Development of a methodology for the assessment of global environmental impacts of traded goods and services

Netherlands Environmental Assessment Agency

SERI Sustainable Europe Research Institute

SEI Stockholm Environment Institute

SCB Statistiska centralbyrån Statistics Sweden

skep Scientific Knowledge for Environmental Protection

www.eipot.eu
www.skep-network.eu

SKEP ERA-NET Project EIPOT (www.eipot.eu)

Development of a methodology for the assessment of global environmental impacts of traded goods and services

Final Report

7th August 2009

Thomas Wiedmann[a], Harry Wilting[b], Stephan Lutter[c], Viveka Palm[d], Stefan Giljum[c], Anders Wadeskog[d] and Durk Nijdam[b]

a) Stockholm Environment Institute (SEI) at the University of York, UK (project coordinator)

b) Netherlands Environmental Assessment Agency (PBL), Bilthoven, The Netherlands

c) Sustainable Europe Research Institute (SERI), Vienna, Austria

d) Statistics Sweden, Environmental Accounting Unit (SCB), Stockholm, Sweden

Product Code: SCHO1009BRAM-E-P

ISBN: 978-1-84911-121-8

Executive Summary

In 2008, the SKEP (Scientific Knowledge for Environmental Protection) network commissioned research to develop a suitable methodology to assess transnational environmental impacts through international trade, which led to the establishment of the EIPOT project (**e**nvironmental **i**m**p**acts **o**f **t**rade). The project was carried out between April 2008 and May 2009 by a consortium of four European research institutions: Stockholm Environment Institute at the University of York (project coordinator), Sustainable Europe Research Institute in Vienna, Netherlands Environmental Assessment Agency in Bilthoven and Statistics Sweden in Stockholm. The project aimed to:

- review and evaluate existing environmental accounting techniques that can be used to illustrate transnational impacts of traded goods and services;
- specify the (theoretical) framework and criteria for environmental accounting methodologies to assess the environmental impacts of imported and exported goods and services;
- identify the most suitable methodology and expand it into an accounting approach which can be used by all SKEP member states;
- identify data requirements and possible data sources for the recommended method;
- elaborate the roles of different regulatory authorities in providing the required data and advice on the practical implementation of the methodology.

During the project, it became clear that a) given the variety of possible research and policy questions to be answered, it would not be appropriate to stipulate one single method but rather put forward a flexible range of compatible methods and b) as a consequence, the focus should be on the developments needed in data and organisational roles. The EIPOT project report will be of interest and use to the SKEP network, national ministries and agencies, national statistical offices (NSO), the European Commission (EC) and Eurostat as well as academia.

In the EIPOT project, an evaluation approach called RACER was adapted for the purposes of the project. RACER is used by the European Commission Directorate General Environment to assess the suitability of methods and indicators for policy-oriented applications. On the basis of assessments carried out here, EIPOT makes recommendations for setting up a method able to fulfil the project's aim of assessing transnational environmental impacts of traded goods and products. The suggested way forward is a methodology incorporating elements of different tools which have proven to be successful, and identification of future needs in order to develop an effective and applicable tool, rather than focussing on one approach and its further development.

The relevance and suitability of any methodology always depends on the particular research or policy question that needs to be answered. The report looked at five policy dimensions – economic, environmental pressure/impact, geography, time, and life cycle stage – in order to understand the specific requirements for the methodology. The primary focus of the EIPOT project was on trade flows between different economies and production sectors within them, rather than on individual traded products.

The report suggests that an ideal basis for a suitable EIPOT methodology would be an environmentally extended multi-region input-output (EE-MRIO) framework closely connected to the System of Economic and Environmental Accounts (SEEA). The main elements of this accounting framework should include the following:

- monetary input-output tables of all EU countries plus an equal number of EU trading partners in a resolution of more than 100 economic sectors;
- detailed, bilateral trade datasets for goods and services in monetary (and possibly physical) units;
- complete tables of environmental accounts, further disaggregated with process analysis and LCA data, for a number of environmental extensions: emissions, material flows, energy use, land use, water use, air emissions, waste production, bioproductivity, biodiversity and other impact categories;
- For specific policy and research questions, data from process analysis and life cycle analysis (LCA) can be incorporated into hybrid approaches and/or to enumerate specific processes (such as international transportation or waste management practices).

The report explores various possibilities of hybridisation between monetary and physical data and between input-output and process analysis. Examples of recent hybrid LCA studies are provided to demonstrate the feasibility and usefulness of such approaches. Further recommendations include:

- Each application should begin with a top-down analysis using the EE-MRIO model. The analysis can then be specified and refined with bottom-up techniques as and when required.
- To investigate local and regional impacts, which can differ significantly between countries and regions, the EE-MRIO model should be integrated with spatially explicit models of environmental impacts.
- Structural path analysis in a multi-region input-output framework (MRIO-SPA) is a suitable technique to identify significant pressures or impacts along (international and national) supply chains. This top-down analysis should be used routinely in MRIO modelling to shape further research and policies.
- Despite the many advantages of an EE-MRIO model, users should be aware of its limitations. These include the effort required to set up the EE-MRIO system, time gaps or assumptions in the update of the IO tables and limited suitability to assess individual products.

In terms of data sources, availability and accuracy, the report describes the requirements for economic, environmental, trade and process/LCA data, including those for transportation and impact characterisation. Uncertainty implications are also discussed in detail. The report recommends:

- Data from the European Framework 7 project EXIOPOL, once available, should be used to construct the basic EE-MRIO framework.
- Data from other meta-databases, such as the Global Trade Analysis Project (GTAP), can be used to fill gaps in country coverage, sector data, and environmental extensions. In contrast to EXIOPOL (the data of which will only be fully available in 2011) the GTAP 7 database has been released in 2009.
- Supply and use tables (SUTs), rather than symmetric input-output tables (SIOTs), should be used if they are more detailed and up to date. Nevertheless, technology assumptions made in symmetric tables are of superior quality and the trade-off between SUTs and SIOTs should be decided on a case–by-case basis.
- Non-survey based balancing procedures should be used to re-balance hybridised IO tables, update matrices and produce time series if no superior original data are available.

- Bilateral trade data are essential in order to estimate trade flows between economic sectors of different countries. We recommend using the UN Comtrade and associated databases in the first instance for consistency and world coverage.
- EXIOPOL will use process and LCA data to disaggregate environmentally relevant sectors further, such as agriculture and food products, metal ores and products, fossil fuels, electricity and waste treatment. If further specification is required, additional life cycle inventory data should be used, for example from the European or International Reference Life Cycle Databases (ELCD, ILCD).

The final chapter looks at possible wider implementation of the method, and makes the following recommendations:

- A 'steward' should be chosen to carry out analyses on the environmental impacts of trade. Possible candidates are the European Commission (in conjunction with Eurostat or the 'Group of Four' (Go4), respectively) and the SKEP consortium.
- Efforts in environmental accounting and data provision should be harmonised amongst the main institutions (Go4, EC, NSO) in order to ensure consistency and avoid duplicating work.
- The feasibility of the proposed approach should be tested with an empirical case study. Several areas of research require long-term attention, including hybridisation of models, computational requirements and widening the scope and linkages to other areas of interest.
- A long-term research strategy is therefore needed to coordinate research that contributes to EIPOT-type analyses. Under the Framework Programme(s) for research and technological development in the EU, a separate branch should be established to support trade-related research based on environmentally extended multi-region input-output modelling in the long term.
- National governments should consider presenting environmental impacts embodied in imports as part of the environmental pressure connected to national consumption. Consumption-based greenhouse gas accounts, for example, could be presented alongside the usual territorial accounts reported under the UN Framework Convention on Climate Change (UNFCCC).
- National statistical offices should produce and make available in short-term intervals symmetric input-output tables (SIOTs) based on superior hybrid technology assumptions.
- All providers of data should document data compilation procedures, underlying assumptions and uncertainty of data in a transparent way.
- National ministries and agencies should maintain their role in funding national research by implementing these recommendations on a national and supra-national level (e.g. through SKEP).

The EIPOT project has not focused on one single method but on identifying a framework consisting of best-suited elements from different existing approaches, as such, the project outcome should be very useful for the task of assessing transnational environmental impacts through international trade. Not only does the project deliver a comprehensive review and evaluation of existing approaches but it also provides detailed elaborations on necessary future procedural steps regarding research needs, risks, and other related issues. Hence, the EIPOT project should be seen as an important step on the way towards a homogeneous and widely applied accounting method which will lead to more effective and target-oriented environmental policies.

Contents

1 Introduction

1.1 Background

The environmental consequences of intensifying international trade have gained importance in European Union (EU) and worldwide policies in the past few years. This is emphasised, for example, in the revised EU Sustainable Development Strategy, the Thematic Strategy on the Sustainable Use of Natural Resources and in the EU Action Plan on Sustainable Consumption and Production (see Nash 2009).

Products are increasingly produced in one part of the world, taken to another country and then redistributed to their final country of consumption. To promote sustainable consumption and production, there is a need to capture the whole life cycle impacts of products and services (in terms of emissions, water use, material flows and so on), to fully quantify the environmental effects of consumption and trade. However, there is no one accepted approach to assessing the transnational impacts of consumption. Many existing methodologies such as life cycle analysis (LCA), resource flow and material flow analysis (MFA) rely on average or outdated data and do not easily allow assessment of the full impacts of production and consumption or infrastructure associated with production, use and disposal. This is especially important when assessing products and services whose production-consumption chains span several national boundaries.

The SKEP ERA-NET (Scientific Knowledge for Environmental Protection) is a partnership of ministries and agencies from 13 European countries, which funds environmental research.[1] The SKEP network aims to promote good practice in developing science to effectively serve the needs of policy makers and support evidence-led modern regulation. In 2008, SKEP commissioned research to develop a methodology to assess transnational environmental impacts through international trade and the EIPOT project (**e**nvironmental **i**m**p**acts **o**f **t**rade)[2] was established.[3]. EIPOT brings together existing knowledge and ongoing research to assess global environmental impacts of traded goods and services. Its purpose is to review past and current accounting methodologies and to identify and specify an integrated approach, which can be applied by SKEP member states and other countries.

The project was carried out between April 2008 and May 2009 by a consortium of four European research institutions: Stockholm Environment Institute at the University of York (project coordinator), Sustainable Europe Research Institute in Vienna, Netherlands Environmental Assessment Agency in Bilthoven and Statistics Sweden in Stockholm. As a quality assurance measure, the research was reviewed throughout the project by three external experts, a SKEP Technical Group of six specialists and the SKEP Call Steering Committee. Further information is provided on the EIPOT project website www.eipot.eu.

1.2 Project scope and goal

The main aim of the EIPOT project was to specify an environmental accounting method to quantify and assess the transnational environmental impacts of traded goods and services.

1 http://www.skep-era.net.

2 We also use the acronym 'EIPOT' as a more general abbreviation for 'environmental impacts of trade'.

3 A second project, called IMEA (Import Environmental Accounting; http://www.imea-eu.org), was funded under the same SKEP Research Call.

More specifically, the project aimed to:

- review and evaluate existing environmental accounting techniques that can be used to illustrate the transnational impacts of traded goods and services;
- specify the (theoretical) framework and criteria for environmental accounting methodologies to assess the environmental impacts of imported and exported goods and services;
- identify the most suitable methodology and expand it into an accounting approach which can be applied by all SKEP member states;
- identify data requirements and possible data sources for the recommended methodology; and
- elaborate the roles of different regulatory authorities in providing data and advice to implement the methodology.

The original project proposal aimed to "develop and specify an environmental accounting methodology"; this is also reflected in the full project title. It was intended to progress the work to a level of methodological specification detailed enough to provide explicit 'guidelines' for the use of the 'best suited methodology'. However, early on in the project it became clear that a) given the variety of possible research and policy questions, it would not be appropriate to stipulate one single method but rather put forward a flexible range of compatible methods and b) as a consequence, the focus should be on the developments needed in data and organisational roles. In that respect, this project can be seen as a critical milestone in the development of the ultimate methodology rather than as an actual and complete development of one particular technique.

1.3 Project approach

RACER is an evaluation approach used by the European Commission Directorate General Environment (DG ENV) to assess the suitability of methods and indicators for policy-oriented applications and uses five major evaluation categories. In the EIPOT project, RACER was adapted (Lutter and Giljum 2008) to include specified sub-categories. RACER stands for:

- **R**elevant – closely linked to the objectives to be reached
- **A**ccepted – for example, by staff and external partners
- **C**redible for non-experts, unambiguous and easy to interpret
- **E**asy to monitor - for example, data collection should be possible at low cost
- **R**obust – for example, against manipulation

In EIPOT, the evaluation of methods was carried out using a system of scoring from zero to two. This scoring enabled judgement on whether a method did not fulfil a criterion (score zero), partly fulfilled it (score one), or was perfectly appropriate to answer the criterion's question (score two). Then, for each RACER category (R-A-C-E-R) the mean score was calculated. These mean values were compared without further weighting into one aggregated score, to produce a more comprehensive picture of the differences between methods. This approach enabled us to distinguish between the performances of different methods with respect to categories linked to the project's aim. As mentioned earlier, the RACER analysis was not intended to select one 'winner', since the best method depends on the policy question. The evaluations carried out by one member of the research team were reviewed by all the other team members to ensure completeness and integrity. The procedure and results of this RACER evaluation are described in detail in two separate reports (Lutter and Giljum 2008, Lutter *et al.* 2008).

Chapter 3 gives an overview of the advantages and drawbacks of the methods assessed in relation to the trade aspect.

On the basis of assessments carried out here, EIPOT makes recommendations for setting up a method able to fulfil the project's aim of assessing transnational environmental impacts of traded goods and products. The suggested way forward is a methodology incorporating elements of different tools which have proven to be successful, and identification of future needs in order to develop an effective and applicable tool, rather than focussing on one approach and its further development.

Data availability, accuracy and other data issues are covered in Chapter 5, along with points raised by project partners who regularly compile different types of data.

Finally, the necessary steps for further development of the suggested method and measures to be taken on behalf of international as well as national institutions are outlined in Chapter 6.

1.4 Target audiences

This report is aimed at several audiences:

- **SKEP network:** As a response to the original Research Call by the SKEP funding consortium, this report provides a thorough "review of environmental accounting approaches associated with the consumption of imported goods and services" and identifies the "data requirements for such techniques and the potential sources of data with reference to the role of the regulatory authorities". This report is therefore a crucial milestone in the ultimate goal to "develop a suitable methodology for SKEP member states to assess transnational environmental impacts".[4] The SKEP network includes:
- **National ministries and agencies:** National (environmental) ministries and agencies play a crucial role in funding national research and implementing recommendations on a national level (possibly alongside supranational research efforts funded by SKEP or through other means).
- **National statistical offices (NSOs):** A similarly important role is that of NSOs who provide essential underlying data for EIPOT-type analyses (input-output data, environmental data, trade data). This report makes recommendations on which kind of data should be collected to set up a powerful analytical system to investigate the environmental impacts of trade.
- **European Commission and Eurostat:** Other target groups are EU administrators and policy-makers. Supranational institutions such as the European Commission with its joint research centres and Eurostat play a central role in collating meta datasets and funding, coordinating and carrying out research on the environmental impacts of European production and consumption.
- **Academia:** This report provides a thorough review and summary of the latest methods for analysing and assessing international environmental issues and thus offers methodological guidance for researchers aiming to set up an international model. The report also provides a detailed description of available datasets for establishing such a model.

[4] All quotes from SKEP Applicants' Guide – Research Call Sustainable Consumption and Production, July 2007.

2 Policy Context – Relevant methodological dimensions

The suitability of any method always depends on the particular research or policy question that needs to be answered. A precise formulation of this question is essential to understand the requirements for the method. It is therefore worthwhile to think about key research and policy questions on the transnational environmental impacts of traded goods and services.

2.1 Economic dimension

This broad subject covers a range of issues and dimensions. First, there is the *economic level* on which the trade analysis should be undertaken, where broadly three levels can be distinguished: macro, meso and micro.

On the *macro* level, the impacts of *total trade flows* of a country come into consideration. Key political questions that have arisen include: How much greenhouse gas (GHG) emissions are embedded in the total imports or exports of a country? What is the trade balance of embedded emissions at the national level? What is the carbon, water or ecological footprint of a country? Which material flows are triggered worldwide by consumption in the European Union? What are the impacts, in situ as well as on a global level, of European and worldwide resource demand?

Consumption-based accounting, especially of greenhouse gases, is becoming increasingly important for policy and decision making. Adopting a consumption-based perspective – alongside the traditional approach of territorial emissions accounting – opens up the possibility of extending the range of policy and research applications and provides new opportunities in climate policy (CP/RAC 2008). One opportunity, for example, is to readdress the problem of carbon leakage and reveal the extent to which a relocation of production and associated shift of embodied emissions has occurred (Peters 2008b, see also Stretesky and Lynch 2009). If these consumers were to become partially responsible for emissions occurring elsewhere, exporting nations (mainly China and other developing countries) might be more willing to play an active role in post-Kyoto climate commitments (Peters and Hertwich 2008b). The wider implications for climate policy from using a consumption-based approach are well presented in Peters (2008a) and Peters and Hertwich (2008a, 2009). How trade may affect climate policy and the effects of imposing carbon tariffs are discussed by Weber and Peters (2009).

On the *meso* level, individual *sectors* of an economy or aggregated product groups come into focus. Questions relate, for example, to industries with potentially high environmental impacts such as energy, steel-making, agriculture and clothes manufacturing, and ask how much environmental pressure is exerted by these sectors through trade with other countries. International supply chains of large global corporations have been scrutinized for their fairness of payments and labour conditions, but increasingly questions are asked about the environmental sustainability of supply chains spanning a number of countries. Recent examples include clothes manufacturing for textile consumption in the Netherlands (Wilting 2008) and agriculture for meat production in the UK (Minx *et al.* 2008a). Another consumption domain that has a high impact on other countries or regions is tourism. Tourists spend their money increasingly in other regions and the demand for sustainable tourism grows.

The *micro* level, finally, turns the attention to individual *products* or product groups. The life cycle assessment (LCA) of a product requires assessment of all production processes which increasingly occur in foreign countries. Modern electronic products, for example, are assembled from parts stemming from many countries delivered through multiple international supply chains. Tracing and quantifying environmental impacts associated with such complex multi-country processes is usually the most difficult task for any method. Standards for LCA (ISO 2006a, ISO 2006b) and carbon footprint of products (BSI 2008) have attempted to address this problem[5], but the data situation remains difficult, especially for internationally applicable or comparable data.

A range of approaches cover all economic levels (Lutter *et al*. 2008). Figure 2.1 relates the methods to policies and applications. The choice of methods will depend on the policy/research question[6] Currently, no one single method covers all levels from macro to micro. At the macro and meso level, *trade flows* are analysed; *products* only appear on the micro level. Analyzing a traded product is performing an LCA of that particular product.[7] Concepts such as emissions embodied in trade or traded product groups, on the other side, imply some form of aggregation.

This study's primary focus is on *trade flows* rather than individual traded products. As has been investigated in several EU projects, analysing a particular traded product does not lend itself to any national or regional policy question.

The concept of environmental impacts embodied in trade implies some form of aggregation. By thinking in terms of flows of aggregated product groups and not individual products, the choice of approach becomes easier, with respect to data and policy. Also, when looking at the entire traded flows, the connection to national policy becomes easier to trace.

However, there are links between the methods at the various levels; for example, high-resolution hybrid LCA at the micro level can be aggregated to the meso level, and macro methods can be disaggregated and/or hybridised to make them more suitable for the meso level. In reality, there is a continuum of methods and current trends suggest that future methods will be able to cover a wider range of this continuum.

5 Another initiative to develop a "Product and Supply Chain Accounting and Reporting Standard" has been instigated by the World Resources Institute and the World Business Council for Sustainable Development (WRI and WBCSD 2008).

6 See also Finnveden and Moberg (2005) for overview of environmental systems analysis tools as well as Heijungs *et al.* (2007, p38) for a schematic of LCA tools.

7 Since LCA covers whole life cycle, impacts from trade should automatically be included, and are normally not discussed in LCA method papers. Some case studies describe details (see Engström *et al.* 2007).

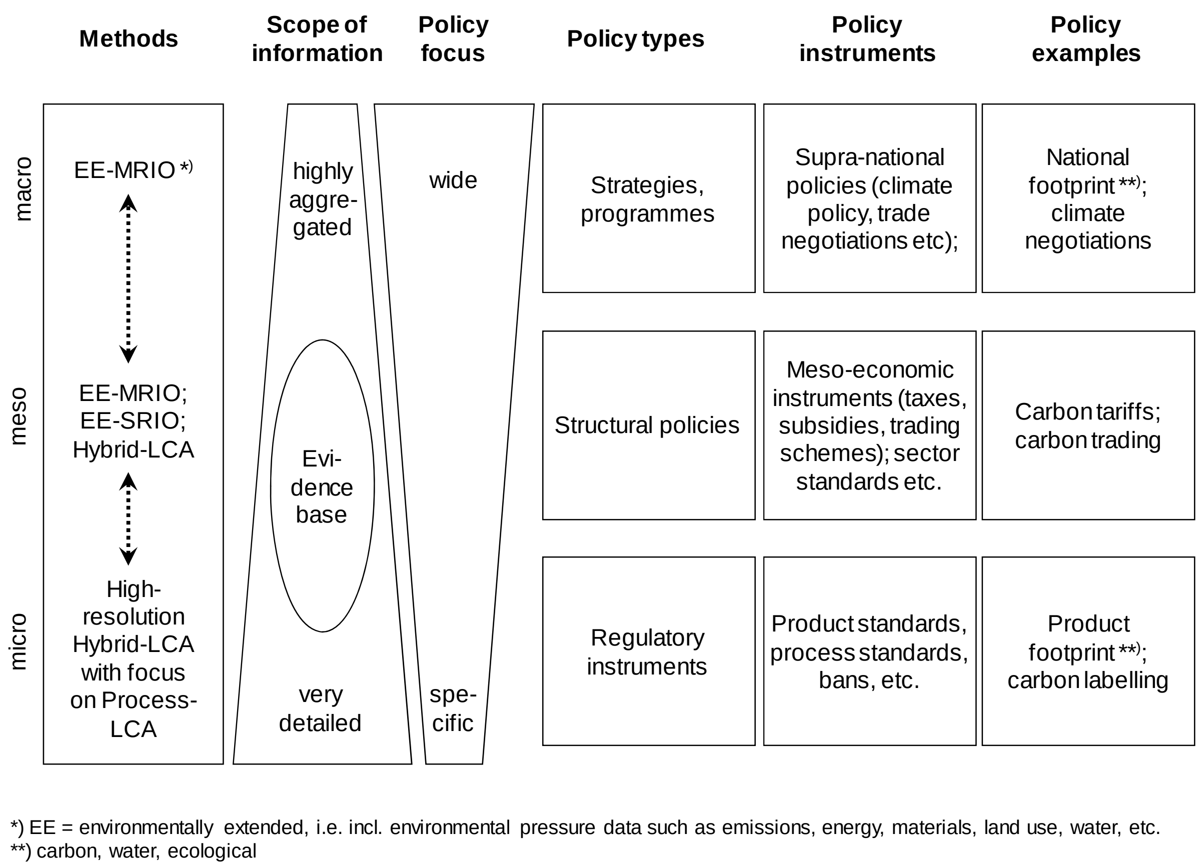

Figure 2.1: EIPOT-methods in relation to policy demands on different economic levels (adapted from Femia and Moll 2005 and Wiedmann *et al.* 2006)

2.2 Environmental dimension

The second dimension that needs to be considered is *environmental impact* or *pressure.* Most methods covered by the RACER analysis (Lutter *et al.* 2008) do not measure environmental impacts (such as global atmospheric temperature rise) or environmental states (such as atmospheric concentrations of GHG or numbers of threatened species[8]) but in most cases environmental pressures (such as emissions to air, water and soil or the use and extraction of resources) are actually covered.

However, pressures can be translated into impacts by using the methods employed in Life Cycle Impact Assessment (LCIA; one of four phases in a comprehensive Life Cycle Assessment, LCA) (ISO 2006a, ISO 2006b). The RACER evaluation therefore considered LCIA impact and similar categories, namely global warming, stratospheric ozone depletion, photochemical oxidant formation, acidification, nutrient enrichment, ecotoxicity, human toxicity, radiation, resource consumption, land use, waste, effects on ecosystems and biodiversity. Again, the environmental impact indicators cover a range of policy questions. They can, for example, be related to different environmental compartments (atmosphere, biosphere, hydrosphere, soils) as well as economic and health considerations. The choice of indicators is partly separate from the choice of methods. This report focuses on the methods.

8 Lenzen *et al.* (2007b) present a blueprint approach for quantifying the influence of international supply chains on numbers of threatened species in trading countries.

2.3 Spatial dimension

The third dimension is *geography*, which considers the spatial aspect of trade and the distribution of its impacts. Naturally, any method that aims to quantify and assess the impacts of international trade needs to be able to distinguish countries or regions of origin and destination as well as their economic structure and production technologies and efficiencies. The geographical scope and the number of countries and sectors considered is therefore an important factor in the evaluation of EIPOT methods. Furthermore, the method should be able to assess environmental pressures that cannot be allocated directly to countries, such as emissions of international transport by water and air.

Although the original focus of the EIPOT project was to build a method for SKEP countries, we aim at formulating a more general framework that is in principle applicable to any country or region. One example is the Mediterranean region where a list of actions has been proposed for applying the consumption-based approach to GHG emissions (CP/RAC 2008). Ultimately, the feasibility of implementing a method in or for a particular country will depend on data availability. This issue is discussed in Chapter 5.

2.4 Temporal dimension

Time is the fourth dimension that needs to be considered. Temporal issues determine policy questions and in turn the choice of methodology or model that is able to address these questions.[9] The methods shown in Figure 2.1 are all ex-post approaches that use data from the past to enumerate previous environmental impacts. Often the results are used as an approximation for present time impacts of production or consumption. This is sufficient to establish the current hotspots of pressures or impacts and to devise environmental or SCP policies that address current production and consumption patterns. However, if the goal is to anticipate future impacts or test the effect of specific policies (such as taxation, trade tariffs, carbon trading, government spending), scenario or dynamic modelling or a combination of both needs to be employed. To cover this policy field, econometric and dynamic models with explicit coverage of international trade were included in the RACER analysis of the EIPOT project (Lutter *et al.* 2008).

2.5 Life cycles

The fifth dimension concerns another system boundary aspect, namely the *life cycle* stages of traded goods. When performing a life cycle assessment of a product, upstream production impacts during the cradle-to-gate or cradle-to-shelf phase need to be included as well as downstream impacts during the use and disposal phase (cradle-to-grave). When comparing products, impacts in all life cycle stages should be considered. The lifetime of a product becomes important in its use phase and methods need to attribute impacts accordingly. With regard to trade, the use phase and/or disposal phase may be (partly) abroad, such as tourist trips or the export of waste to developing countries.

At the macro and meso levels, there should be consistency between the stages. Where materials are recycled in the disposal stage and re-enter the production chain, this should be accounted for in the use of primary and secondary materials in the material stage.

9 Compare to the categorisation of tools for sustainability assessment by Ness *et al*. (2007).

3 Results of RACER Evaluation

To explore the benefits and disadvantages of different methods with respect to environmental impacts of trade, an evaluation exercise was carried out. The assessment was undertaken with the RACER evaluation framework, based on criteria specified by a European Commission DG Environment (DG ENV) project[10]. This chapter briefly discusses the evaluation framework and presents an overview of the evaluation results for different types of methods. Detailed results are presented in the Interim Report of the EIPOT project (Lutter *et al.* 2008). Adaptation of the RACER evaluation framework for this project is described in a work package report (Lutter and Giljum 2008). We refer the reader to these two reports for all details on the RACER process and results.

3.1 RACER evaluation criteria

For the evaluation of methods, a framework was used based on the RACER criteria. In its publication *Impact Assessment Guidelines* (European Commission 2005), the European Commission specified that indicators should fulfil the RACER criteria: **R**elevant, **A**ccepted, **C**redible, **E**asy and **R**obust.

RACER criteria can be used to assess the value of scientific tools, like indicators, in policy-making. Best *et al.* (2008) showed the value of using broad RACER criteria in a DG ENV project.

In this EIPOT project, the five major evaluation categories were further specified and adapted to meet the requirements of this project. For this purpose, sub-criteria were added to each of the main criteria (a similar approach to Best *et al.* 2008). The sub-criteria applied in the EIPOT project are:

Relevant	• Links to the project's aim • Policy support, identification of targets and gaps • Identification of trends • Forecasting and modelling • Coverage of one or several environmental categories • DPSIR coverage • Scale/level of economic activity • Geographical scope
Accepted	• Stakeholder acceptance • Acceptance in academia • Acceptance in policy-making
Credible	• Unambiguous • Repeatability • Transparency • Documentation of assumptions and limitations
Easy	• Data availability • Technical feasibility • Integration

[10] Best *et al.* (2008): Potential of the ecological footprint for monitoring environmental impacts from natural resource use. Analysis of the potential of the ecological footprint and related assessment tools for use in the EU's Thematic Strategy on the Sustainable Use of Natural Resources. Study by Ecologic, SERI and Best Foot Forward for DG Environment. January 2007 to March 2008. Study can be downloaded from www.seri.at/comfootprint.

