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Specification and aggregation errors in environmentally extended international input-output models*

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Abstract

An increasing awareness of embodied emissions and embodied resources in traded products has resulted in attempts to track emissions and natural resource use along the international supply chain. An international input-output (IIO) model is identified to be the appropriate methodological framework to undertake this type of environmental accounting, as direct and indirect, domestic and international environmental impacts can be analyzed within one framework. In this paper, specification and aggregation errors in environmental accounting will be studied by means of the EXIOPOL database.

Regarding the specification errors, we focus on the deviations in environmental accounting that result from (1) assuming that domestic environmental coefficients can be used to calculate the emissions or resources embodied in international trade, and (2) using a single-country framework versus using a inter-country framework to calculate the environmental impacts.

Regarding aggregation errors, the EXIOPOL project has put a major effort in detailing sectors that are important from an environmental point of view. This detail allows us to investigate the errors made when environmental analysis is done for more aggregate industries. Besides, we will compare the IIO model with individual countries, with a model where countries are aggregated into one region, such as the EU27.

Moreover, the detail of the database allows us to investigate whether deviations are larger for specific countries or sectors that are analyzed. We will test the errors made by focusing on CO_2 emissions and water use. Investigating two quite different environmental extensions allows for a generalization of our findings.

Category: World input-output modeling and databases

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1 Introduction

Trends of globalization, the creation of global value chains, stronger international inter-industry linkages, and the rise in outsourcing are all drivers in the search for international comparative data and the construction of comprehensive databases to study these developments. Over the past decades, concern over the environment has steadily risen, and policies are designed and implemented at all levels of governance. Some environmental issues, like global warming through CO_2 emissions, should be addressed at a global level. Other issues result in more localized problems, like water shortages, but their cause can also be global by means international trade in intermediate and final products.

The discussion with regards to the estimation of especially CO_2 emissions has revolved largely around measuring the emissions from a consumer perspective as opposed to a producer perspective. In order to compute the emissions from the consumer perspective, the emissions embodied in imports are included, whereas the emission embodied in exports are excluded from the estimates. (G. P. Peters, 2008; G. Peters & Hertwich, 2008; Serrano & Dietzenbacher, 2010) Including the emissions embodied in imports requires information about trading partners, the production technologies of the trading partners, and the emissions produced in these countries. Only an environmentally extended international input-output model provides for this extensive information requirement. When using a single-country model for the calculation of emissions embodied in consumption, the assumption is made that both the environmental coefficients and the production structure of the country of the country under focus more or less resemble the production technologies of all trading partners. An overview of models used for the estimations from a consumption perspective is given by Wiedmann (2009).

The environmentally extended multi-regional input-output databases compiled in the past decade promise an improvement over previously used methods to estimate environmental indicators like pollution in terms of greenhouse gas emissions and use of natural resources. At the same time, the errors made by approximating lacking information can be studied using the newer generation of environmentally extended input-output models. An early attempt to do so is Lenzen, Pade, & Munksgaard (2004) in which the authors studied the international feedback effects, and hence the errors made when using a single-region input-output model, in a model including 4 countries and a rest of world region. They also study the effect of sector aggregation on the estimations. Their findings suggest that it is important to explicitly include trading partner's technologies in terms of production structure and emission coefficients. Also large errors are found when aggregating the sectors to ten sectors.

In Su, Huang, Ang, & Zhou (2010) it is suggested that a sector detail of around 40 sectors is sufficient to capture the majority of CO_2 emissions embodied in production. These authors, however, use a single country model and only investigate the emissions embodied in exports of China and Singapore. Combining two databases often requires aggregation or disaggregation of one of the two datasets in order to match the classifications. Lenzen (2011) addresses the question whether environmental data should be aggregated or input-output data should be disaggregated, given that the first is in a more detailed classification. Aggregating the environmental data implies a loss of detail which is undesirable, but disaggregating the input-output data can often only be done with partial data which increases the uncertainty about the validity of the final dataset. Using Monte-Carlo simulations it is shown that disaggregating the input-output data should be preferred over aggregating the environmental data in determining the input-output multipliers.

Andrew, Peters, & Lennox (2009) look at the errors in CO_2 estimation introduced by approximations of the full model. They find that, in case the number of regions in the model is small, a unidirectional trade model can give a reasonable approximation to the full model. Especially including the trade partner that is responsible for the largest share in emissions embodied in the imports of a country can significantly improve the estimates. They also show that a world average input-output table can offer a suitable substitute for an aggregate rest of the world table. The authors denounce using a single-country model, although they indicate it is still better than ignoring imports altogether. Spatial aggregation is also subject of study by Su & Ang (2010) in which the authors subdivide the data of China into eight regions. They find that the values of CO_2 emissions embodied in exports of China reduce as the number of regions increases.

In this paper, the specification and aggregation errors made in the calculation of environmental indicators when using approximations in the modelling are investigated using the EXIOPOL database (Tukker et al., 2009).

2 Methodology

2.1 Data and notation

The EXIOPOL database consists of 43 countries; the countries that are part of the EU27 and 16 other large countries – see Appendix 1, for a list of individual country names. All 43 countries are linked to each other through international trade flows (Bouwmeester & Oosterhaven, 2008). The level of sector detail in the EXIOPOL database is 129 industries – see Appendix 2. Compared to the 59 by 59 detail level of the ESA-95, the products and sectors important from an environmental point of view have been disaggregated. These products and sectors are related to food and agriculture products, metals ores and products, mineral products, and energy products. (Wood, Hawkins, van Bree, & Poliakov, 2010). In some of our results we distinguish four final demand categories; household consumption expenditure, government consumption expenditure, gross fixed capital formation, changes in inventories and valuables plus exports to the rest of the world.

Matrices are denoted by bold capitals letters, vectors by bold lower case letters, and scalars by italicized lower case letters. A prime indicates transposed matrices and vectors. A hat indicates a diagonalized vector. The vector **i** is a summation vector with ones, and the identity matrix is denoted by **I**. Indices and parameters used are:

i sectors, from 1 to *I*,

q final demand categories, from 1 to *Q*,

r countries, from 1 to *R*,

● summation over the index at hand.

2.2 *The international input-output model*

In an international input-output (IO) model, all bilateral intermediate trade flows are specified by four indices: the country of origin and destination, and the industry of origin and destination. A matrix representation of the international IO model is given in equation (1).

$$\begin{bmatrix} \mathbf{x}^1 \\ \mathbf{x}^2 \\ \vdots \\ \mathbf{x}^R \end{bmatrix} = \begin{bmatrix} \mathbf{A}^{11} & \mathbf{A}^{12} & \cdots & \mathbf{A}^{1R} \\ \mathbf{A}^{21} & \mathbf{A}^{22} & \cdots & \mathbf{A}^{2R} \\ \vdots & \vdots & \ddots & \vdots \\ \mathbf{A}^{R1} & \mathbf{A}^{R2} & \cdots & \mathbf{A}^{RR} \end{bmatrix} \begin{bmatrix} \mathbf{x}^1 \\ \mathbf{x}^2 \\ \vdots \\ \mathbf{x}^R \end{bmatrix} + \begin{bmatrix} \mathbf{f}^{1\bullet} \\ \mathbf{f}^{2\bullet} \\ \vdots \\ \mathbf{f}^{R\bullet} \end{bmatrix} \quad \textbf{(1)}$$

The vectors $\mathbf{x}^1$ to $\mathbf{x}^R$ represent the total output vectors of countries 1 to *R*. The matrix $\mathbf{A}^{rs}$ shows the imports per unit of output of country *s* with regard to country *r*. The matrices $\mathbf{A}^{11}$ to $\mathbf{A}^{RR}$, on the diagonal, show the domestic input coefficient matrices. The final demand vectors $\mathbf{f}^{r\bullet}$ reflect the country of origin, i.e. they show the final demand of all countries for products produced in *r*.

