuclear (86)
	Production of electricity by hydro (87)
	Production of electricity by wind (88)
	Production of electricity nec including biomass and waste (89)
	Transmission of electricity (90)
	Distribution and trade of electricity (91)
Transport nec (48 – OTP)	Transport via railways (101)
	Other land transport (102)
	Transport via pipelines (103)
Water transport (49 – WTP)	Sea and coastal water transport (104)
	Inland water transport (105)
Air transport (50 – ATP)	Air transport (106)

Potential candidates for disaggregation
Do not need to be disaggregated

Note that not all of these sectors will be disaggregated. Table 1 is just a list of potential candidates. It is likely that one of those sectors will be split which are part of the EU Emissions Trading Scheme (EU ETS), see EU (2003) and EU (2008). This concerns in particular the production of aluminium, production of cement, production of glass, and manufacture of chemicals and chemical products.

ZEW will thus develop a prototype method for such a sector split by disaggregating one sector as a representative example. The steps that are necessary in order to perform the sector split will be identified during this task. Evidently, the use of other data sources is unavoidable, especially for the representation of trade flows and production levels. For instance, these sources can be UN Comtrade, OECD or Eurostat. However, EXIOPOL data would be used to illustrate final and intermediate consumption patterns of different countries. As outlined above, this is a crucial point for a reasonable implementation. So as to achieve these aims a program containing all relevant procedures will be evolved. This program will be provided so that the developed approach can be applied to other sectors. In this way, IO data which serve as the foundation of GTAP based models could be improved enormously.

The base year of the EXIOPOL framework is 2000 (Tukker et al., 2008). Since GTAP 6 is based on data from 2001, it is relatively simple to generate linkages between EXIOPOL and GTAP 6. Connections to the GTAP 7 database (base year 2004) are also desirable. However, a possible extrapolation to a later year (2005 or 2006) as intended in Tukker et al. (2008)

seems unlikely at the current state of the project since this extrapolation can only be performed if enough time resources are available.

4 Link with EIO models: GINFORS

In contrast to CGE models econometric input-output models (EIO) such as GINFORS or E3ME developed by Cambridge Econometrics (for a comparison see Barker et al. 2007) focus more on the econometric estimation of behavioural parameters. Therefore they are mainly based on time series data.

The model GINFORS (**G**lobal **IN**terindustry **FOR**ecasting **S**ystem) has been developed to allow for a global analysis of the economic-environmental interdependencies as a tool for concrete policy planning. It has been used as the simulation engine in the MOSUS project (www.mosus.net), which analysed as part of 5th frame program of the EU commission the impact of European resource strategies on the economic development and resource extractions in the world and all European countries (Giljum et al. 2008, Lutz et al. 2009, Meyer et al. 2007). Current applications include the analysis of future climate regimes (Lutz et al. 2008), the EU FP 6 INDI-LINK project and the Anglo-German Foundation petrE project looking into productivity and Environmental Tax Reform[1].

The model combines econometric-statistical analysis with input-output analysis embedded in a complete macroeconomic framework. The link between the economic developments in the countries is given by international trade, which is the result of global competition in deep sectoral disaggregation. Nearly all parameters of GINFORS are estimated econometrically using international time series data sets from the OECD, the IEA and the IMF.

The main sectoral data sources are OECD Input-Output tables (48 sectors), OECD Bilateral Trade database (BTD, 25 sectors plus services) and IEA Energy Balances and related Carbon emissions. GINFORS always uses the sector breakdown of these official sources. 50 countries and two regions (OPEC and Rest of World) are explicitly modelled. Country model for all EU-27 countries, all OECD countries and their major trading partners including China, India, Russia and Brazil are included.

The econometric estimation of behavioural parameters is a strength of econometric models compared to most CGE models. As EXIOPOL will not deliver time series data, it will not help to improve the econometric base of the models.

But as is the case for CGE models, a more disaggregated database (129 sectors instead of 48 in GINFORS) will be very helpful for different kinds of analysis, among others competitiveness impacts of ETS or ETR on energy-intensive sub-sectors of GINFORS. Information on inter-industry relations of different sub-sectors of different economies will help to better understand the different production structures and the range of potential changes, that may merely happen due to sub-sectoral structural change (on the level of the 129 sectors). The database will also add information on the international trade flows in GINFORS, which is especially limited so far in the sectors agriculture and mining and quarrying, being in the focus of EXIOPOL.

[1] In the INDI-LINK project an updated model description is going to be finished until end of October 2008. For more information on petrE see http://www.petre.org.uk

5 Link with sectoral models: rationale, strategy and models covered

Sectoral models, in many cases shaped as partial equilibrium models, are analytical instruments that allow achieving a high level of detail in a specific sector of the economy (typically agriculture, transport, or the energy system) but that include only a coarse, if any, representation of the markets outside the boundaries of their principal focus. In the trade-off between comprehensiveness and detail, in other words, they go for the latter with unfaltering intent. Economy-wide models, on the contrary, offer all the advantages of a description of the interactions between market forces, comprehensive and consistent with economic theory, but they do it at a cost, the cost of jettisoning much of the detailed bottom-up information content that is the central feature of sectoral model, and one that in certain policy applications simply cannot be done without.

