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EXIOPOL – DEVELOPMENT AND ILLUSTRATIVE ANALYSES OF A DETAILED GLOBAL MR EE SUT/IOT

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EXIOPOL (A New Environmental Accounting Framework Using Externality Data and Input–Output Tools for Policy Analysis) was a European Union (EU)-funded project creating a detailed, global, multiregional environmentally extended Supply and Use table (MR EE SUT) of 43 countries, 129 sectors, 80 resources, and 40 emissions. We sourced primary SUT and input–output tables from Eurostat and non-EU statistical offices. We harmonized and detailed them using auxiliary national accounts data and co-efficient matrices. Imports were allocated to countries of exports using United Nations Commodity Trade Statistics Database trade shares. Optimization procedures removed imbalances in these detailing and trade linking steps. Environmental extensions were added from various sources. We calculated the EU footprint of final consumption with resulting MR EE SUT. EU policies focus mainly on energy and carbon footprints. We show that the EU land, water, and material footprint abroad is much more relevant, and should be prioritized in the EU's environmental product and trade policies.

Keywords: EXIOPOL; MR EE I–O; Resources; Emissions; EU footprint

1. INTRODUCTION

The EXIOPOL (A New Environmental Accounting Framework Using Externality Data and Input–Output Tools for Policy Analysis) was a European Union (EU)-funded project that had two main goals. One part of the project aimed at improving insights in external costs of environmental pressures. The other part, central in this paper, tried to overcome significant limitations in existing data sources in the field of multiregional environmentally extended Supply and Use tables (MR EE SUTs) and input–output tables (IOT). National

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Statistical Institutes provide SUT and IOT for single countries, without trade links. Sector and product detail is not as good as it ought to be. Environmental extensions are often lacking or include only a few types of emissions and primary resource uses. There is little or no harmonization of sector and product classifications across different countries. It is therefore difficult to assess the extent to which a country induces environmental impacts abroad via trade, let alone trends therein. Trade-linked tables are also essential for analyzing the effects of sustainability measures taken in Europe on Europe's economic competitiveness. From a theoretical viewpoint, the MR EE I–O approach is the best way of taking trade into account, but existing studies tend to be aggregated at the sector and regional level and to focus on a fairly small number of environmental extensions.

The MR EE I–O database to be developed in EXIOPOL aimed to make crucial advances in quality. The project's aim was really to leapfrog: it would give the EU a fully fledged, detailed, transparent, public, global MR EE I–O database with externalities, allowing for numerous types of analyses for policy support purposes.

This paper discusses the following topics related to the EXIOPOL project. First, it discusses in more detail the history and motivation for the project (Section 2). We then present the construction of the database, discussing the main data sources and estimation/construction methods (Section 3). We then give a case on impacts of trade with Europe (Section 4) and end with conclusions (Section 5).

2. HISTORY AND BACKGROUND OF THE PROJECT

2.1. Introduction

In Tukker et al. (2009), we describe extensively the MR EE SUT data situation around 2006, when our project was developed. To our knowledge the EU is one of the few major economic blocks globally that produce official SUT and related environmental extensions in the same format (Eurostat, 2011). Other countries do produce SUT and IOT, sometimes at a significant more detailed sector and product detail as the EU, but do not provide official extensions, leaving it to the research community to integrate different data sets (Weber and Matthews, 2007).

The EU data however have significant shortcomings from an environmental perspective. The European System of Accounts 1995 requires EU member states to transmit SUTs (annually) and IOTs (every five years) in a standardized format for 60 sectors and products (EC, 1996). Data for 10–15 emissions to air are available in the same sector format from (voluntary) National Accounting Matrices including Environmental Accounts (Eurostat, 2005). Nevertheless, this material only permits limited environmental-economic assessments. In the first place, the European System of Accounts of 1995 (ESA95) SUTs and IOTs are only for individual countries and are not linked via trade. Second, for environmental analyses differentiation of sub-sectors with highly different impact intensities in, e.g. agriculture, mining, energy production, and transport is essential, typically implying a minimum required resolution of 100–150 sectors (Joshi, 2000; Suh, 2004; Weidema et al., 2005; Tukker et al., 2006); Third, the environmental interventions for which data are gathered are only sufficient to analyze impacts related to global warming, and perhaps acidification, but are insufficient for other important indicators (e.g. external costs, material flow indicators or the ecological footprint [EF]). Recently, the EU undertook an effort to create an aggregated

EU27 EE SUT. This data set however is an aggregate and does not distinguish the 27 EU member states (Eurostat, 2011).[1]

2.2. Implications of Existing Data Limitations

The data situation described before presents important limitations for analysis done on the basis of environmental and economic accounts. A system of integrated environmental and economic accounts based on EE SUT is in principle the most coherent system to analyze how the environmental impacts of consumption relate to environmental impacts of production and vice versa. Yet, the limited sector detail and limited coverage of environmental extensions in existing data sets causes, already as discussed in the former section, significant problems. Since most databases contain just a few extensions (e.g. greenhouse gas emissions), scenario analyses done with such databases cannot identify if emission reductions come at the expense of higher impacts with regard to other impact categories such as land and water use. Analysis of economic and environmental impacts of improvement options by necessity will be crude: with the usual limited sector detail, it is for instance not possible to analyze the impacts of changes of diets with less meat, since all agricultural production is part of just one sector (cf. Tukker et al., 2011). But most importantly, it is well known that in a global economy each country specializes in specific types of production and trade is growing faster than the global economy (Peters and Hertwich, 2008a; 2008b). In some cases, apparent decoupling of territorial CO_2 emissions or primary material use from gross domestic product (GDP) growth is in fact the result of the relocation of material and energy-intensive production to other countries (Giljum et al., 2008; Wiedmann et al., 2008).