Robust	• Defensible theory • Sensitivity • Data quality • Reliability • Consistency • Comparability • Boundaries

The EIPOT document on the RACER evaluation framework (Lutter and Giljum 2008) provides a more detailed description and explanation of these sub-criteria.

3.2 RACER evaluation framework

Our proposed evaluation framework enables an analysis of methods qualitatively and quantitatively. The qualitative step provides, for each sub-criterion, a description of advantages and disadvantages of the methods. In the second step, these descriptions are quantified by allocating numerical scores to each of the sub-criteria, on a three-level scale between zero and two. This scoring can be used to rate whether a method does not fulfil a criterion at all (zero), fulfils it only partly (one), or is appropriate to answer the criterion's question (two).

For each of the five main RACER criteria, an average score was calculated for each method. We refrained from weighting these values or from summing them into one overall score. Instead, we compared the five individual RACER scores for each method to produce a more comprehensive picture of the differences between methods. Presenting average scores in radar diagrams provides an easily readable overview of the evaluation. An overall, weighted or unweighted, RACER score for each of the methods was not calculated as the aggregation of major categories was considered too ambiguous. Not all criteria are of equal importance for decision-making. If decision-making is to be based on correct information, credibility and robustness may be better indicators than acceptance.

The fact that a method is accepted does not necessarily mean it is the best way to support decisions. An unsuitable method could become accepted because the proponents are better marketers, have more resources for dissemination or are better connected. Conversely, if a method is chosen that is credible and robust, it can (on its merit) become accepted through good published information. Just because a method is difficult does not mean it should receive lower priority than an easy method. If the best method for decision-making is difficult, then it just means it has to be supported by experts. One example is perhaps the support for economic policy decisions that are often based on information provided by a handful of economists who use general equilibrium models or econometric models. These are difficult to implement and use, but they are the state-of-the-art in economic modelling. It would not be advisable to replace these with a more simple method just because the latter was easier.

These considerations would make a reasonable argument for multiplying the individual RACER scores with different weights, arguably higher for 'relevance', 'credibility' and 'robustness' and lower for 'easy' and 'acceptance'. However, there is no widely accepted consensus about the value of these weights and it was therefore decided not to apply weighting factors. Instead, qualitative considerations were used in specifying a method, enabling us to distinguish between the performance of different methodologies with respect to categories regarded as of more or less importance to the project's aim. This means that the methodology which had been ranked best in the RACER analysis is not necessarily the sole recommended approach. Instead highly ranked methods play a role as additional modules in a more comprehensive approach.

Given the qualitative and minor quantitative (3-scale score) character of the RACER framework it must be seen as a tool for providing insights into the pros and cons of methods with regard to criteria. The differences in scores should be considered as indicative. In this sense the framework adds value; it is not a strict selection mechanism for the ideal methodology, but it is a structured way to show differences between methods.

3.3 Results of RACER evaluation

A variety of approaches and indicators have been developed to assess the environmental impacts of products. Among them are LCA, material flow analysis, environmentally extended input-output analyses, and water and ecological footprint accounts as well as hybrid, econometric and dynamic approaches. The environmental pressure and indicator categories are emissions, use of energy, land, materials and water, and the ecological footprint. The RACER assessment was carried out for the following method-indicator combinations (for a description of methodologies see the EIPOT Interim Report; Lutter *et al.* 2008):

- **Life Cycle Assessment/Resource Accounting**
  - LCA
  - Material flow accounting on a process basis (MIPS)
  - National ecological footprint accounts and variant methods
  - Water footprint accounting
- **Environmentally Extended Input-Output Analysis (EE-IOA)**
  - Single-region IOA; emissions, energy and land use, and ecological footprint
  - Single-region IOA; materials
  - Single-region IOA; water
  - Partial and full multi-region IOA; emissions, energy, materials and land use
  - Partial and full multi-region IOA; ecological footprint
- **Hybrid approaches**
  - Hybrid LCA (hybrid of IOA and process analysis)
- **Dynamic models**
  - Econometric Models (EM)[11]
  - Dynamic ecological footprint

In our evaluation exercise, the method-indicator combinations were divided amongst the project team members. Each combination was assessed by one project team member and then reviewed by all other team members to cross-check verbal explanations and scoring. Subsequently, three external experts reviewed the evaluation procedure and results, providing useful comments for minor revisions. Cross-reading of evaluations undertaken by other team members helped avoid clear biases, but evaluations of this type inherently retain some subjectivity.

Detailed results are presented in Lutter *et al.* (2008), including summaries of the main method-indicator combinations assessed. The following section summarises the outcomes per method-indicator combination for all sub-criteria in global descriptions for five main approaches: LCA/process analysis, single-region input-output (SRIO) analysis, multi-region input-output (MRIO) analysis, hybrid

[11] Econometric models can be static or dynamic; in the RACER evaluation we did not make this explicit distinction.

analysis and econometric models. Scores for these five methods were determined by using individual scores per indicator. Scores for the main RACER categories per method are depicted in a radar diagram.

The main findings from the qualitative RACER analyses of different methods (in relation to trade) are summarised in the following table (for more detailed information see Lutter *et al.* (2008)).

Table 3.1: Summary of results from RACER evaluation

Key Advantages	Key Disadvantages
Life Cycle Assessment/Resource Accounting	
– Life cycle thinking is seen as an important cornerstone of EU environmental policies. – Complete LCA of a given commodity quantifies almost all impacts on a detailed level (micro or sectoral level) and provides insight into trade flows. – MFA-LCA (MIPS) are suitable for calculation of indirect material flows associated to biotic and abiotic raw materials and products with a relatively low level of processing. – Water footprint indicator of water use in relation to the consumption volume and pattern; highlights sectors of high water use => starting point for political action. – Long-term trend data in national footprint accounts; recognised by some policy-makers; only environmental indicator that puts human demand of biocapacity in relation to supply of biocapacity by global ecosystems.	– LCA: Static account of past or status quo. – Given assumptions and choices, outcomes of similar LCAs may differ strongly. – Running an LCA for each traded commodity requires collection of large amounts of data; lack of standards to guarantee consistency and comparability of underlying physical accounts of production inputs and outputs. – Water quality is addressed only partly in water footprint accounting; for industrial and domestic sector, only the sectoral, national and international level is covered; missing time series of data. – Embodied impacts of services are not modelled in national footprint accounts; built-up land is also assumed not to be 'traded'; especially for footprints embodied in trade, the concept is not defensible; indirect impacts only partly covered due to data restrictions.
Single- Region Input-Output Analysis	
– IO-framework is widely accepted for environmental accounting on environmental impacts of production and trade. – SRIO calculation scheme is simple and extendable to forecasting and modelling in exploring 'what-if' questions. – Can analyse implications for natural resource use of structural changes of the economy, and changes in technology, trade, investments and consumption and lifestyles. – Can be extended to forecasting and modelling applications and could be used as a basis for econometric or dynamic CGE models. – Provides users with indicators and matrices as tools for economic planning. – SRIO of material flows enables opening up the "black box" of economy-wide MFAs and thus provides information on branch and product-specific developments of resource flows and resource productivity.	– Does not enable regional breakdown of environmental impacts; differences in production and supply paths cannot be modelled with a single-region model; not able to capture feedback effects; provides information at the sectoral and macro level, not at the level of individual products. – SRIO-material: physical input-output tables (PIOTs) have only been compiled for a small number of countries; allocating material inputs with a monetary input-output table (MIOT), a PIOT or a hybrid model creates different results, in particular for calculation of trade balances; huge data requirements mean updating is not an easy operation for materials. – SRIO-water: water use data is often not available at the desired level of sectoral detail, but consistent water use accounting in NAMEA[12] style would help with data availability/consistency.

12 National Accounting Matrix including Environmental Accounts (de Haan and Keuning 1996)

Key Advantages	Key Disadvantages
Multi-Region Input-Output Analysis; Partial and Full	
– Enables analysis of the environmental implications of trade with different countries. – Gives insights into environmental consequences of relocation of industries in foreign countries. – Can be extended to forecasting and modelling and could be used as a basis for econometric or dynamic CGE models. – More comprehensive data collection is underway in an EU project aimed at MRIO analyses for EU member states. – Good comparability due to system completeness. – A full MRIO provides more detail on exports and can quantify international supply chain impacts across several countries. – Covers all indirect impacts caused by upstream production.	– Updated regularly, but not every year, others are updated at an irregular basis; basically for static analyses of the past relying on ex-post data; MRIO requires large amounts of data; significant time gap for some IO data (up to several years). – A partial MRIO only allows for uni-directional analysis; does not cover all trade between regions and therefore cannot consider impacts from higher-order international supply chains spanning several regions. – Full MRIO has greater data requirements than partial MRIO. – Has the same problems with availability of data on material and water use as SRIO.
Hybrid approaches; **Hybrid LCA**	
– Hybrid methods combine advantages of LCA (accurate and specific data) with those of IO (ready available, complete and consistent data). – Has fewer data gaps than pure LCA. – Results from hybrid LCA can be compared to pure LCA results or pure IO results.	– Performing a hybrid LCA for each traded commodity requires a large amount of data compilation.
Dynamic models	
– Econometric models: Capacity to design and quantify (policy-oriented) scenarios; potential to cover any category of interest; endorsed by SKEP members; use empiric statistics and time series; integration of EM with other methods possible and promising. – Dynamic EF: Allows for a temporal analysis of country-level consumption, production, land use, GHG emissions, species diversity, and bioproductivity up to 2050; for policy concerns about over-consumption of and impacts on global biological resources, including biodiversity; designed to reproduce long-term historical trends; DEF can be extended to a full scale MRIO model (with sectoral breakdown) or linked to GIS models	– EM require complex and extensive infrastructure; expert knowledge is needed to understand the structure of the model and interpret system-internal effects; assigning indirect impacts to upstream-production processes requires additional steps. – Dynamic EF: in terms of trade embodiments the approach is coarse as it does not have sectoral disaggregation of national economies; not used or recognised by stakeholders or policy-makers yet.

As described above, for all method-indicator combinations, the qualitative descriptions for each sub-criterion were translated into scores. The radar diagram below depicts aggregated scores for RACER categories for five main methods characteristic for the different method-indicator combinations. For each method, the scores depict the average score for all indicators per method[13].

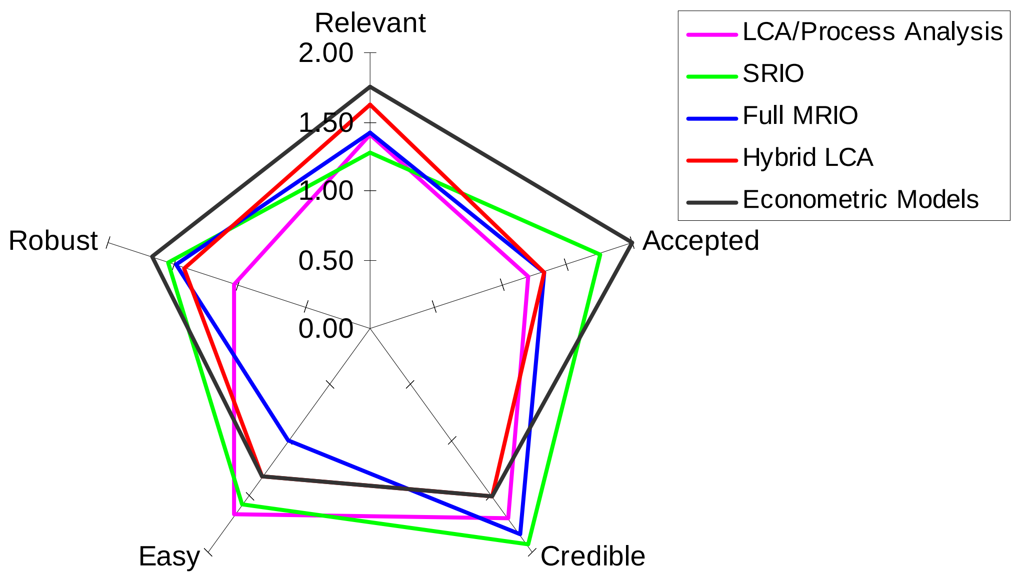

Figure 3.1: Average unweighted scores of five main methods by each RACER criterion

Note: The RACER analysis needs to be considered together with the policy question, see Chapter 2 and qualifying text below.

Further information is required to help interpret this radar diagram.

Relevance:

- Econometric models score high because of their forecasting and modelling qualities and their usefulness in identifying trends.
- Hybrid LCA scores high at the scale level of economic activity (micro/meso/macro). However, hybrid methods starting from LCA are better suited for the micro level and those starting from IO are more appropriate for meso/macro levels.
- SRIO models do not enable a regional breakdown of the environmental impacts of goods and services; differences in production and supply paths cannot be modelled.
- Full MRIO – as opposed to partial MRIO – can be used to analyse international supply chains.
- National footprint methods, which are categorised under process analysis, score higher on the identification of trends due to the availability of time series for some underlying data.

Acceptance:

- EMs have already been endorsed by SKEP members and applied to environmental issues in Europe. Studies have been published in various peer-reviewed articles.

[13] For example, the score for SRIO is based on the scores for SRIO energy use, emissions and land use, SRIO materials, SRIO water and SRIO-EF.

- SRIO is a method with a long tradition. It has been used in many studies and is recognized as a useful tool. The concept has been described in peer-reviewed journals and books.
- A low score on acceptance does not mean that a method is unsuitable. The fact that a method is accepted does not necessarily mean it is the best way to support decisions. If a method is chosen that is credible and robust, it can become accepted through good published information.

Credibility:

- Since SRIO calculations have been more frequently repeated by other researchers, SRIO scores higher on repeatability. The opposite holds for hybrid LCA.
- (Hybrid) LCA may involve assumptions and choices, making outcomes less objective.

Easy:

- SRIO scores higher due to data availability and required software.
- SRIO and LCA are the basic methods; hybrid LCA and MRIO are extensions of these methods and therefore more sophisticated with larger data requirements.
- The difficulty of a method is not related to its usefulness for policy-making. If the best method for decision-making is difficult, it will need to be supported by experts. It would not be advisable to replace such a method with a less suitable but 'easier' one.

Robust:

- MRIO takes into account differences in production, but makes assumptions on trade flows.
- Hybrid LCA is more complete than LCA, but uses less official data than IO.
- MRIO and hybrid LCA have a greater data demand than the less sophisticated methods they are based on. This demand is from less official sources or based on modifications of official data. Therefore MRIO and hybrid LCA score lower on reliability.
- SRIO has high scores on consistency with the System of Economic and Environmental Accounts (SEEA; United Nations 2003b) and other methods and classifications.
- By its nature, the RACER ranking is rather coarse. For example, process LCA scored one for indirect effects, and partial MRIO as well, the latter because it does not deal with feedback effects. In terms of truncation errors, there are large differences between process LCA and partial MRIO.

No single method could be described as "ideal" for tracing environmental impacts of traded goods and services. Consequently, the combination of two (or more) methods seems to be the most promising way to achieve an indicator/method of this capability.

Part of the RACER evaluation (sub-criterion 'Integration' in 'Easy') is the investigation of possibilities for complementary contributions from other methods. All methods assessed offer such possibilities:

- Process LCA provides detailed information on the ecological intensity of goods, but services are generally not taken into account and data requirements are huge, in particular for a larger number of products made in international production networks. Input-output oriented methods could complement LCA for those products for which no LCA factors exist (due to high data collection efforts). Combining (dynamic) water and footprint accounting with MRIO modelling frameworks would be a useful extension, allowing more accurate analyses of trade flows.
- MRIO models have a comprehensive geographical coverage and can trace links between sectors and regions, but in general have a high level of aggregation for sectors and product groups (and lack regularly updated data). Combining them with LCA could provide more detailed data for single products with high environmental impacts.

- Hybrid LCA is already a combination of LCA and SRIO, but is more laborious than the individual methods. However, combining it with MRIO modelling would be a useful extension.

Dynamic models, which are often based on one of the core methods (IO, LCA or hybrid), are a valuable extension to convert into an early warning and forecasting tool. Econometric models explore changes in environmental pressures, for example from policy measures like trade tariffs or regulation. Since most dynamic and econometric approaches are covered by the static core methods (or the data they use), these approaches are not considered explicitly in the remaining chapters.

The most promising way forward appears to combine various methods and synthesise best-suited elements from different existing approaches.

4 Recommendations on Methodology

4.1 General conceptual design

A variety of approaches and indicators have been developed to assess the environmental impacts of products and resource use. Among them are life cycle assessment of products (process LCA), economy-wide material flow analysis (MFA), environmentally extended input-output analysis (EE-IOA) and ecological footprint (EF) analysis. Following the results of our RACER analysis, the most promising way forward seems to be a combination of available or emerging methods. In contrast, the parallel use of, say, three detached methods does not appear to be effective or easily practicable.

EIPOT focussed on trade flows between different economies and production sectors within them, not on specific products. This is a crucial decision, as obviously macro- (and meso-) economic questions can be resolved best with methodologies different to those suited for micro-economic problems.

Life cycle assessment (LCA) originating from engineering and input-output analysis (IOA) originating from economics have several conceptual differences. They differ in their data inputs and guidelines for collecting these data (ISO standards versus System of National Accounts, SNA). Since both methods consider entire production chains, they should in theory generate the same outcomes in analysing the same question. However, given their conceptual differences their applicability is not similar. The environmental impact of one traded product, for instance, is probably quantified best using an LCA approach. LCA theoretically might be applicable to trade flows, however in practice it appears to be unpractical. Apart from unsatisfactory data availability in the foreseeable future, the number of traded products is enormous, and individual supply chains are too complex. On the other hand, IOA is more applicable at the level of aggregated trade flows on the meso and macro level.

Since EIPOT's main aim is to recommend a methodology to quantify and assess environmental impacts of trade flows, rather than individual products, a medium level of aggregation seems appropriate for this purpose. A resolution of around 100 to 200 sectors is a desirable and practical compromise that still allows the distinction of high-impact sectors whilst keeping data and computational requirements at a manageable level. Further details are discussed below.

We therefore regard EE-IOA with the SEEA (System of Economic and Environmental Accounts) framework as an ideal basis for an EIPOT methodology. The RACER analysis proved that EE-IOA is a generally accepted, credible and robust methodology. EE-IOA is commonly used to derive the indirect environmental pressures associated with the final use of products and services in a given economy. EE-IOA can be used to help to sum up all environmental pressures arising along the production chain of a given product. Environmental extensions such as the use of raw materials or emissions of air pollutants can be linearly linked to the input-output framework. However, production technologies in different countries can only be modelled in an MRIO model.

Process- and product-specific bottom-up methods have an important role to play. Even at the meso level, pure top-down approaches reach limitations on precision and the uncertainty stemming from different products being aggregated into individual sectors (problem of homogeneity assumption) can be high (see Chapter 5.3). Furthermore, top-down models are often based on monetary flows that do not always depict physical flows adequately. Process-specific information is valuable in these cases to reduce uncertainty and to extend the range of policy and research questions to the micro level.

Concentrating on the analysis of trade flows implies looking at the meso to macro level. Methods such as MRIO or MFA have often been criticised for their high level of aggregation and, consequently, lack of detail. So far, no method or approach has the necessary detail to separate factories or companies in the supply chain. The challenge lies in coming down from the macro-economic level to the sectoral level – projects such as EXIOPOL[14] or FORWAST[15] show that this is feasible but needs considerable mathematical effort (see, for instance, Tukker 2007; Tukker *et al.* 2009). Any disaggregation of sectors will come at the price of increased resource demand and will be limited in scope. For example, the combination of arable farming and horticulture in one aggregated agricultural sector covers up the different characteristics of individual sub-sectors. Splitting up the aggregated sector into these sub-sectors results in an individual horticultural sector, but still hides the differences between greenhouse vegetables and those grown in the open, or between food and non-food products, like flowers. Alternative ways of using process-specific information will therefore have to be found in these cases.

Currently, no single method can be applied to all research questions associated with trade and the environment. In the future, however, it is conceivable that more sophisticated and detailed models can be developed which cover macro to micro levels. In addition to specifying the conceptual design for such a method, we provide a tentative outlook of emerging approaches that promise greater coverage of micro-level questions.

4.2 Environmentally extended MRIO as methodological basis

Generally, the System of Economic and Environmental Accounts (SEEA) constitutes a solid conceptual fundament for EE-IOA (United Nations 2003a) as it is a satellite account of the System of National (economic) Accounts (SNA, United Nations 1993). Some countries have adopted an even closer integration of economic and environmental accounts in the NAMEA system which stands for "National Accounting Matrix including Environmental Accounts" (de Haan and Keuning 1996). As stated in our interim report, SEEA consistently links economic statistics and environmental statistics, illustrating the contributions of different economic sectors and different actors (producers, final consumers) to the overall economic output and to the related environmental consequences. Information on environmental pressures and impacts, as embraced in the NAMEA tables, can be connected to traded goods and services via monetary input-output tables. The same holds for materials with the design of economy-wide MFA as a fully integrated sub-module.

In general, the SEEA/NAMEA framework is specified at the national level. Since SRIO lacks region/country-specific information, MRIO is more appropriate for quantifying and assessing the transnational environmental impacts of trade flows of goods and services. The full version of MRIO

14 http://www.feem-project.net/exiopol

15 http://forwast.brgm.fr

analysis is required to cover all trade flows between regions and to enable a complete regional and sectoral breakdown of the environmental impacts of goods and services (for a specification of full MRIO see Peters and Hertwich 2004 or Lenzen *et al.* 2004). The use of a full MRIO includes information on bilateral trade flows and enables a full exploration and unravelling of international supply chains.

The last decade has seen a tremendous increase in applications of analytical and forecasting models based on environmentally extended input-output techniques. The crucial advantage of input-output based analysis is that it is possible to attribute environmental impacts to virtually *any consumption activity*, such as consumption of regions, nations, governments, cities, socio-economic groups or individuals, whether domestically or abroad (imports/exports); to virtually *any production activity* of organisations, companies, businesses, product manufacturing, service provision and so on and to virtually *any associated economic activity in between* such as supply chains, trade flows or recycling.

Employing an EE-MRIO model for EIPOT accounting brings the following advantages:

- An EE-MRIO framework is consistent with UN standards on economic (United Nations Statistics Division 1993) and environmental accounting (United Nations 2003b). This underpins its credibility and ensures future data availability and development.
- Since economic and environmental data in an MRIO framework are consistent, these data are the core of global sectoral economic models. For example, the GTAP database (see Chapter 5) is used by many international governmental institutions in their modelling activities.
- Models with a high sector disaggregation can be used to track international supply chains. Structural path analysis (SPA), a technique that can quantify specific supply chain links, has already been applied in multi-region input-output frameworks (Peters and Hertwich 2006, Lenzen *et al.* 2007b, Wood 2008, Wood and Lenzen in press). Although its implementation is not trivial, MRIO-SPA is ideally suited to extract and prioritise impacts from international commodity chains and to link geographical locations of consumption with hot spots of environmental impacts. MRIO-SPA can also be used to prioritise targets for action for corporate or government decision-makers (Wood and Lenzen 2003).
- MRIO is the only practically conceivable method for the comprehensive assessment of activities of multi-national corporations, since these essentially represent a production network spanning multiple sectors in multiple countries.
- Furthermore, comprehensive economic-environmental input-output model systems are well suited to perform scenario simulations of the environmental and socio-economic effects of implementing environmental policy measures. The model can be used to establish which policy strategies and instruments are best capable of reconciling competing policy goals in economic, social and environmental policies.
- A (multi-region) input-output framework can also be used to illustrate the economic *responsibilities* of agents for inducing certain environmental pressures. IO analysis has been used several times to attribute responsibilities for greenhouse gas emissions or ecological footprints to producers and consumers, nationally or internationally (Munksgaard and Pedersen 2001, Gallego and Lenzen 2005, Lenzen *et al.* 2007a, Wilting and Vringer 2007, Andrew and Forgie 2008, Peters and Hertwich 2008a, Rodrigues and Domingos 2008a, Munksgaard *et al.* 2009, Wilting and Ros 2009).

However, as with all modelling approaches there are also disadvantages:

- The update of a system of MRIO tables and related environmental extensions is delicate – IO tables are updated regularly, but not necessarily on an annual basis. For some IO data substantial time gaps can occur (for details on IO data see Section 5.1.1).
- EE-MRIOs are best used for static analyses of the past as they are built on ex-post data. Ex-ante assessments require the use of scenario techniques or, preferably, the dynamisation of the system in econometric simulation tools.
- EE-MRIOs require a large number of harmonised datasets for their construction.
- As mentioned above, EE-MRIO is not suited to assess the environmental impacts of single products, as the level of aggregation is too high.
- MRIOs provide information about environmental pressures associated with production and consumption activities, but cannot illustrate per se local and regional environmental impacts (such as impacts on biodiversity and ecosystem services through land use change, impacts on water scarcity through water use). Linking MRIO results or models with other impact assessment methods is necessary for this task to be accomplished.

It is reasonable to use the above described SEEA/NAMEA structure as a starting point to construct an EE-MRIO. The SEEA framework has been implemented in many countries, especially in Europe where the system is fairly detailed and multidimensional. For other countries no datasets are available yet. Considerable work will be necessary to compile these datasets, and where the respective data are not available gaps will have to be filled using proxy models or process LCA data.

The main elements of a consistent accounting framework should include the following components (see Chapter 5 for details on data requirements):

- Monetary input-output tables of all EU-countries[16] plus a maximum number of EU trading partners in a sectoral resolution of more than 100 (120 to 130 sectors as elaborated in current EU projects such as FORWAST and EXIOPOL is a desirable level).
- Detailed, bilateral trade datasets for goods and services in monetary (and possibly physical) units (see Chapter 5) that can be combined with the monetary IO tables in an MRIO framework.
- Complete NAMEA tables, further disaggregated with process analysis and LCA data, for a number of environmental extensions: material flows, energy use, land use, water use, air emissions, waste production, LCA impact categories, and so on.
- Comprehensive process-based LCA data for tackling more detailed questions on sectoral systems, such as waste management practices, used in a hybrid-type approach (see below). This type of data will help fill out existing input-output tables and fill gaps in current NAMEA tables.

4.3 Options for hybridisation

4.3.1 Hybridisation between monetary and physical data

There are three basic approaches to constructing environmentally-relevant IO tables. Models can use a monetary IO table (MIOT) extended by vectors of environmental extensions in physical units. They can also be based on a physical IO table (PIOT), reflecting all economic transactions in mass units. The third option is to include both monetary and physical information in the inter-industry flow table, resulting in a hybrid IO table (HIOT). Most material and energy intensive sectors, for example, can be represented in physical units while other sectors remain in monetary units.

[16] Since all SKEP countries are within Europe, the focus of this project is on the situation in Europe. However, the principal considerations are valid for any world region.

For applications in multi-regional IO models, most authors so far applied the first approach. The main reason for using purely monetary IO tables is that data availability for PIOTs is still limited and detailed PIOTs have only been compiled for a small number of countries (Weisz and Duchin 2006, Giljum and Hubacek 2008). Furthermore, the debate on how to apply IO analysis based on PIOT models is ongoing (Dietzenbacher 2005).

A MIOT approach follows economic causalities, whereas a PIOT approach follows physical causalities (see Rodrigues and Giljum 2005). Allocating environmental extensions with a MIOT, a PIOT or a hybrid IO model generates different results, in particular for the calculation of trade balances (for example Hubacek and Giljum 2003). While in a PIOT and a hybrid model, environmental extensions are allocated to the most material (and energy) intensive sectors of the domestic economy, in particular the construction sector, the MIOT-based model allocates a larger share to those sectors with high values of economic output; therefore, service sectors of the domestic economy receive more environmental responsibility in the MIOT than in the PIOT model. If exports of a country have a higher value per weight ratio than production for final domestic consumption, the MIOT model allocates a higher share of environmental factors to exports than a PIOT or a hybrid model (Weisz 2006).

Therefore, in the medium term, it would be desirable for pure monetary IO tables to be extended into hybrid tables, which better reflect the physical supply and use structure of industries and thus avoid distorting results by assuming that monetary structures are a proxy of physical economic structures.

Process-specific information from process LCA can be used to fill the physical information missing in monetary supply-use tables, thus allowing the construction of physical supply-use tables (PSUTs) that are consistent from a mass balance perspective and relative to the monetary supply-use tables.

The EU project FORWAST[15] aims to construct such PSUTs. In reality it might not be feasible to compile complete PIOTs or PSUTs, but process data can at least be used for individual conversions and for mixed-unit tables/models.