In the last years, hybrid modelling strategies have picked up momentum, that are based on linking together a chain of heterogeneous models each one of which brings in its own strengths. Examples can be seen in a number of EC-funded large scale projects recently completed or under execution, such as TRANSTOOLS, SENSOR and SEAMLESS, and in some recent policy-support applications such as for instance Neuwahl et al, 2008.

In such hybrid applications, the IO framework can be utilised to expand the analysis with an estimate of the repercussions to the rest of the economy; the IO model can in fact be seen as a "bare" accounting framework free of behavioural equations. This feature limits the ability of the IO model per se to model complex interactions, but makes it excellently suited to integrate -as exogenous specifications- variables calculated externally using sectoral models for those variables at the core of the analytical exercise. It would in fact be much more laborious to align the results of two models if they were both driven by behavioural equations and where there would be no a priori guarantee that –say- the price response to a certain demand change would be the same.

The EXIOPOL EE-IO database has been specified with the explicit intention to maximise the potential for linkages with sectoral models in the areas of agro-food, of transportation and of energy. It does so by including a sufficient number of separate sectors in each of those areas; the EXIOPOL classification features in fact more than 25 agro-food commodities and industries, about ten different fuels, six different techniques for producing electricity, and six transportation modes. This ensures that the information originating from sectoral models can be incorporated in the economy-wide framework while maintaining the essential features of the detailed simulations.

The linkage between a sectoral model and an IO model can be implemented, at least in simple cases, in a straightforward manner by means of the computational structure of the mixed endogenous-exogenous variables IO model, elucidated here with the help of a hypothetical example. Suppose, for instance, that we have calculated, with detailed simulations for the farming sector, prices and output levels of agricultural commodities after the implementation of a CAP reform. The impacts of such changes in those variables on the broader economy can be calculated in the input-output framework with different levels of sophistication, potentially by combining a number of elements such as an IO price model to calculate price ripple effects, a household demand block to calculate the reallocation of budget after price and (real) income changes, etc. When conducting this exercise one has to make sure, however, that those quantities (Q) and prices (P), or the value P*Q, calculated by the sectoral model are not altered when running the IO model. This would not hold with the usual demand-driven IO model, where additional demand always translates into extra supply (demand is fully inelastic, supply fully elastic).

Hence, in order to secure consistency with the sectoral simulation results, the input-output model is implemented through a mixed exogenous-endogenous variables calculation algorithm (see for instance Miller and Blair, 1985), in which a modified demand-driven Leontief model admits as exogenous inputs the final demand in a subset of sectors and the gross outputs in the remaining ones, returning as endogenous variable the gross output and the final demand respectively. In this scheme the usual Leontief equation $X=(I-A)^{-1}Y$ is replaced by Equation 1, assuming that the gross output X of sectors 1 to m and the final demand Y of sectors m+1 to n are specified exogenously, and the final demand of sectors 1 to m and the gross output of sectors m+1 to n are calculated endogenously. Sectors 1 to m are in the present case those producing agricultural commodities, for which the output is to be constrained to the levels given by the sectoral model. The dashed lines in eq. 1 show the matrices partitioned by endogenous specification of the variable.

$$
\begin{bmatrix} Y_1 \\ Y_2 \\ \vdots \\ Y_m \\ \hline X_{m+1} \\ X_{m+2} \\ \vdots \\ X_n \end{bmatrix}
=
\left[\begin{array}{cccc:c}
-1 & 0 & \cdots & 0 & \\
0 & -1 & \cdots & 0 & -A_{1:m,m+1:n} \\
\vdots & \vdots & \ddots & \vdots & \\
0 & 0 & \cdots & -1 & \\
\hdashline
0 & 0 & \cdots & 0 & I_{m+1:n,m+1:n} - \\
0 & 0 & \cdots & 0 & A_{m+1:n,m+1:n} \\
\vdots & \vdots & \ddots & \vdots & \\
0 & 0 & \cdots & 0 &
\end{array}\right]^{-1}
\cdot
\left[\begin{array}{c:cccc}
 & 0 & 0 & \cdots & 0 \\
A_{1:m,1:m} - I_{1:m,1:m} & 0 & 0 & \cdots & 0 \\
 & \vdots & \vdots & \ddots & \vdots \\
 & 0 & 0 & \cdots & 0 \\
\hdashline
 & 1 & 0 & \cdots & 0 \\
 & 0 & 1 & \cdots & 0 \\
A_{m+1:n,1:m} & \vdots & \vdots & \ddots & \vdots \\
 & 0 & 0 & \cdots & 1
\end{array}\right]
\cdot
\begin{bmatrix} X_1 \\ X_2 \\ \vdots \\ X_m \\ \hline Y_{m+1} \\ Y_{m+2} \\ \vdots \\ Y_n \end{bmatrix}
\tag{1}
$$

Besides the adaptation of the computational structure of the IO model, the main elements needed in order to accomplish the linkage of the sectoral and the IO model are related to the alignment of classifications between the sectoral model and the IO framework. In our hypothetical agricultural policy example, the first and foremost step is in fact to map the detailed list of agro-food commodities of the sectoral model onto the list of products included in the IO scheme, in order to be able to translate P and Q changes calculated by the sectoral model into P and Q percentage changes of the (generally more aggregate) corresponding variables of the IO model. Additionally, some other elements may need alignment between the pair of models; for instance, TREMOVE includes a household demand system that calculates a fine-grained budget allocation for transportation needs along with the aggregate expenditure for all other purposes; one would then need to link this demand system to the expenditure basket that drives the IO model. These special instances are discussed case by case in the following subsections.