With in general just EE SUT/IOT available only for single countries, practitioners face the problem of how to calculate pollution embodied in trade. Analysts, including ourselves when performing the Environmental Impacts of Products study, then often apply a shortcut and assume that imported goods and services are made with the same technology as those produced domestically (Hendrickson et al., 2006; Huppes et al., 2006; Palm et al., 2006). This can lead to serious errors (Peters and Hertwich, 2006a; 2006b; Ghertner and Fripp, 2007; Weber and Matthews, 2007; compare also Ahmad, 2003; Ahmad and Wyckoff, 2004).

There are various ways to go beyond this domestic technology assumption, ranging from just including bilateral trade with main trading partners and using EE SUT for these countries to estimate pollution embedded in this bilateral trade, to a fully fledged MR EE SUT/IOT approach that reflects bilateral trade between all countries covered in the data set. The latter approach is the most data-demanding, but also superior since in principle now the ever more globally stretched supply chains can be fully covered. For instance, computers assembled in China may actually consist of components from other countries which produce these with, e.g. totally different energy system. A bilateral approach cannot take this into account

[1] A main problem was that to create an MR EE SUT, one needs to have both the Supply as Use table in basic prices. Under the ESA95 EU member states provide the Use table in purchaser prices, and not for all countries official valuation matrices could be obtained or made public to transform this in a basic price Use table. The need to make estimates for some countries and confidentiality issues led to the solution to publish only an aggregated EU27 table.

and would simply assume that all impacts for production of the imported computers would reflect Chinese technology.

At the start of EXIOPOL, only practitioners that extended the Global Trade Analysis Product (GTAP) database (Dimaranan, 2006) with emissions were able to perform true MR EE I–O analysis (see, e.g. Peters and Hertwich, 2008a; Hertwich and Peters, 2009; Davis and Caldeira, 2010; Peters et al., 2011; Andrew and Peters, 2013). Such analyses are typically confined to one or two emissions of substances, most notably CO_2, and use the 57 sector detail of GTAP. Later the Sustainable Europe Research Institute (SERI) created the Global Resource Accounting Model, which uses the harmonized country IOTs and trade data from the Organisation for Economic Co-operation and Development (OECD) and material extraction data by sector to calculate indirect material flows related to traded products (Bruckner et al., 2010). This database is at the 48 sector detail of the OECD IOTs. Where the efforts of these authors (and others not reviewed in detail here) moved the MR EE SUT/IOT field forward significantly, the fundamental problems of limited sector detail and limitations in number of extensions still remained (cf. Dietzenbacher et al., 2013; Lenzen et al., 2013; Tukker and Dietzenbacher, 2013).

2.3. Aim and Organization of the Project

The EXIOPOL project was launched with the belief that only a fundamental change in the data situation could create a breakthrough in the use of MR EE SUT/IOT for policy analysis. As described in the introduction, such limits include that SUT and IOT are only available for single countries, have no harmonized sector classification, are not linked via trade, have no or limited environmental extensions, and lack detail in the classification of sectors with high environmental impacts. EXIOPOL therefore wanted to realize the following:

- Harmonizing and detailing the SUT/I–O tables of the EU27 and its main trade partners, differentiating in detail the sectors and products most relevant for environmental pressures and that have significant differences in impact intensities.
- Gathering a comprehensive set of environmental extensions per sector (emissions, resource use, etc.) that would make it possible to calculate a broad range of indicators for environmental impacts including life cycle impact indicators, material flow indicators, externalities, and land/carbon footprints.
- Linking the so-produced national EE SUT/IOT by means of international trade data, to an MR EE SUT.
- Embedding this data in a user-friendly, general-purpose database system.

The EXIOPOL project was set up by Fondazione Eni Enrico Mattei, Italy and Netherlands Organisation for Applied Scientific Research (TNO), the Netherlands, with over 35 partners from all over Europe. The project ran between March 2007 and October 2011. It had a budget of almost eight Mio Euro of which five Mio Euro was funded by the EU's 6th Framework Program, and of which half was dedicated to the EE I–O work. The main partners in the EE I–O database construction were the institutes to which the authors of this paper are affiliated, i.e. TNO, Norwegian University of Science and Technology, Institute of Environmental

Sciences, Groningen University, SERI, Wuppertal Institute, Gesellschaft für wirtschaftliche Strukturforschung, and EU DG JRC Institute for Prospective Technological Studies.

3. DATA BASE CONSTRUCTION: MAIN DATA SOURCES AND ESTIMATION METHODOLOGY

3.1. Introduction

The following main steps were taken in constructing the database:

(1) Harmonizing and detailing SUT.
(2) Harmonizing and estimating extensions.
(3) Linking the country SUT via trade to an MR EE SUT.
(4) Transforming the MR EE SUT in various types of MR EE IOT.

We will discus our approach in brief in the following sections, ending with a description of the full database. At the start of the project the most recent year that most of the data was available was 2000: hence this was chosen as the base year. In our discussion we refrain from explaining the basic structure of IOT/SUT accounting frameworks. We assume ESR readers to be familiar with this or otherwise refer to, e.g. manuals as provided by Eurostat (2008).

3.2. Harmonizing and Detailing SUT

The first step was creating a standard set of tables needed as input for detailing in original classification. It concerns a Supply table in basic prices, a domestic Use table in basic prices, an import Use table in basic prices, and Valuation matrices (transport, retail, and taxes less subsidies). In EXIOPOL this was done via the following steps:

(1) First, primary data were gathered. It concerned SUT from the EU27 via Eurostat, and SUT and IOT sourced from national statistical institutes for 16 non-EU countries (covering in total 95% of the global GDP). For some EU countries, most notably Cyprus, SUT were missing. Here, the SUT was estimated via a ‘same country assumption’ by using the Greek technology structure in combination with macro-economic data (GDP, total industry output by industry, total output of products by category).
(2) Some countries only produce IOTs and no SUTs. In that case, an artificial SUT was created by assuming a perfectly diagonal Supply table, leading to a Supply and Use table in basic prices. Valuation matrices were estimated as per point 3 below but used to create the Use table in purchaser prices from the Usebp, instead of the other way around.
(3) For countries producing SUT, the Use table is normally in purchaser prices and must be converted to basic prices. For this conversion valuation matrices are required of the transport/retail margins and taxes less subsidies. Normally, only valuation vectors are provided in the Supply table, giving the average difference in purchaser and basic prices for a product. This is problematic since usually there is difference between basic and purchaser price between using industries (i.e. tax margins or transport margins depend on the using industry). We used the following approach to estimate valuation matrices:

(a) If valuation matrices were available, this information was used.
(b) If valuation matrices were available for other than the base year, their structure was used to distribute the valuation vectors from the Supply table.
(c) If no valuation matrices were available for a country, but for the base year both SUT and IOT are available, a choice could be made between two options. One can 'reverse engineer' the Usebp from the IOT (which is in basic prices) and the Supply table, or one can proportionally distribute the valuation vector from the Supply table (a procedure that can be 'enriched' by using any known structure from a similar country). In EXIOPOL reversed engineering was usually applied (Rueda-Cantuche et al., 2007; Eurostat, 2008, p. 352f).

(4) The Use table had to be split into a domestic part and an import part. However, SUT normally only provides an import vector. This vector does not indicate which industries are responsible for which fraction of the import of a product. The split of the Use table into domestic and import parts was done as follows:
(a) If import Use matrices were available this information was used.
(b) If import Use matrices were available from other years, the structure was used to distribute the import vector in the Supply table.
(c) If no further information was available, the import vector in the Supply table was proportionally distributed using the structure of the Use table (i.e. it is assumed that each industry uses the same fraction of imported products).

This led to a SUT in basic prices, valuation matrices, and a split of the Use table into Import and Domestic parts. This data set now had to be detailed and harmonized to the desired Exiopol Database (EXIOBASE) classification. This was done via the following approach.

(1) Correspondence tables between the SUT in original product and industry classification and the EXIOBASE classification were made.
(2) Using relative shares from auxiliary data sources that provide this higher detail, it was usually possible to create detail in various row and column totals of the SUT: total exports and imports, total industry output, and total supply/use of products. Examples of auxiliary data sources are: United Nations Commodity Trade Statistics Database (UN COMTRADE, undated) for imports/exports, Production Communautaire database (PRODCOM, undated) for product output for European countries, Food an Agriculture Organisation of the United Nations Statistics (FAOSTAT, undated) for agricultural products, the International Energy Agency (IEA) database (undated) for production of energy products, and the SERI database (undated) for total resource extraction, etc.
(3) Auxiliary data sets that give coefficients for the use and supply of products by industry in EXIOBASE classification can be used in combination with (2) to estimate intermediate demand and supply. Such datasets included an AgriSams data set for agriculture in Europe, input and output coefficients from countries with a detailed SUT/IOT, the IEA database, etc.
(4) Obviously, the auxiliary datasets helping to estimate row and column totals in the EXIOBASE classification, and the auxiliary datasets with estimates of coefficients did not lead to a balanced system (total estimated supply does not match total use). Therefore, a nonlinear programming approach was applied harmonizing all estimates brought in by the auxiliary data sets (for full details of the implementation of such an approach, see Canning and Wang, 2005; Lemelin, 2009; Lenzen et al., 2009; Müller et al., 2009;

Wood, 2011). This results in SUTs which satisfy all basic input–output relationships and at the same time minimizes the distance between the initial estimate based on auxiliary data and the final fully consistent and balanced SUT. The distance between two datasets is measured by a chosen penalty function, (such as in the RAS technique (Stone and Brown, 1962)). The choice of target function comes down to the computationally demanding entropy function, which weights differences according to the value of the variable size, to a weighted quadratic function, which weights differences according to the value of the initial estimate. The whole system of SUTs including all the layers was hence finally balanced using this mathematical programming approach. For details about countries covered, and the extent to which auxiliary data was need to arrive at the desired detail per country, we refer to the relevant EXIOPOL documentation (Wood et al., 2010).

This then resulted in harmonized, detailed SUT for 43 countries representing almost 95% of the global economy in the EXIOBASE classification. A rest of world (RoW) that combined some 150 small countries was estimated in a rather rough way, using in essence the 'similar country' assumption indicated before – we used in essence ideal coefficients derived from countries with tables with detailed SUT/IOT such as Japan and the USA, combined with macro-economic production data from sources like United Nations Industrial Development Organisation Industry Statistics database (UNIDO INDSTAT, undated) and others as well as data on primary production of major agricultural commodities and natural resources. The imports and exports from the trade linking (see below) were imposed on the RoW. Again with standard coefficients a rough estimate of the RoW SUT was made. This obviously is a crude approach, but the RoW only is responsible for around 5–7% of the global GDP and related emissions. It is mainly included to take into account the emissions and resource extractions related to exports by the RoW. Since these exports are imposed on the RoW, these can be seen as realistic estimates making the overall error in pollution embodied in trade from the RoW limited. Currencies were converted to Euros using market exchange rates.

3.3. Harmonizing and Estimating Extensions

The environmental extensions include the use of primary resources (materials, water, energy, and land) and emissions. EXIOBASE obviously aimed at including both extensions related to industrial production as emissions related to final consumption activities. The approach to the inventory and allocation of extensions was as follows:

(1) Resource data were sourced from the material flow databases of SERI and the Wuppertal Institute. These in turn are derived from physical primary resource extractions that can be found in, e.g. FAOSTAT (agricultural products), the IEA database (energy resources), and a United States Geological Survey (USGS, 2012) database (mineral resources). The main challenge here was to allocate primary resource extractions to the correct sector that de facto does the extraction. Developing this allocation matrix proved to be relatively straightforward. Specific physical agricultural products can be easily allocated to specific agricultural sectors. IEA energy extractions could be clearly linked to, e.g. oil, gas, or coal-extracting industries.