In the EXIOPOL database the categorical and geographical destination of this final demand is also given. The categories distinguished are: household consumption expenditure, government consumption expenditure, gross fixed capital formation, and exports to the rest of the world combined with changes in inventories and valuables. In the case of the EXIOPOL database, the exports to the rest of the world relate to exports to countries that are not included in the database. Each of the *R* final demand vectors shown in equation (1) thus result from the following aggregation.

$$\mathbf{f}^{r\bullet} = \mathbf{F}^{r1}\mathbf{i} + \mathbf{F}^{r2}\mathbf{i} + \cdots + \mathbf{F}^{rR}\mathbf{i} \qquad \textbf{(2)}$$

If the country superscripts are omitted, system (1) can simply be represented as:

$$\mathbf{x} = \mathbf{A}\mathbf{x} + \mathbf{f} \qquad \textbf{(3)}$$

Its well-known solution is straightforward (see inter alia (Miller & Blair, 2009)):

$$\mathbf{x} = \left(\mathbf{I} - \mathbf{A}\right)^{-1}\mathbf{f} = \mathbf{L}\,\mathbf{f} \qquad \textbf{(4)}$$

The matrix $(\mathbf{I} - \mathbf{A})^{-1}$ is commonly referred to as the Leontief-inverse and denoted by **L**.

2.3 An environmentally extended international IO model

Any input-output table can be extended with satellite accounts with additional information. These are often related to the column totals of the IO table, representing for example total labor used, total water used, or total CO_2 emitted sector by each sector. Dividing, e.g. sectoral emissions, by total sectoral output gives a row **d'** with emission coefficients, indicating the total sectoral emissions per unit of output of each sector, in each country. Multiplication with the total output by sector, by country reproduces the direct emissions by sector, by country:

$$\mathbf{e}' = \mathbf{d}'\hat{\mathbf{x}} \qquad \textbf{(5)}$$

Where **e'** is the row vector of pollutants emitted or material resources used by each sector, in each country. Total emissions or total material use at the world level is then given by:

$$e = \mathbf{d}'\mathbf{L}\,\mathbf{f} \qquad \textbf{(6)}$$

This total *e* can be disaggregated from different points of view. To see how, we write (6) in its fullest possible partitioned form:

$$\begin{bmatrix} \mathbf{E}^{11} & \mathbf{E}^{12} & \cdots & \mathbf{E}^{1R} \\ \mathbf{E}^{21} & \mathbf{E}^{22} & \cdots & \mathbf{E}^{2R} \\ \vdots & \vdots & \ddots & \vdots \\ \mathbf{E}^{R1} & \mathbf{E}^{R2} & \cdots & \mathbf{E}^{RR} \end{bmatrix} = \begin{bmatrix} \hat{\mathbf{d}}^{1} & 0 & \cdots & 0 \\ 0 & \hat{\mathbf{d}}^{2} & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & \hat{\mathbf{d}}^{R} \end{bmatrix} \begin{bmatrix} \mathbf{L}^{11} & \mathbf{L}^{12} & \cdots & \mathbf{L}^{1R} \\ \mathbf{L}^{21} & \mathbf{L}^{22} & \cdots & \mathbf{L}^{2R} \\ \vdots & \vdots & \ddots & \vdots \\ \mathbf{L}^{R1} & \mathbf{L}^{R2} & \cdots & \mathbf{L}^{RR} \end{bmatrix} \begin{bmatrix} \mathbf{F}^{11} & \mathbf{F}^{12} & \cdots & \mathbf{F}^{1R} \\ \mathbf{F}^{21} & \mathbf{F}^{22} & \cdots & \mathbf{F}^{2R} \\ \vdots & \vdots & \ddots & \vdots \\ \mathbf{F}^{R1} & \mathbf{F}^{R2} & \cdots & \mathbf{F}^{RR} \end{bmatrix} \quad \textbf{(7)}$$

Note that the submatrices $\mathbf{E}^{rs} = \hat{\mathbf{d}}^{r} \sum_{k} \mathbf{L}^{rk} \mathbf{F}^{ks}$ have dimension *I* x *Q*, and indicate which part of the direct emissions by sector *i* in country *r* is explained by the final demand of category *q* of country *s*.

Hence, matrix **E** directly combines on all possible causes (types of final demand by country) with all possible impacts (direct emissions or resource use by sector by country). Aggregation along a row of **E** gives the total emissions by sector by country, i.e. an aggregation according to the producer responsibility principle. Aggregation along the columns of **E** gives the total worldwide emissions caused by the final demand of each category in each country, i.e. an aggregation according to an extended consumer responsibility principle. (G. P. Peters, 2008, G. Peters & Hertwich, 2008, Serrano & Dietzenbacher, 2010) We use the word 'extended' as part of the worldwide emissions has to be allocated to government expenditures and private investments.

2.4 Specification errors

We compare the outcomes of the classical, in our case extended, consumer responsibility study with the outcome based on the use of the full environmentally extended international IO model of equation (7), thus aggregated by column. In the classical study, typically (e.g. Wyckoff & Roop, 1994 or Lenzen, 1998), the foreign import coefficient matrix (i.e. $\sum_{s \neq r} \mathbf{A}^{sr}$) is added to the domestic input coefficient matrix (i.e. $\mathbf{A}^{rr}$), and the associated Leontief-inverse (i.e. $(\mathbf{I} - \sum_{s} \mathbf{A}^{sr})^{-1}$) is pre-multiplied with the row domestic emission coefficients $\mathbf{d}^{s}$'. Compared with the full international IO model two specification errors are made. The first specification error is the use of domestic emission coefficients where foreign emission coefficients should have been used. The second is the use of the single-country Leontief-inverse, with imports coefficients included, where the full international Leontief-inverse should have been used. We study these errors consecutively such that their sum equals to total specification error.