5.1 Energy system models: POLES

5.1.1 General overview

POLES[2] (Policy Outlook on Long-term Energy Systems) is a modelling tool for the global energy sector successively developed under EU research projects. It is a dynamic partial equilibrium model which simulates global energy systems and their global environmental impacts in the long term (up to 2050).

Based on scenarios and year-by-year recursive simulation, it gives projections for energy demand, supply and prices by main regions and sectors, which makes possible the analysis of CO2 emission reduction options in an international perspective (e.g. emission trading systems under different market configurations and trading rules) and the analysis of impacts of technological change (e.g. technology improvement scenarios with exogenous or endogenous technological change) and R&D strategies.

5.1.2 The model in detail

Basically, market equilibrium is (recursively) simulated by matching, at country/region and sector levels, energy supply and demand which adapt, with a certain time lag, to changes in the international energy prices. And a feedback loop computes the endogenous price changes derived from the supply and demand balance adjustment in the previous period (Figure 1). Thereby consistent long-term energy scenarios (exogenous: GDP, population, CO2 constraints, and, optionally, technological innovation) are simulated on a year-by-year basis and respective abatement policies can be economically assessed.

In POLES, fossil fuel prices are computed within an international framework: world market for oil (single price) and regional market (America, Europe, and Asia) for gas and coal (three different prices for each fuel).

[2] The current version of POLES is POLES 5.

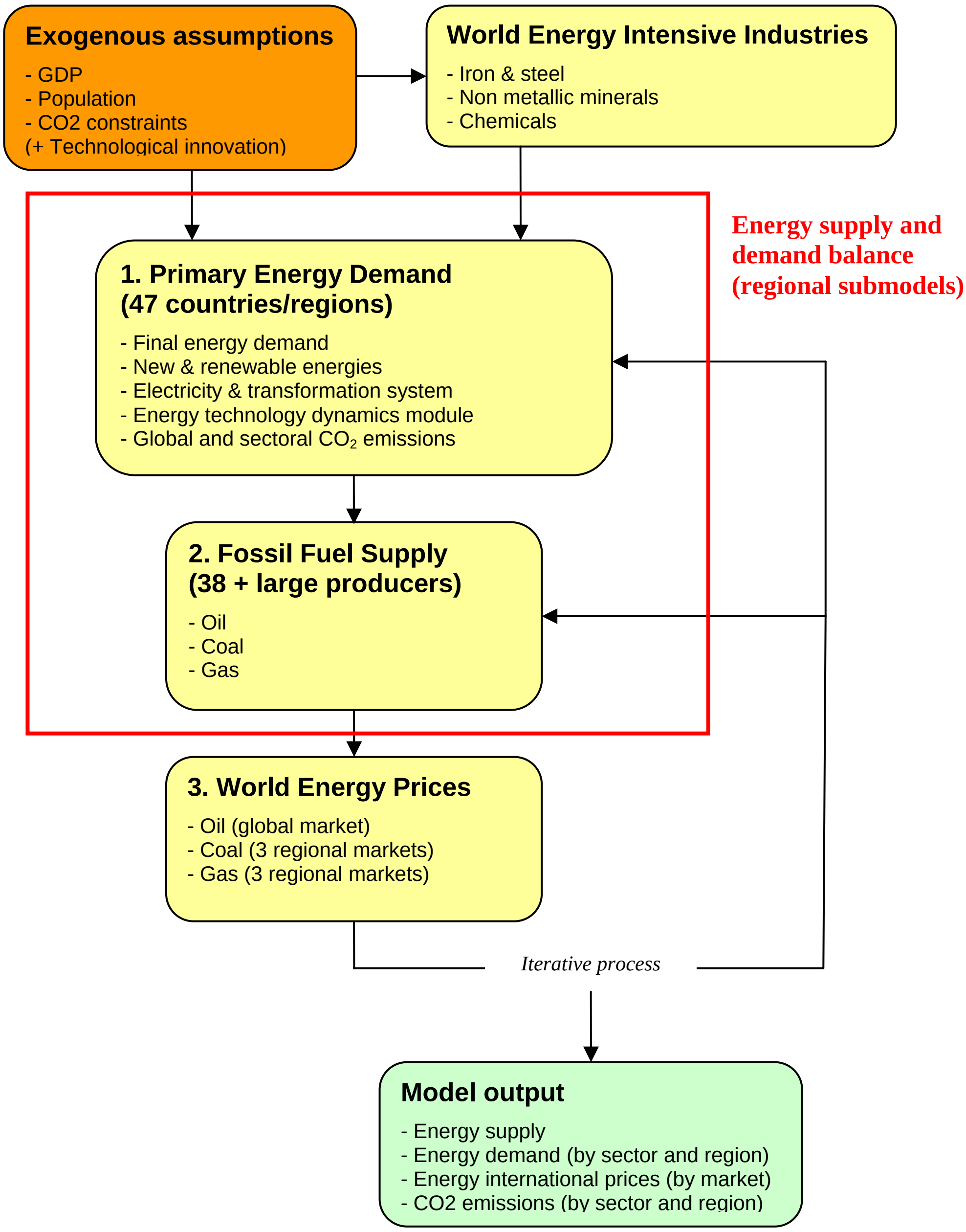

Figure 1: POLES 5 simulation process

The energy supply and demand in POLES is disaggregated into 47 interconnected national/regional sub-models which balance supply and demand at the national/regional sector level. There is a detailed national submodel (with 13 final sectors) for each EU Member State, USA, Canada, Japan, Russia, Mexico, Brazil, India, South Korea, and China, while other countries/regions are dealt with simplified (with 6 final sectors) submodels.