(2) For emissions, two approaches were considered. One was to use international emission inventory databases and the other to calculate emissions using emission factors and activity variables (e.g. with the IEA energy database for energy-related emissions). An objection to the first approach is that it would rely on data supplied to the United Framework Convention on Climate Change (UNFCCC) or the Convention on Long Range Transport of Air Pollution (CLRTAP), but many important countries (such as China and India) are not signatories of the relevant conventions and hence do not report. Furthermore, emission values reported to e.g. the UNFCCC have in fact quite often been calculated using the second approach, although it is possible that slightly different assumptions were used.[2] EXIOPOL therefore used the second approach. In short, this implied:
   (a) For energy-related emissions, the IEA database that maps the production and use of around 60 energy commodities by (IEA) industries was used as a basis. It was first transformed into a supply-and-use framework. The IEA database uses the territorial principle and had to be converted into energy use from a residence perspective, which was done with auxiliary data (for particularly transport fuels). Then, the IEA products and sectors were mapped on the EXIOBASE classifications – for products simple many to one mapping; for industries a more complicated situation. A mix of physical (e.g. life cycle inventory-based) and economic variables was used to estimate the use of IEA energy products by EXIOBASE sector. TNO has developed a major database that derives the right emission factors for such energy-related emissions by country and sector and energy input. This then allowed calculating emissions (Pulles et al., 2007).
   (b) For non-energy emissions, similar 'activity variables' were inventoried (e.g. the amount of cows, pigs, chicken in a country). Then again, emission factors were used to calculate emissions.

(3) Land use data were obtained from FAO, and could be allocated directly to the agricultural and forestry activities with the information present in that database. EXIOPOL did neglect direct land use by industrial sites, human settlements, and other infrastructure, but this is just a small part of land use.

(4) The data on agricultural water use used for the EXIOPOL project were computed with the LPJmL model (Rost et al., 2008). Agriculture is one of the most important water users globally. Other water extractions, particularly by industry and for cooling water, are more difficult to estimate – a variety of data sources and assumptions was used here described in Lutter et al. (2011). We concentrated on physical water, the use in terms of green water (roughly equivalent to rain water) and blue water (which is extracted from rivers or aquifers).[3]

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[2] Indeed, one of the reasons to calculate emissions using energy databases (dubbed the 'energy first' approach) is that this enabled us to calculate emissions across countries in a fully comparable way. The degrees of freedom left by official emission inventory protocols led to the situation that countries have slightly different approaches to emission inventories.

[3] Sometimes authors also discern gray water. Gray water use reflects pollution in discharged water. It is calculated by looking at the volume of the discharge and the concentration of pollutants, and calculating to how much the water has to be diluted to be of legal quality standard. This calculation is highly controversial, since it does not take into account the way some substances degrade quickly, whereas others are persistent or (e.g. metals) do not degrade at all (cf. Guinée et al., 2002). We therefore did not calculate the gray water use.

This led to a list of hundreds of individual extensions and policy is usually better served by more aggregated indicators. The aim of the project was to inventory at least those emissions and resource uses that allow environmental pressures to be expressed in the following widely used indicators:

(1) various environmental themes from Life Cycle Impact Assessment (LCIA), most notably Global Warming Potential (GWP), Ozone Depletion Potential, Photochemical Oxidant Creation Potential, acidification, eutrophication, and, where possible, ecotoxicity and human toxicity (see, e.g. Guinée, 2002).
(2) various material flow-based indicators such as 'Total Material Requirement' or 'Domestic Material Consumption' which usually add up all resource extractions to a number expressed in tons of materials (Eurostat, 2001; OECD, 2007).
(3) A proxy of the EF (Wackernagel et al., 2005). EXIOPOL can provide a proxy of the EF, most notably the land use related to final consumption of products and the 'virtual land use' as calculated by the EF methodology related to greenhouse gas emissions.

External costs (re-developed in the externality stream of EXIOPOL for use with EE I–O). Externalities are usually calculated with a detailed specification of the location and timing of emissions. EE SUTs and EE IOTs reveal annual emissions per sector in a country and hence are inherently incapable of providing such detail. The solution in EXIOPOL was that the average external cost factors per kilogram of a specific emission per sector in a country were calculated for the most relevant emissions, using generic information about stack heights and location (for instance: high stack for power plants, low stack for emissions from households, street level for emissions from cars). For some emissions less relevant for external costs LCIA indicators were calculated via the first approach above, resulting in disability adjusted life years lost and potentially affected fractions of species, which could be multiplied with external costs for these parameters (compare Guinée, 2002). A specific problem was posed by non-EU countries, for which no willingness to pay data were available with regard to e.g. a life year lost. Here, no option was possible other than to use a crude approach that applies European values corrected with purchasing power parities (PPPs).

3.4. Linking the country SUT via trade to an MR EE SUT

The University of Groningen developed a semi-survey method to link SUT and IOT via trade (van der Linden and Oosterhaven, 1995; Oosterhaven et al., 2008). EXIOPOL used an updated version of that approach (Bouwmeester, 2011). Using trade shares from trade statistics,[4] the harmonized import Use tables are spatially disaggregated into bilateral import Use tables that specify the country of origin. Per country, 42 bilateral import matrices are obtained by assuming that each industry and each final demand category imports the same share of a given product from the exporting country.[5] When considering the group of matrices with the same country of origin, the summation over the sectors and countries

[4] The trade statistics were obtained from the synchronized UN COMTRADE trade database as published by Feenstra et al. (2005). Service trade data were sourced from the UN Service Trade Database. Both data sets needed further elaboration and creation of correspondence tables to the EXIOPOL classification (Bouwmeester, 2011).
[5] This assumption has been referred to as the proportionality assumption. The implications of this assumption are discussed in Koopman et al. (2010) and Puzzello (2012), among others.

of destination should equal the exports as reported by the country of origin. Yet, since imports are valued in c.i.f. (cost, insurance, freight) prices and exports are valued in f.o.b. (free on board) prices, the implicit exports from the import Use tables will not match the explicit national export vector. The asymmetry is caused by trade and transport margins, taxes less subsidies, and statistical errors (Eurostat, 2006). To estimate environmental effects of production and consumption it is vital to link them to values of actual products that are undistorted by trade and transport margins or taxes less subsidies. As the first step in making the export and import data consistent, the total exports are re-scaled to match the overall total of the imports. The difference between the original export column and the re-scaled column is entered in the final table as a discrepancy column in order to maintain the original accounting identities. This discrepancy column does not distort the input coefficients of the ultimate I–O model, which would have been the case if the total imports would have been re-scaled. Second, the information contained in the product structure of the exports vector is used to bi-proportionally adjust the import matrices to make them structurally consistent with the export data.[6] The adjustment of the import matrices is favored over adjusting the export data as the latter are in the desired valuation. The difference between the original import table and the adjusted import table gives a crude estimation of the trade and transport margins involved in international trade.[7] The information on origin and destination of the inputs used in production as recorded in the bilateral import Use tables can be combined with the national Supply tables to obtain an import-based MR SUT.