2.4.1 Error of using domestic emission coefficients

We measure the effect of using domestic emission coefficients, instead of foreign emission coefficients, by means of the extended international IO model. In that way, we obtain the pure specification error associated with assuming that foreign industries have domestic emission coefficients. We measure the *absolute* coefficient errors country-by-country, as follows:

$$\tilde{e}^r - e^r = \begin{bmatrix} \mathbf{d}^r \\ \mathbf{d}^r \\ \vdots \\ \mathbf{d}^r \end{bmatrix}' \begin{bmatrix} \mathbf{L}^{11} & \mathbf{L}^{12} & \cdots & \mathbf{L}^{1R} \\ \mathbf{L}^{21} & \mathbf{L}^{22} & \cdots & \mathbf{L}^{2R} \\ \vdots & \vdots & \ddots & \vdots \\ \mathbf{L}^{R1} & \mathbf{L}^{R2} & \cdots & \mathbf{L}^{RR} \end{bmatrix} \begin{bmatrix} \mathbf{f}^{1r} \\ \mathbf{f}^{2r} \\ \vdots \\ \mathbf{f}^{Rr} \end{bmatrix} - \begin{bmatrix} \mathbf{d}^1 \\ \mathbf{d}^2 \\ \vdots \\ \mathbf{d}^R \end{bmatrix}' \begin{bmatrix} \mathbf{L}^{11} & \mathbf{L}^{12} & \cdots & \mathbf{L}^{1R} \\ \mathbf{L}^{21} & \mathbf{L}^{22} & \cdots & \mathbf{L}^{2R} \\ \vdots & \vdots & \ddots & \vdots \\ \mathbf{L}^{R1} & \mathbf{L}^{R2} & \cdots & \mathbf{L}^{RR} \end{bmatrix} \begin{bmatrix} \mathbf{f}^{1r} \\ \mathbf{f}^{2r} \\ \vdots \\ \mathbf{f}^{Rr} \end{bmatrix} \quad \textbf{(8)}$$

The last term of (8) indicates the true total worldwide emission caused by country *r*'s total final demand, while the first term indicates the estimate of this total, made by assuming that the foreign $\mathbf{d}^s$ equal the domestic $\mathbf{d}^r$.

Besides absolute country-by-country errors, which will of course be larger the larger the country, we also study the related *relative* coefficient errors. In shorthand, these equal:

$$\left(\tilde{e}^r - e^r\right) \Big/ e^r = \left(\mathbf{d}^{r\prime}\, \mathbf{L}\mathbf{f}^r - \mathbf{d}'\mathbf{L}\mathbf{f}^r\right) \Big/ \mathbf{d}'\mathbf{L}\mathbf{f}^r \quad \textbf{(9)}$$

The *total relative world* error then equals:

$$\tilde{\varepsilon} = \left(\sum\nolimits_r \tilde{e}^r - \sum\nolimits_r e^r\right) \Big/ \sum\nolimits_r e^r \quad \textbf{(10)}$$

We present it separately by causing *sector-specific* final demand, by means of:

$$\tilde{\varepsilon}_i = \left(\sum\nolimits_r \tilde{e}_i^r - \sum\nolimits_r e_i^r\right) \Big/ \sum\nolimits_r e_i^r \quad \textbf{(11)}$$

Where e_i^r and $\tilde{e}_i^r$ are calculated as:

$$e_i^r = \mathbf{d}'\mathbf{l}_i^r\, f_i^r \text{ and } \tilde{e}_i^r = \mathbf{d}^{r\prime}\, \mathbf{l}_i^r\, f_i^r \quad \textbf{(12)}$$

Finally, we present the errors separately by causing *category-specific* final demand errors, with $\tilde{\varepsilon}_q$ calculated analogously to (11).

2.4.2 *Error of using a single-country IO model*

To get a pure estimate of the error made when using a single-country IO model, as opposed to an international IO model, we use the domestic emission coefficients of the country at hand in both cases. The *absolute* single-country errors are thus calculated as follows:

$$\bar{e}^r - \tilde{e}^r = \mathbf{d}^{r\prime}\left(\mathbf{I} - \mathbf{A}^{\bullet r}\right)^{-1}\mathbf{f}^{\bullet r} - \mathbf{d}^{r\prime}\left(\mathbf{I} - \mathbf{A}\right)^{-1}\mathbf{f}^r \qquad \textbf{(13)}$$

The last term of (13) equals the first term of (8), and in the first term of (13) we use:[1]

$$\mathbf{A}^{\bullet r} = \mathbf{A}^{1r} + \mathbf{A}^{2r} + \cdots + \mathbf{A}^{Rr} \text{ and } \mathbf{f}^{\bullet r} = \mathbf{f}^{1r} + \mathbf{f}^{2r} + \cdots + \mathbf{f}^{Rr} \qquad \textbf{(14)}$$

Besides absolute errors, which vary mainly by country size, we again also present relative country-by-country errors, which are calculated as follows:

$$\left(\bar{e}^r - \tilde{e}^r\right)\big/ e^r = \left(\mathbf{d}^{r\prime}\left(\mathbf{I} - \mathbf{A}^{\bullet r}\right)^{-1}\mathbf{f}^{\bullet r} - \mathbf{d}^{r\prime}\,\mathbf{L}\mathbf{f}^r\right)\Big/ \mathbf{d}'\mathbf{L}\mathbf{f}^r \qquad \textbf{(15)}$$

Note that these relative single-country errors are expressed as a ratio of the true value e^r, instead of by $\tilde{e}^r$. In this way, the first set of relative errors of (9) can be added to the second set of relative errors of (15), to obtain the total relative error of the classical extended single-country IO model compared to the present extended international IO model.

The relative single-country specification error for worldwide total emissions is defined as:

$$\bar{\varepsilon} = \left(\sum\nolimits_r \bar{e}^r - \sum\nolimits_r \tilde{e}^r\right)\Big/ \sum\nolimits_r e^r \qquad \textbf{(16)}$$

We present a disaggregation of this total by causing *sector-specific* final demand analogously to (11):

$$\bar{\varepsilon}_i = \left(\sum\nolimits_r \bar{e}_i^r - \sum\nolimits_r \tilde{e}_i^r\right)\Big/ \sum\nolimits_r e_i^r \qquad \textbf{(17)}$$

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[1] The total coefficient matrix $\mathbf{A}^{\bullet r}$, used here, deviates from the IO data published by the individual countries due to the estimation method of the international input-output table (see, Bouwmeester & Oosterhaven, 2008, for details). The country-by-country trade flows have been made consistent, and in the process they revalued in basic prices of the producing (i.e. exporting instead of importing) country.

And, the disaggregation by causing *category-specific* of final demand into $\bar{\varepsilon}_q$ again proceeds analogously.

Finally, in all cases, the total relative specification error can be decomposed into the specification errors due to using domestic emissions coefficients and those due to using a single-country IO model, respectively, e.g. in the case of the worldwide total emissions:

$$\varepsilon = \frac{\sum_r \bar{e}^r - \sum_r e^r}{\sum_r e^r} = \frac{\sum_r \bar{e}^r - \sum_r \tilde{e}^r}{\sum_r e^r} + \frac{\sum_r \tilde{e}^r - \sum_r e^r}{\sum_r e^r} \qquad \textbf{(18)}$$

2.5 Aggregation errors

Next to specification errors, we investigate aggregation errors. In an international IO model aggregation errors can be due to either sectoral aggregation or spatial aggregation.

In order to understand the nature of aggregation errors, it is important to be aware that, for any base year, equation (6) will always result in exactly the same estimate of emissions **e**, no matter the actual level of sectoral or spatial aggregation. This is simply the case, because base year **L** times base year **f** in (6) always reproduces base year **x** at the aggregation level chosen. The same holds for base year $\hat{\mathbf{d}}$ times base year **x** that always reproduces base year **e**, at the chosen level of aggregation. Aggregation errors will only occur when the actual final demand weights are different from those of *total* final demand in the base year, from which the models´ parameters in **d** and **A** are derived, at the aggregation level chosen.