Each submodels consists of 5 modules: (1) final energy demand by main sectors, (2) new and renewable energy technologies, (3) hydrogen and CO2 capture and sequestration technologies and infrastructures, (4) conventional energy and electricity transformation system, and (5) fossil fuel supply. Figure 2 shows the vertical integration of the different modules in the submodels.

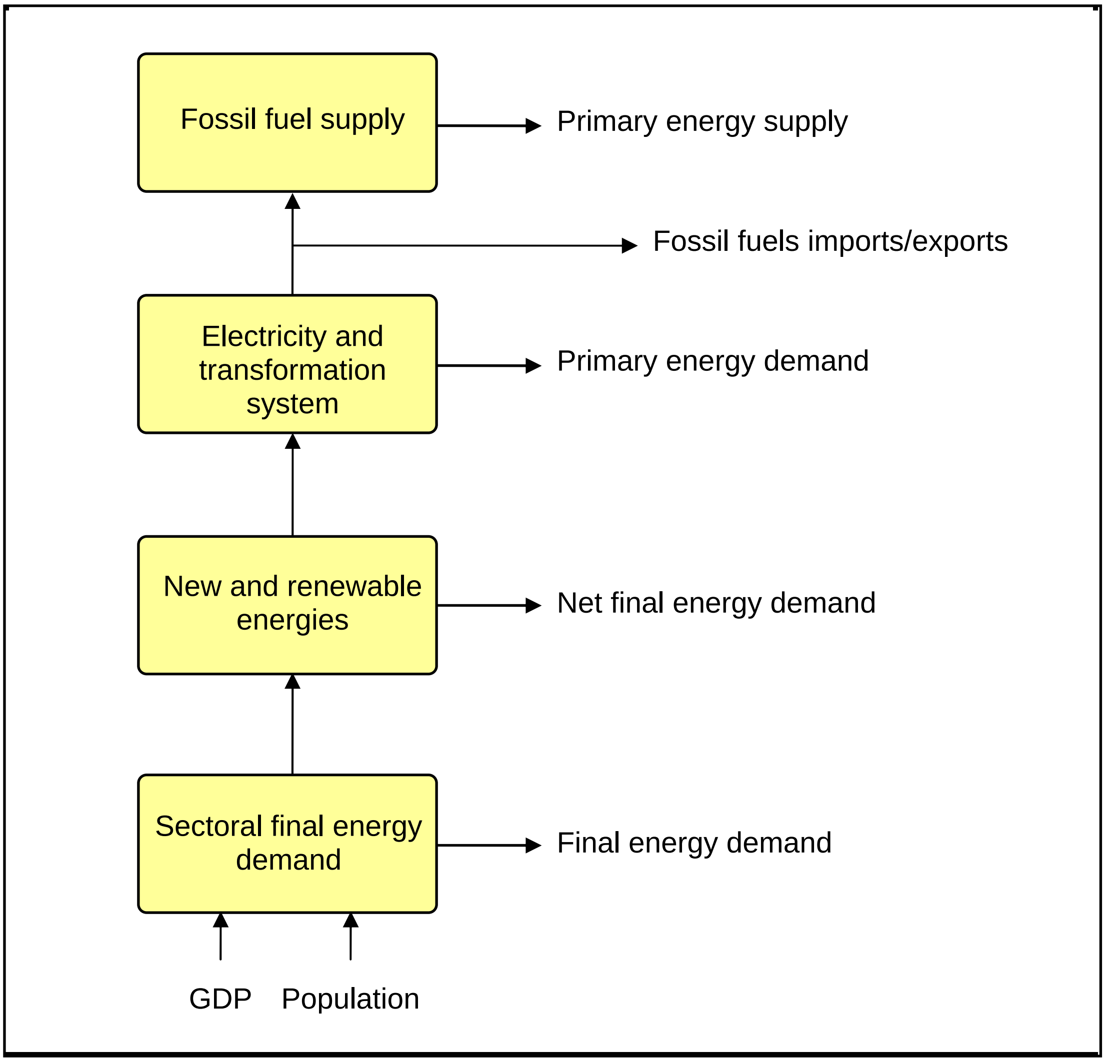

Figure 2: Vertical integration of the modules in POLES submodels

5.1.3 Possible linkages with EXIOPOL

The POLES model disaggregates the energy system (supply and demand) at country and sector level. In terms of country coverage (Table 2), POLES matches quite well the EXIOPOL countries, with country-specific submodels for almost all of them (in particular for all EU MS). Indeed, only Taiwan, Indonesia, and South Africa are not addressed specifically but dealt rather at continent level (Sub-Saharan Africa for South Africa and South-East Asia for Taiwan and Indonesia). Furthermore, most important countries are addressed with a detailed submodel (13 final sectors) which should make easier the integration of POLES results in EXIOPOL modelling.