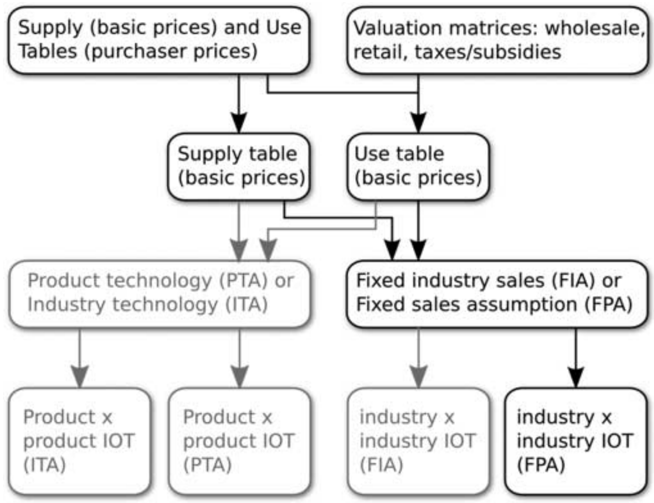
3.5. Transforming the MR EE SUT in Various Types of MR EE IOT

Most analytical applications and computable general equilibrium (CGE) models are based on IOTs rather than SUT (for an exception, see e.g. ten Raa and Rueda-Cantuche, 2007b). Using assumptions about sales structure or technology used, symmetric IOTs can be derived from the SUT in basic price. We refer to the standard literature, including Leontief and Ford (1970), Miller and Blair (2009), ten Raa (2005) and Eurostat, 2008, as well as ten Raa and Rueda-Cantuche (2003, 2007a) for a detailed description of this transformation step. EXIOPOL can in principle make the four most prevailing IOTs as shown in Figure 1. Two of these models, industry by industry (FIA) and product by product (PTA) are preferable theoretically but they have the disadvantage of producing negative numbers. Due to this problem, many users apply the industry by industry (FPA) or product by product (ITA) despite various theoretical issues, because they are guaranteed to produce positive numbers. EXIOPOL therefore produced industry by industry and product by product tables with the latter assumptions. The product by product (ITA) table assumes that each industry has its own specific way of production, irrespective of its product mix. The industry by industry (FPA) assumes that each product has its own specific sales structure, irrespective of the industry where it is produced. The case study in this paper (Section 4) uses an industry by industry (FPA)

[6] The bi-proportional adjustment method used is GRAS, a generalized version of RAS that can also deal with negative values, such as subsidies and changes in inventories (Junius and Oosterhaven, 2003).

[7] This estimation is crude because any statistical discrepancies, asymmetries, and methodological differences between the data used that affect the structure of the table are also included in this difference.

FIGURE 1. Simplified input–output framework (modified from Rueda-Cantuche et al., 2007) and the route to the industry by industry IOT (FPA) used in Section 4.



IOT because the industry by industry input–output tables are said to be closer to statistical sources and actual observations than product by product tables (Eurostat, 2008). The transformation route followed for the case in this paper is emphasized in black in Figure 1.

3.6. Characteristics of the Constructed Database

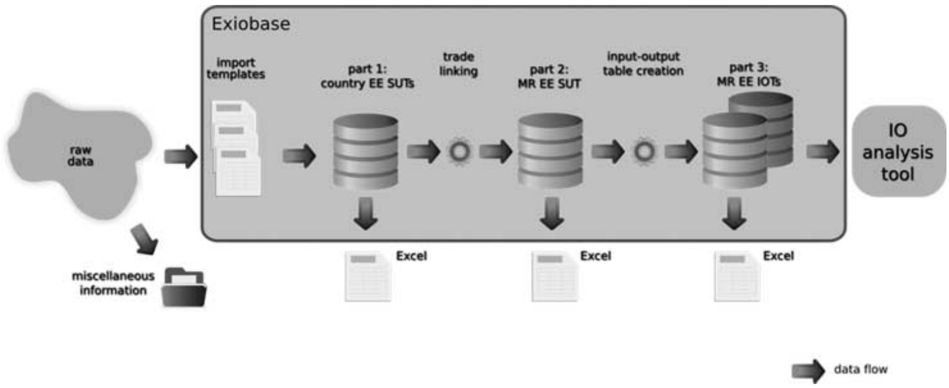
The result of the former steps is visualized in Figure 2: the EXIOBASE database. In essence it consists of three parts, shown as three drums in the figure:

(1) *Part 1*: A storage facility for the single country environmentally extended Supply–Use tables. Into this block all data from the harmonization steps are imported and EE SUT for countries are created.
(2) *Part 2*: The storage of the international Supply–Use table (interlinked Supply–Use table or MR EE SUT).
(3) *Part 3*: The storage of the international input–output table (interlinked country input–output table or MR EE IOT).

Between Parts 1 and 2 a script is installed that performs the trade-linking procedure as described in the section discussed above. Since most analytical applications use IOT rather than SUT, another script creates in Part 3 the MR EE IOT (both of industry by industry (FPA) and product by product (ITA) MR EE IOTs). The MR EE SUT and MR EE IOTs that are available have the following characteristics:

- Covering 43 countries (95% of the global economy) and a RoW (the other 150+ countries in the world combined).
- Distinguishing 129 industry sectors and products.
- Covering 30 emitted substances and 80 resources as extensions by industry.