4.3.2 Hybridisation between IOA and Process LCA

A description of input-output analysis (IOA) and process-based LCA as well as their respective strengths and weaknesses is given in Lutter *et al*. (2008).

A *Hybrid Life Cycle Assessment* (**Hybrid LCA**) is carried out through the combination of process-based (process LCA) and sectoral input-output and environmental accounts data (IO-LCA). The methodological framework has its roots in energy-economic modelling of the 1970s (Bullard *et al.* 1978). In these studies, IO modelling supplied information for sector typical products or processes, while all remaining processes were modelled using process data (Suh *et al.* 2004). Such a hybrid approach for a full life cycle assessment was first used by Moriguchi *et al*. (1993). Wilting (1996) empirically investigates a hybrid energy analysis method and compares the outcomes with those of an input-output energy analysis. Over time three interrelated ways of conducting a hybrid LCA have been developed (Suh and Huppes 2005) (see also Minx *et al.* 2008b):

Tiered hybrid analysis uses process-based analysis for the use and disposal phase of products as well as for several important upstream processes, while the remaining input requirements are calculated separately with IO-based LCA. Tiered hybrid analysis can be performed simply by adding IO-based life cycle inventories to process-based data or replacing them with the latter ones.

IO-based hybrid analysis is carried out by selectively disaggregating industry sectors in the IO table, thus expanding the technical coefficient matrix by using process and trading information. The use phase and end-of-life phase (reuse, remanufacturing, recycling or disposal) of a product can be treated as a hypothetical industry sector that draws inputs from the existing sectors and has some associated environmental burden.

Integrated hybrid analysis is the most sophisticated combination: The IO table (in monetary units) is fully interconnected with the matrix representation of the physical product (or process) system in physical units, thus forming one consistent computational structure. The interconnection is located at upstream and downstream cut-off points where process data are not available. Note that, computationally, integrated hybrid LCA is a functional generalisation of IOA and tiered hybrid LCA.

Compared to process LCA, the main difference of the hybrid life cycle method is that it can overcome problems of additivity and truncation (system boundary) by using sectoral data from environmental IOA as an additional source of secondary data, where no primary or secondary process level data is available. Thus, data gaps in the LCA system can be filled with much less effort than would be required to obtain process data. The advantages of IO (ready available, complete and consistent data) are combined with those of process LCA (precise and process-specific data).

Consider, for example, a hybrid LCA of a new car: The material composition is known and cost calculations are available. For the major materials (steel, plastics and glass) and the main assembly, process LCA data are available and used in the analysis. For some minor materials, assembly processes (such as for electric components), capital goods, trade storage and so on, LCA data are missing. Because the costs of these items are known, and the industrial sectors that deliver them are known, these data can be obtained from environmental IO databases (SRIO or MRIO).

The following table, taken from Suh and Huppes (2005), lists the various approaches together with their main characteristics.

Table 4.1: Criteria for choosing Life Cycle Inventory (LCI) methods (from Suh and Huppes 2005)

	LCI based on process analysis		Input–output based LCI	Hybrid LCI		
	Process flow diagram	Matrix representation		Tiered hybrid analysis	IO-based hybrid analysis	Integrated hybrid analysis
Data requirements	Commodity and environmental flows per process	Commodity and environmental flows per process	Commodity and environmental flows per sector	Commodity and environmental flows per sector and process	Commodity and environmental. flows per sector and process-based LCIs	Commodity and environmental. Flows per sector and process
Uncertainty of source data	Low	Low	Medium to high	Depends[a]	Depends[a]	Low
Upstream system boundary	Medium to poor	Medium to poor	Complete	Complete	Complete	Complete
Technological system boundary	Complete	Complete	Medium to poor	Depends[a]	Depends[a]	Complete
Geographical system boundary	Not limited	Not limited	Domestic activities only	Depends[a]	Domestic activities only	Not limited
Applicable analytical tools	Rare	Abundant, e.g. in Heijungs and Suh [10]	Rare	Rare	Abundant (analytical tools for IOA disaggregated IO part)	Abundant (both analytical tools for IOA and LCA for entire system)
Time- and labour intensity	High	High	Low, if environm. data available	Depends[a]	Depends[a]	High
Simplicity of application	Simple	Simple	Simple	Simple	Complex	Complex
Required computational tools	Excel or similar (no matrix inversion)	Matrix inversion (e.g. MatLab, Mathematica.)	Excel or similar	Excel or similar	Matrix inversion (e.g. MatLab, Mathematica.)	Matrix inversion (e.g. MatLab, Mathematica.)
Available software tools	Most available LCA software tools	CMLCA	MIET, EIOLCA	MIET+LCA software tool	–	CMLCA

[a] Dependant upon the shares of process analysis and IO-based system.

Hybrid LCA can be used to estimate the embodied impacts of traded goods and services. While national SRIO hybrid LCA studies have been described in the literature, no trade specific analysis has yet been published. However, it is conceivable that process-based analyses of international supply chains could be combined with data from MRIO models. Such a method would especially be suited to complex commodities.

From a statistical point of view, process LCA data play three roles: firstly, to provide "disaggregation factors" that allow representation of NAMEA data at a lower aggregation level than allowed by the confidentiality restrictions on the original NAMEA data, and at lower levels than possible from the way NAMEA data are collected. Secondly, process-specific emission factors can help to replace or qualify average emission intensities of IO sectors. And thirdly, Life Cycle Impact Assessment (LCIA) provides characterisation factors needed to express environmental pressures as impacts (see Section 4.5.1).

Below we provide several **examples of recent hybrid LCA studies**[17] to demonstrate the feasibility and usefulness of such approaches, even if they do not explicitly deal with traded goods and services.

Benders *et al*. (2001) developed a tiered hybrid analysis tool for determining energy use and greenhouse gas emissions related to household consumption items focussing on reduction in energy use and greenhouse gas emissions. This tool, the energy analysis program (EAP), is a computer program that consists of a number of fill-in screens corresponding to steps in a hybrid method (developed by van Engelenburg *et al.* 1994) in which some main steps are covered with LCA data and some minor steps with input-output data. One of the applications of the program concerns the calculation of the total energy requirement of Dutch households by combining household budget data with energy intensities of about 350 products and services (Biesiot and Moll 1995).

The environmental assessment study of Swedish agriculture presented by Engström *et al*. (2007) is a classical example of tiered hybrid analysis where SRIO model data are extended or replaced with process LCA data. This is done for the purpose of specifying emission intensities (such as for N_2O emissions from the production of nitrogen fertilizers which fall under the broad IO sector of 'chemical products) or for extending pressure variables to LCA impact categories such as global warming, acidification, eutrophication and so on.

Similar tiered hybrid analyses have been run by Kofoworola and Gheewala (2008) for the life cycle assessment of an office building in Thailand or by Junnila (2008) for the life cycle management of energy-consuming products. In these cases LCA data describe site-specific processes that replace IO data or augment these by adding downstream life cycle impacts to the system.

The quantification of impacts from *international transportation* is an important area for tiered hybrid analysis using process data. The main question is how to assign emissions from the combustion of fuels from bunkers for international aviation and shipping. From a production perspective (such as when following SNA93 principles; United Nations Statistics Division 1993), bunker emissions should be assigned to ship or plane operators' country of domicile and – in the case of passenger transport – counted as exports if passengers are non-resident, otherwise as domestic consumption. From a consumption perspective (as taken by an EIPOT MRIO model), emissions of residents using international passenger transport should be counted as consumption emissions of their country. For goods, bunker emissions from imports are allocated to country of import and bunker emissions from exports are not counted. In any case a bottom-up approach using process data is needed, which requires the following information:

[17] The selection is non-exhaustive.

Air transport:

- statistics on the movement of passengers and freight by origin, destination and distance;
- statistics on the residency of passengers;
- aircraft emission factors for short and long-haul flights (per passenger, per tonne of freight).

Marine transport:

- statistics on the volume of freight shipped by port of origin and destination;
- information on vessel size and volume of freight tonnage;
- vessel emission factors by vessel type and size.

Several pioneering studies have tried to quantify emissions associated with international transportation by using bottom-up approaches (Corbett and Koehler 2003, Det Norske Veritas 2007, Kim *et al.* 2007) These methods could potentially be merged with an MRIO framework, although further research is required in this area.

A life cycle assessment (LCA) for regions in Japan based on inter-regional IO modelling is presented by Yi *et al.* (2007). This study makes use of 47 regional IO tables for each prefecture in Japan and one full MRIO table for nine larger regions (compiled by the Ministry of Economy, Trade and Industry in Japan). The authors create an 'Expanded Inter-regional Input Output Method' (EIOM) which combines prefecture-specific emission databases and technology matrices with the inter-regional trade flows presented by the nine-region MRIO. This allows results to be more specific to the lowest spatial level. Emissions for CO_2, SO_x, NO_x and SPM are calculated and the corresponding damage to human health is expressed in DALY (Disability Adjusted Life Years; an LCA endpoint indicator).

In an IO-based hybrid analysis of construction projects, Sharrard *et al.* (2008) describe their hybrid LCA procedure of replacing IO with process data: "*The new EIO-LCA-based "hybrid" feature allows hypothetical custom product/process sectors to be created… This hybrid feature instructs users to select the existing EIO-LCA sector that most closely approximates the product or process they want to model. The framework then allows the user to manipulate the actual EIO-LCA direct matrix to create a modified direct supply chain for their custom product. This feature allows the user to make as many or as few changes to the chosen IO sector as necessary, while comparing their hybrid customized product process to the base sector they are modifying. This top-down method provides the user with supply chain values to build from, versus a bottom-up approach that would require the user to create their own sector piecemeal… Consequently, the EIO-LCA hybrid feature creates a system that has the benefit of EIO-LCA's large boundary while allowing for process-level user input that specializes the analysis*."

This is, in principle, possible for sectors stretching across countries as in a MRIO system. However, the problem with this matrix-based approach – already mentioned by Treloar (1997) and by Strømman and Solli (2008) – is that only a first-order hybridisation can be implemented this way, since it is not possible to make one particular change of a second-order path without changing the entire system.

Another problem that can arise is double-counting. Whilst the combination of input-output and physical inventory data on coefficient level is a convenient way of constructing a detailed and complete hybrid life cycle inventory (LCI), there is also the danger of (partially) overlapping monetary and physical data leading potentially to double-counting.[18] Strømman *et al.* (2009) present algorithms for inventory compilation and identification and adjustment of double-counting in tiered hybrid LCIs. The identification is performed with structural path analysis (SPA).

Structural path analysis (SPA) (Defourny and Thorbecke 1984, Treloar 1997, Lenzen 2003, Lenzen 2007, Peters and Hertwich 2006) – an analytical technique based on power series expansion of the Leontief system – is a useful tool in several regards. Not only can it quantify and unravel upstream production/supply chains, even in multi-region input-output frameworks (Peters and Hertwich 2006, Lenzen *et al.* 2007b, Wood 2008, Wood and Lenzen in press), but it can also be used as a vehicle for hybridisation as it enables the replacement of individual supply path data with bottom-up process and supply specific data (Treloar 1997, see also Suh and Heijungs 2007).

4.4 Country and sector resolution

In analysing the environmental impacts of trade flows and traded products, the sectoral and regional detail strongly depends on the application under consideration. In determining the share of exports in the territorial emissions of a specific country, a single-region IO analysis is sufficient. The same holds for broadening this application to emissions (impacts) embodied in total bilateral trade between regions (EEBT) where only export shares of nations need to be calculated. In analysing more detailed studies on traded goods, such as in consumption (footprint) studies where embodied emissions (impacts) in trade to final consumption (EEC) of a nation are considered, a full multi-region IO analysis becomes necessary.[19] Structural path analyses considering complete supply chains of (traded) goods and services require full MRIO analyses covering all countries and sectors at a detailed level.

4.4.1 Countries

When deciding on the number of countries to be included in the accounting framework, it seems reasonable to set up criteria for which countries should be chosen. Again, we compare here with the approach used in EXIOPOL. Here, the criteria selected were:

- share of global GDP;
- share of trade with the EU27;
- environmental impact related to goods imported by the EU27;
- percentage of GDP traded with the EU27 in a specific country.

The last criterion would enable analysis of the impact of EU policies on countries highly dependent on trade with the EU. This implies that many small countries, mainly in Africa, would have to be included.

The first three criteria lead to roughly the same country sets in EXIOPOL[20], allowing coverage of over 90 per cent of global GDP and over 80 per cent of imports to EU27 with just 16 additional EU trading partner countries for which, in most cases, reasonable data is available for recent years.

18 Another type of double counting occurs if a full life cycle / supply chain / footprint analysis which has been developed to quantify the total impact of *consumption* or *consumer items* is applied in the same manner to *production* or *producer items* (Lenzen et al. 2007a, Lenzen 2008).

19 For a distinction and definition of the EEBT and EEC approaches see Peters (2008a).

20 In EXIOPOL the selected countries are: United States, Japan, China, Canada, South Korea, Brazil, India, Mexico, Russia, Australia, Switzerland, Turkey, Taiwan, Norway, Indonesia and South Africa. These are countries from a EU27 perspective; in general, each country will have a set of relevant countries.

Choosing a smaller country set reduces the workload and complexity; and there is a strategic advantage to having a trustworthy dataset when concentrating on a limited number of countries with good data.

Today, all countries are more or less interconnected. To capture the impacts in all countries, including those not in the selected dataset, a 'Rest of the world' region should be defined in the framework. It may be useful to distinguish several residual regions in case this 'Rest of the world' region is a mix of countries all over the world, thus allowing for a more specific attribution analysis. The data for these residual regions might be based on other countries (as done in GTAP).

4.4.2 Sectors

Several studies have shown that a resolution of 60 sectors is not sufficient for detailed environmental applications. Agriculture, mining, energy production and transport are areas with high environmental impact intensities, which differ considerably between sub-sectors. Hence, a much higher resolution of at least 100-150 sectors is essential for allocating sustainability impacts in a meaningful way to sectors, products and so on (Tukker *et al.* 2006, Weidema *et al.* 2005).

Generally, in the ESA95, 60 products and sectors are discerned. The EXIOPOL project attempted to add 69 additional industries and products mainly in the field of agriculture and food, resource extraction and processing, and some other sectors, following industry classification NACE 1.1 and product classification CPA 1.1

In many cases, a higher resolution of industries and products can be obtained from supply and use tables (SUTs) directly produced by NSO. Often, more than 100, in some cases even several hundred sectors, especially for commodities, are distinguished. For this reason, SUTs have been used directly in the technology matrix of IO and even MRIO frameworks. Lenzen *et al.* (2004) calculate CO_2 multipliers for multi-directional trade between Denmark, Germany, Norway, Sweden and the rest of the world by constructing a consistent MRIO system which, as a central element, features domestic make and use matrices as well as use matrices for traded goods and services between all trading partners. Using this extensive MRIO model, a compound total requirements matrix with the dimensions 1199 x 1199 is constructed, resulting in total region-specific multipliers of intermediate demand, trade, energy consumption and CO_2 emissions. With this closed model, it is possible to include feedback loops and capture direct, indirect, and induced effects of trade.

Another compelling reason to use SUTs is that they are often more up-to-date than symmetric IO tables. This is particularly true for tables from the UK where the last analytical (symmetric) tables were produced for 1995, whereas the latest SUTs are available for 2006. In their UK-MRIO, Wiedmann *et al.* (2008a) also use the supply and use tables directly (see discussion in Section 5.1.1).

4.5 Coverage of environmental categories

4.5.1 Generalisation of the input-output system

One of the advantages of an accounting framework based on MRIO is its ability to link any kind of environmental category to the monetary economic information given in the input-output tables, to enable integrated environmental and economic model calculations. This is done via environmental extensions – environmentally relevant parameters in physical units. The process of extending the IO framework in this way is also referred to as 'generalisation'.

A reasonable way of arranging the environmental extension parameters is to augment the balanced monetary SUT-scheme with satellite environmental accounts. Satellite accounts are external vectors and/or matrices which are added to the monetary core SUT-scheme, arranged in a compatible way to the SUT column and row headings. Most commonly, the environmental extensions are arranged to the use table part, likewise the value added (see Chapter 5 on data requirements). Consequently, whatever physical information is available in terms of environmental categories can be linked to economic transactions. This offers an enormous advantage as the effect of different policy options on environmental categories can be modelled in parallel and synergies or trade-offs can be identified.

In most cases environmental **pressure** data will be added to the system, such as material use, emissions, land use, water consumption, or waste production. In a multi-regional framework, all data should be as specific as possible to the country or region that is being distinguished in the system, as production technologies and efficiencies are different across the world.

Distinction of regional or even local peculiarities becomes even more important when the actual environmental **impact** of an activity (such as trade) is to be expressed. The impact of water extraction, for instance, very much depends on the mechanisms of the local water cycle. Impacts of land use and land use changes on soil degradation or biodiversity depend on the local circumstances, as do the impacts of acidifying or eutrophying substances. Even the impact of carbon dioxide varies with the location of its release into the atmosphere. In most cases, its contribution to global warming is seen as site-independent, due to its longevity in the atmosphere, but notable exceptions are emissions from aircrafts at higher altitude which are reported to have a greater impact.

The translation from environmental pressure to impact is performed in life cycle assessments using characterisation factors or models. The same procedure can be used in an EE-MRIO framework. Country-specific pressure data are multiplied (or modelled) with country-specific (or site-specific) characterisation factors *prior* to the input-output calculations.

Examples include the life cycle impact assessment of acidification based on damage to plant species in European forest ecosystems (van Zelm *et al.* 2007), of land use impacts based on local species diversity in Central Europe (Koellner and Scholz 2007, Koellner and Scholz 2008) or of global warming based on damages to humans and ecosystems (De Schryver *et al.* 2009).

Another example specific to a sector is the aforementioned impact of flying: CO_2 emissions from the aviation sector should be multiplied with an agreed impact (characterisation) factor, prior to IO calculations, to reflect the higher influence on global warming of this sector.

The result of the subsequent environmentally extended input-output calculations is a set of 'multipliers' that show the total environmental load of one unit of final demand and therefore constitute a **multi-region life cycle inventory** of a financial transaction up to the point of sale to the final consumer. 'Total' in this context means all indirect country-specific pressures or impacts along the production line.

4.5.2 Examples of environmental extensions

Generalising IO frameworks with **emissions** data is in most cases straightforward as emissions to air, in particular of greenhouse gases, are well covered in national environmental accounting. Many single- and multi-region input-output models extended with GHG accounts have been constructed and applied to empirical research as a result of the increased interest in climate change (for a review, see Wiedmann *et al.* 2007a).

Material flows are of great relevance for the purpose of EIPOT. According to the London Group on Environmental Accounting (2008), in the new SEEA manual on MFA, economy-wide MFA will be designed as a fully integrated sub-module. While economy-wide MFA reveals no information on flows within an economy, a MRIO model can show the interaction of the economy with other countries and world regions in a breakdown by type of material. Flows of material within the economy are the focus of other sub-modules, such as physical IO tables (PIOT).

For the "**footprint family**" of indicators, these approaches should be further developed to make them compatible with the SEEA accounting framework and thus also with input-output and MRIO models. This would constitute a valuable extension of the MRIO approach in terms of environmental impact through the use of land and water. For the ecological footprint, for example, detailed data on the bioproductivity of a country would need to be compiled (or transferred from existing national footprint accounts which are mostly based on data from the FAO) and assigned to the respective industry sectors, such as agriculture, forestry and fishery.

With regard to **water**, the best approach would be consistent water use accounting in NAMEA style, which would help with data availability/consistency. As elaborated in an earlier EIPOT report (Lutter *et al.* 2008), experiences of combining the input-output framework with water use data (for instance, using the virtual water concept) have shown that it is an effective means to explore the economic sectors with the highest indirect consumption of water. The interrelationship between different sectors in terms of water use can be determined and recommendations for political action be made (see Guan and Hubacek 2007). Furthermore, it allows judgment of whether the use of water resources for economic productivity or environmental flows is reasonable. For water quality, especially on the downstream side of a water-using industry, decision-making can be improved by using the detailed sectoral breakdown per euro or dollar of contribution to GDP (Lenzen and Foran 2001).

Land use is another category where international trade matters, one example being the destruction of primary rainforest for the production of soy beans, meat or palm oil. A starting point for generalising the MRIO system is to add the estimated size in hectares of land used by different industries. Further division of the physical area is possible, for example in land cover types (forest, cropland, pasture land and so on), crop types and tree species (Lee *et al.* 2005). A second step is to characterise the environmental impact of land use, such as soil quality or biodiversity. This will depend on the availability of country-specific data (characterisation factors). It might be possible in some countries to obtain data on the felling of a particular rare tree species which can then be linked through the MRIO system to furniture production and consumption worldwide. However, it is unlikely that official statistics in most countries can provide this level of detail.

One possibility to account for impacts of land use is to introduce 'land disturbance factors' that characterise the intensity of different types of land use (Lenzen and Murray 2001). Land disturbance is expressed in "disturbed hectares", calculated from actual areas by weighting with factors describing the deviation of the biodiversity of vascular plants from a pristine condition. This approach therefore establishes a link between local land management practices, biodiversity and consumption patterns elsewhere, thus adding crucial information to policy for long-term planning. Another approach to assess human-induced changes in **biodiversity** is via the Means Species Abundance (MSA) indicator that describes the mean abundance of original species relative to their abundance in undisturbed ecosystems (Alkemade *et al.* 2009). The MSA is based on simple cause-effect relationships between environmental drivers (namely land-cover change, land-use intensity, fragmentation, climate change, atmospheric nitrogen deposition, and infrastructure development) and biodiversity impacts.

The production and treatment of **waste** can also be dealt with in an input-output framework. Nakamura and Kondo describe the concept and application of waste input-output (WIO) analysis (Nakamura and Kondo 2009). The WIO table is an extended input-output table that represents the interdependence between the flow of goods and the flow of waste.[21] WIO is a variant of NAMEA. A distinguishing

[21] For a description of WIO see http://www.f.waseda.jp/nakashin/WIO.html where most of this text is from.

feature of WIO consists in its detailed description of waste stream and waste management. The waste input-output (WIO) is a hybrid methodology of LCA capable of taking into account all phases of a product life cycle, that is production, use, and end of life (EoL) phase. Exclusion of the EoL phase used to be mentioned as a limitation of IO Analysis (IOA) for LCA (while the conventional IOA does not cover the use phase, its incorporation is rather straightforward). This, however, does not apply to the WIO because of its explicit consideration of the flow of waste and waste management activities including waste recycling. The WIO corresponds to LCA-based hybrid analysis, where the technology matrix of a product system in LCA (in particular the foreground processes that refer to waste management and recycling) is fully integrated with technical coefficients matrix of an economy (background processes that refer to the traditional flow of goods and services) in IOA. In principle, this hybrid system can be constructed for each country in a MRIO model if sufficient data is available.

4.6 Summary of recommendations on methodology

- MRIO analysis extended with environmental data based on the SEEA/NAMEA framework is the most promising approach for the analysis of environmental impacts of traded goods and services.
- We suggest setting up an EE-MRIO model based on available data and starting each application with a top-down analysis. The analysis can then be specified and refined with bottom-up techniques as and when required. A wide range of policy and research questions can be covered in a cost-efficient manner and with a continuum of consistent methods from macro to micro level.
- The suggested EE-MRIO model should comprise all EU countries plus an approximately equal number of important EU trading partners.
- The sectoral resolution is determined by the application. While more than 100 sectors seem desirable and feasible, for time-series analysis based on official statistics, the sectoral resolution will probably not exceed 60 sectors in the foreseeable future. This is also the resolution chosen for NAMEA data (see Chapter 5). Substantial work is still needed to make the 60 sector data available from more countries as well as more research and separate analysis with a higher resolution.
- For specific policy and research questions, data from process analysis and LCA can be incorporated into hybrid approaches (hybrid LCA) and/or to enumerate specific processes (such as international transportation). Life cycle inventory (LCI) data and characterisation factors for life cycle impact assessment (LCIA) should be as locally relevant as possible, that is, should be specific to the country where the process and the impact take place.
- The suggested EE-MRIO model potentially covers a large number of environmental pressures. To investigate local and regional impacts, the model should be integrated with spatially explicit models of environmental impacts. For example, ecological models of local or regional ecosystems, which illustrate impacts of, for example, land cover change, material extraction or water uptake on ecosystem structure and the provision of ecosystem services can be coupled with environmental pressure data prior to the input-output calculations. All relevant environmental impact categories should be included in the model framework. In some areas, further research is required to complete and harmonise datasets; examples include water, land use and waste.
- Structural path analysis in a multi-region input-output framework (MRIO-SPA) can be used to identify major pressures or impacts along (international and national) supply chains. This top-down analysis should be used routinely in MRIO modelling to shape further research (such as on the hybridisation of the system) or policies early on.

- Despite the many advantages of an EE-MRIO based model, users should be aware of its inherent limitations. These include the major effort needed to set up the EE-MRIO system, time gaps or assumptions in the update of IO tables and limited suitability to assess individual products.

5 Data requirements for EIPOT modelling

This chapter deals with the data requirements for analysing environmental aspects of international trade flows. All of the following types of data are needed for an environmentally extended MRIO model that allows for various degrees of hybridisation:

- National **economic accounts** data showing financial transactions between producing and consuming entities (supply, use, input-output tables).
- **Environmental accounts** data including resource use and emissions by economic sector and country as well as additional environmental pressure or impact data if required (such as bioproductivity, number of endangered species, waste).
- International **trade statistics** covering the bilateral trade in goods and services in an adequate resolution of countries and sectors.
- Process **specific data and factors** for resource use, emissions and environmental impacts from life cycle inventories (LCI) and other technical databases for hybridisation and completion. While the first three categories of data are essential and of high priority, these data are only needed if specific questions at the micro level need to be addressed.

A MRIO model needs a whole set of IO, trade and environmental data. All of these datasets exist already, but the challenge is to convert these data into the MRIO format and keep them up to date. The bottleneck will be the availability of resources to compile, provide and update the necessary data.

For the foreseeable future, IO, trade and environmental accounts data will be the most widely available and consistent data for environmental analysis of international trade flows. Many of these data are officially published by national statistical offices (NSO). The data are usually compiled further at international statistical agencies such as Eurostat, UN, Organisation for Economic Cooperation and Development (OECD) and the World Bank. Further useful data sources include projects such as EXIOPOL and GTAP as well as commercial data sources for LCA.

The main focus in this chapter is on the collation and preparation of economic data (SUT, SIOT), environmental data, and trade data for the purpose of an environmentally extended MRIO model as well as possible refinements using process-based LCA data. The experiences from Statistics Sweden in previous work have been used to make the presentation as concrete as possible. Furthermore, experiences with hybrid approaches (using process-based LCA data) from projects such as EXIOPOL are presented to illustrate the viability of such approaches.

5.1 Data sources

5.1.1 Data sources for economic data

The most widely available and consistent data are found in national economic accounts and trade statistics. Both are cornerstones of most statistical agencies and they are more or less completely harmonized in the EU and worldwide through the work of Eurostat, OECD, the UN, and others.

Input-output tables (IOT) are a core component of the System of National Accounts (United Nations Statistics Division 1993) and, while there are some data gaps and variations between counties, IOT exist for around 100 countries. This is a solid basis to draw from and far in excess of what is achievable for process/life cycle inventories in the foreseeable future.

Supply and use tables (SUTs)

Since the SNA 93 (United Nations Statistics Division 1993) and ESA 95 (Eurostat 2009), yearly national accounts are compiled in the form of standardized supply and use tables (SUT). These are annual tables used to compile a consistent set of accounts. This process ensures consistency between what is supplied in terms of products (goods and services) and the use of these products as:

- inputs into industries that produce the products;
- products bought by private or public consumers nationally or exported to other countries;
- investment goods or products put into stocks for future use.

The dimensions of the SUT compiled vary between countries. The tables collected by Eurostat are on the two-digit NACE level, which means roughly 60 products/industries.[22] The level of detail used in the tables for compiling the finished SUT can run to thousands of products and well over 100 industries. The Swedish system works with roughly 400 products and 135 industries. Published SUT (both domestically and through Eurostat) are often at greatly reduced level of detail due to confidentiality.

On the final demand side, private consumption is often cross-classified between NACE and the Classification of Individual Consumption by Purpose (COICOP, around 108 categories). The latter is used in most household expenditure surveys.

[22] NACE revision 2, introduced in 2008, identifies 88 divisions on Level 2 (two-digit numerical codes); see http://circa.europa.eu/irc/dsis/nacecpacon/info/data/en/index.htm and http://ec.europa.eu/eurostat/ramon/index.cfm?TargetUrl=DSP_PUB_WELC.