Table 2: Country coverage in EXIOPOL and POLES

EXIOPOL Country	POLES coverage
EU27 Member States (individually) United States Canada Mexico Brazil Japan South Korea China India Russia	Detailed country-specific submodel
Australia[1] Turkey	Simplified country-specific submodel
Switzerland[2] Norway[2]	Simplified region-specific submodel
Taiwan Indonesia South Africa	Simplified continent-specific submodel

[1] In POLES, New Zealand is joined to Australia;

[2] In POLES, Switzerland, Norway and Iceland are joined together.

Besides, within a detailed submodel, POLES addresses the following sectors:

- Energy
  - Fuels:
    - Oil
    - Coal
    - Gas
    - Biofuels (3 conventional technologies)
  - Electricity:
    - 12 different large scale power generation technologies, including Advanced thermodynamic cycle (coal-powered), Supercritical pulverised coal (with/without CO2 capture), Integrated coal gasification in combined cycle (with/without CO2 capture), Coal-powered conventional thermal, Lignite-powered conventional thermal, Gas conventional thermal, Gas-powered gas turbine in combined cycle (with/without CO2 capture), Oil-powered conventional thermal, Oil fired gas turbine in combined cycle, Light-water nuclear reactor (including EPR), New nuclear design (Generation 4), and Large size hydroelectricity

        - Large number of new and renewable energy technologies, including Small hydropower (<10 MWe), Wind power, Solar thermal power, Waste incineration (CHP), Biomass gasification in gas turbine, Combined heat and power (small co-generation), Rural photovoltaics, Building integrated photovoltaic systems (windows), Proton exchange membrane fuel cell (vehicles), Proton exchange membrane fuel cell (stationary), and Solid oxide fuel cell (cogeneration)
        - Hydrogen production (8 types)
- Iron & Steelmaking
- Chemical industry and feedstock related industry
- Non-metallic mineral products (Glass, Cement, Brick)
- Other industries (e.g. pulp & paper, non-energy use industries)
- Transportation
    - Road (discerning passenger and freight)
    - Rail (discerning passenger and freight)
    - Air
    - Other transport (mainly water transport)
- Agriculture
- Service sector
- Residential demand

As a result, POLES is suitable to analyse national and international energy markets as well as inter-technology and inter-fuel substitution, in particular in the case of GHG emission constraints. POLES remaining a partial equilibrium model, it makes sense to consider possible linkages with EXIOPOL to enable the tool to analyse the impacts of change in energy supply/demand on the rest of the economy.

A first approach, given a mixed exogenous-endogenous variables IO model (exogenous for energy) from EXIOPOL, can be to use the energy supply and prices computed in POLES to reshape the energy output of the IO model. This could be done as far as energy classifications between the sector model and the IO framework has been aligned. A tentative alignment between POLES and EXIOPOL is given in Table 3.

Table 3: Tentative classification alignment between POLES and EXIOPOL

Sector	**EXIOPOL category**	**POLES category**
Electricity	Electricity by coal (84)	Advanced Thermodynamic Cycle
		Super Critical Pulverised Coal
		Integrated Coal Gasification Combined Cycle
		Coal Conventional Thermal
		Lignite Conventional Thermal
	Electricity by gas (85)	Gas Conventional Thermal

		Gas Turbines Combined Cycle
	Electricity by nuclear (86)	Nuclear LWR
		New Nuclear Design
	Electricity by hydro (87)	Large Hydro
		Small Hydro
	Electricity by wind (88)	Wind Turbines
	Electricity nec (89)	Oil Conventional Thermal Oil Fired Gas Turbines Waste Incineration CHP Biomass Gasification with Gas Turbines Photovoltaics (windows) Rural Photovoltaics Solar Thermal Powerplants Combined Heat and Power Proton Exchange Membrane Fuel Cell (Fixed) Solid Oxide Fuel Cell (Fixed Cogeneration) Fuel Cell Vehicle (PEM) Hydrogen production
Fuels	Coke oven products (51)	Coal
	Motor spirit (52)	Oil
	Kerosene, including kerosene type jet fuel (53)	
	Gas oils (54)	
	Petroleum gases and other gaseous hydrocarbons, except natural gas (56)	
	Gas and distribution services of gaseous fuels through mains (92)	Gas
	Manufacture of fuel oils n.e.c. (55)	Biofuels for transport

Need transformation for matching
Do not need transformation for matching

Note that data transformation should be needed where POLES sectors are not enough detailed (e.g. oil) or do not exactly intersect with those of EXIOPOL (e.g. biofuels compared to other fuel oils). In those cases, additional assumptions will be needed.

A second approach can be to link the energy demand of POLES with the intermediate and final energy consumption, in the EXIOPOL IO structure, of, respectively, non-energy sectors and consumers. In particular, the residential sector of POLES could be identified as the final energy demand of EXIOPOL and the other final sector of POLES as the industrial energy demand of EXIOPOL. In this approach, POLES results can be used to reshape both the final demand (Y) and the technical coefficients (A) of EXIOPOL. However as regards the technical coefficients, further assumptions will be needed since the POLES industrial sectors, except for transportation, are much less detailed than the EXIOPOL ones (for instance agriculture represents one sector in POLES and 17 in EXIOPOL).