To investigate the impact of the aggregation of sectors and countries, we again evaluate the errors from the extended consumer responsibility perspective. Hence, we will measure the aggregation errors by using the weights of the four different types of final demand available in the EXIOPOL database, for the 43 countries distinguished, which results in 172 different weighting options.

2.5.1 Sectoral aggregation errors

To investigate the impact of the aggregation of sectors, CO_2 emissions and water use are calculated at three levels of sectoral detail. The 'true' value of the worldwide emissions that are embodied in final demand category *q* of country *r*, is calculated at the most disaggregate level of 129 industries:

$$e_q^r = \begin{bmatrix} \mathbf{d}^1 \\ \mathbf{d}^2 \\ \vdots \\ \mathbf{d}^R \end{bmatrix}' \begin{bmatrix} \mathbf{L}^{11} & \mathbf{L}^{12} & \cdots & \mathbf{L}^{1R} \\ \mathbf{L}^{21} & \mathbf{L}^{22} & \cdots & \mathbf{L}^{2R} \\ \vdots & \vdots & \ddots & \vdots \\ \mathbf{L}^{R1} & \mathbf{L}^{R2} & \cdots & \mathbf{L}^{RR} \end{bmatrix} \begin{bmatrix} \mathbf{f}_q^{1r} \\ \mathbf{f}_q^{2r} \\ \vdots \\ \mathbf{f}_q^{Rr} \end{bmatrix} = \mathbf{d}'\mathbf{L}\mathbf{f}_q^r \qquad \textbf{(19)}$$

This results in Q x R = 172 different 'true' values. Besides, (19) is calculated at the level of the 59 sectors of the EU27 input-output tables, and at the level of 10 very aggregate industries, which results in $e_q^r(59)$ and $e_q^r(10)$, respectively (see Appendix 3, for details on the sectors that are combined).

We will compare only *relative* aggregation errors, and do that sequentially, such that the total error from aggregating 127 detailed industries to 10 broad sectors equals the sum of the two partial aggregation errors:

$$\left[e_q^r(10) - e_q^r\right] / e_q^r = \left[e_q^r(10) - e_q^r(59)\right] / e_q^r + \left[e_q^r(59) - e_q^r\right] / e_q^r \qquad \textbf{(20)}$$

Note that the two partial errors do not necessarily have the same sign. They may compensate each other, possibly making the total error even absolutely smaller that than each of the two partial errors. The results of comparison (20) will be combined and presented at two levels.

First, we present the effects of aggregation for each of the 4 final demand categories, and do that at the level of the 10 broad sectors to see which sectors are most heavily impacted. For this purpose we post-multiply with the diagonal matrix of the final demand column used in (19):

$$\mathbf{e}_q = \mathbf{d}'\mathbf{L}\hat{\mathbf{f}}_q^{\bullet} \qquad \textbf{(21)}$$

Where $\mathbf{e}_q$ has 10 elements showing the impact of the worldwide final demand category q on the value of the water used or CO_2 emitted by each of the 10 broad sectors. The 3 x 40 outcomes of (21) are compared as indicated in (20).

Second, we present the effects of sectoral aggregation for each of the 43 countries to see which countries are most heavily impacted. For this purpose we post-multiply with total final demand by country, instead of with the separate categories as was done in (19):

$$e^r = \mathbf{d}'\mathbf{L}\mathbf{f}^r \qquad \textbf{(22)}$$

The 3 x 43 outcomes of (22) are compared as indicated in (20).

2.5.2 *Spatial aggregation errors*

As we want to compare the impact of spatial aggregation for each individual country *r*, the spatial aggregation relates to the each time different set of the 42 remaining countries $s \neq r$. Again we present only the results for total final demand and not those for each of the 4 categories separately. Hence, the 'true' values of the worldwide water use and CO_2 emissions are calculated with the extended international IO model with all 43 individual countries included, as shown in (22).

These 43 'true' values are compared with calculations at two higher levels of aggregation for the remaining 42 countries:

1. The remaining countries are split into EU countries and non-EU countries, and both groups of countries are further split into developed and developing ones. The latter subdivision is based on GDP/capita data (see Appendix 4 for details). This results in an aggregation into 5 regions, which are each time a little different.
2. The remaining countries are aggregated into one Rest of the World region. This results in an aggregation into 2 regions, again each time a little different.

The 3 x 43 outcomes of (22) are sequentially compared analogously to (20):

$$\left[e^r(2)-e^r\right]/e^r=\left[e^r(2)-e^r(5)\right]/e^r+\left[e^r(5)-e^r\right]/e^r \tag{23}$$

Where e^r is the worldwide water use or worldwide CO_2 emission allocated to the total final demand of country *r*, as calculated with the full 43 country model, whereas $e^r(2)$ and $e^r(5)$ are calculated with the aggregated model, with 2 and 5 regions, respectively.

3 Results

In this section we compare the differences in CO_2 emissions and water use estimations due to alternative specifications and varying sector and spatial detail. The analysis is based on the EXIOPOL database consisting of 43 countries. The estimates for the full model are considered to be the 'true' values. We first discuss the specification errors made when (1) assuming that domestic environmental coefficients can be used to calculate the emissions or resources embodied in international trade, and (2) using a single-country framework versus using an inter-country framework to calculate the environmental impacts. Next, we turn to the differences in the results stemming from sector and spatial aggregation.

3.1 Specification errors

Table 3-1 reports the specification errors for each of the 43 EXIOPOL countries. The column with heading $\tilde{e}-e$ represents error of using domestic emissions coefficients for all industries both domestic and foreign. The column with $\tilde{\varepsilon}$ shows the error of using domestic emissions coefficients as percentage of the 'true' estimates. The column representing $\bar{e}-\tilde{e}$ shows the absolute difference between the estimate of the single-country model and the domestic coefficients model. The final column of $\bar{\varepsilon}$ shows the error of the single-country model compared to an international model as percentage of the 'true' estimates. Note that for each country the sum of the values in the columns $\tilde{e}-e$ and $\bar{e}-\tilde{e}$ results in a value for the total error $\bar{e}-e$, which comparable studies generally focus on, for example (Andrew et al., 2009).

For the CO_2 estimations a striking result is that the errors of using a single-country model (partially) cancel out the errors made from using domestic emission coefficients for 21 of the 42 countries. India, the United States, Finland and Greece are especially noteworthy. Using the domestic coefficients in an international model, which represents all the international inter-industry linkages, largely overestimates the CO_2 emissions for these countries. This indicates these countries have relatively high CO_2 emissions per unit of production. However, when a single-country model is used, the domestic technology structure cancels out the effects of the high CO_2 coefficients.

Looking at the results for water use, the impact of using domestic emission coefficients in an international model is remarkable in term of percentage error for Norway. Water is abundant in Norway and water use is abundantly used by the Norwegian sectors. The result for Russia stands out in terms of absolute error, albeit the percentage error is also considerable. Water use in Japan, South Korea, the Netherlands and the United Kingdom largely reduces when estimated with domestic emission coefficients compared to the results of the full model.

Table 3-2 shows the results for the same specification errors but now by industry. The results have been calculated at the 129 sector level, but are represented at the 59 sector level. Also here we observe generally positive values for $\tilde{e}-e$ and negative values for $\bar{e}-\tilde{e}$ with regards to the CO_2 emission estimates. For water use the sectors i27 basic metals, i28 fabricated metal products, i29 machinery and equipment n.e.c., i65 financial intermediation and i67 activities auxiliary to financial intermediation are associated with large percentage errors of using domestic emissions coefficients in the international model.