Table 5.1: Availability of supply and use tables in current prices from Eurostat in 2008

Availability of Supply and Use Tables, Current Prices

	ESA 95 Table	1500 Supply													1600 Use												
Code	Country	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
BE	Belgium	x		x		x	x	x	x	x	x				x		x		x	x	x	x	x	x			
BG	Bulgaria								2008			2009										2008			2009		
CZ	Czech Republic	x	x	x	x	x	x	x	x	x	x	x			x	x	x	x	x	x	x	x	x	x	x		
DK	Denmark	x	x	x	x	x	x	x	x	x	x				x	x	x	x	x	x	x	x	x	x			
DE	Germany	x		x	x	x	x	x	x	x	x	x			x		x	x	x	x	x	x	x	x	x		
EE	Estonia			x			x	x	x	x	x						x			x	x	x	x	x			
IE	Ireland	/	/	/	x	/	x	x	x		2008	2009	2010		/	/	/	x	/	x	x	x		2008	2009	2010	
GR	Greece						x	x	x	x	x	x	x	x						x	x	x	x	x	x	x	x
ES	Spain	x	x	x	x	x	x	x			x				x	x	x	x	x	x	x			x			
FR	France	x	x	x	x	x	x	x	x	x	x	x			x	x	x	x	x	x	x	x	x	x	x		
IT	Italy	x	x	x	x	x	x	x	x	x	x				x	x	x	x	x	x	x	x	x	x			
CY	Cyprus										2008													2008			
LV	Latvia		x		x		/	/	/	/						x		x		/	/	/	/				
LT	Lithuania						x	x	x	x	x									x	x	x	x	x			
LU	Luxembourg	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
HU	Hungary				x	x	x	x	x	x	x	x						x	x	x	x	x	x	x	x		
MT	Malta						x	x												x	x						
NL	Netherlands	x	x	x	x	x	x	x	x	x	x				x	x	x	x	x	x	x	x	x	x			
AT	Austria	x	/	x	/	x	x	x	x	x	x				x	/	x	/	x	x	x	x	x	x			
PL	Poland	x	x	x	x	x	x	x	x	x	x				x	x	x	x	x	x	x	x	x	x			
PT	Portugal	x	x	x	x	x	x	x	x	x	x	x	x		x	x	x	x	x	x	x	x	x	x	x	x	
RO	Romania						x		2008	x	x	x								x		2008	x	x	x		
SI	Slovenia		x				x	x	x	x	x	x				x				x	x	x	x	x	x		
SK	Slovakia	x	x	x	x	x	x	x	x	x	x				x	x	x	x	x	x	x	x	x	x			
FI	Finland	x	x	x	x	x	x	x	x	x	x	x			x	x	x	x	x	x	x	x	x	x	x		
SE	Sweden	x	x	x	x	x	x	x	x	x	x	x			x	x	x	x	x	x	x	x	x	x	x		
UK	United Kingdom	x	x	x	x	x	x	x	x	x					x	x	x	x	x	x	x	x	x				
HR	Croatia																										
MK	FYR Macedonia											x													x		
TR	Turkey								x													x					
NO	Norway							x	x	x	x										x	x	x	x			

Key to table cells: X available, derogation, YYYY derogation until year.

The annual SUT are compiled and sent to Eurostat in the agreed two-digit NACE format. There is no requirement to send separate domestic production use tables in a more detailed format. All tables are in current prices and some in constant prices of the previous year to help chain linking to prices in reference years. The table above shows the availability of European SUT as of 2008. The average time lag for publication is about two years.

Current price tables can be used in IO models for one year and in most cases for time series. However, if structural decomposition analyses or similar analyses are to be performed, tables in constant prices are required. Eurostat's SUTs in constant prices are more sparsely populated, see Table 5.2.

Table 5.2: Availability of supply and use tables in constant prices of the previous year from Eurostat in 2008

Availability of Supply and Use Tables, Constant Prices of the previous year

ESA 95 Table: 1500 Supply

Code	Country	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
BE	Belgium													
BG	Bulgaria							2010						
CZ	Czech Republic													
DK	Denmark								x	x	x			
DE	Germany									x				
EE	Estonia							2009						
IE	Ireland						2015							
GR	Greece							x	x	x	x	x	x	x
ES	Spain						2008							
FR	France													
IT	Italy						2008							
CY	Cyprus								2008		2009		2010	
LV	Latvia													
LT	Lithuania						2012					2010		
LU	Luxembourg													
HU	Hungary									x	x	x		
MT	Malta													
NL	Netherlands													
AT	Austria													
PL	Poland						2009							
PT	Portugal	x	x	x	x	x	x	x	x	x	x	x	x	
RO	Romania						2008							
SI	Slovenia													
SK	Slovakia	2008												
FI	Finland													
SE	Sweden	x	x	x	x	x								
UK	United Kingdom						2009							
HR	Croatia													
MK	FYR Macedonia													
TR	Turkey													
NO	Norway													

ESA 95 Table: 1600 Use

Code	Country	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
BE	Belgium													
BG	Bulgaria							2010						
CZ	Czech Republic													
DK	Denmark								x	x	x			
DE	Germany									x				
EE	Estonia							2009						
IE	Ireland						2015							
GR	Greece							x	x	x	x	x	x	x
ES	Spain						2008							
FR	France													
IT	Italy						2008							
CY	Cyprus								2008		2009		2010	
LV	Latvia													
LT	Lithuania						2012					2010		
LU	Luxembourg													
HU	Hungary									x	x	x		
MT	Malta													
NL	Netherlands													
AT	Austria													
PL	Poland						2009							
PT	Portugal	x	x	x	x	x	x	x	x	x	x	x	x	
RO	Romania						2008							
SI	Slovenia													
SK	Slovakia	2008												
FI	Finland													
SE	Sweden	x	x	x	x	x								
UK	United Kingdom						2009							
HR	Croatia													
MK	FYR Macedonia													
TR	Turkey													
NO	Norway													

Key to table cells: X available, [ ] derogation, YYYY derogation until year.

Often, input-output tables are only published in purchasers' prices, the values include trading margins (wholesale and retail trade), transport margins and taxes (less subsidies). To make the use table consistent with the supply table, the intermediate flow matrix needs to be transformed from purchasers’ into basic prices. This is a better and more stable reflection of the actual transactions between economic sectors. It therefore becomes necessary to either estimate tables in basic prices from previous years or to convert tables from purchasers' to basic prices. The former can be applied if a use table at basic prices or 'valuation matrix' (also called 'transition matrix') containing all margins and taxes is available for one year (see Section 5.2.3 for the actual updating procedure). The latter procedure, the direct conversion, requires the exclusion of direct taxes and re-distribution of trade margins and is described in Chapter 6 of the *Eurostat Manual of Supply, Use and Input-Output Tables* (Eurostat 2008). Depending on the availability and quality of data for taxes and margins, uncertainty can be introduced by either of the procedures.

Imports matrices

The report requirements of SUTs do not include the separation of domestic and imported use of products. However, the separation of intermediate and final imports from domestic intermediate and final demand is absolutely crucial for MRIO modelling. In a unidirectional MRIO, all imports to the country under investigation need to be known in matrix form, for instance, by product and by industry, for each country issuing the imports. In a full MRIO model, all imports from all countries to all countries need to be known.

Matrices of total imports to intermediate and final demand are compiled by NSIs in regular intervals, for example together with the production of symmetric IO tables (see below). These tables are compiled by using bottom-up trade information from customs offices and are superior to any estimated or imputed matrix. For years where these tables are not available, balancing and optimisation can be used to update them to the desired year (see Section 5.2.3 below). National import tables often have rows with so-called non-competitive imports which are goods and services that are not produced domestically, such as bananas or cotton in Northern European countries. In a SRIO analysis for competitive imports, it is assumed that they are produced in a similar way to domestic production. Since the non-competitive imports are not produced domestically, such an assumption cannot be made. This is an extra argument for an MRIO approach that covers all products and industries.

Individual trade flow matrices by country, that is, the off-diagonal elements in a full, multidirectional MRIO model deserve special attention. In most cases, only vectors of total imports of commodities from one economy to another are known and thus the matrices showing imports to using sectors are not known. One solution to the estimation problem for off-diagonal trade flow matrices is to use bilateral trade coefficients, also called trade shares (Lenzen *et al.* 2004, Peters and Hertwich 2004). This procedure assumes that trade coefficients are identical for all entries along a row of total imports matrix, that is for all using domestic industries. Section 5.3 discusses the uncertainty implications of this widely used assumption.

Symmetric input-output tables (SIOTs)

A symmetric input-output table (SIOT) is the combination of a supply (supply of goods and services by product and industry, distinguishing between domestic industries and imports) and a use matrix (use of goods, services and value-added by product and by type of use, such as intermediate and final demand) in one table. The values in such a table – which can be produced in industry-by-industry or product-by-product format – represent financial transactions that take into account the fact that most industries produce more than one product (Eurostat 2008).

While product-by-product input-output tables are believed to be more homogeneous (each column indicates one type of product, meaning only products produced by the main activity of that sector), industry-by-industry input-output tables are closer to statistical sources and actual observations (heterogeneous sectors are presented, including firms with the same main activity/product but different secondary activities/products). In empirical research, the best suited input-output table for economic analysis depends on the objectives of the analysis (Rueda-Cantuche *et al.* 2009).

In most cases, industries produce several different products, including byproducts and auxiliary products. When constructing a SIOT, it can be assumed that products are made with the technology of the supplying industry (industry technology assumption, ITA) or with a technology specific to the product (commodity technology assumption, CTA) or with a combination of both (hybrid technology assumption, HTA) (see Bohlin and Widell 2006, Rueda-Cantuche and ten Raa 2007, ten Raa and Rueda-Cantuche 2007). Thus, a symmetric input-output table gives a detailed description of the domestic production processes and transactions within an economy.

Both SUTs and SIOTs are components of the above mentioned System of National Accounts (SNA; United Nations 1993) and European System of Accounts, ESA95 (Eurostat 2009). The SIOT is the standard framework for a detailed structural analysis of economic activity (input-output analysis, IOA); however, as the merging of the SUT into a single table requires additional resources and inherent assumptions – hence loss of information – the SUT is the preferred accounting framework for SNA and ESA95. On the other hand, officially published SIOTs produced with a HTA are often preferred for modelling purposes as they incorporate superior information on the production structure of a country.

Research by Bohlin and Widell (2006), based on data for Sweden, shows that the impact of making different technology assumptions can be large. The authors conclude that it is more important to produce SIOTs annually than to waste time deciding what compilation method to choose.

There are several pros and cons for using SUTs versus SIOTs; see separate discussion below.

Eurostat dataset

Most European countries produce a SIOT every five years and report it to Eurostat. Some countries, such as Denmark and the Netherlands, produce symmetric tables annually. Table 5.4 shows the availability of SIOTs at Eurostat. There are large differences between countries, ranging from 1995 for the last SIOT from the UK to annual reporting by some countries. Constant price SIOTs are not requested by Eurostat. Although most countries prefer to report the symmetric IO table in the form of a product-by-product table, some (Denmark, France and Netherlands) report industry-by-industry tables.

The Institute for Prospective Technological Studies (IPTS) is elaborating a complete homogeneous set of 27 symmetric input-output tables (at individual Member State level) and an aggregate EU27 table for the period 1995-2005. The input-output database, which is established for the European Commission, is shaped around the Eurostat supply and use tables and symmetric IO tables (Rueda-Cantuche *et al.* 2009).

Table 5.3: Availability of symmetric IO tables from Eurostat in 2008

		Availability of SymmetricTables, Current Prices																																							
	ESA 95 Table	1700 Siot													1800 Domestic														1900 Imports													
Code	Country	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	pp/ii
BE	Belgium	x					x								x					x								x					x								pp
BG	Bulgaria											2009													2009													2009			
CZ	Czech Republic						x					x													x													x			pp
DK	Denmark	x					x	x	x	x	x				x					x	x	x	x	x				x					x	x	x	x	x				ii
DE	Germany	x					x	x	x	x	x	x			x					x	x	x	x	x	x			x					x	x	x	x	x	x			pp
EE	Estonia			x			x										x			x										x			x								pp
IE	Ireland				x		x	/				2009						x		x	/				2009						x		x		/	/	/	2009			pp
GR	Greece						2008													2008													2008								pp
ES	Spain	x					x					2009			x					x					2009			x					x					2009			pp
FR	France	x				x	x	x	x	x	x	x			x				x	x	x	x	x	x	x			x				x	x	x	x	x	x	x			pp
IT	Italy	x					x								x					x								x					x								pp
CY	Cyprus						2009					2011								2009					2011								2009					2011			
LV	Latvia		x		x		/									x		x		/									x		x		/								pp
LT	Lithuania						x													x													x								pp
LU	Luxembourg	x	x	x	x	x	x	x	x	x	x	x	x	x																											pp
HU	Hungary				x		x					x						x		x					x						x		x					x			pp + ii
MT	Malta																																								
NL	Netherlands	x	x	x	x	x	x	x	x		x				x	x	x	x	x	x	x	x		x				x	x	x	x	x	x	x	x		x				ii
AT	Austria	x					x								x					x								x					x								pp
PL	Poland						x()*													x()*													x()*								pp
PT	Portugal					x													x													x									pp
RO	Romania						x			x	x	x								x			x	x	x								x			x	x	x			pp
SI	Slovenia		x				x	x				x				x				x	x				x				x				x	x				x			pp
SK	Slovakia	x					x								x					x								x					x								pp
FI	Finland	x					x	x	x		x	x			x					x	x	x		x	x			x					x	x	x		x	x			ii
SE	Sweden	x					x					x			x					x					x			x					x					x			pp
UK	United Kingdom	x					2011					2011			x					2011					2011			x					2011					2011			pp + ii
HR	Croatia																																								
MK	FYR Macedonia																																								
TR	Turkey								x													x													x						
NO	Norway							x	x												x	x												x	x						ii

Key to table cells: X available, [ ] derogation, YYYY derogation until year.

OECD dataset

The 2006 edition of IO tables published by the OECD includes 28 OECD countries (except Iceland and Luxemburg) and nine non-OECD countries (Argentina, Brazil, China, India, Indonesia, Israel, Russia, Singapore and Taiwan) in 48 harmonised sectors. The latest edition of the OECD dataset is due to be released in early 2009.

The tables of the 2006 edition are based around the year 2000 (Yamano and Ahmad 2006, 2007). The underlying data are submitted to the OECD by national statistical offices, which provide data in accordance with the ISIC Revision 3 harmonised industry structure. Furthermore, NSOs can submit any relevant data (such as supply-use tables) at the most detailed and practicable level to maximise compliance and minimise costs. Most countries have submitted data using national industrial classification systems. IO tables are not compiled by all NSOs, but they do produce supply-use-tables. By using standard assumptions, these can easily be converted into symmetric IO tables.

As Table.4 and Table 5.5 illustrate, most of the received data as well as those submitted in earlier years need to be converted to the requested structure, to be consistent with the industry classification used in OECD systems and are on the same price basis. The harmonisation process is explicitly described.

Table 5.6 provides an overview of considered industries and discloses future potentials of disaggregation.

Table 5.4: Data sources for the OECD IO industry-by-industry database, OECD countries (Yamano and Ahmad 2006)

	OECD - Country	Source	Year	Tables				
				Supply	Use total	Use import	I-O total	I-O import
1	Australia	Australian Bureau of Statistics	1998/99				x	x
2	Austria	Eurostat	2000	x	x		x c	x c
3	Belgium	National Bank of Belgium	2000	x	x		x c	x c
4	Canada	Statistics Canada	2000				x	x
5	Czech Republi	Czech Statistical Office	2000	x	x	x		
6	Denmark	Danmarks Statistik	2000				x	x
7	Finland	Eurostat	2000				x	x
8	France	National Institute of Statistics and Economic	2000	x	x		x c	
9	Germany	Eurostat	2000	x	x		x c	x c
10	Greece	Eurostat	2000	x	x			
11	Hungary	Eurostat	2000	x	x		x c	x c
12	Ireland	Eurostat	1998	x	x		x c	x c
13	Italy	Eurostat	2000	x	x		x c	x c
14	Japan	Ministry of Economy, Trade and Industry	2000	x			x c	x c
15	Korea	Bank of Korea	2000				x c	x c
16	Mexico	National Institute of Statistics, Geography a	2003				x	x
17	Netherlands	Statistics Netherlands	2000				x	x
18	New Zealand	Statistics New Zealand	1995/96				x	x
19	Norway	Eurostat	2001				x	x
20	Poland	Eurostat	2000	x	x		x c	x c
21	Portugal	Eurostat	1999	x	x PU		x c	x c
22	Slovak Republi	Eurostat	2000	x	x PP		x c	
23	Spain	Eurostat	2000	x	x	x		
24	Sweden	Eurostat	2000	x	x PU		x c	x c
25	Switzerland	Federal Institute of Technology	2001	x	x		x c	
26	Turkey	Turkish Statistical Institute	1998	x	x		x c	x c
27	United Kingdor	The Office for National Statistics	2000	x	x PU			
28	United States	Bureau of Labor Statistics	2000	x	x PR			

c: Commodity-by-commodity tables; **PU**: Purchasers' Prices; **PR**: Producers' Prices.

Table 5.5: Data sources for the OECD IO industry-by-industry database, non-OECD countries (Yamano and Ahmad 2006)

	Non - OECD - Country	Source	Year	Tables				
				Supply	Use total	Use import	I-O total	I-O import
1	Argentina	National Institute of Statistics and Censuses	1997				x	x
2	Brazil	Brazilian Institute of Geography and Statistics	2000				x	x
3	China	National Bureau of Statistics	2000				x c PR	x c PR
4	Chinese Taipei	Directorate General of Budget, Accounting and Statistics	2001				x	x
5	India	Ministry of Statistics and Programme Implementation	1998/99	x	x	x		
6	Indonesia	Badan Pusat Statistk	2000				x c	x c
7	Israel	Central Bureau of Statistics	1995	x	x	x		
8	Russia	Federal State Statistics Service	2000	x	x			
9	Singapore	Statistics Singapore	2000				x	x

c: Commodity-by-commodity tables; **PU**: Purchasers' Prices; **PR**: Producers' Prices.

Alongside the IO tables which show total inter-industry requirements and total final demand in million US dollars, the OECD provides two sub-tables of the overall IO table for each country – one shows the inter-industry requirements on domestic production and final demand produced and consumed domestically in the country, while the other represents intermediate and final demand requirements on foreign production (import matrix).

Table 5.6: OECD IO Database – Industry classification and concordance with ISIC Revision 3 (Yamano and Ahmad 2006)

ISIC Rev. 3 code	IO industry	BTD industry	Description
1+2+5	1	1	Agriculture, hunting, forestry and fishing
10+11+12	2	2	Mining and quarrying (energy)
13+14	3	2	Mining and quarrying (non-energy)
15+16	4	3	Food products, beverages and tobacco
17+18+19	5	4	Textiles, textile products, leather and footwear
20	6	5	Wood and products of wood and cork
21+22	7	6	Pulp, paper, paper products, printing and publishing
23	8	7	Coke, refined petroleum products and nuclear fuel
24ex2423	9	8	Chemicals excluding pharmaceuticals
2423	10	9	Pharmaceuticals
25	11	10	Rubber and plastics products
26	12	11	Other non-metallic mineral products
271+2731	13	12	Iron & steel
272+2732	14	13	Non-ferrous metals
28	15	14	Fabricated metal products, except machinery and equipment
29	16	15	Machinery and equipment, nec
30	17	16	Office, accounting and computing machinery
31	18	17	Electrical machinery and apparatus, nec
32	19	18	Radio, television and communication equipment
33	20	19	Medical, precision and optical instruments
34	21	20	Motor vehicles, trailers and semi-trailers
351	22	21	Building & repairing of ships and boats
353	23	22	Aircraft and spacecraft
352+359	24	23	Railroad equipment and transport equipment n.e.c.
36+37	25	24	Manufacturing nec; recycling (include Furniture)
401	26	25	Production, collection and distribution of electricity
402	27	25	Manufacture of gas; distribution of gaseous fuels through mains
403	28	25	Steam and hot water supply
41	29	Services	Collection, purification and distribution of water
45	30		Construction
50+51+52	31		Wholesale and retail trade; repairs
55	32		Hotels and restaurants
60	33		Land transport; transport via pipelines
61	34		Water transport
62	35		Air transport
63	36		Supporting & auxiliary transport activities; activities of travel agencies
64	37		Post and telecommunications
65+66+67	38		Finance and insurance
70	39		Real estate activities
71	40		Renting of machinery and equipment
72	41		Computer and related activities
73	42		Research and development
74	43		Other Business Activities
75	44		Public administration and defence; compulsory social security
80	45		Education
85	46		Health and social work
90-93	47		Other community, social and personal services
95+99	48		Private households with employed persons & extra-territorial organisations & bodies

GTAP database

GTAP (Global Trade Analysis Project) is a global network of researchers and policy-makers conducting quantitative analysis of international policy issues.[23] Products from GTAP include data, models and utilities for multi-region, applied general equilibrium analysis of global economic issues. The GTAP project is coordinated by the Center for Global Trade Analysis, Purdue University, USA.

The GTAP database is a publicly available global database which contains complete input-output tables, bilateral trade information, transport and protection linkages, among all GTAP regions for all GTAP commodities. Supplementary energy and emissions data are also being compiled (see below).

23 http://www.gtap.agecon.purdue.edu

Version 7, published in 2009, corresponds to the global economy in 2004 as reference year and covers 57 sectors and 113 countries and world regions.[24] The database is most commonly used with the GTAP model, a multi-region, multi-sector applied general equilibrium model of the global economy.

GTAP receives IO tables from various institutions around the world and applies balancing techniques to fit them with the standard GTAP format. It is usually the case that the contributed IO tables are not based on one particular year, because national statistical offices usually only build (symmetric) IO tables every five to ten years. Therefore, tables from some countries can be several years old. Since the reference periods of the IO tables vary, they are updated and reconciled to a common base year of the GTAP database (2004 for GTAP 7 database) using the macroeconomic dataset and other international datasets on trade, protection, energy, value-added data and so on. This is done using entropy techniques and is based on the premise that shares in the contributed IO tables, although not from 2004, do not change much over time.[25] The regional databases are then assembled to construct an interim global data file. Both product-by-product and industry-by-industry SIOTs are submitted to GTAP and the re-balanced final tables in GTAP are therefore a mix of industries and commodities.

There have been criticisms about the way IO data is handled by GTAP. Peters (2007) mentions the re-engineering process: "*Perhaps the biggest uncertainty with the GTAP database are the manipulations required for use in computable general equilibrium (CGE) modelling. For CGE modelling, it is necessary to calibrate the database so that the initial database is in equilibrium. Since the IO, energy, and trade data come from different sources this data is generally unbalanced and has many inconsistencies. The magnitude of the manipulations performed by GTAP is uncertain and is difficult to test systematically without working closely with the GTAP (access to the raw data and manipulation procedures is needed). There are many anomalies in the data that are relatively straightforward to detect. For instance, there is significant trade in electricity between Canada and the Pacific Islands, amongst the Pacific Islands, France and Thailand, North America and Africa, and so on. Similar data discrepancies are found in many other areas of the database. Arguably, MRIO models are more sensitive to the manipulations than CGE models. For MRIO modelling, the balancing procedures are not needed and they clearly affect the results. Considerable challenges are required in preparing the trade data. The main problems are services data, transport data, re-exports, and inconsistencies between and within datasets*."

Input-output tables from EXIOPOL

EXIOPOL[26] sets up a detailed economy-environment model to estimate environmental impacts and external costs of different economic sectors and of the consumption of natural resources (energy, materials, land) for countries in the European Union. One of the main aims of EXIOPOL is to create a detailed environmentally extended input-output database, with links to other socio-economic models, in which as many of these estimates as possible are included and which allows the user to estimate environmental impacts and external costs of economic sector activities, final consumption and resource consumption for countries in the EU. As such, EXIOPOL provides a framework for actual/future data collection for the area of environmental-economic policy analysis.

The main goals of EXIOPOL are as follows (Tukker and Heijungs 2007b, Tukker *et al*. in press):

24 https://www.gtap.agecon.purdue.edu/databases/v7/default.asp

25 The process for updating the tables is described further in the GTAP database documentation: https://www.gtap.agecon.purdue.edu/databases/v7/v7_doco.asp, in particular Chapter 15: https://www.gtap.agecon.purdue.edu/resources/res_display.asp?RecordID=2938.

26 http://www.feem-project.net/exiopol

- to synthesise and develop further estimates of the external costs of key environmental impacts for Europe (Cluster II);
- to set up an environmentally extended (EE) input-output (IO) framework in which as many of these estimates as possible are included, allowing the estimation of environmental impacts and external costs of different economic sector activities, final consumption activities and resource consumption for countries in the EU (Cluster III);
- to apply the results of the external cost estimates and EE IO analysis to the analysis of policy questions of importance, and the evaluation of the impact of past research on external costs on policy-making in the EU (Cluster IV).

To reach these goals, a multi-regional input-output framework is developed in EXIOPOL with a resolution of about 130 economic sectors to which the same number of categories of environmental extensions is attached. The IO-tables are constructed using supply and use tables which contain the 130 sectors in NACE rev.1 for sectors and CPA 1.1 for products.

To complete national datasets, reach this level of disaggregation and harmonise existing SUTs, various transformations and estimations are necessary (see Section 5.1.5 for the approach used in EXIOPOL).

The final dataset of EXIOPOL will be available by 2011, with possible releases of test versions already in 2010. The base year will be 2000, with some of the environmental datasets available up to the year 2005. The main question for the EXIOPOL dataset is whether its maintenance and updates will be institutionalised within institutions of the European Commission.

World Input-Output Database (WIOD)

This project started in May 2009 and aims to develop databases, accounting frameworks, models and a consistent expert-system with the following characteristics[27]:

- A worldwide set of national input-output (IO) tables (covering 80 per cent of world GDP) that are fully linked through bilateral trade data.
- A time series (1995-2006) of such linked IO tables in current and constant international prices to take the dynamics of internationalization into account.
- The development of both environmental and socio-economic accounts to study the relationships and trade-offs between the main socio-economic and environmental trends. These include data on different labour-skill types, investment flows, and environmental and resources data.

SUTs versus SIOTs - a comparison

Supply and use tables (SUTs) and balanced symmetric IO tables (SIOTs) each have advantages and disadvantages for MRIO modelling. SUTs can be used directly in an MRIO framework as shown by Lenzen *et al.* (2004).[28] Depending on the way SUTs and physical data are situated in the respective sections of the multi-regional transaction matrix, the same IO multipliers are obtained as when using a SIOT compiled by assuming industry technology. SUT blocks allow physical data to be assembled under commodities or industries or both, enabling users to derive more specific multipliers depending on the research question and/or data availability. Finally, SIOTs can always be constructed from SUTs mechanically, without specific information on co-production, by using a mix of commodity and industry technology assumptions (see Konijn 1994, Bohlin and Widell 2006).

[27] Project website: http://www.ggdc.net/projects/wiod.htm.

[28] The UK-MRIO model also uses SUTs for the UK directly (Wiedmann *et al.* 2008b, 2008c).

The following criteria should be considered by modellers when choosing SUTs or SIOTs:

- Frequency of publication: in most cases SUTs are published more frequently than SIOTs and are more up to date, with a time lag of only one to three years.
- Level of sectoral disaggregation: SUTs often have a finer sector disaggregation than SIOTs. The sector breakdown for products in particular is often considerably higher in SUTs. However, some NSOs choose to publish aggregated information only or suppress data for confidentiality reasons. In these cases, the supply tables from Eurostat may provide more detailed information and can be used instead (the UK is one such example, see Wiedmann *et al.* 2008b).
- Flexibility: arranging data in SUT blocks in an MRIO allows the user to associate physical information, such as resource use or environmental pressures, to industries and commodities. This allows a wider range of policy and research questions to be addressed. One important issue for hybridisation is the fact that information on production processes can more readily be associated with the original information on supply and use than with altered SIOT data.
- Quality of information: SIOTs produced by statistical offices contain superior information on co-production, as they are normally produced with a hybrid technology assumption based on primary financial information at the firm level. Supply matrices are often restricted by confidentiality which is reflected in crossed-out cell values and/or a higher sector aggregation. On the other hand they reveal valuable information on co-production.
- Consistency: Supra-national databases such as those from Eurostat, OECD or GTAP adhere to a standardised, consistent format which allows for simple direct comparisons. Whilst Eurostat reports in both SUT and SIOT format, OECD and GTAP report symmetric tables only.

In the FP-7-EU project EXIOPOL, both SUT and IOT play a central role. While analysis is performed using SIOTs, national SUTs provide the foundation for constructing symmetric tables. Environmental extensions are added in various ways to the SUTs (related to products and industries). SUTs (which can be rectangular) are then linked via the trade of products (Bouwmeester and Oosterhaven 2008). This results in multi-regional, environmentally extended SUTs which in turn are transformed into various types of SIOTs (Rueda-Cantuche *et al.* 2009).

The approach taken in EXIOPOL appears to be comprehensive and feasible. Certainly, the construction of IOTs out of SUTs is time-consuming. However, once this procedure has been carried out, it is far easier to repeat it to include additional years.