A third approach can be to use the POLES simulation to build a hybrid-units energy IO model where the non energy flows are depicted, as usual, in monetary terms but the energy flows in physical units (e.g. Btu). Practically, POLES results will be used to draw up the physical energy flows (based on the computed supply and demand).

5.2 Agricultural models: CAPRI

5.2.1 General overview

CAPRI (Common Agricultural Policy Regional Impacts) is an economic modelling system developed to assist in analysing impacts of the Common Agricultural Policy (CAP), of European agri-environmental measures or of agricultural trade policies from regional to global scale. It combines the representation of regional agricultural policies and production with political and economic conditions on regional, Member State, EU and global agricultural commodity markets. An activity based approach allows the direct implementation of relevant CAP policy measures and the technological definition of appropriate environmental indicators related to the agricultural production activities. Product and activity coverage are in line with the Economic Accounts for Agriculture (EAA) by a combined top down / bottom up approach.

The CAPRI model is widely used in the EC and includes a database, COCO, (based mainly on EUROSTAT data for production and FAOSTAT for trade) which covers a large number of agricultural primary and processed commodities (70 marketable goods, plus intermediates). Data are available at the geographical resolution of NUTS level 2, which represents about 300 EU regions.

5.2.2 The model in detail

Basically, the model is split up into a supply and a market component. An iterative process between the supply and the market component establishes a comparative static equilibrium and returns market clearing prices for tradable agricultural products and young animals.

In a more detailed way, the supply module consists of independent aggregate non-linear programming models representing activities of all farmers at regional or farm type level captured by the EAA. The programming models are a kind of hybrid approach, as they combine a Leontief-technology for variable costs covering a low and high yield variant for the different production activities with a non-linear cost function which captures the effects of labour and capital on farmers' decisions. Prices are exogenous in the supply module and provided by the market module.

The market module consists of two sub-modules. The first one, for marketable agricultural outputs, is a spatial, non-stochastic global multi-commodity model for about 40 primary and processed agricultural products, covering about 40 countries or country blocks in 18 trading blocks. Bi-lateral trade flows and attached prices are modelled based on the Armington assumptions (Armington, 1969). This sub-module delivers prices used in the supply module. A second sub-module deals with prices for young animals.

As the supply models are solved independently at fixed prices, the link between the supply and market modules is based on an iterative procedure which stops when both modules are balanced (equilibrium). Note that CAPRI can be run without any market module (fixed exogenous prices), which allows for instance to model regional supply for a specific Member State.

In addition, CAPRI computes the calculation of different income indicators (variable costs, revenues, gross margins) and environmental indicators (NPK balances, GHG emissions from agriculture). As well, a welfare analysis at different scale levels completes the tool.

5.2.3 Possible linkages with EXIOPOL

CAPRI allows for agriculture market analysis at global, EU and national scale. The CAPRI country cover is as follows: EU27 MS, USA, Canada, Mexico, China, India, Japan, Algeria, Morocco, Tunisia, Egypt, Turkey, Israel, Bolivia, Chile, Argentina, Brazil, Uruguay, Paraguay, Rest of South America, LDCs, Non LDC ACP countries, and Rest of the World. While it does not match exactly the EXIOPOL countries (Table 4), feasible and meaningful links to EXIOPOL should be achieved given that most important countries are covered in CAPRI (except Russia and Australia).

Table 4: Country coverage in EXIOPOL and POLES

CAPRI coverage	EXIOPOL Country
Match	EU27 Member States (individually) United States Canada Mexico Brazil Japan South Korea China India Turkey
Do not match	Australia Russia Switzerland Norway Taiwan Indonesia

	South Africa Rest of the World

A simple manner to link CAPRI to EXIOPOL is to use the prices and supplies of agriculture commodities computed in CAPRI into a mixed endogenous-exogenous variables IO model based on EXIOPOL. Beyond the (possible) country gap between CAPRI and EXIOPOL, the main step will be to map the detailed list of agro-food commodities of CAPRI onto the list of products included in the EXIOPOL scheme. A data transformation process is currently underway at IPTS-AGRILIFE and aims[3] to reach a level of 50 agro-food sectors (MAC classification, see Table 5), that can be easily mapped onto the EXIOPOL classification (17 agriculture and 12 food sectors).

Table 5: Agri and food sectors of Modified Agro-industry Classification (MAC) under development at IPTS- AGRILIFE

Agri Sectors	**Food sectors**
1 Durum wheat	41 Meat of bovine animals
2 Other wheat	42 Meat of swine
3 Barley	43 Meat of sheep
4 Grain maize	44 Poultry meat
5 Paddy rice	45 Meat and meat products n.e.c.
6 Other cereals	46 Fish and fish products
7 Potatoes	47 Fruit and vegetables
8 Other starch and protein plants	48 Animal oils and fats
9 Soya seed	49 Vegetable oils and fats
10 Rape seed	50 Oil-cake and other solid residues
11 Sunflower seed	51 Milk powder
12 Other oil plants	52 Fresh milk products
13 Sugar beet	53 Processed milk products
14 Other sugar plants	54 Processed rice
15 Fodder crops	55 Grain mill products, except rice
16 Fibre plants	56 Starches and starch products
17 Other crops	57 Prepared animal feeds
18 Fresh vegetables	58 Processed sugar
19 Live plants	59 Other food products
20 Grapes	60 Beverages

[3] This work aims at the generation of Social Accounting Matrices (SAMs) for the 27 EU MS.