Table 3-1: Absolute and relative specification errors, by final demand, by country

	CO_2 emissions				water use			
	$\tilde{e}-e$	$\tilde{\varepsilon}$	$\bar{e}-\tilde{e}$	$\bar{\varepsilon}$	$\tilde{e}-e$	$\tilde{\varepsilon}$	$\bar{e}-\tilde{e}$	$\bar{\varepsilon}$
Australia	3	4	-3	-4	43	26	-41	-25
Austria	0.2	2	-2	-20	-8	-28	-1	-2
Belgium	-4	-19	5	24	-18	-48	-2	-6
Brazil	7	10	-7	-10	-111	-9	14	1
Bulgaria	-0.4	-11	1	27	1	3	1	6
Canada	38	44	-15	-17	102	33	-55	-18
China	13	7	3	2	-73	-5	40	3
Cyprus	4	97	2	44	-3	-62	0.3	8
Czech Republic	6	13	9	18	-2	-5	3	7
Denmark	-4	-38	-0.5	-5	-8	-41	-0.4	-2
Estonia	0.2	10	0.2	10	2	45	3	53
Finland	33	131	-29	-116	-4	-20	0.4	2
France	-13	-22	-9	-16	-49	-22	12	5
Germany	-23	-23	-0.2	-0.2	110	44	-98	-39
Greece	28	142	-18	-91	-4	-6	2	3
Hungary	0.1	1	1	13	4	12	4	14
India	1943	838	-1742	-752	-35	-1	23	1
Indonesia	18	24	-6	-9	169	5	254	8
Ireland	2	25	-2	-17	-3	-20	1	5
Italy	-12	-18	-2	-3	-27	-14	11	6
Japan	26	13	-25	-13	-584	-82	-5	-1
Latvia	3	76	-2	-62	-1	-4	-0.1	-0.2
Lithuania	4	86	-2	-42	-10	-22	-0.1	-0.2
Luxembourg	-0.5	-41	-0.1	-10	-1	-19	1	25
Malta	2	81	2	107	-1	-99	0.001	0.2
Mexico	6	6	-7	-8	591	49	-91	-8
Netherlands	29	108	3	9	-40	-86	0.5	1
Norway	2	21	-3	-25	266	2158	-69	-564
Poland	-4	-19	-1	-2	-0.1	-0.03	-1	-1
Portugal	10	96	-0.1	-1	-2	-4	5	13
Romania	4	69	-0.2	-3	4	6	12	21
Russian Federation	23	37	-5	-8	3443	251	-179	-13
Slovak Republic	-1	-30	-0.04	-2	-1	-3	1	4
Slovenia	1	37	-1	-30	-3	-53	1	13
South Africa	5	29	-4	-21	29	18	-4	-3
South Korea	6	8	3	4	-110	-62	-9	-5
Spain	-6	-13	-1	-2	-5	-2	-6	-3
Sweden	11	37	-6	-22	10	26	-13	-32
Switzerland	-1	-7	-3	-26	21	44	0.4	1
Taiwan	11	24	3	6	1	1	-37	-41
Turkey	2	6	4	11	11	8	-18	-12
United Kingdom	-35	-40	-0.5	-1	-75	-51	-10	-7
United States	1195	80	-1105	-74	-231	-8	71	2

Table 3-2: Absolute and relative specification errors, by final demand, by industry

		CO_2 emissions				water use			
		$\bar{e}-\tilde{e}$	$\tilde{\varepsilon}$	$\bar{e}-\tilde{e}$	$\bar{\varepsilon}$	$\bar{e}-\tilde{e}$	$\tilde{\varepsilon}$	$\bar{e}-\tilde{e}$	$\bar{\varepsilon}$
i01	Agriculture, hunting	191	377	-164	-325	2265	32	-60	-1
i02	Forestry, logging	2	94	-1	-75	13	19	3	4
i05	Fishing	4	92	-3	-72	-14	-5	-2	-1
i10	Mining of coal and lignite - peat	0.1	6	-0.1	-3	0.1	7	0.01	0.4
i11	Crude petroleum and natural gas	3	42	-2	-28	1	8	-1	-5
i12	Mining of uranium and thorium ores	0.2	54	-0.1	-41	-0.04	-9	-0.01	-3
i13	Mining of metal ores	-0.4	-11	0.5	15	3	47	-2	-27
i14	Other mining and quarrying	0.01	-0.2	-0.1	3	0.3	16	0.01	0.4
i15	Food products and beverages	224	118	-176	-93	971	23	-137	-3
i16	Tobacco products	17	219	-13	-160	-0.3	0.0	77	7
i17	Textiles	140	510	-133	-483	-35	-24	-14	-10
i18	Wearing apparel, fur	58	214	-59	-219	-26	-22	-12	-10
i19	Leather products	18	112	-19	-119	-9	-14	8	13
i20	Wood, cork and straw products	4	38	-3	-32	-1	-1	2	2
i21	Pulp, paper and paper products	29	93	-24	-78	-17	-8	17	8
i22	Publishing, printing, recorded media	35	118	-25	-85	-13	-19	-0.4	-1
i23	Coke, refined petroleum products and nuclear fuels	71	62	-26	-22	-1	-9	1	5
i24	Chemicals and chemical products	287	340	-244	-289	19	11	-13	-8
i25	Rubber and plastic products	113	330	-109	-318	-40	-14	22	8
i26	Non-metallic mineral products	32	230	-29	-213	2	20	-2	-21
i27	Basic metals	25	117	-25	-116	30	467	-4	-66
i28	Fabricated metal products	37	191	-33	-170	20	129	-8	-53
i29	Machinery and equipment n.e.c.	197	290	-177	-261	71	109	-38	-59
i30	Office machinery and computers	30	154	-25	-131	1	4	-10	-29
i31	Electrical machinery and apparatus n.e.c.	171	570	-159	-531	14	28	10	20
i32	Radio, television and communication equipment	94	272	-88	-255	-6	-10	-6	-11
i33	Medical, precision and optical instruments	24	133	-20	-113	10	57	-6	-37
i34	Motor vehicles, trailers and semi-trailers	267	276	-249	-257	21	20	-5	-5
i35	Other transport equipment	62	251	-58	-236	10	33	8	29
i36	Furniture; manufacturing n.e.c.	114	83	-130	-94	-12	-10	-8	-7
i37	Recycling	-0.3	-19	-0.1	-6	0.04	11	-0.2	-51
i40	Electricity, gas, steam and hot water supply	15	3	-9	-2	0.3	1	-0.3	-1
i41	Collection, purification and distribution of water	2	53	-2	-47	-0.3	-10	-0.1	-4
i45	Construction	330	99	-291	-88	-19	-2	15	2
i50	Sale, maintenance and repair of motor vehicles	29	69	-26	-62	-2	-3	2	3
i51	Wholesale trade and commission trade	15	34	-13	-29	4	5	-3	-4
i52	Retail trade; repair personal and household goods	50	37	-42	-31	16	8	2	1
i55	Hotels and restaurants	51	36	-45	-32	-19	-2	-39	-5
i60	Land transport; transport via pipelines	58	85	-56	-82	0.3	1	5	10
i61	Water transport	54	32	-75	-45	-1	-4	2	6
i62	Air transport	62	218	-55	-195	4	8	6	12
i63	Supporting transport activities; travel agencies	4	36	-3	-29	1	12	-1	-11
i64	Post and telecommunications	13	55	-12	-48	5	19	-5	-20
i65	Financial intermediation	12	84	-10	-71	26	110	-11	-46
i66	Insurance and pension funding	7	57	-7	-53	7	33	-1	-4
i67	Activities auxiliary to financial intermediation	0.4	2	-1	-6	25	156	-2	-13
i70	Real estate activities	23	22	-18	-18	8	4	2	1
i71	Renting of machinery and equipment	1	31	-1	-26	-0.02	-0.4	0.1	2
i72	Computer and related activities	6	44	-5	-38	-2	-11	-1	-6
i73	Research and development	6	78	-5	-65	2	6	-1	-1
i74	Other business activities	7	43	-5	-33	-1	-2	1	2
i75	Public administration and defense	100	44	-83	-36	44	12	9	2
i80	Education	11	25	-10	-22	2	3	-1	-1
i85	Health and social work	159	117	-132	-98	19	5	17	5
i90	Sewage and refuse disposal, sanitation	1	7	-1	-6	0.2	3	1	7
i91	Activities of membership organisation n.e.c.	14	60	-12	-53	-2	-5	1	2
i92	Recreational, cultural and sporting activities	15	53	-13	-47	-1	-2	-3	-4
i93	Other service activities	38	191	-36	-178	1	4	0.5	2
i95	Private households with employed persons	2	18	-1	-13	0.2	1	7	18