FIGURE 2. The EXIOBASE system.



- Full trade matrices: insight is given into which product from which country is exported to which industry sector in another country.

4. APPLICATION EXAMPLE THAT HIGHLIGHTS THE CHARACTERISTIC FEATURES OF THE DATA

4.1. Presentation of Some Analytical Results

The final result of the steps detailed earlier is in essence a global economic input–output database with environmental extensions by industry or product by country. Calculating impacts related to final consumption is a well-known exercise and is done as follows.

An input–output model describes how supply $\mathbf{x}$ follows demand with the following identity:

$$\mathbf{x} = \mathbf{Ax} + \mathbf{f}.$$

In this $\mathbf{x}$ is total output, $\mathbf{A}$ the matrix of direct input coefficients, and $\mathbf{f}$ the vector of final demand. Solving the model for output gives (Miller and Blair, 2009):

$$\mathbf{x} = (\mathbf{I} - \mathbf{A})^{-1}\mathbf{f} = \mathbf{Lf}.$$

The matrix $(\mathbf{I} - \mathbf{A})^{-1}$ is commonly referred to as the Leontief-inverse and denoted by $\mathbf{L}$, the multiplier matrix of direct and indirect industry output requirements per unit of final demand. In the Leontief quantity model, from which the backward multipliers are derived, the assumption is made that prices are fixed in the short term. Another assumption in I–O modeling is that input coefficients do not change regardless of output, final demand, or other relevant changes. The structure of the economy is taken to be constant, at least in the short term.

The environmental extensions are given as a matrix of direct impact coefficients $\mathbf{D} = d_{kj}$ of which each element represents the amount (in physical units per Euro worth of output) of the environmental factor k used in the production of sector j. These environmental extensions can be emissions, pollution, raw material use, land use, water use, etc. The total requirement of environmental factors **e** can be calculated as:

$$\mathbf{e} = \mathbf{D}\mathbf{x} = \mathbf{D}(\mathbf{I} - \mathbf{A})^{-1}\mathbf{f}.$$

For an international input–output table the same equation holds, where **e** is now a vector of all individual country sub-vectors $\mathbf{e}_R$, for all countries R.

The total requirement of environmental factors **e** (both resources and emissions/sinks) signifies the dependency of a country on environmental resource inputs. Resource use and emissions may take place domestically, but especially for the countries that are not endowed with material resources, these requirements will be imported. In the next sections, we will give some illustrative analyses with the database, most notably the pollution embodied in imports and exports to and from Europe for various indicators that can be constructed with the database (see Box 1 and Figure 3). Figures 4, 5, and Table 1 present the main results, discussed in the following sections.

Box 1: The relation between impacts of production and final consumption from the EU and non-EU in EXIOBASE

Because EXIOBASE covers the global economy it is possible to create a complete regionalized picture of the impacts related to all economic activities. As a general rule, the impacts as a result of the operation of the world economy that makes a distinction between the EU and non-EU countries can be subdivided into four different parts; see the figure below.

(Ee) emissions within the EU as a result of the final consumption of the EU.
(Ne) emissions outside the EU as a result of the final consumption of the EU which might be labeled emission embodied in imports to satisfy EU final demand.
(En) emissions within the EU as a result of the final consumption of non-EU countries which might be labeled as emissions embodied in exports of the EU to satisfy non-EU final demand.
(Nn) emissions outside the EU as a result of the final consumption of the non-EU countries.

The impacts on European territory are the sum of Ee + En and are indicated by E. Emissions outside Europe are the sum of Ne + Nn indicated by N. Finally the impacts related to final consumption of Europe are the sum of Ee + Ne. The impacts related to EU final consumption are hence equal to impacts in its territory (E) plus imported impacts (Ne) minus exported impacts.

4.2. Final Demand and Value Added

EXIOBASE has combined SUT of 43 countries and a RoW to a global MR EE SUT. In our base year, Europe created around 25% of the global GDP and was responsible for around 25% of final consumption. Figure 4 shows that just over 10% of the EU's GDP is imported and exported to other countries.

As a validity check we analyzed if the global GDP in the database equals GDP from other sources. Global final demand is per definition equal to global GDP: the world has

FIGURE 3. Impacts in the EU (E) and non-EU (N) and impacts embodied in trade from the non-EU to the EU (Ne) and from the EU to non-EU (En).

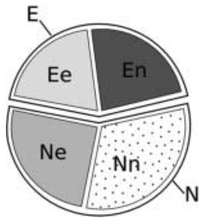
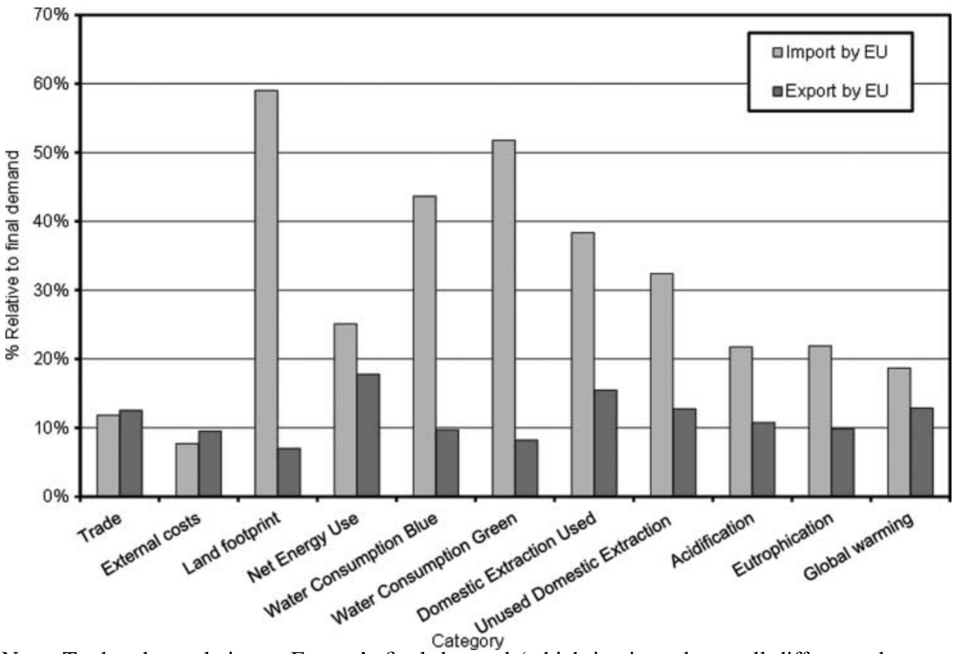


FIGURE 4. Impacts embodied in Europe's imports and exports, relative to impacts caused by EU final demand in 2000.