21 Other plant products 22 Live cattle 23 Cow milk 24 Live sheep, goats, and equines 25 Sheep and goat milk 26 Wool and animal hair 27 Pig farming 28 Live poultry 29 Eggs 30 Silkworm cocoons 31 Other animal products 32 Agricultural services 33 Forestry, logging 34 Fishing	61 Tobacco products

While the original CAPRI classification is certainly too detailed for EXIOPOL (it includes for instance 6 different types of animal fodder), the agricultural details adopted by the MAC or by its further re-aggregation to the EXIOPOL classification may be a straightforward option.

5.3 Transportation models: TREMOVE

5.3.1 General overview

TREMOVE is a modelling tool developed by the Catholic University of Leuven and Transport & Mobility Leuven and with the participation of the European Commission to analyse in detail transportation activities and their environmental impacts. It is a partial equilibrium model that evaluates the effects of policy measures adopted in the transportation sector and in the environment.

TREMOVE models at national level both passenger and freight transport in 31 countries, including the EU27 countries, Switzerland, Norway, Croatia and Turkey, and covers the period 1995-2030. On a yearly basis, it estimates the transport demand, the modal split (i.e. road, rail, air, and maritime with an ad-hoc module), the vehicle fleet along with the vehicle stock turnover, the transport energy consumption, the emissions of air pollutants, and the welfare impacts under different policy scenarios (e.g. incentive mechanisms or emission standards).

5.3.2 The model in detail

The model core consists of three main inter-linked modules and also includes two supplementary modules. Figure 3 shows the schematic structure of TREMOVE.

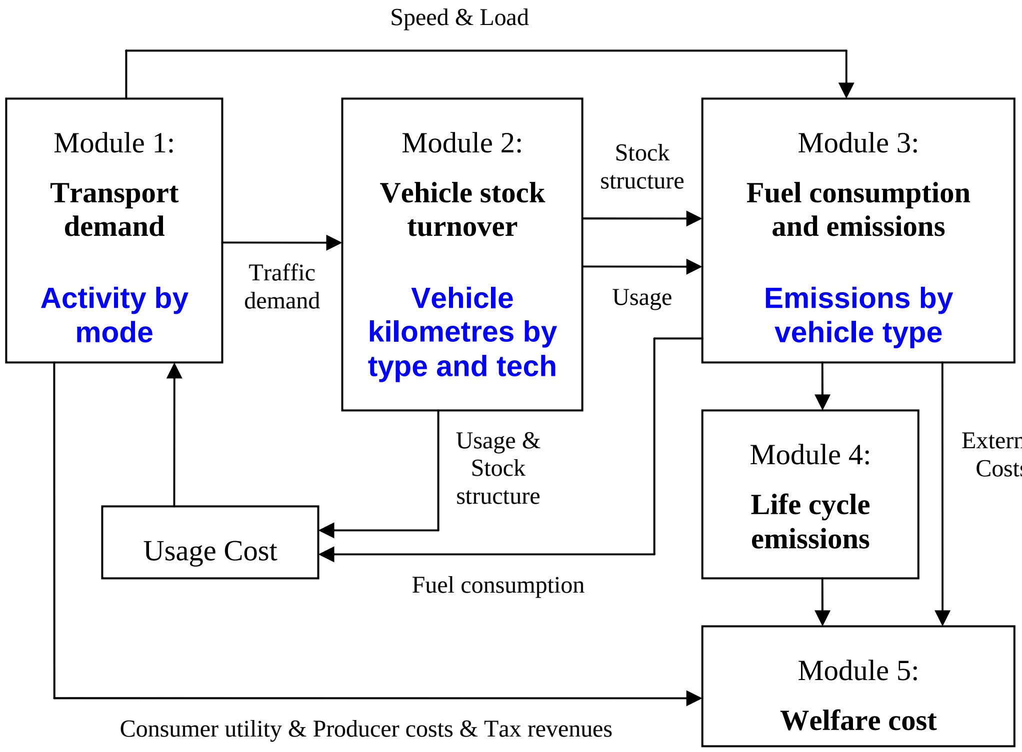

Figure 3: TREMOVE modular structure

- **Module 1: Transport demand**

Based on a nested structure, this module describes how households and firms choose first between transport (respectively, for commuting and non-work trips and for freight and business trips) and other goods or inputs; and then among different transportation options or modes (respectively, to maximize utility or minimize costs of production). All in all, there are 160 different transport types for households and 228 transport types for firms. The model estimates for each type, accordingly, either the demand for passenger transportation (in passenger kilometre) or for freight (in ton kilometre), then converted into vehicle kilometres (with fixed occupancy rates and load factors). At the end, the transport demand (vehicle kilometres) is aggregated by transport mode (e.g. car, bus, etc.).

In particular, the calculations are based on congestion functions, generalised transport prices (including time costs), and constant elasticities of substitution. In addition, the labour supply and the level of production are kept constant.