3.2 Aggregation errors

3.2.1 Sector aggregation

Table 3-3 shows the differences in estimated CO_2 emissions and water use when reducing sector detail from 129 sectors to 59 sectors and to 10 sectors. The results are presented by sector (at the 10 sector level) and by final demand category. The results for CO_2 emissions are rather mixed showing no distinctive cases. The large percentage errors found for the aggregation from 129 to 59 sectors for final demand category 4: changes in inventories and valuables and exports to the rest of the world seem to indicate a data construction issue. Extreme percentage errors are found for water use, especially in the aggregation from 59 to 10 sectors. Sector E – Electricity, gas and water supply shows the largest percentage errors. Sector F – Construction and sector I – Transport, storage and communication are also associated with large percentage errors for the aggregation to 10 sectors for household consumption expenditure, government consumption expenditure and gross fixed capital formation. Water use percentage errors resulting from the aggregation to 10 sectors are relatively large for all sectors satisfying the final demand category gross fixed capital formation

Table 3-4 reports the percentage errors resulting from sector aggregation for the 43 EXIOPOL countries. The largest errors for CO_2 emissions are related to the aggregation to 10 sectors. The overestimation of CO_2 emissions at the 10 sector level is highest for Greece, Norway and the Russian Federation. For water use the percentage errors obtained from aggregating to 59 sectors partially cancel when aggregation to 10 sectors.

Table 3-3: Sectoral aggregation errors, by final demand, by impacted sector

	CO_2 emissions			water use		
	ε (129 $\gg$ 59)	ε (59 $\gg$ 10)	ε (129 $\gg$ 10)	ε (129 $\gg$ 59)	ε (59 $\gg$ 10)	ε (129 $\gg$ 10)
Final demand 1: household consumption						
ABC	-3	-4	-7	9	-32	-22
D	0.02	4	4	-1	-33	-34
E	18	-0.4	17	-46	2236	2190
F	-1	-16	-17	-50	221	171
GH	-8	-7	-14	23	-40	-17
I	11	-6	5	-15	120	105
JK	-15	12	-3	-51	67	16
L	-4	-10	-14	-36	79	43
MN	-12	-2	-14	-26	29	2
OPQ	-7	-3	-11	-23	54	31
Final demand 2: government consumption						
ABC	-2	-1	-3	-2	-26	-28
D	-9	-24	-33	-13	-1	-14
E	-30	75	45	-32	1601	1570
F	-18	12	-6	-48	131	84
GH	-0.3	-10	-10	9	-48	-38
I	4	6	10	-17	123	106
JK	-46	8	-37	37	27	64
L	-2	-10	-12	-28	61	32
MN	2	-6	-4	-17	50	34
OPQ	1	-6	-5	-15	4	-11
Final demand 3: gross fixed capital formation						
ABC	-8	-6	-14	12	110	123
D	-8	46	38	-47	498	451
E	16	7	23	-44	939	894
F	-4	-16	-20	-53	125	72
GH	-4	21	17	-37	147	110
I	30	-37	-6	-5	127	122
JK	-12	-10	-22	-46	91	45
L	-4	6	2	-52	233	181
MN	7	72	79	5	523	528
OPQ	-0.3	11	10	-21	35	14
Final demand 4: changes in inventories and valuables; export to the rest of the world						
ABC	-156	-53	-209	-26	-7	-33
D	-88	3	-84	-84	8	-75
E	-88	-9	-97	-155	-8296	-8451
F	-88	1	-87	-97	52	-45
GH	-91	1	-89	-99	1	-99
I	-94	-3	-98	-103	7	-96
JK	-98	-0.01	-98	-99	1	-98
L	-89	-1	-90	-95	12	-83
MN	-73	-11	-84	-77	31	-46
OPQ	-95	2	-93	-96	2	-94

Table 3-4 Sectoral aggregation errors, by final demand, by country

	CO_2 emissions			water use		
	ε (129 $\gg$ 59)	ε (59 $\gg$ 10)	ε (129 $\gg$ 10)	ε (129 $\gg$ 59)	ε (59 $\gg$ 10)	ε (129 $\gg$ 10)
Australia	0.1	0.4	0.4	-16	4	-12
Austria	-0.3	-4	-5	-8	57	49
Belgium	-5	-5	-10	-10	21	10
Brazil	2	2	4	-6	-3	-9
Bulgaria	4	4	9	7	52	59
Canada	6	6	12	-15	-5	-19
China	9	2	12	-1	2	1
Cyprus	-6	0.3	-5	5	23	28
Czech Republic	6	-1	5	-4	36	33
Denmark	-5	29	24	-13	29	17
Estonia	-8	-3	-10	33	-1	32
Finland	-1	-11	-13	-6	54	48
France	1	-6	-5	-1	25	24
Germany	-7	8	1	3	47	50
Greece	13	83	96	-6	7	1
Hungary	1	-7	-6	-18	22	4
India	-2	6	4	-0.5	-3	-3
Indonesia	1	4	5	22	-28	-5
Ireland	1	-7	-5	-6	24	18
Italy	-3	-4	-7	-6	39	32
Japan	1	2	3	-39	69	31
Latvia	-3	6	3	-1	-15	-16
Lithuania	-14	2	-12	-19	1	-18
Luxembourg	-7	-10	-18	-37	43	7
Malta	-2	-15	-17	23	24	47
Mexico	-8	-6	-13	-3	-24	-28
Netherlands	-15	13	-3	10	38	48
Norway	-3	63	60	43	35	78
Poland	-0.3	-2	-2	-9	8	-1
Portugal	6	3	9	12	15	28
Romania	-1	7	7	5	9	13
Russian Federation	11	22	33	-1	-40	-41
Slovak Republic	11	-1	9	-11	42	31
Slovenia	6	-3	2	-24	27	3
South Africa	-3	-1	-4	0.4	-43	-42
South Korea	2	6	8	-42	102	60
Spain	-3	-4	-6	-8	19	11
Sweden	-1	5	5	-1	16	15
Switzerland	-4	6	2	-44	14	-30
Taiwan	0.4	1	2	-17	67	50
Turkey	12	-10	2	51	5	57
United Kingdom	-0.1	-19	-19	3	41	43
United States	-0.4	-3	-4	-5	24	19