5.1.2 Data sources for environmental data

European data

Most environmental accounts in Europe follow the Dutch NAMEA perspective (de Haan and Keuning 1996) where all environmental data are compiled per industry as in the SUTs. This means that all environmental variables are a direct satellite account to the national accounts and to economic activities of industries and that the same system borders, classifications and definitions are used. Some environmentally relevant economic activities occur in the final demand part of the IO tables – private transport and housing – and are also included.

Normally, energy statistics are used as the basis for compiling and allocating emission data over industries and final demand. Thus, there is consistency between energy use per fuel and emissions to air from this fuel use. Some countries base emissions in their environmental accounts on emission inventories directly, using different methods of allocating inventory data over industries and final demand.

Data compiled and published in the environmental accounts differ between countries but all countries adhere to the Handbook on Integrated Environmental and Economic Accounting (SEEA 2003) published by the UN (United Nations 2003b), now being reworked into a standard. The emphasis in terms of pressure and impact areas can differ substantially.

Eurostat has a bi-annual compilation cycle for environmental accounts. The most recent was in the autumn of 2008. The published time series at Eurostat covers the period from 1995 up to 2005 or 2006, depending on how the national environmental accounting is compiled.

As environmental accounting is a satellite system to national accounts, the aim is to have the same two-digit NACE level reporting. Some countries achieve this while others have more aggregated data due to confidentiality and a lack of data to allocate over industries at that level. The same applies for time series for some countries which don't have a yearly compilation of environmental accounts data.

The European Commission (Eurostat) is developing a legal basis for environmental accounting. There is general support for this legal basis, based on an approach allowing step-by-step inclusion of modules, and ensuring coordination with the current European System of Accounts (ESA) revision. Air emissions by industry are seen as the highest priority. Other candidates for additional modules to be included in the first round are environmental taxes and economy-wide material flows. The texts will be further refined and discussed at the coming directors meeting as well as at the Statistical Programme Committee (SPC) in the autumn of 2009. After approval by the SPC the text will be considered by the European Commission and the European Parliament. Table 5.7 below shows the different levels of aggregations in the 2006 round of data for Eurostat. It covers CO_2 emissions and the year 2002. The table shows different types of aggregations from the two-digit NACE level for member states. The least common denominator in terms of sectors is a 10-sector level where all countries report data, except Ireland, Poland, Slovenia and France.

Table 5.7: CO_2 emissions data for 2002 compiled by Eurostat
(unit ktonne CO_2, column headers = countries, row headers = NACE sector classification)

	bg	ch	de	dk	es	fr	hu	ie	it	nl	no	pl	pt	se	si	uk
A_B	3 428.4	1 082.0						542.4							230.0	
A							9 686.5			8 959.8		11 041.2				
A01	3 428.4		9 093.1	1 880.9	8 648.0	11 599.4			7 574.3		409.0		1 008.4	1 705.2		5 380.0
A02	0.0		14.8	35.9	103.0	64 837.7			19.8		51.0		6.8	655.1		207.8
B			207.3	628.4	2 795.0	2 061.4	70.2		736.5	916.9	1 510.0	368.6	341.0	286.6		301.5
C		0.0					326.4	709.3				378.4	713.2	526.5	58.2	
CA10	19.7		1 405.6	0.0	853.0	93.0			0.3	0.0	8.0					206.9
CA11	12.6		745.2	2 058.0	308.0	1 113.2			14.2	2 116.5	12 815.0				0.0	22 212.9
CA12_CB13_CB14						1 091.3						378.4				
CA12	0.1		0.0	0.0	0.0				0.0	0.0	0.0					0.0
CB13	32.8		5.0	0.0	197.0				11.8	0.0	27.0					23.2
CB14	69.7		10 311.1	327.9	540.0				1 179.7	418.9	126.0					898.4
D	7 699.3					146 505.0	13 915.9	7 147.0				77 887.6			2 009.8	
DA		807.0				15 587.0		1 553.8		4 602.4	734.0	6 128.1		857.6	181.3	
DA15	382.5		12 155.1	1 734.4	5 528.0				8 110.0				1 854.2			11 488.0
DA16	40.7		165.5	7.8	20.0				71.2				1.2			63.0
DB17_DB18_DC19						2 168.7		99.8		312.9		751.6				
DB17	113.1	223.0	1 354.2	89.6	1 579.0				8 557.6		21.0		1 503.8	86.9		2 488.3
DB18	104.0	32.0	165.7	10.4	145.0				990.0		2.0		144.7	6.3		252.8
DC19	3.7	36.0	108.6	5.1	129.0				1 053.2		3.0		30.3	3.8		139.2
DD20	60.7	138.0	1 319.6	63.8	490.0	1 186.6		14.6	1 198.1	192.1	65.0		376.2	131.1		3 267.8
DE								15.7				1 555.5			476.3	
DE21	420.6	534.0	7 845.1	192.5	2 969.0	13 835.8		15.7	6 064.8	1 411.9	483.0		4 276.9	2 285.7		3 642.6
DE22	0.5	160.0	2 207.5	64.0	206.0	507.7			1 298.2	233.3	40.0		31.1	57.3		2 150.2
DF23_DG24		1 687.0						1 335.7			4 409.0	13 577.6				
DF23	1 858.8		16 991.4	972.5	20 346.0	22 642.4			27 524.4	11 328.6			3 444.6	2 610.2	19.6	19 988.9
DG24	989.4		23 589.7	603.2	7 700.0	15 999.3		1 335.7	13 971.0	15 515.5			3 743.7	1 700.6	202.9	15 732.5
DH25	30.8	64.0	2 006.1	129.9	140.0	3 669.2		13.6	2 548.1	227.5	33.0		143.5	97.6		4 503.3
DI26	1 865.9	3 745.0	49 406.8	3 360.5	48 438.0	25 291.9		3 319.7	42 268.1	2 360.2	1 715.0	6 663.1	10 349.0	3 345.5	540.2	15 486.0
DJ27	1 706.7	456.0	11 243.0	94.4	14 066.0	21 819.7			21 170.1	6 712.0	4 250.0	15 399.1	234.4	4 868.2	589.4	23 180.4
DJ28	9.2	0.0	4 355.0	239.1	433.0	3 013.2			1 342.1	522.2	45.0		152.0	277.5		2 245.7
DK29	66.9	574.0	3 800.2	231.7	518.0	2 183.4		42.1	3 403.9	323.0	55.0		288.2	192.7	0.0	2 191.9
DL		340.0				1 433.4		73.0		366.2		400.7				
DL30	1.1		264.9	2.6	8.0			35.9	39.2		0.0		0.9	2.8		123.7
DL31	16.2		1 082.9	47.4	107.0				1 030.5		96.0		18.3	41.2		833.5
DL32	1.5		571.1	24.2	9.0				392.8		2.0		10.5	14.8		348.7
DL33	0.6		760.8	24.6	7.0				288.0		1.0		7.2	15.5		313.9
DM								6.1		222.6		523.2				
DM34	5.5	28.0	3 640.2	25.9	229.0	2 674.3			2 348.2		21.0		18.7	324.7		2 636.8
DM35	8.3	64.0	772.1	36.4	80.0	1 131.5			542.7		49.0		4.9	69.6		1 178.4
DN36	12.5	71.0	1 102.4	86.5	227.0				1 108.0	327.8	21.0		59.2	55.2		2 075.4
DN37		0.0	530.5	3.7	356.0				88.5	60.6	29.0		15.6	105.7		2 683.1
E		389.0					21 593.2	16 877.7				169 486.2			7 247.0	
E40	22 284.8		362 849.7	24 131.1	100 231.0	35 622.7			135 052.4	54 274.1	445.0		21 106.6	8 712.4		163 108.8
E41	0.9		71.0	1.9	605.0	18.9			41.1	34.3	5.0		41.1	0.8		1 283.0
F	37.4	937.0	9 673.7	1 227.2	2 871.0	13 580.5	279.0	0.0	3 143.3	1 555.7	651.0		3 310.4	1 775.3		6 561.2
G		1 797.0				15 309.4	369.3				441.0	7 664.4		1 573.8		
G50	0.9		2 303.4	264.7	1 436.0				1 642.4	800.4			517.2			2 048.3
G51	22.7		6 867.6	621.1	2 878.0				7 372.2	1 569.8			906.0			5 233.0
G52	2.1		10 722.0	222.8	1 390.0				8 148.3	852.9			240.0			3 774.8
H	21.7	1 008.0	2 989.6	93.6	2 983.0	3 449.9	180.4		2 161.2	1 431.1	54.0		147.6	93.0		2 096.7
I	24.6	8 084.0				39 195.0	7 772.4					30 744.8			3 800.0	
I60_TO_I63	18.3	7 921.0				37 931.5						30 744.8			3 800.0	
I60	7.1		13 710.0	2 096.4	20 876.0	31 299.6			22 147.3	7 706.7	3 566.0		3 062.6	3 019.9	3 797.6	29 851.8
I61	1.0		859.5	20 560.1	3 309.0	2 137.4			4 931.7	7 054.4	12 920.0		278.3	4 593.7		21 869.5
I62			21 128.0	2 029.1	7 035.0	4 494.4			7 478.3	12 296.9	1 226.0		549.5	2 245.6	2.3	35 731.2
I63	10.2	67.0	14 910.5	117.3	1 728.0				1 627.8	345.2	176.0		595.0	273.2		699.7
I64	6.3	163.0	1 668.0	71.7	257.0				1 016.6	205.2	316.0		60.0	150.7		1 801.9
J	2.0	300.0					187.8				150.0					
J65	2.0		1 593.1	26.1	63.0				380.0	351.1			4.4	22.9		342.0
J66			569.9	7.8	19.0				23.8	156.9			7.7	20.5		268.9
J67			511.6	3.1	149.0				484.0	96.8			2.1	9.6		271.1
K70_TO_Q99	924.4					12 290.8									0.0	
K	7.7	665.0					492.3				135.0					
K70	0.7		795.9	73.4	109.0				501.6	224.9			106.0	523.7		866.2
K71			2 271.1	14.2	126.0				708.0	1 626.3			70.1	149.3		1 141.8
K72	0.1		1 822.0	40.4	44.0				741.3	259.5			28.5	84.5		324.0
K73	1.9		1 281.4	9.7	0.0				43.3	195.5			60.7	8.2		256.4
K74	5.0		10 044.2	266.9	351.0				4 144.2	1 360.2			306.3	495.2		2 376.5
L	25.7	1 191.0	8 315.0	330.3	826.0		884.7		2 200.4	2 541.2	483.0		1 078.8	1 115.0	0.0	9 408.7
M	50.7	310.0	7 859.6	146.7	602.0	4 693.7	1 947.1		781.5	989.3	143.0		186.4	153.2		4 204.1
N	198.5	487.0	6 331.8	220.1	1 010.0	3 929.0	2 058.0		1 824.3	2 028.8	356.0		2 861.2	192.1		6 091.4
O							1 112.5									
O90	641.1	1 851.0	4 992.1	113.9	712.0	116.4			1 559.2	7 694.3	8.0		432.6	138.0		1 877.4
O91	0.2	272.0	553.9	15.5	58.0	399.2			88.9	0.0	29.0		196.7	121.4		401.2
O92	0.1	63.0	6 641.3	91.8	205.0	2 544.5			726.2	1 066.2	25.0		61.9	83.1		1 270.8
O93	0.4	53.0	2 623.6	37.7	129.0	608.1			841.0	609.4	218.0		98.8	55.1		689.2
P95	0.0	0.0	0.0	0.0	0.0		0.0		0.0	0.0	0.0		0.0	0.0		0.0
Q	0.0	0.0	0.0	0.0	0.0		0.0		0.0	0.0	0.0		0.0	0.0		0.0
EP_HOUS	6 280.4	20 648.0	207 707.9	10 201.5	59 150.0	161 273.3	20 726.8	4 901.8	109 292.4	38 060.8	5 330.0	29 188.5	9 168.6	13 562.3	1 737.3	153 410.4

EXIOPOL data

To enable the estimation of environmental impacts and external costs of different economic sector activities, final consumption activities and resource consumption for countries in the EU, EXIOPOL is setting up a multi-regional input-output framework where environmental interventions are taken account of via satellite accounts – so-called environmental extensions. These extensions – in total around 130 – comprise material input, area and water usage, energy input and emissions.

The compilation of *material input* data in EXIOPOL followed the nomenclature and categorisation of materials listed in the handbook for economy-wide material flow accounting published by the Statistical Office of the European Union (Weisz *et al.* 2007). The material section encompasses the aggregated material categories 'fossil fuels', 'metals', 'construction and industrial minerals', and 'biomass'; within these categories, materials are divided into sub-categories. For all these categories, extension data in EXIOPOL include used and unused extraction.

Land area was included in the EXIOPOL database for the area used to generate biomass for economic processing using the categories 'arable land', 'pasture', and 'forest'.

With respect to *water use*, the database focuses on water consumption in the agricultural sector, by far the biggest water consumer. The main data source for the EXIOPOL database was the study *Water Footprints of Nations* by UNESCO-IHE Institute for Water Education (Chapagain and Hoekstra 2004), based widely on the FAO-AQUASTAT database where water use data are given in yearly averages for five-year periods. Additionally, data from the LPJmL model (Rost *et al*. 2008) were used, to disaggregate blue (water retrieved from rivers, lakes and so on used for irrigation purposes) and green (precipitation) water consumption.

To set up the *energy* extensions for EXIOPOL, the accounting principles as published by International Energy Agency (IEA)/OECD and Eurostat (OECD *et al*. 2004) were used. The main source of energy input data were IEA energy balances (IEA 2007a, b). IEA records the supply and use of around 60 energy commodities which then had to be transferred into the SUT-format of EXIOPOL. For this process, LCA factors were used to get more detailed information on energy consumption by specific production processes.

Emissions related to certain economic activities were calculated using energy use as auxiliary data. Values of energy use in certain sectors ('activity data') were multiplied with emission coefficients taken from international guidelines such as UNFCCC (IPCC 2006) or EMEP/CORINAIR (EEA 2007). This resulted in around 40 environmental extension vectors including air pollutants such as GHGs, metals, and others.

Global datasets

Energy use and CO_2 emissions from fossil fuel use for 140 countries are available from a database provided by the International Energy Agency (IEA 2008). The data is consistent with the Intergovernmental Panel on Climate Change's sectoral approach (see IEA, 2006: chapter 5) and thus does not include emissions from international marine bunkers and international aviation. The IEA data distinguish only 18 sectors. This means that for some important industries CO_2 intensities cannot be distinguished, a relatively far-reaching limitation if trade volumes for these sectors are high. A detailed sector analysis in the course of the UK-MRIO project (Wiedmann *et al.* 2008b) showed, for example, that using the same average carbon intensity for the sectors 'electricity supply', 'gas supply' and 'water collection and supply' is completely inadequate. Therefore other data sources, such as EDGAR or GTAP, must be used to further disaggregate sectoral emissions (see Wilting and Vringer 2007).

The GTAP database provides information on CO_2 emissions from the combustion of fossil fuels by sector. These figures are based on IEA energy volume data per energy type and made compatible with the sectoral and regional classification in the GTAP input-output database (Lee 2005). Peters (2007) compares the GTAP CO_2 data (version 6) with other national data sources and discovers considerable variations. As reasons, he mentions differences in system boundaries for energy and economic statistics, data manipulations for consistency in the entire dataset, an error in overestimating emissions in the petroleum refinery sector, and a lack of use of region-specific emission factors and fuel contents. Since 2009 the CO_2 emissions database for GTAP version 7 (base year 2001) has been available, but it is not known yet if these data show the same differences with national CO_2 statistics.

The GTAP emissions database was further extended by including non-CO_2 greenhouse gas emissions (CH_4, N_2O, HFC, PFC, SF_6). The latest version of this database has recently been published and is compatible with GTAP 6 covering inputs/outputs and bilateral trade of 57 commodities (and producing industries) of each of the 87 countries/regions for the year 2001 (Rose and Lee 2008).

Sectoral estimates of GHG emissions are also available from the EDGAR database (van Aardenne *et al.* 2005)[29]. The EDGAR information system stores global emission inventories of direct and indirect greenhouse gases from anthropogenic sources on a per country (234 countries) and region basis as well as on a grid. The EDGAR system can generate global, regional and national emissions data in various formats. For all compounds and sources, this has been done for 1990 and 1995. The EDGAR 3.2 Fast Track 2000 dataset is the latest version and represents a fast update of the EDGAR database containing emissions for 2000 on grid and per country for greenhouse gases and air pollutants.

The EDGAR database contains more emissions sources than other databases like the IEA and the GTAP/EPA database. Besides fossil-fuel related CO_2 emissions and agricultural emissions, the EDGAR database also consists of process emissions, for example in the production of concrete, emissions allocated to non-energy use and chemical feedstock, emissions from waste processing, emissions related to biomass burning and emissions caused by tropical forest, savannah, shrubs and grassland fires. On the other hand, the sectoral level of emissions in the EDGAR database is not very detailed. Sectoral emissions are presented at the level of the main agricultural, industrial and energy processes (differs per substance), international transport and the remaining sector 'other' which contains all the remaining sectors including households. Wilting and Vringer (2007) use the EDGAR emission data as boundary conditions in their calculations and subdivide these data further on the basis of sectoral data in the GTAP/EPA project.

Several other, more or less official, sources are built on national data and are sometimes enhanced or adjusted for specific purposes. These tie in with EXIOPOL and GTAP.

One source used in several projects at Statistics Sweden is the Climate Analysis Indicators Tool (CAIT) online database from the World Resources Institute[30]. In this dataset, total CO_2 emissions and GDP per country are compiled for more than 170 countries and 10 world regions and the world. The series run from 1965 up to 2004 (as of late 2008). The following picture shows an excerpt from that table. This is probably the most aggregated version of the data needed to look at emissions in other countries from imports to one country.

29 http://www.mnp.nl/edgar

30 http://cait.wri.org

Table 5.8: Excerpt from the WRI CAIT database showing CO_2 emissions per GDP by country

Units: Metric tons of CO2 per million constant 2005 $US

		2004	2003	2002	2001	2000	1999	1998	1997	1996	1995	1994	1993
World													
World		846.8	841.7	827.3	823.4	830.1	845.2	860.3	882.6	912.9	924.4	935.5	977.4
		2004	2003	2002	2001	2000	1999	1998	1997	1996	1995	1994	1993
Region/Classification													
Asia (excluding Middle East)		12382.2	10763.5	9120.4	8087.5	7911.6	7824.5	7360.9	6980.3	7025.5	6888	6603.4	6111.1
Central America & Caribbean		690.5	703.8	710.5	696.8	685.2	718.5	741.3	731.3	738.1	739.7	731	721.9
Europe		640.3	657	646	658.4	660.3	682.2	706.1	732.1	771.4	781.2	798.9	865.6
Middle East & North Africa		1463.3	1491.5	1494.2	1472.5	1465.2	1468.3	1450	1425.8	1430	1439.6	1430.3	1398.5
North America		557.4	571.4	585.3	590.7	602.4	606.5	623.6	647	658.4	663.6	679.7	696.1
Oceania		759.7	767.1	788.5	786.9	830.9	836.7	847.7	864.9	869.8	843.3	867.7	901.2
South America		613.1	618.1	639.1	632.1	640.2	653.3	642.1	630	635.4	603.2	605.6	594
Sub-Saharan Africa		1701	1657.1	1612	1663.9	1657.7	1685.1	1699.4	1771.6	1827.4	1875.1	1857.3	1862.6
Developed Countries		565.7	577.1	577.6	583.6	590.9	601.3	614.9	631.3	652.1	659.9	676.3	707.1
Developing Countries		14967.1	13306.2	11466.1	10288	10139.2	10132	9698.1	9465.7	9756	9684.1	9343.5	8858
		2004	2003	2002	2001	2000	1999	1998	1997	1996	1995	1994	1993
Country													
Albania	ALB	1123.7	981.2	930.4	830.8	873.8	903.7	550.1	541	641.6	695.2	912.6	916.7
Algeria	DZA	1428.1	1515.9	1532	1513.9	1652.1	1663.1	1636.7	1660	1648.1	1781.3	1781.5	1805.1
Angola	AGO	1599.4	1689.4	1358.8	1467.8	1424.6	1453.5	1382.4	1489.9	1562	1644.7	1134.2	1224.8
Antigua and Barbuda	ATG	538.4	541.2	525.7	510.5	518	529.8	528.4	558.1	559.8	597.1	553.2	573.8
Argentina	ARG	507	499.7	509.9	480	496.6	493.2	468.9	484.3	507.7	506.1	492.7	490.4
Armenia	ARM	1290.9	1285.5	1301.1	1719.3	1846.2	1721	1981.8	2052	1676.8	2383	2028.3	3908.3
Australia	AUS	790.2	794.3	818.4	811.3	863.7	869.6	880	897	907	879.7	907.2	944.6

Concluding remarks on environmental data

Data from official environmental accounts are well suited to IO analyses of environmental effects of trade, as they conform to the definitions, system boundaries and so on of national economic accounts.

If the reporting and compilation goals of Eurostat succeed, with economic and environmental data for all member states published at the two-digit NACE level, we could analyse trade effects on the environment. So far, the coverage in terms of years, substances and level of aggregation is far from complete.

It is of course possible to use other sources. One way would be to develop LCA-based inventory data to fill the gaps. This second-best solution should not diminish efforts to make official environmental accounts data more complete in coverage and detail.

5.1.3 Data sources for trade data

From the point of view of analysing environmental effects of trade through the use of IOA, the purpose of the trade data is to allow total imports (and possibly exports) to be represented as a row or matrix in the IO tables over all trading partners. Ideally, this should include imports of both commodities and services. Often the latter is part of the balance of payments statistics and comes in a much broader classification than commodity trade data.

Commodity trade data is usually provided in several different classification schemes, such as HS, CN, SITC or versions of NACE[31]. Apart from the monetary value, physical units of traded volumes such as kg and m^2 are often presented. The combination of value and volume units is useful to overcome extreme price differences between countries.

[31] See the UN Classifications Registry, http://unstats.un.org/unsd/cr/registry/default.asp?Lg=1.

Usually there are differences between the valuation of exports and imports. Exports are often valued in f.o.b. (free on board) prices which consist of transaction value, including the cost of transportation and insurance to bring the merchandise to the frontier of the exporting country or territory. Imports are valued in c.i.f. (cost, insurance, freight) prices meaning transaction value plus the cost of transportation and insurance to the frontier of the importing country or territory. Prices in c.i.f. valuation do not include import taxes and subsidies.

The most common international trade statistics are listed below (see also Bouwmeester and Oosterhaven (2007) for a more comprehensive overview of trade data):

- Eurostat (http://epp.eurostat.ec.europa.eu/newxtweb)
- OECD Bilateral Trade Database (http://stats.oecd.org/wbos/Index.aspx?DatasetCode=BTDNEW&lang=en)
- United Nations Commodity Trade Statistics Database (UN Comtrade), UN Statistics Division, (http://comtrade.un.org)

Eurostat

The Eurostat trade database includes data on trade within the EU27 as well as external trade data[32]. Furthermore, distinction is made between modes of transports and to different classification systems. The following list illustrates the main external trade data offered by EUROSTAT:

- EU27 trade since 1995 by CN8
- EU27 trade since 1995 by HS2,4,6,8
- EU27 trade since 1995 by HS6
- EU27 trade since 1995 by HS2-HS4
- EU27 trade since 1995 by SITC
- EU27 trade since 1995 by BEC
- Extra EU27 trade since 1999 by mode of transport (NSTR)
- Extra EU27 trade since 2000 by mode of transport (HS6)
- Extra EU27 trade since 2000 by mode of transport (HS2-HS4)
- Adjusted EU-extra imports by tariff regime, by CN8
- Adjusted EU-extra imports by tariff regime, by HS6
- Adjusted EU-extra imports by tariff regime, by HS2 - HS4
- EFTA trade since 1995 by SITC
- EFTA trade since 2003 by HS2,4,6
- EFTA trade since 2003 by national products – CH
- EFTA trade since 2003 by national products – NO
- EFTA trade since 2003 by national products - IS

OECD trade data

The bilateral trade data (BTD) from OECD are based on the ISIC Revision 3 as are the IO tables provided by OECD. In total, the BTD comprise imports and exports of goods for each OECD country broken down by 61 trading partners and 25 industries. The 2006 version covers the years 1988 to

32 Data can be retrieved from http://epp.eurostat.ec.europa.eu/newxtweb.

2004. The dataset is derived from OECD's International Trade by Commodities Statistics (ITCS, OECD 2008). For compiling the BTD dataset, ITCS data can be converted from product classification to an industry classification using a standard conversion key (OECD 2006).

However, the BTD set captures only trade within the OECD and with the rest of the world, while trade between two non-OECD countries is not recorded. Thus, some of the main material-consuming countries such as China and India and their trade flows with major material-extracting countries such as Brazil, South Africa and Russia are not included in the dataset. As these trade flows are crucial for calculations of direct and indirect material flows on global and country scales and to close a trade model on the global level, the database can be completed by UN Comtrade data and country-by-country trade data from the Direction of Trade Statistics from the IMF (2006 edition)[33], see below. If no other sector information on bilateral trade flows is available, the export structure of countries to the OECD from the BTD data can be applied to exports to non-OECD countries. OECD has announced a new version of the BTD including full trade information for important non-OECD countries such as China and India which will further improve the consistency of the approach. The above approach has been used in the compilation of the Global Resource Accounting Model (GRAM) (Giljum *et al.* 2008).

UN Comtrade

The United Nations Commodity Trade Statistics Database (UN Comtrade) consists of international trade statistics data for over 140 countries. These countries report on their annual trade detailed by commodities and partner countries. These data are transformed into the United Nations Statistics Division standard format with consistent coding and valuation. All commodity values are converted from national currency into US dollars using exchange rates supplied by the reporter countries, or derived from monthly market rates and volume of trade. Quantities, when provided with the reporting country data and when possible, are converted into metric units. Commodities are classified according to SITC (Rev.1, 2, 3 and 4), the Harmonized System (HS) (from 1988 with revisions in 1996, 2002 and 2007) and Broad Economic Categories (BEC). Time series of data for reporting countries start from 1962 and go up to the most recent completed year. Data is published annually in the International Trade Statistics Yearbook and can be retrieved from the internet (full access only for registered users) and purchased through the UN Sales department.

The databases mentioned (Eurostat, UN Comtrade and OECD) are based on data delivered by reporting countries. These datasets are not always consistent, for instance, in the case of bilateral data the trade flow reported by the importing country match with the trade flow reported by the exporting country. A number of researchers and institutions are constructing more consistent datasets by correcting, balancing and adjusting the 'raw' data. Examples of databases which provide a more global picture of international trade are:

- World Trade Organization, International Trade Statistics (http://www.wto.org/english/res_e/statis_e/statis_e.htm),
- BACI (http://www.cepii.fr/anglaisgraph/bdd/baci.htm)
- NBER, United Nations Trade Data (http://www.nber.org/data, http://cid.econ.ucdavis.edu),
- GTAP (https://www.gtap.agecon.purdue.edu/databases/v7/default.asp).

[33] http://www.imfstatistics.org/dot/DOTCompo.htm and http://www.imf.org/external/pubs/cat/longres.cfm?sk=154.0

WTO, International Trade Statistics

International Trade Statistics 2008 from the World Trade Organisation (WTO) offers a comprehensive overview of the latest developments in world trade, covering the details of merchandise trade by product and trade in commercial services by category. Each chapter starts with highlights of the most salient trends in the data and illustrates them with charts and maps. A methodological chapter explains essential concepts and definitions used in compiling the statistics, and an appendix gives detailed data on trade by region up to 2007. The 2008 edition expands the coverage of merchandise trade, including new tables on exports and imports of food and fuels.

BACI

BACI is the new world database for international trade analysis at the product-level from the French Research Centre in International Economics (CEPII). BACI aims to provide the most disaggregated international trade database (more than 5,000 products) for the largest number of countries (over 200) and years (from 1995), with careful treatment of unit values. Original procedures are developed to reconcile data reported by countries to United Nations Comtrade (Gaulier and Zignago 2008).

NBER, Trade dataset

The NBER UN trade database covers a set of bilateral trade data by commodity for the period 1962-2000 (Feenstra *et al.* 2005). The NBER-UN data are organized by the four-digit Standard International Trade Classification, Revision 2 and are based on UN data for trade flows on which corrections and additions are made. In the NBER-UN dataset, primacy is given to the importers' reports, assuming that these are more accurate than reports by the exporter. If the importer report is not available for a country-pair, the corresponding exporter report is used. If the importer's report is deficient in various ways, exporters' reports and other information are used to adjust them. The data include both quantities and values of imports and exports.