Note: Trade taken relative to Europe's final demand (which is given the small difference between exports and imports close to GDP). The global warming excludes emissions from land use change.

neither imports nor exports. This GDP can also be calculated from the total value added in the MR EE IOT. The EXIOPOL database estimates via both approaches a global GDP of 34.1 Trillion (10^{12}) Euro in 2000 which is in line with other statistics. Differences with other statistics may be at stake due to:

- The use of country SUT to estimate GDP (officially published GDP estimates are often refined over time, but the SUT are not adjusted to this)
- The estimate of the real RoW. In order to create a table that was balanced and was otherwise realistic (e.g. a positive final demand) assumptions had to be made that led to a slightly different GDP as could be calculated from e.g. UN statistics.

FIGURE 5. Impacts in the EU (E) and non-EU (N) and impacts embodied in trade from the Non-EU to the EU (Ne) and from the EU to non-EU (En).

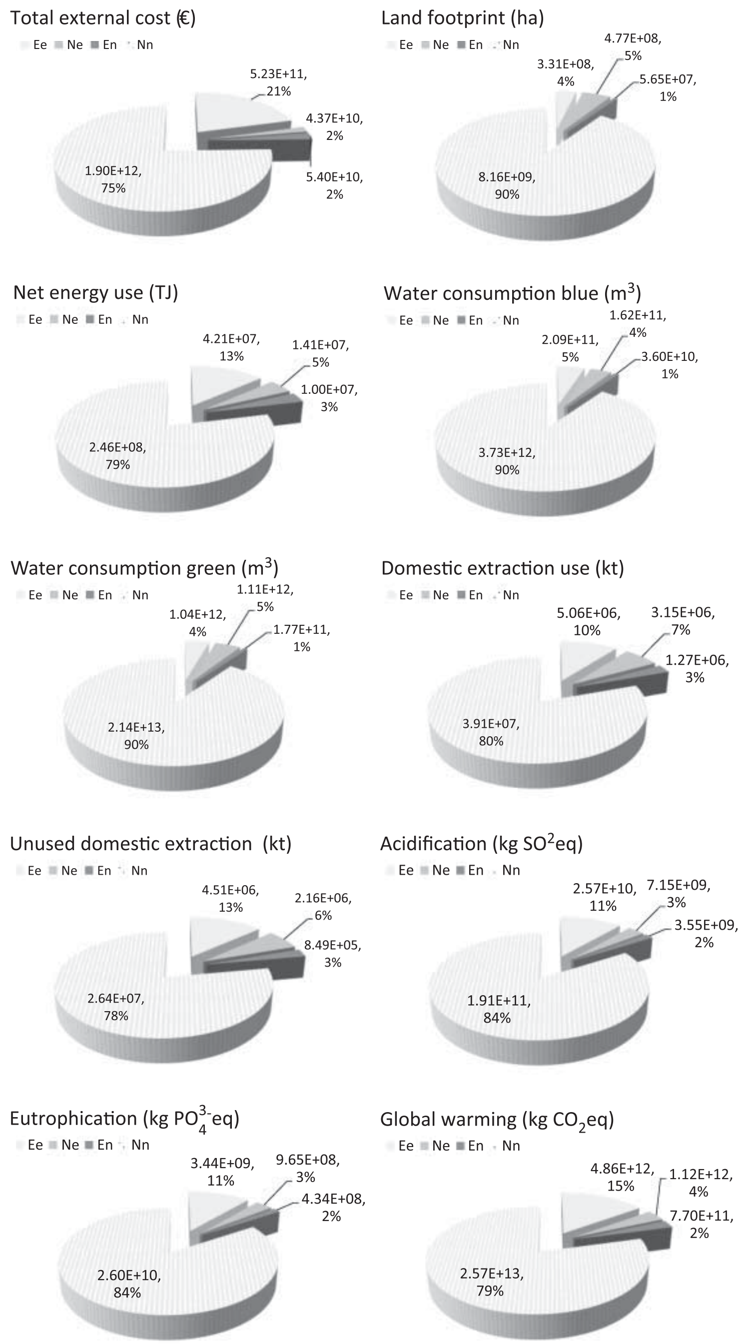


TABLE 1. Impacts per capita related to EU27 final demand, 2000, as well as impacts related to EU27 imports and exports per capita.[a]

Impact type	Unit	Final demand	Import	Export
External costs	Euro	1,173	90	112
Land footprint	ha	1.7	1.0	0.1
Net energy use	GJ	116	29	21
Water consumption blue	m^3	767	335	75
Water consumption green	m^3	4,446	2,301	367
Domestic extraction used	ton	17.0	6.5	2.6
Unused domestic extraction	ton	13.8	4.5	1.8
Acidification	kg SO_2 eq.	68.0	14.8	7.3
Eutrophication	kg PO_4–eq.	9.1	2.0	0.9
Global warming potential (all greenhouse gases)	ton CO_2 eq.	12.4	2.3	1.6
Carbon footprint (CO_2 only)	ton CO_2	10.1	1.87	1.37

[a]Assuming an EU27 population of 483 Million in 2000 (figure taken from Eurostat, http://epp.eurostat.ec.europa.eu/cache/ITY_OFFPUB/KS-QA-09-031/EN/KS-QA-09-031-EN.PDF (accessed 2 September 2011).