3.2.2 Spatial aggregation

Table 3-5 shows the percentage errors resulting from spatial aggregation. Each countries CO_2 emissions and water use from the full model are compared to the estimations of each country in a setting with four other regions, and in a setting with one large rest of world table. The regions and rest of world table both result from the aggregation of the remaining 42 partners of the country in focus. The regions formed in the setting combining the country table with four sets of countries can be found in Appendix 4.

The CO_2 emissions which are overestimated when reducing the international model to one country and a rest of world occur when the four regions are combined into a rest of world table. In contrast, the CO_2 emissions that are underestimated at the most aggregated spatial level show the larger error at the aggregation of the individual countries to the regions.

The errors in the estimation of water use are more extreme compared to the spatial aggregation errors of the CO_2 estimates. Norway, Luxembourg en Switzerland stand out with regards to the overestimation of the water use as the trading partners of the focus country become more aggregated. Again, underestimations made occur at the aggregation of the individual countries to the four general regions, whereas the overestimation occurs mostly at the aggregation of the four regions into a rest of the world region.

Table 3-5 Spatial aggregation errors, by final demand, by country

	CO_2 emissions			water use		
	$\mathcal{E}$ (43 ≫ 5)	$\mathcal{E}$ (5 ≫ 2)	$\mathcal{E}$ (43 ≫ 2)	$\mathcal{E}$ (43 ≫ 5)	$\mathcal{E}$ (5 ≫ 2)	$\mathcal{E}$ (43 ≫ 2)
Australia	2	-0.1	2	-15	2	-13
Austria	-1	18	17	-2	64	62
Belgium	-2	17	15	-18	91	73
Brazil	-0.5	0.5	0.02	-7	-1	-8
Bulgaria	-9	-13	-23	4	-2	2
Canada	-1	1	-0.04	-14	11	-4
China	2	1	2	-3	-1	-4
Cyprus	0.02	-16	-16	79	-15	65
Czech Republic	-1	2	1	-0.3	11	11
Denmark	-11	9	-2	-8	51	43
Estonia	-21	4	-17	-0.2	9	9
Finland	-2	5	2	-5	14	8
France	-3	18	15	-6	29	23
Germany	-7	15	9	-2	38	36
Greece	-1	8	6	-4	22	19
Hungary	4	6	10	-5	10	5
India	-1	-0.5	-1	-1	-0.5	-1
Indonesia	0.3	1	1	0.03	0.005	0.04
Ireland	2	13	15	-6	69	63
Italy	-3	8	4	-10	37	27
Japan	2	1	2	-16	-3	-20
Latvia	-11	-1	-12	-20	2	-18
Lithuania	-29	-3	-31	-24	0.5	-23
Luxembourg	-12	44	32	-9	185	176
Malta	1	-10	-10	-21	104	83
Mexico	-6	0.1	-6	-3	0.5	-2
Netherlands	-13	16	3	-13	61	48
Norway	-11	12	1	100	153	253
Poland	-17	4	-13	-3	4	1
Portugal	4	14	18	-5	49	44
Romania	-5	0.4	-4	0.4	2	2
Russian Federation	-1	1	1	2	-1	2
Slovak Republic	-26	0.1	-26	-3	10	7
Slovenia	3	18	21	-13	30	17
South Africa	3	4	7	-4	1	-3
South Korea	4	0.4	4	-27	-10	-37
Spain	-5	10	6	-3	16	13
Sweden	0.2	12	12	-4	35	31
Switzerland	-2	29	27	28	116	144
Taiwan	4	2	6	-30	6	-24
Turkey	5	-0.03	5	-5	7	2
United Kingdom	-4	-1	-5	-10	46	36
United States	-2	-0.05	-2	-7	2	-5

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Appendices

Appendix 1: EXIOPOL country list

The 43 EXIOPOL countries – the 27 EU member countries are marked

Australia		Hungary	(EU)	South Korea	
Austria	(EU)	India		Romania	(EU)
Belgium	(EU)	Indonesia		Russian Federation	
Bulgaria	(EU)	Ireland	(EU)	Slovakia	(EU)
Brazil		Italy	(EU)	Slovenia	(EU)
Canada		Japan		South Africa	
China		Latvia	(EU)	Spain	(EU)
Cyprus	(EU)	Lithuania	(EU)	Sweden	(EU)
Czech Republic	(EU)	Luxembourg	(EU)	Switzerland	
Denmark	(EU)	Malta	(EU)	Taiwan	
Estonia	(EU)	Mexico		Turkey	
Finland	(EU)	Netherlands	(EU)	United States	
France	(EU)	Norway		United Kingdom	(EU)
Germany	(EU)	Poland	(EU)		
Greece	(EU)	Portugal	(EU)		

Appendix 2: EXIOPOL sector classification

i01.a	Cultivation of paddy rice
i01.b	Cultivation of wheat
i01.c	Cultivation of cereal grains nec
i01.d	Cultivation of vegetables, fruit, nuts
i01.e	Cultivation of oil seeds
i01.f	Cultivation of sugar cane, sugar beet
i01.g	Cultivation of plant-based fibers
i01.h	Cultivation of crops nec
i01.i	Cattle farming
i01.j	Pigs farming
i01.k	Poultry farming
i01.l	Meat animals nec
i01.m	Animal products nec
i01.n	Raw milk
i01.o	Wool, silk-worm cocoons
i02	Forestry, logging and related service activities (02)
i05	Fishing, operating of fish hatcheries and fish farms; service activities incidental to fishing (05)
i10	Mining of coal and lignite; extraction of peat (10)
i11.a	Extraction of crude petroleum and services related to crude oil extraction, excluding surveying
i11.b	Extraction of natural gas and services related to natural gas extraction, excluding surveying
i11.c	Extraction, liquefaction, and regasification of other petroleum and gaseous materials
i12	Mining of uranium and thorium ores (12)
i13.1	Mining of iron ores
i13.20.11	Mining of copper ores and concentrates
i13.20.12	Mining of nickel ores and concentrates
i13.20.13	Mining of aluminum ores and concentrates
i13.20.14	Mining of precious metal ores and concentrates
i13.20.15	Mining of lead, zinc and tin ores and concentrates
i13.20.16	Mining of other non-ferrous metal ores and concentrates
i14.1	Quarrying of stone
i14.2	Quarrying of sand and clay
i14.3	Mining of chemical and fertilizer minerals, production of salt, other mining and quarrying n.e.c.
i15.a	Processing of meat cattle
i15.b	Processing of meat pigs
i15.c	Processing of meat poultry
i15.d	Production of meat products nec
i15.e	Processing vegetable oils and fats
i15.f	Processing of dairy products
i15.g	Processed rice
i15.h	Sugar refining
i15.i	Processing of Food products nec
i15.j	Manufacture of beverages
i15.k	Manufacture of fish products
i16	Manufacture of tobacco products (16)
i17	Manufacture of textiles (17)
i18	Manufacture of wearing apparel; dressing and dyeing of fur (18)
i19	Tanning and dressing of leather; manufacture of luggage, handbags, saddlery, harness and footwear (19)
i20	Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials (20)
i21	Manufacture of pulp, paper and paper products (21)
i22	Publishing, printing and reproduction of recorded media (22)
i23.1	Manufacture of coke oven products
i23.20.a	Manufacture of motor spirit (gasoline)
i23.20.b	Manufacture of kerosene, including kerosene type jet fuel
i23.20.c	Manufacture of gas oils
i23.20.d	Manufacture of fuel oils n.e.c.
i23.20.e	Manufacture of petroleum gases and other gaseous hydrocarbons, except natural gas
i23.20.f	Manufacture of other petroleum products
i23.3	Processing of nuclear fuel
i24	Manufacture of chemicals and chemical products (24)
i25	Manufacture of rubber and plastic products (25)
i26.a	Manufacture of glass and glass products
i26.b	Manufacture of ceramic goods
i26.c	Manufacture of bricks, tiles and construction products, in baked clay