GTAP

The GTAP database also comprises bilateral trade data. The trade data for 87 countries (Version 6) has relied almost entirely on publicly available trade records. A major source for the bilateral trade data is the UN Comtrade dataset (McDougall 2006). Since the Comtrade dataset only covers merchandise trade (goods, including electricity), GTAP uses other data sources for services. For GTAP Versions 5 and 6, the IMF balance of payments statistics was used. For compiling the trade data, data reported according to the Harmonized System (HS) classification were used, since this classification matches better with the GTAP sector classification. For other classification schemes or unspecified trade or partners, adjustments were made (Gehlhar 1996).

5.1.4 Data sources for international transportation

Another type of data that may be relevant for assessing the environmental impacts of trade covers transport flows. International transport flow statistics report on quantities of transported weights by mode of transport and locations of origin and destination. Extra information about the mode of transport for specific flows may be useful in the environmental accounting of these flows. An example of transport flow statistics is the ETIS (European Transport Policy Information System) database[34]. In general, trade flow and transport statistics are independent statistics, although there are attempts to integrate these data (Linders *et al.* 2008).

[34] Available at http://www.iccr-international.org/etis/index.html.

International transport statistics from official sources are often inadequate for modelling purposes and other data sources such as Lloyd's database (http://www.lr.org/Industries/Marine) may also need to be consulted (see also Corbett and Koehler 2003).

5.1.5 Data sources for process and LCA data

Process-specific emission factors and more comprehensive life cycle inventory (LCI) data are essential for model hybridisation. Pure top-down IO models lack precision for specific transactions or processes and therefore – depending on the question to be investigated – additional, detailed information may be needed to quantify the associated environmental impacts.

In some cases, a straightforward multiplication with emission factors will suffice, for example when enumerating emissions from international transport. The mileage of marine vessels, aircrafts or trucks is multiplied with factors that specify the emissions per tonne-km or passenger-km or similar. These emissions factors can be derived from disparate data sources such as national emission inventories, publications from transport statistics or LCI databases like the Ecoinvent database (Frischknecht *et al.* 2004, 2005)[35], the Franklin database[36] or the EU database ELCD[37].

If whole rows and columns in SUTs or SIOTs are to be disaggregated or newly defined (see Section 4.3.2) more detailed information is required, likely to encompass parts of or whole life cycles of products or processes (production recipes). The necessary data can be derived from LCI datasets such as the previously mentioned Ecoinvent LCI database (Frischknecht *et al.* 2004, 2005). There are several more LCI databases (including old, small and commercial databases); for an overview see http://www.pre.nl/simapro/inventory_databases.htm. Buwal and ETH databases are the predecessors of the Eco-invent database. The Franklin is a large well-known (American) commercial database[36]. Idemat is an old Dutch database (Technical University of Delft) with an emphasis on building materials, IVAM is a Dutch database from the University of Amsterdam focussed on building materials and agricultural commodities. LCA food is from a Danish food LCA project.

A European Reference Life Cycle Database (ELCD) is currently been compiled, foreseen to contribute data to the upcoming International Life Cycle Data (ILCD) Network.[38] To this end, the European Platform on Life Cycle Assessment[39] was established by the European Commission. This came in response to the communication on Integrated Product Policy (IPP) to increase the availability and exchange of life cycle data and use of life cycle assessment (LCA) in business and public authorities. To ensure greater coherence and quality assurance, the Platform supports the development of the ILCD, the ELCD, the international resources directory, as well as a discussion forum.

In the case of EIPOT, there is a need for transnational data. Depending on the policy or research question asked, whole international supply chains might have to be hybridised by using LCI data. In other words, the data should cover the whole life cycle, including transnational production. The problem is that the data available for each commodity is representative of only part of global production. Hence, extensive data gaps exist and much work is needed to fill them.

35 http://www.ecoinvent.ch

36 http://www.fal.com/life cycle.htm

37 http://lca.jrc.ec.europa.eu/lcainfohub/datasetArea.vm

38 http://lca.jrc.ec.europa.eu/lcainfohub/index.vm

39 http://lca.jrc.ec.europa.eu/EPLCA/index.htm

One use of LCA data in a MRIO, for instance, is for the disaggregation of environmental extensions such as energy use. This approach was used in the EU-FP6 Project EXIOPOL,where for environmental extension data on energy use, the IEA energy balances were used as the main data source. These balances comprise around 60 energy commodities which are too broad for EXIOPOL requirements. Hence, these 60 commodities had to be allocated to detailed industries. The general approach here was to combine LCA-data on energy use for detailed products/industries with the data on physical output of the respective detailed products/industries, to calculate the share of industry in the total energy use of an aggregated group of industries. The main problems in this process were obtaining physical output data. Alternatively, auxiliary data such as employment numbers were used (Lutter *et al.*, forthcoming).

5.2 MRIO-specific data requirements

The next step in compiling an MRIO framework, after collecting all the data, is the construction of the multi-region input-output table. There are several ways to do this, for example by starting from the trade data or from the input-output data (see Bouwmeester and Oosterhaven (2007) for a suggested methodology). In constructing the MRIO table, several issues play a role like valuation, disaggregation of data, balancing and so on. These issues are discussed in this section.

5.2.1 Currency conversion

With respect to currency conversion, Peters (2007) writes: *"[Country-specific IO] data eventually needs to be converted to a common currency [in an MRIO model]. The GTAP solves these problems simultaneously by scaling the values using GDP data in US$ converted with Market Exchange Rates (MERs). The trade data is also converted in MERs. In effect this process accounts for inflation and currency differences. In terms of inflation this process assumes that all sectors have the same inflation rate. Given the immense size of the database, this is probably the most realistic approach. In terms of currency conversion several issues arise. For MRIO modelling there has been some discussion on whether to use Purchasing Power Parity (PPP) or MERs for currency conversions… PPPs are better for cross-country comparisons of GDP and MERs are better for trade data. In MRIO modelling it might be best to use some weighting of the two or use other hybrid techniques to help reflect additional problems due to product and quality differentiation, inflation, and so on. Ideally physical data should be used where possible, such as for electricity flows. Consistent conversion of data from a range of countries to a uniform currency and year (via inflation) is an area that needs further investigation, particularly in regards to the correct use of MERs and PPPs.*"

5.2.2 Disaggregating data

In most cases, environmental data come in a different, often more aggregated, sectoral breakdown than IO data. With certain limitations and assumptions, the data can still be used by disaggregating and/or making further adjustments.

In the absence of better information, emissions and other pressure and impact data can be broken down proportionally to total industry output. For example, emissions of sector e_j can be broken down into two sub-sectors e_{j1} and e_{j2} given available information on total industry output g_{j1} and g_{j2} by

Equation 1 $$e_j = e_{j1} + e_{j2} = \frac{g_{j1}}{g_j} e_j + \frac{g_{j2}}{g_j} e_j$$
$$with\ g_j = g_{j1} + g_{j2}$$

As a direct consequence, CO_2 intensities d_{j1} and d_{j2} in these sub-sectors will be equal to the CO_2 intensity in the aggregate sector d_j, that is

Equation 2 $$d_{j1} = \frac{e_{j1}}{g_{j1}} = \frac{e_j}{g_j} = d_j = \frac{e_{j2}}{g_{j2}} = d_{j2}$$

The next best possibility is to use the information from more disaggregated environmental accounts from other countries or data sources (see Druckman and Jackson 2008).

If the detail of the input-output data is not sufficient, data from other countries or regions can also be used. An example is the EIPRO project (Tukker *et al*. 2006) in which the environmental impacts of consumption in EU-25 were determined by Europeanising the US CEDA model. Since for Europe no detailed input-output table was available (the 35 sector OECD IO table was used), the structure of the 480 sector was used to receive more detail in the calculations.

As explained above, the EU-FP6-project EXIOPOL is setting up an environmentally extended IO framework disaggregated into about 130 sectors. As generally such detailed IO tables are not available, various transformations and estimations are necessary to complete national datasets, reach this level of disaggregation and harmonise existing SUTs. The following list summarises the approaches used (Tukker and Heijungs 2007a):

Completing the basic dataset
- Using SIOT to construct a fully absent SUT.
- Estimating valuation matrices that can convert a use table in purchaser's prices into basic prices.
- Estimating import matrices (assuming proportional use of domestic and imported products in all sectors; or using known import matrices from 'similar' countries).
- Estimating missing and confidential data. For example, some NSIs 'hide' certain cells in their SUTs and SIOTs.
- Estimating data of missing countries via 'similar' countries.

Harmonizing SUT across countries
- Mapping the country SUT on the EXIOPOL classification (many-to-one => aggregation; one-to-many => sectors/products split up; many-to-many => split up and re-allocation to EXIOPOL classification).
- Adjusting to a common base year. Scaling up or down the SUT to match the base year output.
- Adjusting to a common unit (monetary).
- Estimating data of missing countries via 'similar' countries.

Detailing sectors
- Using data on environmental extensions, energy statistics technology transfer assumptions from countries with detailed tables.

5.2.3 Updating data and the production of time series

As mentioned above, the publication of IO tables and environmental data always lags a few years behind the current year and symmetric IO tables are normally only constructed every five years. For the purpose of (environmental) analyses, it is advantageous to have up-to-date information to inform decision-makers about recent impacts and to provide a relevant basis for scenario analysis. Furthermore, for the purpose of historical analysis and to derive relationships helpful for forecasting, it is desirable to have time series of all relevant data. Structural decomposition analysis (SDA), a very useful technique to identify the driving forces behind change, requires a time series of constant price tables (recently a number of studies used SDA in a national context to identify the underlying causes for changes in emissions, some of them including trade, such as de Haan 2001, Peters and Hertwich 2006, Wilting *et al.* 2006, Guan *et al.* 2008, Yamakawa and Peters 2008, Minx *et al.* 2009, Wachsmann *et al.* 2009, Wood *et al*. 2009).

A common problem in compiling and updating input-output tables and environmental accounts is incomplete data. Missing matrix elements may be due to costly and incomplete industry surveys, or the suppression of confidential information. External data points can be used to formulate a system of equations that constrain the unknown matrix elements. However, unknowns usually outnumber external constraints, resulting in the system being underdetermined. Undetermined here means that the data exhibits too many degrees of freedom to be solved analytically. The two most prominent numerical approaches for reconciling such an underdetermined system are probably the RAS method, and constrained optimisation. During the past 40 years, both approaches have successfully tackled a number of challenges, leading to several useful features. Ideally, the technique should:

- incorporate constraints on arbitrarily sized and shaped subsets of matrix elements, instead of only fixing row and column sums;
- allow consideration of the reliability of the initial estimate;
- allow consideration of the reliability of external constraints;
- be able to handle negative values and to preserve the sign of matrix elements if required;
- be able to handle conflicting external data.

Lenzen *et al.* (2006, 2009) present a new RAS variant (referred to as KRAS) able to handle conflicting external data and inconsistent constraints. This was achieved by introducing standard error estimates for external data. The authors apply this method to the 1993-94 Australian National Accounts. (Wiedmann *et al.* 2007b) use the KRAS method to construct a time series of IO tables for the UK from 1992 to 2004 (Wiedmann *et al.* 2008b).

A new method of updating and projecting input-output tables, called the "Euro" method, has also been described by Eurostat (2008, p461). The basic idea of the approach is to derive input-output tables consistent with official macroeconomic forecasts for GDP but avoiding arbitrary adjustments of input coefficients to ensure the consistency of supply and demand.

The following assumptions form the basis of the new Euro update procedure: Substitution processes change inputs (rows), production effects influence outputs (columns) and price effects affect inputs and outputs. Euro corresponds to the basic idea of the RAS approach. However, it encompasses all the elements of an input-output table and, consequently, all quadrants of an input-output table in an activity analysis approach. In this interpretation, the columns of the input-output table represent basic activities which are treated on an equal basis. The new method only uses official macroeconomic forecasts as exogenous input for the iterative procedure. Column and row vectors for intermediate consumption and final demand are derived as endogenous variables, rather than accepted as exogenous variables from unspecified sources.

Eurostat will update input-output tables based on this new method to cover the time lag between the last reported SIOT and the latest set of national accounts from member states. Limited data requirements, low costs and the potential for greater automation are the main benefits of the Euro procedure. Rueda-Cantuche *et al*. (2009) use the Euro method to show how a projection of an input-output table 2000 can be established for Greece on the basis of the latest available SIOT for 1998.

Finally, Oosterhaven *et al.* (2008) present four non-survey methods to construct a full-information international input-output table from national IO tables and international import and export statistics and test these methods against the semi-survey Asian-Pacific IO tables constructed by the Institute of Developing Economies in Japan. The results show that the estimated table improves when more information from both sources is used, despite the well-known inconsistencies between import and export data in trade statistics. The authors conclude that the new procedure can be useful as a critical analysis of newly published (semi-)survey international tables and/or as an early updating tool during the construction process.

5.3 Uncertainty implications

Uncertainty is as vital a piece of information as the absolute value it qualifies. The knowledge of uncertainty in underlying data and – more importantly – of error margins of results is important for the reliability of any calculation and essential for decision-making.

However, few practitioners in LCA, footprint and IO analysis routinely run an uncertainty analysis. Only recently, more attention has been paid to uncertainties associated with these types of environmental analysis and modelling. One early example is the study by Wilting (1996), who investigated uncertainties in energy intensities of industries and commodities calculated with (single-region) input-output analysis and hybrid energy analysis, respectively. Calculations were carried out with Monte Carlo simulations (10,000 runs) with assumptions on uncertainties in input-output, energy and LCA data. The stochastic analysis resulted in uncertainties between six and eight per cent for sectoral energy intensities (based on 95 per cent confidence interval boundaries). Due to other assumptions on the uncertainties of the base data, uncertainties in the energy intensities of commodities were slightly higher. Another example for a Monte-Carlo-type uncertainty analysis is presented by Yamakawa and Peters (2008) who evaluated the uncertainty of a single-region input-output model using a time series of current-price IO tables and NAMEA data for 13 years from 1990 to 2002. They found annual variations in both datasets and applied a regression analysis to remove trends from underlying data and estimate uncertainty in the raw IO tables. They then calculated emissions for various final uses and sectors to estimate the uncertainties from typical EE-IOA investigations.

There are few empirical studies of error estimates in MRIO analysis, particularly for environmental MRIO studies. Multi-regional models inherit all uncertainties specific to single-region input-output analysis which include uncertainties in source (survey) data, imputation and balancing, allocation, assuming proportionality and homogeneity, aggregation, temporal discrepancies, model inputs, and multipliers (Lenzen 2001, Hawkins *et al*. 2007, Weber 2008). SRIO models also assume that the production technology of imported goods and services is identical to the economy under investigation. Relaxation of this assumption and reduction of the associated uncertainty is the very reason for the desire to create multi-region input-output models.

However, MRIO models introduce additional uncertainties.[40] Lenzen *et al*. (2004) examine the effect of two types of errors on Danish carbon multipliers and trade balances: the effect of the omission of feedback facilitated by international trade, and sector aggregation. Whilst the inclusion of Danish

[40] See also Peters (2007) who discusses the uncertainty associated with the GTAP 6 database (and appendices in Reinvang and Peters 2008 and WWF 2008).

exports led only to minor corrections, explicit modelling of Danish imports and sector disaggregation were concluded to be important for overall accuracy. Weber (2008) presents a detailed discussion and empirical investigation of uncertainties in MRIO modelling. Three major uncertainties specific to MRIO are examined by using a series of models built using input-output data from the United States and seven of its largest trading partners. They relate to aggregation and concordance to a common sectoral scheme, treatment of the rest-of-world (ROW) region, and monetary exchange rates. These are MRIO-specific sources of error that come in addition to uncertainties common to standard, single-region input-output analysis (Weber 2008) and can introduce substantial additional errors.

With their environmental MRIO used to calculate emissions embodied in US trade, Weber and Matthews (2007) performed a sensitivity analysis by assuming the ROW was represented by the most CO_2-intensive and least CO_2-intensive countries in the data; they found considerable variation due to this uncertainty, in the order of 20 per cent of total embodied emissions of CO_2.

Aggregation is a problem particularly when high and low impacting sectors are combined in one aggregated sector. Examples are pulp/paper and publishing, cement and non-metallic minerals, post and telecommunications (see Weber 2008), or aluminium and other non-ferrous metals. Lenzen *et al.* (2004) analysed the error associated with aggregation by merging their 39-133 sector MRIO to 10 aggregated sectors and found significant errors, particularly when aggregating electricity with gas and water production.

The sensitivity of MRIO calculations to the use of MER or PPP to convert currencies was tested by Weber and Matthews (2007) as well as Kanemoto and Tonooka (2009). Weber (2008) found that the ratio of the rates (MER/PPP) could be as high as 4:7 for China versus the US and recommended the use of hybrid currencies within the compound A matrix, along with sector-specific exchange rates (see also Lenzen *et al.* 2004).

The trade flow matrices, for instance the off-diagonal elements in a full, multidirectional MRIO model, also deserve attention. These matrices represent imports from one region to another and are in most cases not known. The necessary information to estimate them originates from two data sources: survey-based payment information collected through business inquiries and statistics on trade in goods and services. Imputation techniques with inherent assumptions are required to produce these trade flow matrices. One solution to the estimation problem for off-diagonal trade flow matrices is to use trade coefficients (Lenzen *et al*. 2004). This procedure assumes that the trade coefficients are identical for all entries along a row of the imports matrix, that is, for all using domestic industries – clearly an assumption with considerable impact on the accuracy of MRIO models.

Weber (2008) states that "*it is likely that these inherent [MRIO] uncertainties often end up raising total uncertainty beyond the levels of a detailed (i.e. >200 sector) single-region model*" and concludes that "*detailed single-region models with simplified trade modelling should also be considered, especially if the analysis only requires a few commodities to be modelled and a hybrid analysis using SPA*[41] *is possible*."

The first comprehensive Monte-Carlo analysis of uncertainties in a global multi-region input-output model is presented by Wiedmann *et al*. (2008a, 2008c).[42] Functions for the stochastic uncertainty of all input variables to the model were determined, that is IO, CO_2 emissions and trade data. The IO tables' uncertainties were estimated from constraint uncertainties and matrix balancing; 5,000 Monte-Carlo

41 Structural Path Analysis (Defourny & Thorbecke 1984, Treloar 1997, Peters & Hertwich 2006, Lenzen 2007)

42 Weber and Matthews (2007) vary their MRIO calculations by using different input parameters for two of the major uncertainties in their model, the ROW approximation and the MER/PPP issue, and present "feasible ranges for EEE and EEI"; but they do not carry out a Monte-Carlo analysis.

simulation runs were carried out to determine the multiplier uncertainties and the error propagation for embedded emissions was calculated. The results of this MRIO uncertainty analysis show that, with statistical significance, CO_2 emissions embedded in UK imports (EEI) were higher than those for exports (EEE) in all years from 1992 to 2004 and that EEI were growing faster than EEE, thus widening the gap between territorial (producer) emissions and consumer emissions. For aggregated results (CO_2 consumer emissions), the relative standard error was shown to be between 3.3 per cent and 5.5 per cent. Therefore, the estimate of total embedded emissions can be regarded as robust and reliable. The authors emphasise, however, that on an individual sector level these errors are generally higher and that the accuracy is not sufficient to calculate a footprint or life cycle assessment of individual products.

Although Monte-Carlo analysis of the UK-MRIO model tries to capture all possible stochastic variations of underlying data and calculation procedures, it does not deal with possible systematic error sources such as structural changes and sectoral price changes in foreign IO data over time, systematic over- and underestimation of carbon intensities of foreign industries due to the mismatch of sectors in UK and foreign IO and CO_2 data, change of import structure over time, or choice of currency conversion factors.

Finally, further work is being carried out by Rodrigues and Domingos (2008b) to quantify estimation errors of international inter-industry transactions in a MRIO model based on the GTAP 6 database.

5.4 Conclusions and recommendations on data

Compilations of supranational data from (national) economic and environmental accounts provide a solid basis for the data required by the suggested EIPOT method. Standardised input-output datasets are available from Eurostat (EU member states and Norway), OECD and GTAP; trade data are compiled by the UN, OECD, GTAP and others; and environmental data are provided by IEA, GTAP and others. The latter ones, however, only comprise greenhouse gas emissions and land use data (GTAP) which is the reason why national environmental accounts (NAMEA, SEEA) are irreplaceable when it comes to providing additional environmental pressure and impact data. They are also essential for the provision of detailed sectoral data on a national level. If additional sectoral detail is required or if analyses are targeted on one or a few countries only, it is advisable to replace data from the above mentioned supranational sources with more detailed IO tables and environmental data from national economic and environmental accounts. In most cases this will yield more disaggregated data for the country or countries under investigation (e.g. IO tables for the U.S. are available with nearly 500 sectors).

Where this level of detail is not available, auxiliary data and estimation must be used. Estimation of this additional data must be done using consistent data, in a way that can be easily understood by the model user, and within a reasonable time frame. NSO provide data applicable for such concerns. In EXIOPOL, all MRIO databases for non-EU countries are derived from these data. In the case of non-EU member states and when data are not available from Eurostat, this information is given priority.

To provide further detail to the data to be obtained from NSO, a number of topical datasets can be used: International Energy Agency (IEA), British Geological Survey, US Geological Survey, and United Nations Food and Agriculture Organisation (FAO). This data, often given in non-monetary units or physical flows such as kilowatt-hours or tonnes, is used as auxiliary data for sector disaggregation. Certainly, when using data in physical units, estimated prices of the physical flows must be used to divide the monetary values. When there is little variation in price, the connection between physical and monetary flows can be made using a representative price. In cases where prices vary significantly, it is necessary to know the prices of the most significant flows as well as the relative share of each.

In cases where no data (direct nor auxiliary) is available, it is possible to adopt the structure of a similar sector in the same country or of the matching sector in a similar country.

The principles applied in EXIOPOL to disaggregate sectors are as follows (Hawkins *et al.* 2008):

- Consistency across countries is achieved through the use of data sources such as Eurostat for EU member states and the International Energy Agency, UN FAO, and British Geological Survey which provide consistent data for a number of countries included in the EXIOPOL database.
- Transparency is achieved through the use of publicly available data and data provided by national statistical offices (NSO).
- Data provided in monetary values directly are preferable to those which must be converted using price information, due to variation in prices within sectors.
- Data transformations performed within NSO are preferred to those that would be used to estimate a dataset. Data transformations performed by other third-party organisations such as OECD or GTAP are less preferable where they are less transparent than another option.

Generally, it is more important to include more countries than to make the disaggregation of product groups very fine. This recommendation stems partly from advice from a statistical office, given the confidentiality problems that surround company data. To obtain truthful answers on surveys, companies are often assured that their data will not be published in a form that can be traced back to them. However, if the disaggregation is too detailed, this problem becomes apparent.

A too detailed disaggregation can also be troublesome in terms of quality. Uncertainty increases as the aggregates become smaller. Environmental and energy use data are not collected in a bottom-up fashion from all companies. This type of data collection would be too expensive for any company to handle. Particularly for small and medium-sized companies, but also for large parts of the service sector and for households, the results are built on surveys that together can model the resource use and the resulting environmental pressure. In that sense, the disaggregation in modelling tools will typically be done by using other disaggregated data, such as number of employees or similar.

Some data providers/compilers may concentrate on data quality and timeliness. The GTAP approach is to use the latest trade data whereas the EXIOPOL approach is to use the most detailed IO tables. Ideally, the EIPOT method should combine the strengths of both – which, again, is an argument for hybridisation of models – but ultimately the policy question will decide the exact approach.

Chapter 6 discusses the role of institutions in data provision and implementation.

5.5 Summary of recommendations on data

- Data from the EXIOPOL project, once available, should be the ideal basis for a European-focussed EIPOT model and should be used to construct the basic EE-MRIO framework.
- Data from other consistent meta-databases, such as GTAP, can be used to fill gaps in country coverage, sector data, and environmental extensions. In contrast to EXIOPOL – the data of which will only be fully available in 2011 – the GTAP 7 database was released in 2009.
- Supply and use tables (SUTs), rather than symmetric input-output tables (SIOTs), should be used if they provide significantly more sectoral detail and are more up-to-date. Nevertheless, the

technology assumptions made in symmetric tables are of superior quality and the trade-off between SUTs and SIOTs needs to be decided on a case-by-case basis.

- Non-survey based balancing procedures should be used to re-balance hybridised IO tables, update matrices and produce time series if no superior original data are available.
- Bilateral trade data are essential to estimate trade flows between the economic sectors of different countries (off-diagonal trade flow matrices). We recommend using the UN Comtrade and associated databases[43] in the first instance for consistency and world coverage.
- EXIOPOL will use process and LCA data to disaggregate environmentally relevant sectors further, such as agriculture and food products, metal ores and products, fossil fuels, electricity and waste treatment. If further specification is required, additional life cycle inventory data should be used, for example from the European or International Reference Life Cycle Databases (ELCD, ILCD).

6 General Recommendations

Recommendations on methodology and data are made in Chapters 4 and 5, respectively. This chapter looks at possible implementation of the methodology on a wider scale and discusses the role of institutions in such a process. Future research needs and policy applications are also discussed here.

6.1 Further development of methods and tools for decision-making

There is a clear link between the (real or perceived) importance and urgency of problems, the societal, political and economic driving forces and the sophistication of analytical methods and tools used to address these problems. Economic growth has been the paradigm of modern times and consequently economic analyses and indicators. While economic growth still seems to be the aim, a shift is occurring towards the decoupling of economic growth from the use of natural resources; as we are beginning to understand that the current growth in worldwide resource consumption cannot be sustained indefinitely without risking the global ecological, social, and economic equilibrium.

As outlined in Chapter 1.4 (Policy Context), many facets of political and corporate decision-making from the macro to the micro scale require suitable models. As widespread as the range of policy and research questions might be, several common elements will boost the need for further development of existing approaches:

- Increasing environmental pressures: global warming, land and soil degradation, acidification of oceans, pollution of fresh and ocean water, loss of natural habitat are but some of the continuing environmental and ecological problems worldwide (UNEP 2007).
- Increasing globalisation and international trade: despite the global economic crisis of 2008/09 there is little doubt that the trend of increased specialisation in production, internationalisation of corporations and trade across all sectors will continue.
- Europe and other industrialised countries, as well as emerging economies such as China or India, are increasingly dependent on resources not available in their own territory. Consequently, these countries import increasing amounts of resources from resource-rich countries with manifold consequences. The dependency of these countries on exporting countries and the environmental, social and economic consequences the exploitation has in situ, are at least partly the responsibility

[43] In particular BACI (http://www.cepii.fr/anglaisgraph/bdd/baci.htm) and NBER (http://www.nber.org/data).

of the importing countries. Not only direct consequences, but also indirect impacts such as the food price crisis caused by the enormous demand for agricultural products for energy consumption and resulting speculations, must be taken into account.

Understanding and addressing these problems now and in the future requires continuing development of adequate methods and tools, to assess the consequences and impacts of current resource consumption, trading patterns and so on and to evaluate policy options for their effectiveness and practicability. In this report we reviewed the latest methods able to analyse environmental impacts of trade and suggest a combination of methods as a promising way forward. We discuss data sources and availability as well as uncertainty – all of which influence the reliability of methods for decision-making. Further research is needed to address outstanding issues and to further bring in line technical capabilities with the need to answer pressing questions.

The framework proposed in this report (EE-MRIO with hybrid extensions) enables several kinds of policy applications. For most countries, the environmental impacts of imports are an essential part of the environmental impacts of final demand, such as consumption. Quantification of these impacts in terms of regions and sectors where impacts take place may help to reduce the negative effects of consumption. Another analytical objective, for instance, may be to establish the environmental consequences of changes in final demand.

Although international climate policies are traditionally based on territorial emissions at national levels, the demand for policies based on consumption-related impacts grows. For example, developing countries do not want to pay for all their emissions since (major) parts of these emissions are for exports for which they do not feel responsible. A comparison of consumption-based emissions between countries is interesting from a policy perspective because they take into account the differences in levels of welfare and consumption between individual countries.

Supply-chain or structural path analyses of products like meat, cotton and palm oil[44], which have high impacts on the environment, may support policy-makers with information on these impacts in other regions. This information may be used to understand environmental aspects in corporate social responsibility (CSR) policies. Furthermore, implementing the multi-regional framework in a dynamic model enables the exploration of scenarios directed at reducing global environmental impacts.

This chapter makes general recommendations on the implementation of the methodology suggested here and on future research needs. As in many fields, one project cannot resolve all problems. Research is continuing on the best methods to use for the IPCC emission inventories – an endeavour almost three decades old. A common framework and adequately funded institutional backing to develop methods over time is essential as new data, models and definitions emerge.

6.2 Recommendations for implementation

6.2.1 The role of data providers

Today, the analysis of environment and trade is still under development and somewhat patchy. It is driven partly from the environmental policy side, where debate on the environmental impact of consumption is in need of solid estimates of the size and nature of the problem. However, it is also partly driven by the UN recommendation to build the system of environmental and economic accounts. Thus, a theoretical framework is already in place. Through work to build a common manual for the

[44] In order to analyse these specific products they have to be discernable in the input-output framework.

system, a good deal of harmonisation has already been done. For some countries, the first estimates are already in place.