- **Module 2: Vehicle stock turnover**

The module calculates the optimum stock of vehicles that is needed to fulfil the transport demand by firms and households. Given a transport mode, the difference between optimum stock and existing stock represents the overall sales of new vehicles that is then split up into the purchase of different types of vehicles by applying a discrete choice model based on vehicle prices, other vehicle characteristics, and consumers' preferences. The module output is the disaggregated transport demand by vehicle type, vehicle technology and vehicle age.

The main other vehicle characteristics (than prices) taken into account in the discrete choice model include lifetime, sizes, fuel type, and annual mileage.

- **Module 3: Fuel consumption and emissions (environmental module)**

The module estimates for all modes the fuel consumption and air emissions based on the vehicle stock structure, the number of kilometres driven by each vehicle type, and the driving conditions. The emissions are estimated for the following components: CO_2, CH_4, N_2O, CO, NMVOC, NOx, PM, SO_2, C_6H_6, and Tropospheric Ozone Formation Potential.

- **Supplementary modules: Life cycle emissions & Welfare cost**

Life cycle emissions module enables to calculate the well-to-tank emissions, namely the emissions during the production of fuels and electricity. It also accounts for the effects of the use of (blended) biofuels.

Adding them with the transport emissions previously estimated, the module gives the well-to-wheel emissions focused on the fuel cycle (for instance, the emissions due to the production of vehicle is not taken into account).

In addition, a welfare cost module makes also part of the tool and computes the costs for the society of different policy scenarios including externalities for pollution and traffic congestion.

5.3.3 Possible linkages with EXIOPOL

TREMOVE remains a partial equilibrium model; as such, it neglects the interaction of the transportation sectors with the rest of the economy. Hence a link with an environmental IO framework such as EXIOPOL would broaden the potential of the tool.

Diverse ways of integrating TREMOVE into the EXIOPOL framework can be envisaged, with different levels of technical complexity. At a limited level of complexity, it can be envisaged to link some elements of the final demand vector and the IO structure of EXIOPOL to model the household demand for transport and the firms' purchase of transportation service respectively. In particular, the sales of new vehicles, the fuel consumption and the consumption of transportation services by households could be used to reshape the final demand structure such as to reflect changing household consumption patterns under different policy scenarios. And the transport demand by firms computed with the transport demand module could further be integrated by modifying the sales structure of the transportation sectors in the IO matrix. In both cases, a minimum requirement is that the TREMOVE transport categories can match the ones of EXIOPOL. This should be manageable thanks to the EXIOPOL sectoral definition, which has been devised in such as way as to give a minimum workable level of details for the transport sector. A tentative linkage between TREMOVE and EXIOPOL is given in Table 6 as regards passenger and freight transportation.

Table 6: Possible linkage between TREMOVE and EXIOPOL

Sector	**TREMOVE category**	**EXIOPOL category**	**Possible mismatch**
Passenger transportation (Households & Firms)			
Vehicle purchase	Sales of new vehicles	Sale, maintenance, repair of motor vehicles, motor vehicles parts, motorcycles, motor cycles parts and accessoiries (96)	EXIOPOL also includes other goods/services than vehicle purchase (e. g. repairing, spare parts)
Fuel consumption	Petrol	Motor spirit (52)	
	Diesel	Gas oils (54)	
	LPG CNG	Petroleum gases and other gaseous hydrocarbons, except natural gas (56)	EXIOPOL also includes other gaseous hydrocarbons (e.g. ethylene, propylene, butylene and butadiene)
	Biofuels	Fuel oils n.e.c. (55)	EXIOPOL also includes other goods/services than biofuels
Passenger transport service	Road (network)	Other land transportation services (102)	EXIOPOL also includes freight service
	Rail	Railway transportation services (101)	EXIOPOL also includes freight service
	Air	Air transport services (106)	EXIOPOL also includes freight service
Freight transportation (Firms)			
Road freight	Bulk, cargo and unitised road freight	Other land transportation services (102)	EXIOPOL also includes passenger transportation
Rail freight	Bulk, cargo and unitised rail freight	Railway transportation services (101)	EXIOPOL also includes passenger transportation
Maritime freight	Maritime freight	Sea and coastal water transportation	EXIOPOL also includes passenger

		services (104)	transportation

Need transformation for matching
Do not need transformation for matching

Whenever there is a need for transformation, it comes generally from the fact that EXIOPOL sectors cannot match exactly the high detail of TREMOVE sectors. Hence assumptions will be needed to split up EXIOPOL sectors.

It should be noted that in TREMOVE, the philosophy retained for households (the same applies to firms) is to model a fine-grained budget allocation for transportation needs along with the aggregate expenditure for all other purposes. A second approach can be then to use the whole household demand for transportation computed in TREMOVE and link it, by using a bridge matrix, to the expenditure basket that drives the IO model (See for instance Mongelli *et al.*, 2008). In this case, a special attention should be paid on building the bridge matrix.

Another way to link TREMOVE with EXIOPOL is to integrate the transport and fuel emissions computed in TREMOVE (with the implementation of different scenarios) with the environmental extension of EXIOPOL. This should be achievable given that the TREMOVE emissions match with the EXIOPOL ones in terms of pollutants (CO2, CH4, N2O, CO, NMVOC, NOx, PM, SO2, and C6H6) and provided that the linkage between the TREMOVE and EXIOPOL subsectors has been done as previously.

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