i26.d	Manufacture of cement, lime and plaster
i26.e	Manufacture of other non-metallic mineral products n.e.c.
i27.a	Manufacture of basic iron and steel and of ferro-alloys and first products thereof
i27.41	Precious metals production
i27.42	Aluminum production
i27.43	Lead, zinc and tin production
i27.44	Copper production
i27.45	Other non-ferrous metal production
i27.5	Casting of metals
i28	Manufacture of fabricated metal products, except machinery and equipment (28)
i29	Manufacture of machinery and equipment n.e.c. (29)
i30	Manufacture of office machinery and computers (30)
i31	Manufacture of electrical machinery and apparatus n.e.c. (31)
i32	Manufacture of radio, television and communication equipment and apparatus (32)
i33	Manufacture of medical, precision and optical instruments, watches and clocks (33)
i34	Manufacture of motor vehicles, trailers and semi-trailers (34)
i35	Manufacture of other transport equipment (35)
i36	Manufacture of furniture; manufacturing n.e.c. (36)
i37.1	Recycling of metal waste and scrap
i37.2	Recycling of non-metal waste and scrap
i40.11.a	Production of electricity by coal
i40.11.b	Production of electricity by gas
i40.11.c	Production of electricity by nuclear
i40.11.d	Production of electricity by hydro
i40.11.e	Production of electricity by wind
i40.11.f	Production of electricity nec, including biomass and waste
i40.12	Transmission of electricity
i40.13	Distribution and trade of electricity
i40.2	Manufacture of gas; distribution of gaseous fuels through mains
i40.3	Steam and hot water supply
i41	Collection, purification and distribution of water (41)
i45	Construction (45)
i50.a	Sale, maintenance, repair of motor vehicles, motor vehicles parts, motorcycles, motor cycles parts and accessories
i50.b	Retail sale of automotive fuel
i51	Wholesale trade and commission trade, except of motor vehicles and motorcycles (51)
i52	Retail trade, except of motor vehicles and motorcycles; repair of personal and household goods (52)
i55	Hotels and restaurants (55)
i60.1	Transport via railways
i60.2	Other land transport
i60.3	Transport via pipelines
i61.1	Sea and coastal water transport
i61.2	Inland water transport
i62	Air transport (62)
i63	Supporting and auxiliary transport activities; activities of travel agencies (63)
i64	Post and telecommunications (64)
i65	Financial intermediation, except insurance and pension funding (65)
i66	Insurance and pension funding, except compulsory social security (66)
i67	Activities auxiliary to financial intermediation (67)
i70	Real estate activities (70)
i71	Renting of machinery and equipment without operator and of personal and household goods (71)
i72	Computer and related activities (72)
i73	Research and development (73)
i74	Other business activities (74)
i75	Public administration and defense; compulsory social security (75)
i80	Education (80)
i85	Health and social work (85)
i90.01	Collection and treatment of sewage
i90.02.a	Collection of waste
i90.02.b	Incineration of waste
i90.02.c	Landfill of waste
i90.03	Sanitation, remediation and similar activities
i91	Activities of membership organization n.e.c. (91)
i92	Recreational, cultural and sporting activities (92)
i93	Other service activities (93)
i95	Private households with employed persons (95)
i99	Extra-territorial organizations and bodies

Appendix 3: Sector aggregation

	NACE Rev. 1.1 classification*	EXIOPOL sectors				
A	Agriculture, hunting and forestry	i01	i02			
B	Fishing	i05				
C	Mining and quarrying	i10	i11	i12	i13	i14
D	Manufacturing	i15	i16	i17	i18	i19
		i20	i21	i22	i23	i24
		i25	i26	i27	i28	i29
		i30	i31	i32	i33	i34
		i35	i36	i37		
E	Electricity, gas and water supply	i40	i41			
F	Construction	i45				
G	Wholesale and retail trade; repair of motor vehicles, motorcycles and personal and	i50	i51	i52		
H	Hotels and restaurants	i55				
I	Transport, storage and communication	i60	i61	i62	i63	i64
J	Financial intermediation	65	i66	i67		
K	Real estate, renting and business activities	i70	i71	i72	i73	i74
L	Public administration and defense; compulsory social security	i75				
M	Education	i80				
N	Health and social work	i85				
O	Other community, social and personal service activities	i90	i91	i92	i93	
P	Activities of households	i95	i96	i97		
Q	Extra-territorial organizations and bodies	i99				

* A description of the NACE Rev. 1.1 classification can be found at:

http://ec.europa.eu/eurostat/ramon/nomenclatures/index.cfm?TargetUrl=DSP_GEN_DESC_VIEW_NOHDR&StrNom=NACE_1_1&StrLanguageCode=EN

Appendix 4: Spatial aggregation

EU-high	PPP int$
Luxembourg	53652
Netherlands	29403
Denmark	28829
Austria	28773
Ireland	28639
Sweden	27961
Belgium	27612
United Kingdom	26072
Germany	25945
Finland	25653
Italy	25595
France	25328
Spain	21323

EU-low	PPP int$
Cyprus	19412
Greece	18412
Malta	18291
Portugal	17751
Slovenia	17474
Czech Republic	14993
Hungary	12266
Slovak Republic	10997
Poland	10514
Estonia	9882
Lithuania	8602
Latvia	8031
Bulgaria	6301
Romania	5654

Other-high	PPP int$
Norway	36130
United States	35081
Switzerland	31731
Canada	28407
Australia	26422
Japan	25619
Taiwan	19866
Korea, Rep.	17219

Other-low	PPP int$
Mexico	9201
Turkey	8867
Brazil	7021
Russian Federation	6824
South Africa	6773
Indonesia	2417
China	2364
India	1574

Data on GDP per capita, PPP (current international $) for 2000
World Development Indicators, http://data.worldbank.org/indicator, accessed 25-3-2011
Source: World Bank national accounts data, and OECD National Accounts data files.