However, the international system is still not under way. As discussed in previous chapters, modelling exercises already exist to investigate the issue in a multi-regional input-output system. However, the models are largely driven by non-governmental, partly imputed data, put together by researchers and projects rather than statistical offices. This brings the danger of inconsistency, lack of transparency, discontinuation, or even waste of resources, and it will become a crucial issue once 'tough' decisions have to be made, for example in the context of international climate policy.

As discussed earlier, much of the economic statistical data needed for the analysis is available, unlike environmental statistics. In the EU, a statistics regulation of the SEEA would help to improve the data situation. Regulation is expected in the coming year or shortly thereafter. Previously, the data were provided by gentlemen's agreement, but this has not generated sufficient coverage for all European countries. The details of the data to be collected are not yet decided. Air emissions, energy use and economic instruments are likely to be EU priorities.

The 'Group of Four' (Go4) – Eurostat, together with DG Environment (DG ENV), the European Environment Agency (EEA) and the Joint Research Centre (JRC) – have signed a technical arrangement to establish ten data centres: natural resources, products (IPP), waste, soil, forestry, air, climate change, water, biodiversity, and land use. The main purpose of these data centres is to improve knowledge of the relationship between resource use, economic growth and environmental impacts. The Go4 arrangement outlines the short and medium-term division of responsibilities, clear reporting procedures to European bodies and coherent dissemination to data users. Eurostat is the lead organisation for three environmental data centres: natural resources, products (supporting integrated product policy) and waste. The EEA acts as data centre on air, climate change, water, biodiversity and land use; the JRC as a data centre on soil and forestry. The data centres will communicate to ensure that work is not duplicated.

The main goals of the data centre on waste are exemplary for all Go4 data providers:

- to provide data, indicators and other information to assess policy effectiveness;
- to manage data, perform quality assurance, and coordinate data and information managed by other bodies (DG Environment, Joint Research Centre, European Environment Agency, other EU institutions, international organisations such as OECD and UN and so on);
- to be the central entry point for reporting data under EU laws on waste;
- to be the reference point for policy questions requiring (statistical) information on waste and associated environmental impacts;
- to develop and coordinate methodologies to produce statistical data, information and indicators on the environmental impacts of waste generation and management, taking a life cycle perspective, in cooperation with the Go4 partners.

A number of European policies, such as the Integrated Product Policy (IPP) Communication, the two Thematic Strategies on Sustainable Use of Natural Resources and on the Prevention and Recycling of Waste as well as the upcoming Sustainable Consumption and Production (SCP) Action Plan require life cycle-based indicators to monitor their effectiveness.

Three data centres on resources, products and waste have so far been established. These centres will provide the necessary information to support the implementation and monitoring of these policy areas.

The JRC IES will develop by 2010, life cycle-based environmental indicators for the three data centres through the following tasks:

- provision of the three sets of decoupling indicators set out in the Thematic Strategy on Natural Resources, namely the overall EU eco-efficiency indicator, resource productivity and resource-specific impact indicators;
- provision of product environmental impact indicators, covering the main product groups consumed or used in the EU;
- provision of waste environmental indicators, covering the main waste types generated and treated in the EU.

These indicators will be based on a framework built on the requirements of the International Life Cycle Data System (ILCD), in particular the life cycle inventory datasets and impact assessment methods and factors. Sub-indicators will provide information on carbon and ecological footprints.

Institutions must be active in setting up national systems to ensure that future studies can be conducted and data collected. It is essential that international institutions agree on one main methodology and common standards of data compilation, to ensure data consistency and enable automating of data collection. We recommend using the SEEA and SNA as a starting point for the EIPOT methodology.

The national accounts departments in most countries have not prioritized the symmetric IO data. It is important that new uses/users of the data can show their interest to the departments at national agencies and at Eurostat. Both have a lot of other pressing needs for their scarce resources.

Countries must produce and report IO tables and NAMEA data regularly. At present, data collection in the EU+EFTA[45] area is based on a gentlemen's agreement. Plans are being finalised for statistical regulation which will make it obligatory to report. Such regulation, together with existing manuals, will improve the data situation for many countries. Nevertheless, data will need to be checked and some countries will need more time than others to report. Resources and institutional structure are needed to ensure consistency of data.

Data provision from countries outside Europe also needs attention. Continued coordination between European institutions and the UN, OECD, WTO and others will be important to ensure consistency of data compilation. Capacity building in developing countries to construct the necessary data will be needed.

The alternative is to develop IO tables outside official departments. This could be done in different ways, for example by means of the ten environmental data centres outlined here. Agreement on the structure of data collection and processing would enable synchronisation between these centres.

A final point concerns terminology. The structural framework for analysing trade flows is based around the accounting framework. Some call it environmentally extended input-output analyses (EE-IOA) or multi-regional input-output analyses (MRIOA), others call it system of environmental and economic accounts (SEEA) or NAMEA. We recommend aligning the terminology, as it is likely to be confusing to people outside of the modelling world.

[45] The European Free Trade Association (EFTA) is an intergovernmental organisation set up for the promotion of free trade and economic integration to the benefit of its four Member States: Iceland, Liechtenstein, Norway and Switzerland.

6.2.2 Stewardship for EIPOT analysis

To implement the methods suggested here, a common framework and adequately funded institutional backing is needed. Developing the methods will be a long-term commitment as new data, methods, definitions and so on emerge.

If the EIPOT type of analysis is to be useful for policy-making, there needs to be a strong institutional link between statistics, research and policy. This raises the questions:

- Which institution would be best suited to ensure this connection?
- What criteria does a 'steward' for EIPOT-type analyses have to fulfil?

The Sustainable Development Strategy and other sustainability policies of the EU need to be based on factual evidence and data. Current environmental policies are mainly formed by the obligations of nations or activities within national borders. Initiatives to extend policy beyond national borders have largely come from non-governmental organisations. Certified products, mainly agricultural products, sold in eco-labelling schemes are the best known examples of such policies.

The aforementioned 'Group of Four' is well-placed to ensure the provision of data needed for EIPOT analysis based on EE-MRIO. The European Commission as a research funding body could provide the link between EIPOT related research and policy applications.

The SKEP consortium is another institution with dual outreach to research and policy. Member States contributing to SKEP commit to enhancing environmental research across Europe and the national funding bodies have direct links to environmental policy-making (such as environmental agencies and ministries). The SKEP consortium could help to communicate needs from national and international policy-makers to the 'Group of Four'.

On a global scale, it is conceivable that bodies such as the IPCC could become involved in EIPOT modelling in order to support evidence for consumption-based accounting of greenhouse gases or for issues of trade and climate change. With its Special Reports, the IPCC has an instrument to focus on particular areas of interest and to draw on high-quality research around the world.

6.3 Recommendations for future research

Investigating and instigating a best practice method to measure the environmental impact of trade flows does not mean that other methods will cease to exist. Methods such as LCA, EF will be around for many years to come and will play an important role in the future. Different methods meet different needs and maintaining a pool of methods allows for a wider range of questions to be answered.

Areas where further research is needed are listed below. Many of these are being addressed in the EXIOPOL project, but it is important that this research continues beyond current projects.

Hybridisation – Although conceptually well-described for some time, hybrid models combining IOA and LCA remain rare and empirical experience is thin.

Computation – The mathematical skills and computation tasks involved in global MRIO modelling are substantial. Systems with more than one billion variables – which are reached by models with high (above 100) resolution of countries and sectors – require a supercomputer. There is no precedence or experience in this field of supermodelling to date. Although hardware computer power does not necessarily constitute a restriction, algorithms for parallelisation need to be developed.

Currency conversion – Future research should look at the best ways of dealing with currency conversion. In the context of MRIO modelling, the pros and cons of Purchasing Power Parity (PPP) or

Market Exchange Rate (MER) as a mean for currency conversion have been discussed (Ahmad and Wyckoff 2003, Peters 2007) and the difference between the two methods has been quantified in a MRIO study (Weber and Matthews 2007). Arguably, PPPs are better for cross-country comparisons of GDP and MERs are better for trade data. Whether the use of PPP and MER can be combined in an automated hybrid technique and what the quantitative effect would be of using one method over the other in the UK-MRIO model should be investigated.

Linking to economic policy – Other types of studies could be of interest for traded goods. The environmental pressure is often largely connected to the kind of energy system being used. Environmental policies are different across the world and the price of fuel is influenced by national pricing policies, such as taxes or subsidies. Price effects could also be studied.

Including toxic products in a harmonised way – Another interesting question is how to capture effects from the use of toxic material, such as pesticides in agriculture or chemicals used in the textile industry. Given the large number of chemicals, and the fact that their toxic effects are not always known, systematic data collection is difficult to accomplish. If environmental and economic accounting were in place internationally, this problem could at least partly be addressed.

Including land use and types of management – There is a need for more data and harmonised methods to record the links between land use and traded goods. Examples include the impacts of biofuels or agricultural mega-crops on primary rainforests in the developing world.

6.4 How to use results of EIPOT studies in policy?

The first issue that people discuss when the data on environmental pressure in other countries are being presented is whether the environmental improvement witnessed over the last few years an illusion. Meaning, is the reduced environmental impact merely an effect of moving production to other countries? In Sweden, it is easy to point to environmental policies and activities that have been successful. Air and water pollution have decreased because environmental management has made a difference. Still, high consumption implies responsibility for environmentally polluting activities in other countries. This responsibility is only partly the consumers', as the producers are those with the power to change production methods.

In some studies, the environmental trade balance has been calculated to address the question of emissions being exported to other countries. The trade balance has often been calculated as the difference between emissions from imports and emissions from exports, or vice versa. However, trade flows and environmental pressures connected to them are more complex than this. The environmental trade balance is different for each pollutant, and it is not an easy task to figure out why it is high or low, nor if that is good or bad.

After struggling with that measure of the environmental trade balance without knowing what to make of it, Swedish studies have returned to basics and presented imported embodied emissions as a part of the environmental pressure connected to Swedish consumption. This relates the size of the embodied emissions to national environmental goals, and thus shows it in perspective to a known figure.

In addition to direct resource use, the indirect resources necessary to produce products for final demand can be quantified by economic-environmental models and statistical analysis. Thereby, interdependencies of different sectors are taken into account and consequently the total amount of resources required to produce final products is illustrated. These findings reflect economic activities and final demand for goods in monetary terms, which are extended by environmental data to calculate environmental pressures, such as material use, emissions and so on. Consequently, the material requirements along the whole production chain of a given final-demand product can be determined. Furthermore, so-called "hot spots" can be identified – economic sectors with especially high resource use, or sectors with the greatest potential to increase resource efficiency respectively.[46]

One application that could be considered by national governments is to routinely calculate the national carbon footprint, to present environmental impacts embodied in imports as part of the environmental pressure connected to national consumption. These consumption-based greenhouse gas accounts could be presented alongside the usual territorial accounts reported under the UNFCCC. The UK is leading by way of example and has included a consumption-based time series of CO_2 emissions in its set of sustainable development indicators (Defra 2008, p.24).

A useful illustration of further examples is provided by Moll and Watson (2009):

Table 6.1: Research and policy questions that can be answered using environmentally extended input-output analysis and NAMEA tables (taken from Moll and Watson (2009), only those questions relating to the 'consumption perspective' are included)

(Policy) Question	Perspective	Time coverage	Scope
Which consumed product groups are most responsible for indirect pressures activated by consumption? *Ranking and comparison of products*	"consumption"	single year	all product groups in one economy;
Eco- intensities of product groups: Which product groups are most (least) intensive in terms of 'embodied' environmental pressure per Euro?	"consumption"	single year	all product groups in one economy; one product group across economies
How are indirect environmental pressures distributed across the categories of final use (private household consumption, government consumption, investments, exports)?	"consumption"	single year	all final use categories in one economy; one final use category across economies
Have the indirect pressures caused by national consumption been decoupled from growth in consumption expenditure?	"consumption"	two year points, or time series	one economy;
To what extent has decoupling of indirect pressures from growth in consumption occurred as a result of changes in types of products being consumed, and to what extent as a result of eco-efficiency improvements along the production chain of individual product groups?	"consumption"	two year points, or time series	one economy;
What is the ratio of indirect environmental pressures caused by national consumption which are emitted domestically compared to those taking place in the rest of the world? (problem shifting)	"consumption"	single year	one economy; across economies (can also be broken down by product groups)
How do environmental pressures activated by national consumption compare with environmental pressures activated by national production?	"consumption" versus 'production'	single year	one economy; across economies

46 For example, research by the Wuppertal Institute (Acosta-Fernández 2007) shows that ten production sectors account for more than 50 per cent of German Total Material Requirements (TMR). Three areas are of strategic importance because a large number of technological interactions among production sectors take place here: (1) stones, construction, and housing, (2) metals and car manufacturing, and (3) agriculture, food and nutrition. It is, for instance, these three "hot spots" where political action could boost efficiency.

6.5 Summary of general recommendations

- We recommend establishing a 'steward' for analyses of environmental impacts of trade. Possible candidates for institutions to support this type of research are the European Commission (in conjunction with Eurostat/Group of Four). Whilst the Group of Four could back the data provision, the Commission would be well-suited to initiate and participate in the dialogue of how statistics, research and policy could be adequately integrated. The SKEP consortium could also provide support to the Go4 with national research and policy needs.
- Efforts in environmental accounting and data provision should be harmonised amongst the main institutions (Go4, EC, NSO) to ensure consistency and avoid duplicating work.
- We recommend exploring the feasibility of the proposed approach with an empirical case study. Furthermore, several areas of research require long-term attention, including hybridisation of models, computational problems and widening the scope and links to other areas of interest.
- Therefore, a long-term strategy is needed to coordinate and link research activities that contribute to EIPOT-type analyses (as is currently done by EXIOPOL). Under the Framework Programme(s) for research and technological development in the EU, a separate branch should be established to support trade-related research based on environmentally extended multi-region input-output modelling in the long term.
- National governments should consider presenting environmental impacts embodied in imports as part of the environmental pressure connected to national consumption. Consumption-based greenhouse gas accounts, for example, could be presented alongside the usual territorial accounts reported under the UNFCCC.
- National statistical offices should produce and make available in short-term intervals symmetric input-output tables (SIOTs) based on superior hybrid technology assumptions.
- All providers of data should document data compilation procedures, underlying assumptions and uncertainty of data in a transparent way.
- National ministries and agencies should maintain their role in funding national research by implementing the recommendations on a national and supranational level.

7 Acknowledgements

The EIPOT project was funded by national ministries and agencies under the SKEP network (http://www.skep-era.net) within its First Call for Research. We would like to thank the SKEP Call Secretariat and the UK Environmental Agency for their support of the project management and the publishing of the report. In particular, we thank our three external experts, Professor Manfred Lenzen, Dr Glen Peters and Dr Jesper Munksgaard for their helpful reviews and remarks as well as numerous anonymous reviewers for their comments.

8 List of Abbreviations

BACI	A World Database of International Trade at the Product Level
BEC	Broad Economic Categories
BTD	Bilateral Trade Data

c.i.f.	Cost, insurance, freight
CAIT	Climate Analysis Indicators Tool
CEPII	French Research Centre in International Economics
CF	Characterisation Factor
CGE	Computable General Equilibrium
CN	Combined Nomenclature
CO_2	Carbon dioxide
COICOP	Classification of Individual Consumption by Purpose
COMTRADE	UN database on the trade of commodities
CORINAIR	Core Inventory of Air Emissions
CP/RAC	Cleaner Production/Regional Activity Centre
CPA	Classification of Products by Activity
CSR	Corporate Social Responsibility
CTA	Commodity Technology Assumption
DALY	Disability Adjusted Life Years
DG ENV	Directorate General Environment of the European Commission
EA	Environmental Account(s)
EDGAR	Emission Database for Global Atmospheric Research
EEA	European Environment Agency
EEBT	Emissions (impacts) Embodied in total Bilateral Trade (between regions)
EEC	Emissions (impacts) Embodied in (final) Consumption
EEE	Emissions Embodied in Exports
EEI	Emissions Embodied in Imports
EE-IOA	Environmentally Extended Input-Output Analysis
EE-MRIO	Environmentally Extended Multi-Region Input-Output (analysis/model)
EF	Ecological Footprint
EFTA	European Free Trade Association
EIO-LCA	Economic Input-Output Life Cycle Analysis
EIPOT	Environmental ImPacts of Trade
ELCD	European Reference Life Cycle Database
EM	Econometric Model
EMEP	European Monitoring and Evaluation Programme
ERA-NET	European Research Area Networks
ESA95	European System of Accounts (from 1995)
ETIS	European Transport Policy Information System
EU	European Union
EXIOPOL	Environmental Accounting Framework Using Externality Data and Input-Output Tools for Policy Analysis
f.o.b.	Free on board
FAO	Food and Agriculture Organization
FORWAST	EU FP 6 project *Overall mapping of physical flows and stocks of resources to FORecast WASTe quantities in Europe and identify life cycle environmental stakes of waste prevention and recycling*
GDP	Gross Domestic Production
GHG	Greenhouse Gas
Go4	Group of Four
GRAM	Global Resource Accounting Model
GTAP	Global Trade Analysis Project
HIOT	Hybrid Input-Output Table

HS	Harmonized System
Hybrid LCA	Life Cycle Assessment based on a combination of Process and IO-LCA
IEA	International Energy Agency
IES	Institute for Environment and Sustainability
ILCD	International Reference Life Cycle Database
IO	Input-Output
IOA	Input-Output Analysis
IO-LCA	Life Cycle Assessment based on (pure) Input-Output analysis
IOT	Input-Output Table
IPCC	Intergovernmental Panel on Climate Change
IPP	Integrated Product Policy
IPTS	Institute for Prospective Technological Studies
ISO	International Standards Organisation
ITA	Industry Technology Assumption
JRC	Joint Research Centre
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory (analysis)
LCIA	Life Cycle Impact Assessment
MER	Market Exchange Rate
MSA	Means Species Abundance
MFA	Material Flow Analysis/Accounting
MIOT	Monetary Input-Output Table
MIPS	Material Intensity Per Service unit
MRIO	Multi-Region Input-Output (analysis/model)
MRIO-SPA	Structural Path Analysis in a Multi-Region Input-Output framework
NACE	Nomenclature statistique des Activités économiques dans la Communauté Européenne (Classification of Economic Activities in the European Community)
NAMEA	National Accounting Matrix including Environmental Accounts
NBER	National Bureau of Economic Research
NFA	National Footprint Account
NSO	National Statistical Office
OECD	Organisation for Economic Cooperation and Development
PBL	Netherlands Environmental Assessment Agency
PIOT	Physical Input-Output Table
PPP	Purchasing Power Parity
Process LCA	Life Cycle Assessment based on (pure) Process analysis
PSUT	Physical Supply and Use Table
RACER	Assessment method using the categories Relevant, Accepted, Credible, Easy and Robust
RAS	Synonym for a matrix balancing approach used mainly to update input-output tables, developed by Sir Richard Stone and named after the typical sequence of matrices in the procedure
ROW	Rest Of World
SCB	Statistics Sweden
SCP	Sustainable Consumption and Production
SDA	Structural Decomposition Analysis
SEEA	System of Economic and Environmental Accounts
SEI	Stockholm Environment Institute
SERI	Sustainable Europe Research Institute

SITC	Standard Industrial Trade Classification
SIOT	Symmetric Input-Output Table
SKEP	Scientific Knowledge for Environmental Protection
SNA	System of National Accounts
SPA	Structural Path Analysis
SPC	Statistical Programme Committee
SRIO	Single-Region Input-Output (analysis/model)
SUT	Supply and Use Table
UK	United Kingdom
UN	United Nations
UNFCCC	United Nations Framework Convention on Climate Change
WIO	Waste Input-Output (analysis)
WIOD	World Input-Output Database
WRI	World Resources Institute
WTO	World Trade Organisation

9 References

Acosta-Fernández, J. (2007) Identifikation prioritärer Handlungsfelder für die Erhöhung der gesamtwirtschaftlichen Ressourcenproduktivität in Deutschland. Wuppertal Institut, Wuppertal.

Ahmad, N. and Wyckoff, A. W. (2003) *Carbon dioxide emissions embodied in international trade of goods.* STI Working Paper 2003/15 (DSTI/DOC(2003)15). Organisation for Economic Co-operation and Development (OECD), Paris, France. http://www.oecd.org/sti/working-papers

Alkemade, R., van Oorschot, M., Miles, L., Nellemann, C., Bakkenes, M. and ten Brink, B. (2009) GLOBIO3: A Framework to Investigate Options for Reducing Global Terrestrial Biodiversity Loss. *Ecosystems* 12(3): 374-390.

Andrew, R. and Forgie, V. (2008) A three-perspective view of greenhouse gas emission responsibilities in New Zealand. *Ecological Economics* 68(1-2): 194-204. http://dx.doi.org/10.1016/j.ecolecon.2008.02.016.

Benders, R. M. J., Wilting, H. C., Kramer, K. J. and Moll, H. C. (2001) Description and application of the EAP computer program for calculating life-cycle energy use and greenhouse gas emissions of household consumption items. *International Journal of Environment and Pollution* 15(2): 171-182.

Best, A., Giljum, S., Simmons, C., Blobel, D., Lewis, K., Hammer, M., Cavalieri, S., Lutter, S. and Maguire, C. (2008) *Potential of the Ecological Footprint for monitoring environmental impacts from natural resource use: Analysis of the potential of the Ecological Footprint and related assessment tools for use in the EU's Thematic Strategy on the Sustainable Use of Natural Resources.* Report to the European Commission, DG Environment, Brussels. http://ec.europa.eu/environment/natres/studies.htm.

Biesiot, W. and Moll, H. C. (1995) Reduction of CO_2 emissions by lifestyle changes: Final report to the National Research Program Global Air Pollution and Climate Change. IVEM research report no. 80. University of Groningen (in cooperation with NW&S, University of Utrecht), The Netherlands.

Bohlin, L. and Widell, L. M. (2006) Estimation of commodity-by-commodity input-output matrices. *Economic Systems Research* 18(2), 205-215. http://dx.doi.org/10.1080/09535310600653164.

Bouwmeester, M. C. and Oosterhaven, J. (2007) *Technical report: Inventory of trade data and options for creating linkages.* Report of the EXIOPOL project. University of Groningen, Groningen, NL.

Bouwmeester, M. C. and Oosterhaven, J. (2008) Methodology for the Construction of an International Supply-Use Table. International Input-Output Meeting on Managing the Environment, 9-11 July 2008. Seville, Spain. http://www.upo.es/econ/IIOMME08/index.php.

BSI (2008) PAS 2050:2008 - *Specification for the assessment of the life cycle greenhouse gas emissions of goods and services.* October 2008. British Standards Institution, London, UK.

Bullard, C. W., Penner, P. S. and Pilati, D. A. (1978) Net energy analysis : Handbook for combining process and input-output analysis. *Resources and Energy* 1(3): 267-313. http://dx.doi.org/10.1016/0165-0572(78)90008-7.

Chapagain, A. K. and Hoekstra, A. Y. (2004) *Water Footprints of Nations*. 16. UNESCO-IHE, Delft, the Netherlands.

Corbett, J. J. and Koehler, H. W. (2003) Updated emissions from ocean shipping. *Journal of Geophysical Research - Atmospheres* 108(D20): 4650-4666. http://dx.doi.org/10.1029/2003JD003751.

CP/RAC (2008) Methodological challenges and strategic opportunities of the consumption-based approach to greenhouse gas emissions in the Mediterranean - Summary of Key Opportunities and Recommendations. Workshop on Consumption and Climate Change, 4 November 2008. Barcelona, Spain, Regional Activity Centre for Cleaner Production (CP/RAC), Mediterranean Action Plan, United Nations Environment Programme.

de Haan, M. (2001) A structural decomposition analysis of pollution in the Netherlands. *Economic Systems Research* 13(2): 181. http://dx.doi.org/10.1080/09537320120052452.

de Haan, M. and Keuning, S. J. (1996) Taking the environment into account: The NAMEA approach. *The Review of Income and Wealth* 42(2): 131-147.

De Schryver, A. M., Brakkee, K. W., Goedkoop, M. J. and Huijbregts, M. A. J. (2009) Characterization factors for global warming in life cycle assessment based on damages to humans and ecosystems. *Environmental Science & Technology* 43(6): 1689-1695. http://dx.doi.org/10.1021/es800456m.

Defourny, J. and Thorbecke, E. (1984) Structural path analysis and multiplier decomposition within a social accounting matrix framework. *Economic Journal* 94: 111-136.

Defra (2008) *Sustainable development indicators in your pocket 2008 - An update of the UK Government Strategy indicators*. UK Department for Environment, Food and Rural Affairs, London. http://www.sustainable-development.gov.uk/progress/data-resources/sdiyp.htm.

Det Norske Veritas (2007) *Ship Emissions of the future*. DNV Rep. No. 2007-1325. http://www.dnv.com/resources/publications.

Dietzenbacher, E. (2005) Waste treatment in physical input-output analysis. *Ecological Economics* 55(1): 11-23.

Druckman, A. and Jackson, T. (2008) The carbon footprint of UK households 1990-2004: a socio-economically disaggregated, quasi-multi-regional input-output model. International Input-Output Meeting on Managing the Environment, 9-11 July 2008. Seville, Spain. http://www.upo.es/econ/IIOMME08/index.php (also submitted to Ecological Economics).

EEA (2007) *EMEP/CORINAIR Emission Inventory Guidebook - 2007*. Technical report No 16/2007. European Environment Agency, Copenhagen.

Engström, R., Wadeskog, A. and Finnveden, G. (2007) Environmental assessment of Swedish agriculture. *Ecological Economics* 60(3): 550-563. http://dx.doi.org/10.1016/j.ecolecon.2005.12.013.

European Commission (2005) *Impact Assessment Guidelines*. SEC(2005) 791. European Commission, Brussels, Belgium. http://ec.europa.eu/governance/impact/docs/SEC2005_791_IA%20guidelines_annexes.pdf

Eurostat (2008) *Eurostat Manual of Supply, Use and Input-Output Tables, 2008 edition. Methodologies and Working Papers*. Office for Official Publications of the European Communities, Luxembourg. http://ec.europa.eu/eurostat.

Eurostat (2009) *European system of accounts (1995).* from http://circa.europa.eu/irc/dsis/nfaccount/info/data/esa95/en/titelen.htm.

Feenstra, R. C., Lipsey, R. E., Deng, H., Ma, A. C. and Mo, H. (2005) *World Trade Flows: 1962-2000*. Working Paper 11040. National Bureau of Economic Research, Cambridge, MA, USA. http://www.nber.org/papers/w11040.

Femia, A. and Moll, S. (2005) *Use of MFA-Related Family of Tools In Environmental Policy-Making - Overview of Possibilities, Limitations and Existing Examples of Application In Practice*. Working Paper 3.1 rev., 22 March 2005. European Environment Agency, European Topic Centre on Waste and Material Flows, Copenhagen.

Finnveden, G. and Moberg, Å. (2005) Environmental systems analysis tools - an overview. *Journal of Cleaner Production* 13(12): 1165-1173. http://dx.doi.org/10.1016/j.jclepro.2004.06.004.

Frischknecht, R., Jungbluth, N., Althaus, H.-J. r., Doka, G., Dones, R., Heck, T., Hellweg, S., Hischier, R., Nemecek, T., Rebitzer, G. and Spielmann, M. (2004) *Ecoinvent Report No. 1: Overview and Methodology.* Data v1.1 (2004). Ecoinvent Report No. 1. Swiss Centre for Life Cycle Inventories, D bendorf. www.ecoinvent.ch, http://www.ecoinvent.ch/download/01_OverviewAndMethodology.pdf

Gallego, B. and Lenzen, M. (2005) A consistent input-output formulation of shared producer and consumer responsibility. *Economic Systems Research* 17(4): 365-391. http://dx.doi.org/10.1080/09535310500283492

Gaulier, G. and Zignago, S. (2008) *BACI: A World Database of International Trade at the Product-level - The 1995-2004 Version. CEPII Working Paper 2008*, July 2008. French Research Centre in International Economics (CEPII), Paris, France.

Gehlhar, M. J. (1996) Reconciling Bilateral Trade data for Use in GTAP. GTAP Technical Paper No. 10. Center for Global Trade Analysis, Purdue University, West Lafayette, Indiana, USA. https://www.gtap.agecon.purdue.edu/resources/download/38.pdf.

Giljum, S. and Hubacek, K. (2008) Conceptual foundations and applications of physical input-output tables. In: S. Suh, *Handbook of input-output economics for industrial ecology*, Springer, Dordrecht, The Netherlands.

Giljum, S., Lutz, C. and Jungnitz, A. (2008) *The Global Resource Accounting Model (GRAM). A methodological concept paper.* SERI Studies No 8. Sustainable Europe Research Institute, Vienna.