- Trade linking. Since imports and exports are not balanced if one builds a global MR SUT from country SUT, a reconciliation must be applied – which inevitably results in minor changes in imports and exports from countries, and hence GDP. For the global GDP, the difference between the sum of GDP from country SUT and the MR SUT is about 0.2% or close to 100 billion Euro.

4.3. Land, Water, Energy, and Material Footprints

Figures 4, 5, and Table 1 show the results for various resource-related indicators: land use, material extraction (used and unused), (blue and green) water use, and energy use. They show that for virtually all resource uses embodied in trade, Europe is a net importer. There are however significant differences between types of resources:

- Land footprint: according to this analysis, the land use embodied in Europe's imports is higher than the domestic land use in Europe.
- Green (rain) and blue (river and aquifer) water use embodied in Europe's imports are 70–90% of Europe's domestic use.
- The used and unused material extractions embodied in Europe's imports are around 40–50% of the used and unused material extractions within Europe.
- The net energy use embodied in imports and exports are in the same order of magnitude. Imports of embodied energy are around 20% of the total energy use for final European consumption.

These figures suggest that particularly for production of goods depending on land use and water Europe is depending highly on non-EU countries. The same applies but to a lesser extent for materials.

4.4. LCIA Impact Assessment Categories: Global Warming Potential (GWP), Acidification (AC), and Eutrophication

LCIA indicators aggregate emissions with the same type of impacts to a single score for that impact. For instance, the indicator GWP reflects the impact of greenhouse gases such as CO_2, CH_4, and N_2O combined. We refer to Guinée (2002) for which substances are covered under GWP, acidification, and Eutrophication. Figures 4, 5, and Table 1 show that for all LCIA indicators the pollution embodied in Europe's imports is higher as for pollution embodied in Europe's exports. This can have three major reasons

(a) Europe uses cleaner technologies, and the European industry is more efficient than foreign industries (less inputs are needed to produce the same output).
(b) Europe concentrates on relatively 'clean' industries and products, and has outsourced more resource- and energy-intensive production abroad.
(c) Per Euro imports compared to Euro production in Europe, more physical goods are imported as produced in Europe – i.e. the price of imports is relatively low. This then automatically implies that emissions per Euro imports will be relatively high.

The pollution embodied in imports and exports is relatively low compared to domestic pollution (10–20%). The GWP embodied in imports is somewhat higher as the GWP embodied in exports, but this difference is more pronounced for Acidification and Eutrophication. This is probably because reduction of greenhouse gases cannot easily be reduced by simple measures such as end-of-pipe technologies, end of pipe measures have been highly successful in reducing acidifying and eutrophying emissions. It is hence most probable that we see here the effect that Europe's industry is relatively clean compared to industry abroad.

4.5. External Costs

A striking finding of this study is also that the external costs created by our current economic system are significant. The externality assessment in our study is far from complete, neglecting for instance the value of ecosystem services and biodiversity. But such emission-related external costs are over 1000 Euro per European per annum, mainly due to climate impacts and respiratory health effects (Table 1). We calculated that for the world as a whole external costs included in EXIOBASE are truly significant, around 7% of the global GDP.

It is interesting to see that Europe is a net exporter of external costs, where it is a net importer of embodied pollution (Figure 4). The main reason for this is probably that externalities in economies that have a lower wealth tend to count less. For non-EU countries, due to the lack of data the relatively crude assumption was applied of using European external cost data weighted via PPP. Particularly the dense populated fast-developing economies outside Europe (e.g. China and India), have relatively low PPPs, implying that in the approach used here (health) damage weights not as heavy as in Europe. This obviously is a relatively subjective assumption, which can be questioned from an ethical perspective. The issue of how to deal with the relative value of damage done to human health, ecosystem health, and economic production in rich and poor countries is in our view an important issue for future research for the externality community.

5. CONCLUSION

The EXIOPOL project created a detailed, global, MR EE SUT. The project also created a rich toolbox for the consortium allowing for redoing database construction in a much quicker way for more recent base years.

This paper used the database to do a fairly simple analysis of pollution and resource use embodied in trade to and from the EU27. Figure 4 is probably the best summary from the EXIOPOL EE I–O work, comparing monetary value of imports, exports, and domestic production with resources and pollution embodied in imports and exports as well as for Europe itself. The overall picture of this particular analysis is that Europe is a net importer of natural resources. This is particularly true for land and water. The land use embodied in trade is higher as the land use in Europe itself. There is also a significant material imports embodied in trade. For energy and greenhouse gases, we see that the flows embodied in imports and exports are relatively close. This alone is already a highly policy relevant conclusion. The EU's product policy is currently mainly focused on energy use and climate aspects, where it is in fact these other environmental aspects of land use, water use, and material extraction, which are related to the most important impacts abroad induced by EU final consumption. Our case study creates a compelling argument that the EU should put much more emphasis on such non-climate and non-energy impacts in its trade and product policies.

Our simple case study does not exploit in all respects the unique detail of our database. More advanced case studies and scenario analysis would for instance trace in detail which sector in which country forms a hot spot of impacts due to European consumption, would do comparative assessments of the impacts of final consumption between countries, would assess the global change of impacts of e.g. detailed changes in consumer expenditure with regard to diets, mobility patterns, etc. (compare Tukker et al., 2011).

At this stage, EXIOBASE is available for the year 2000 only. In the context of a follow-up project called Compiling and Refining Economic and Environmental Accounts, almost the same consortium currently updates the database to 2007, while at the same time creating a higher product and sector detail. An aggregated version of EXIOBASE and detailed example file for one country is freely available via www.exiobase.eu. The consortium decided to make the detailed EXIOBASE database available for a not for profit fee, so that income is generated that allows the consortium to make continuous future updates without being dependent on uncertain external project funding.[8]

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[8] Prices are in the range of 1,500 Euro for a single user. For more details see www.exiobase.eu

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