Guan, D. and Hubacek, K. (2007) Assessment of Regional Trade and Virtual Water Flows in China. *Ecological Economics* 61(1): 159-170. http://dx.doi.org/10.1016/j.ecolecon.2006.02.022

Guan, D., Hubacek, K., Weber, C. L., Peters, G. P. and Reiner, D. M. (2008) The drivers of Chinese CO2 emissions from 1980 to 2030. *Global Environmental Change* 18(4): 626-634. http://dx.doi.org/10.1016/j.gloenvcha.2008.08.001.

Hawkins, T., Hendrickson, C. and Matthews, H. S. (2007) Uncertainty in the Mixed-Unit Input-Output Life Cycle Assessment (MUIO-LCA) Model of the US Economy. 16th International Input-Output Conference of the International Input-Output Association (IIOA), 2-6 July 2007. Istanbul, Turkey. http://www.iioa.org/Conference/16th-downable%20paper.html, http://www.io2007.itu.edu.tr.

Heijungs R. et al. (2007) *Scope and Scientific Framework for the CALCAS Coordination Action*. CALCAS D1 Scope Paper. Institute of Environmental Sciences (CML), Leiden University (coordinator).

Hubacek, K. and Giljum, S. (2003) Applying physical input-output analysis to estimate land appropriation (ecological footprints) of international trade activities. *Ecological Economics* 44(1): 137-151.

IEA (2007a) *Energy balances of non-OECD countries, 1971-2005. 2007*.

IEA (2007b) *Energy balances of OECD countries, 1960-2005. 2007*.

IEA (2008) *CO_2 Emissions from Fuel Combustion*, 2008 Edition. International Energy Agency, Paris, France. http://www.iea.org/Textbase/publications/free_new_Desc.asp?PUBS_ID=1825.

IPCC (2006) *2006 IPCC Guidelines for National Greenhouse Gas Inventories*. Prepared by the National Greenhouse Gas Inventories Programme IGES, Japan.

ISO (2006a) *International Standard ISO 14040: Environmental Management - Life Cycle Assessment - Principles and Framework*. ISO 14040:2006(E), Second edition 2006-07-01. International Organization for Standardisation, Geneva, Switzerland. http://www.iso.org.

ISO (2006b) *International Standard ISO 14044: Environmental Management - Life Cycle Assessment - Requirements and Guidelines*. ISO 14044:2006(E), First edition 2006-07-01. International Organization for Standardisation, Geneva, Switzerland. http://www.iso.org.

Junnila, S. (2008) Life cycle management of energy-consuming products in companies using IO-LCA. *International Journal of Life Cycle Assessment* 13(5): 432-439. http://dx.doi.org/10.1007/s11367-008-0015-y.

Kanemoto, K. and Tonooka, Y. (2009) Embodied CO_2 Emissions in Japan's International Trade. *Journal of Japan Society of Energy and Resources* 30(2).

Kim, B. Y., Fleming, G. G., Lee, J. J., Waitz, I. A., Clarke, J.-P., Balasubramanian, S., Malwitz, A., Klima, K., Locke, M., Holsclaw, C. A., Maurice, L. Q. and Gupta, M. L. (2007) System for assessing Aviation's Global Emissions (SAGE), Part 1: Model description and inventory results. *Transportation Research Part D: Transport and Environment* 12(5): 325-346. http://dx.doi.org/10.1016/j.trd.2007.03.007.

Koellner, T. and Scholz, R. (2007) Assessment of land use impacts on the natural environment - Part 1: An analytical framework for pure land occupation and land use change. *International Journal of Life Cycle Assessment* 12(1): 16-23. http://dx.doi.org/10.1065/lca2006.12.292.1.

Koellner, T. and Scholz, R. (2008) Assessment of land use impacts on the natural environment - Part 2: Generic characterization factors for local species diversity in Central Europe. *International Journal of Life Cycle Assessment* 13(1): 32-48. http://dx.doi.org/10.1065/lca2006.12.292.2.

Kofoworola, O. and Gheewala, S. (2008) Environmental life cycle assessment of a commercial office building in Thailand. *International Journal of Life Cycle Assessment* 13(6): 498-511. http://dx.doi.org/10.1007/s11367-008-0012-1.

Konijn, P. J. A. (1994) *The make and use of commodities by industries: on the compilation of input-output data from the national accounts*. Ph.D thesis. University of Twente, Enschede, The Netherlands.

Lee, H.-L. (2005) *An Emissions Data Base for Integrated Assessment of Climate Change Policy Using GTAP.* GTAP Resource #1143. Center for Global Trade Analysis, Purdue University, West Lafayette, Indiana, USA. https://www.gtap.agecon.purdue.edu/resources/res_display.asp?RecordID=1143.

Lee, H.-L., Hertel, T. W., Sohngen, B. and Ramankutty, N. (2005) *Towards an Integrated Land Use Data Base for Assessing the Potential for Greenhouse Gas Mitigation.* GTAP Technical Paper No. 25. Center for Global Trade Analysis, Purdue University, West Lafayette, Indiana, USA. https://www.gtap.agecon.purdue.edu.

Lenzen, M. (2001) Errors in Conventional and Input-Output-based Life-Cycle Inventories. *Journal of Industrial Ecology* 4(4): 127-148. http://dx.doi.org/10.1162/10881980052541981.

Lenzen, M. (2003) Environmentally important paths, linkages and key sectors in the Australian economy. *Structural Change and Economic Dynamics* 14(1): 1-34. http://dx.doi.org/10.1016/S0954-349X(02)00025-5.

Lenzen, M. (2007) Structural path analysis of ecosystem networks. *Ecological Modelling* 200(3-4): 334. http://dx.doi.org/10.1016/j.ecolmodel.2006.07.041

Lenzen, M. (2008) Double-counting in life cycle calculations. *Journal of Industrial Ecology* 12(4): 583-599. http://dx.doi.org/10.1111/j.1530-9290.2008.00067.x.

Lenzen, M. and Foran, B. (2001) An input-output analysis of Australian water usage. *Water Policy* 3: 321-340.

Lenzen, M., Gallego, B. and Wood, R. (2009) Matrix balancing under conflicting information. *Economic Systems Research* 21(1): 23-44. http://dx.doi.org/10.1080/09535310802688661.

Lenzen, M., Murray, J., Sack, F. and Wiedmann, T. (2007a) Shared producer and consumer responsibility - Theory and practice. *Ecological Economics* 61(1): 27-42. http://dx.doi.org/10.1016/j.ecolecon.2006.05.018

Lenzen, M. and Murray, S. A. (2001) A modified ecological footprint method and its application to Australia. *Ecological Economics* 37(2): 229-255. http://dx.doi.org/10.1016/S0921-8009(00)00275-5.

Lenzen, M., Pade, L.-L. and Munksgaard, J. (2004) CO_2 Multipliers in Multi-region Input-Output Models. *Economic Systems Research* 16(4): 391-412. http://dx.doi.org/10.1080/0953531042000304272.

Lenzen, M., Wiedmann, T., Foran, B., Dey, C., Widmer-Cooper, A., Williams, M. and Ohlemüller, R. (2007b) *Forecasting the Ecological Footprint of Nations: a blueprint for a dynamic approach*. ISA Research Report 07-01, May 2007. The University of Sydney, Stockholm Environment Institute, University of York. http://www.isa.org.usyd.edu.au/publications/DEF.pdf.

Lenzen, M., Wood, R. and Gallego, B. (2006) RAS matrix balancing under conflicting information. The Intermediate International Input-Output Conference of the International Input-Output Association, , 26-28 July 2006. Sendai, Japan, International Input-Output Association. http://www.iioa.org/pdf/Intermediate-2006/Full%20paper_Lenzen2.pdf.

Linders, G.-J., de Blois, C., Boonstra, H. J., de Groot, H. and Exel, J. (2008) *Integration of international trade and transport flow statistics for the Netherlands.* Statistics Netherlands, Voorburg/Heerlen, NL. http://www.cbs.nl/NR/rdonlyres/D120A0EF-653B-426A-A8E4-8FD1CB8C6551/0/2004integrationofinternationaltradeandtransportflowstatisticspub.pdf.

Lutter, S. and Giljum, S. (2008) *Development of RACER Evaluation Framework*. 7 October 2008. ERA-NET SKEP Project EIPOT (Development of a methodology for the assessment of global environmental impacts of traded goods and services). http://www.eipot.eu.

Lutter, S., Wilting, H., Wiedmann, T., Palm, V. and Giljum, S. (2008) *Interim Report on the results of the evaluation of methodologies assessed with the RACER framework*. 7 October 2008. ERA-NET SKEP Project EIPOT (Development of a methodology for the assessment of global environmental impacts of traded goods and services). http://www.eipot.eu.

McDougall, R. (2006) Construction of the Trade Data. In: B. V. Dimaranan, *Global Trade, Assistance, and Production*: *The GTAP 6 Data Base*, Center for Global Trade Analysis, Purdue University, West Lafayette, Indiana, USA.

Minx, J., Baiocchi, G., Wiedmann, T. and Barrett, J. (2009) *Understanding Changes in UK CO_2 Emissions from Consumption 1992-2004: A Structural Decomposition Approach*. Report to the Department for Environment, Food and Rural Affairs by Stockholm Environment Institute at the University of York and the University of Durham. Project Ref.: EV0423, February 2009. Defra, London, UK. http://randd.defra.gov.uk.

Minx, J., Peters, G., Wiedmann, T. and Barrett, J. (2008a) GHG emissions in the global supply chain of food products. International Input-Output Meeting on Managing the Environment, 9-11 July 2008. Seville, Spain. http://www.upo.es/econ/IIOMME08/index.php.

Minx, J., Wiedmann, T., Barrett, J. and Suh, S. (2008b) *Methods review to support the PAS process for the calculation of greenhouse gas emissions embodied in goods and services*. Report to the UK Department for Environment, Food and Rural Affairs by Stockholm Environment Institute at the University of York and Department for Bio-based Products at the University of Minnesota. Project Ref.: EV2074, February 2008. Defra, London, UK. Executive summary: http://randd.defra.gov.uk/Document.aspx?Document=EV02074_7070_EXE.pdf. Full report: http://randd.defra.gov.uk/Document.aspx?Document=EV02074_7071_FRP.pdf.

Moll, S. and Watson, D. (2009) *Environmental Pressures from European Consumption and Production - A study in integrated environmental and economic analysis*. ETC/SCP working paper 1/2009, 24 February 2009. European Topic Centre on Sustainable Consumption and Production, Copenhagen, DK.

Moriguchi, Y., Kondo, Y. and Shimizu, H. (1993) Analyzing the life cycle impact of cars: the case of CO_2. *Industry and Environment* 16(1): 42-45.

Munksgaard, J., Minx, J. C., Christofferson, L. B., Pade, L.-L. and Suh, S. (2009) Models for National CO_2 Accounting. In: S. Suh, *Handbook on Input-output Economics for Industrial Ecology*. *Eco-Efficiency in Industry and Science*, Volume 23, Springer. http://www.springer.com/earth+sciences/geostatistics/book/978-1-4020-4083-2?detailsPage=toc.

Munksgaard, J. and Pedersen, K. A. (2001) CO_2 accounts for open economies: producer or consumer responsibility? *Energy Policy* 29(4): 327-334. http://dx.doi.org/10.1016/S0301-4215(00)00120-8.

Nakamura, S. and Kondo, Y. (2009) *Waste Input-Output Analysis - Concepts and Application to Industrial Ecology. Eco-Efficiency in Industry and Science*, Volume 26. Springer, Dordrecht, NL. http://www.springer.com/environment/book/978-1-4020-9901-4.

Nash, H. A. (2009) The European Commission's sustainable consumption and production and sustainable industrial policy action plan. *Journal of Cleaner Production* 17(4): 496-498. http://dx.doi.org/10.1016/j.jclepro.2008.08.020.

Ness, B., Urbel-Piirsalu, E., Anderberg, S. and Olsson, L. (2007) Categorising tools for sustainability assessment. *Ecological Economics* 60(3): 498-508. http://dx.doi.org/10.1016/j.ecolecon.2006.07.023.

OECD (2006) *STAN Bilateral Trade Database (Edition 2006): 1988-2004*. Organisation for Economic Co-operation and Development, Paris.

OECD (2008) *International Trade by Commodity Statistics*. Organisation for Economic Co-operation and Development, Paris.

OECD, IEA and Eurostat (2004) *Energy Statistics Manual*. Paris.

Oosterhaven, J., Stelder, D. and Inomata, S. (2008) Estimating international interindustry linkages: non-survey simulations of the Asian-Pacific Economy. *Economic Systems Research* 20(4): 395-414. http://dx.doi.org/10.1080/09535310802551448.

Peters, G. (2008a) From production-based to consumption-based national emission inventories. *Ecological Economics* 65(1): 13-23 http://dx.doi.org/10.1016/j.ecolecon.2007.10.014.

Peters, G. (2008b) Reassessing Carbon Leakage. Eleventh Annual Conference on Global Economic Analysis - "Future of Global Economy", 12-14 June 2008. Helsinki, Finland.

Peters, G. P. (2007) Opportunities and challenges for environmental MRIO modelling: Illustrations with the GTAP database. 16th International Input-Output Conference of the International Input-Output Association (IIOA), 2-6 July 2007. Istanbul, Turkey. http://www.iioa.org/Conference/16th-downable%20paper.html, http://www.io2007.itu.edu.tr.

Peters, G. P. and Hertwich, E. (2004) *Production Factors and Pollution Embodied in Trade: Theoretical Development.* Industrial Ecology Programme (IndEcol). Working Papers 5/2004. University of Science and Technology (NTNU), Trondheim, Norway. http://www.indecol.ntnu.no/indecolwebnew/publications/papers/workingpaper04/workingpaper5_04web.pdf

Peters, G. P. and Hertwich, E. G. (2006) Structural analysis of international trade: Environmental impacts of Norway. *Economic Systems Research* 18(2): 155-181 http://dx.doi.org/10.1080/09535310600653008

Peters, G. P. and Hertwich, E. G. (2008a) Post-Kyoto greenhouse gas inventories: production versus consumption. *Climatic Change* 86: 51-66. http://dx.doi.org/10.1007/s10584-007-9280-1

Peters, G. P. and Hertwich, E. G. (2008b) Trading Kyoto. *Nature Reports Climate Change* 2: 40-41. http://dx.doi.org/10.1038/climate.2008.25.

Peters, G. P. and Hertwich, E. G. (2009) The Application of Multi-Regional Input-Output Analysis to Industrial Ecology: Evaluating Trans-boundary Environmental Impacts. In: S. Suh, *Handbook on Input-output Economics for Industrial Ecology. Eco-Efficiency in Industry and Science*, Volume 23, Springer. http://www.springer.com/earth+sciences/geostatistics/book/978-1-4020-4083-2?detailsPage=toc.

Reinvang, R. and Peters, G. (2008) *Norwegian Consumption, Chinese pollution - An example of how OECD imports generate CO_2 emissions in developing countries*. WWF Norway, WWF China Programme Office, Norwegian University of Science and Technology, Trondheim, Norway.

Rodrigues, J. and Domingos, T. (2008a) Consumer and producer environmental responsibility: Comparing two approaches. *Ecological Economics* 66(2-3): 533-546. http://dx.doi.org/10.1016/j.ecolecon.2007.12.010.

Rodrigues, J. and Domingos, T. (2008b) The estimation error in multi-regional input-output environmental models. Presentation at the International Input-Output Meeting on Managing the Environment, 9-11 July 2008. Seville, Spain. http://www.upo.es/econ/IIOMME08/index.php.

Rodrigues, J. and Giljum, S. (2005) The accounting of indirect material requirements in material flow-based indicators. *ICFAI Journal of Environmental Economics* III(2): 51-69.

Rose, S. and Lee, H. L. (2008*) Non-CO_2 Greenhouse Gas Emission Data for Climate Change Economic Analysis. Economic Analysis of Land-Use in Climate Change Policy*. London.

Rost, S., Gerten, D., Bondeau, A., Lucht, W., Rohwer, J. and, Schaphoff S. (2008) Agricultural green and blue water consumption and its influence on the global water system. *Water Resource Research* 44: W09405. http://dx.doi.org/10.1029/2007WR006331.

Rueda-Cantuche, J. M., Beutel, J., Neuwahl, F., Mongelli, I. and Loeschel, A. (2009) A Symmetric Input-Output Table for EU27: Latest Progress. *Economic Systems Research* 21(1): 59-79. http://dx.doi.org/10.1080/09535310802703429.

Rueda-Cantuche, J. M. and ten Raa, T. (2007) Symmetric Input-Output Tables: Products or Industries? . 16th International Input-Output Conference of the International Input-Output Association (IIOA), 2-6 July 2007. Istanbul, Turkey. http://www.iioa.org/Conference/16th-downable%20paper.html, http://www.io2007.itu.edu.tr.

Sharrard, A. L., Matthews, H. S. and Ries, R. J. (2008) Estimating construction project environmental effects using an input-output-based hybrid life-cycle assessment model. *Journal of Infrastructure Systems* 14(4): 327-336. http://dx.doi.org/10.1061/(ASCE)1076-0342(2008)14:4(327).

Stretesky, P. B. and Lynch, M. J. (2009) A cross-national study of the association between per capita carbon dioxide emissions and exports to the United States. *Social Science Research* 38(1): 239-250. http://dx.doi.org/10.1016/j.ssresearch.2008.08.004.

Strømman, A. H., Peters, G. P. and Hertwich, E. G. (2009) Approaches to correct for double counting in tiered hybrid life cycle inventories. *Journal of Cleaner Production* 17(2): 248-254. http://dx.doi.org/10.1016/j.jclepro.2008.05.003.

Strømman, A. H. and Solli, C. (2008) Applying Leontief's Price Model to estimate missing elements in hybrid life cycle inventories. *Journal of Industrial Ecology* 12(1): 26-33. http://dx.doi.org/10.1111/j.1530-9290.2008.00011.x.

Suh, S. and Heijungs, R. (2007) Power series expansion and structural analysis for life cycle assessment. *International Journal of Life Cycle Assessment* 12(6): 381-390. http://dx.doi.org/10.1065/lca2007.08.360.

Suh, S. and Huppes, G. (2005) Methods for life cycle inventory of a product. *Journal of Cleaner Production* 13(7): 687-697. http://dx.doi.org/10.1016/j.jclepro.2003.04.001

Suh, S., Lenzen, M., Treloar, G. J., Hondo, H., Horvath, A., Huppes, G., Jolliet, O., Klann, U., Krewitt, W., Moriguchi, Y., Munksgaard, J. and Norris, G. (2004) System boundary selection in life-cycle inventories using hybrid approaches. *Environmental Science & Technology* 38(3): 657-664. http://dx.doi.org/10.1021/es0263745.

ten Raa, T. and Rueda-Cantuche, J. M. (2007) A generalized expression for the commodity and the industry technology models in input-output analysis. *Economic Systems Research* 19(1): 99-104. http://dx.doi.org/10.1080/09535310601164849.

Treloar, G. (1997) Extracting embodied energy paths from input-output tables: towards an input-output-based hybrid energy analysis method. *Economic Systems Research* 9(4): 375-391.

Tukker, A. (2007) EXIOPOL: Blueprint for a Global Regionalised Environmentally Extended Input-Output Database. 16th International Input-Output Conference of the International Input-Output Association (IIOA), 2-6 July 2007. Istanbul, Turkey. http://www.iioa.org/Conference/16th-downable%20paper.html, http://www.io2007.itu.edu.tr.

Tukker, A., Eder, P. and Suh, S. (2006) Environmental impacts of products: policy relevant information and data challenges. *Journal of Industrial Ecology* 10(3): 183. http://www.mitpressjournals.org/doi/abs/10.1162/jiec.2006.10.3.183

Tukker, A. and Heijungs, R. (2007b) *EXIOPOL - Technical report: Definition study of the EE IO database. Report of the EXIOPOL project*. Deliverable D III 1 a 5.

Tukker, A., Poliakov, E., Heijungs, R., Hawkins, T., Neuwahl, F., Rueda-Cantuche, J. M., Giljum, S., Moll, S., Oosterhaven, J. and Bouwmeester, M. (in press) Towards a global multi-regional environmentally extended input-output database. *Ecological Economics* in press, corrected Proof. http://dx.doi.org/10.1016/j.ecolecon.2008.11.010.

Tukker, A., Poliakov, E., Heijungs, R., Hawkins, T., Neuwahld, F., Rueda-Cantuche, J. M., Giljum, S., Moll, S., Oosterhaven, J. and Bouwmeester, M. (2009) Towards a global multi-regional environmentally extended input–output database. *Ecological Economics* forthcoming.

UNEP (2007) *Global Environmental Outlook* - 4. Progress Press Ltd, Malta.

United Nations (1993) *Handbook of National Accounting: Integrated Environmental and Economic Accounting.* Studies in Methods. No. 61. United Nations, New York.

United Nations (2003) *Handbook of National Accounting: Integrated Environmental and Economic Accounting 2003.* Studies in Methods, Series F, United Nations; European Commission; International Monetary Fund; Organisation for Economic Co-operation and Development; World Bank. http://unstats.un.org/unsd/envAccounting/seea2003.pdf

United Nations Statistics Division (1993) *System of National Accounts 1993*. http://unstats.un.org/unsd/sna1993/toctop.asp. United Nations Statistics Division, UNSD, New York, USA.

van Aardenne, J. A., Dentener, F. D., Olivier, J. G. J., Peters, J. A. H. W. and Ganzeveld, L. N. (2005) *The EDGAR 3.2 Fast Track 2000 dataset (32FT2000).* http://www.mnp.nl/edgar/model/v32ft2000edgar.

van Engelenburg, B. C. W., van Rossum, T. F. M., Blok, K. and Vringer, K. (1994) Calculating the energy requirements of household purchases : A practical step-by-step method. *Energy Policy* 22(8): 648-656. http://www.sciencedirect.com/science/article/B6V2W-48XDHK7-3F/2/ef954a7cea97741408c2e1e5828493a2

van Zelm, R., Huijbregts, M. A. J., van Jaarsveld, H. A., Reinds, G. J., de Zwart, D., Struijs, J. and van de Meent, D. (2007) Time horizon dependent characterization factors for acidification in life-cycle assessment based on forest plant species occurrence in Europe. *Environmental Science & Technology* 41(3): 922-927. http://dx.doi.org/10.1021/es061433q.

Wachsmann, U., Wood, R., Lenzen, M. and Schaeffer, R. (2009) Structural decomposition of energy use in Brazil from 1970 to 1996. *Applied Energy* 86(4): 578-587. http://dx.doi.org/10.1016/j.apenergy.2008.08.003.

Weber, C. L. (2008) Uncertainties in Constructing Environmental Multiregional Input-Output Models. International Input-Output Meeting on Managing the Environment, 9-11 July 2008. Seville, Spain. http://www.upo.es/econ/IIOMME08/index.php.

Weber, C. L. and Matthews, H. S. (2007) Embodied environmental emissions in U.S. international trade, 1997-2004. *Environmental Science and Technology* 41(14): 4875-4881. http://dx.doi.org/10.1021/es0629110.

Weber, C. L. and Peters, G. P. (2009) Climate change policy and international trade: Policy considerations in the US. *Energy Policy* 37(2): 432-440. http://dx.doi.org/10.1016/j.enpol.2008.09.073.

Weidema, B. P., Nielson, A. M., Christiansen, K., Norris, G., Notten, P., Suh, S. and Madsen, J. (2005) *Prioritisation within the Integrated Product Policy*. Environmental Project Nr. 980 2005 Milj›projekt. Danish EPA, Danish Ministry of the Environment, Copenhagn.

Weisz, H. (2006) *Accounting for raw material equivalents of traded goods. A comparison of input-output approaches in physical, monetary, and mixed units*. 87. IFF/Social Ecology, Vienna.

Weisz, H. and Duchin, F. (2006) Physical and monetary input–output analysis: What makes the difference? *Ecological Economics* 57: 534-541.

Weisz, H., Krausmann, F., Eisenmenger, N., Schütz, H., Haas, W. and Schaffartzik, A. (2007) *Economy-wide Material Flow Accounting. A compilation guide*. European Commission, Eurostat, Luxembourg.

Wiedmann, T., Lenzen, M., Turner, K. and Barrett, J. (2007a) Examining the global environmental impact of regional consumption activities - Part 2: Review of input-output models for the assessment of environmental impacts embodied in trade. *Ecological Economics* 61 (1): 15-26. http://dx.doi.org/10.1016/j.ecolecon.2006.12.003.

Wiedmann, T., Lenzen, M. and Wood, R. (2008a) *Uncertainty Analysis of the UK-MRIO Model – Results from a Monte-Carlo Analysis of the UK Multi-Region Input-Output Model (Embedded Carbon Dioxide Emissions Indicator).* Report to the UK Department for Environment, Food and Rural Affairs by Stockholm Environment Institute at the University of York and Centre for Integrated Sustainability Analysis at the University of Sydney. Project Ref.: EV02033, July 2008. Defra, London, UK. http://randd.defra.gov.uk/Document.aspx?Document=EV02033_7332_FRP.pdf.

Wiedmann, T., Minx, J., Barrett, J., Vanner, R. and Ekins, P. (2006) *Sustainable Consumption and Production - Development of an Evidence Base: Resource Flows.* Final Project Report, August 2006. Department for Environment, Food and Rural Affairs, London, UK, London. http://randd.defra.gov.uk/.

Wiedmann, T., Wood, R., Lenzen, M., Harris, R., Guan, D. and Minx, J. (2007b) Application of a novel matrix balancing approach to the estimation of UK input-output tables. 16th International Input-Output Conference of the International Input-Output Association (IIOA), 2-6 July 2007. Istanbul, Turkey. http://www.iioa.org/Conference/16th-downable%20paper.html, http://www.io2007.itu.edu.tr.

Wiedmann, T., Wood, R., Lenzen, M., Minx, J., Guan, D. and Barrett, J. (2008b) *Development of an Embedded Carbon Emissions Indicator - Producing a Time Series of Input-Output Tables and Embedded Carbon Dioxide Emissions for the UK by Using a MRIO Data Optimisation System.* Final Report to the Department for Environment, Food and Rural Affairs by Stockholm Environment Institute at the University of York and Centre for Integrated Sustainability Analysis at the University of Sydney. Project Ref.: EV02033, July 2008. Defra, London, UK. Executive summary: http://randd.defra.gov.uk/Document.aspx?Document=EV02033_7333_EXE.pdf. Full report: http://randd.defra.gov.uk/Document.aspx?Document=EV02033_7331_FRP.pdf.

Wiedmann, T., Wood, R., Minx, J., Lenzen, M. and Harris, R. (2008c) Emissions Embedded in UK Trade – UK-MRIO Model Results and Error Estimates. International Input-Output Meeting on Managing the Environment, 9-11 July 2008. Seville, Spain. http://www.iioa.org/pdf/Intermediate-2008/Papers/5d3_Wiedmann.pdf.

Wilting, H. C. (2008) Analysis of the Sustainability of Supply Chains with a Multi-Regional Input-Output Model. International Input-Output Meeting on Managing the Environment, 9-11 July 2008. Seville, Spain. http://www.upo.es/econ/IIOMME08/index.php.

Wilting, H. C., Hoekstra, R. and Schenau, S. (2006) Emissions and Trade; a Structural Decomposition Analysis for the Netherlands. The Intermediate International Input-Output Conference of the International Input-Output Association, 26-28 July 2006. Sendai, Japan, International Input-Output Association. http://www.iioa.org/Conference/intermediate2006-downable%20paper.htm.

Wilting, H. C. and Ros, J. P. M. (2009) Comparing the environmental effects of production and consumption in a region; a tool for policy. In: S. Suh, *Handbook on Input-output Economics for Industrial Ecology. Eco-Efficiency in Industry and Science*, Volume 23, Springer. http://www.springer.com/earth+sciences/geostatistics/book/978-1-4020-4083-2?detailsPage=toc.

Wilting, H. C. and Vringer, K. (2007) Environmental Accounting from a Producer or a Consumer Principle; an Empirical Examination covering the World. 16th International Input-Output Conference of the International Input-Output Association (IIOA), 2-6 July 2007. Istanbul, Turkey. http://www.iioa.org/Conference/16th-downable%20paper.html, http://www.io2007.itu.edu.tr.

Wood, R. (2008) Spatial Structural Path Analysis – Analysing the Greenhouse impacts of trade substitution. International Input-Output Meeting on Managing the Environment, 9-11 July 2008. Seville, Spain. http://www.upo.es/econ/IIOMME08/index.php.

Wood, R. and Lenzen, M. (2003) An application of a modified ecological footprint method and structural path analysis in a comparative institutional study. *Local Environment* 8(4): 365-384. http://dx.doi.org/10.1080/13549830320001185\43.

Wood, R. and Lenzen, M. (in press) Temporal Structural Path Analysis. *Energy Economics* in press.

Wood, R., Lenzen, M. and Suh, S. (2009) Principal methodological approaches to studying sustainable consumption: scenario analysis, ecological footprints and structural decomposition analysis. In: S. Suh, *Handbook on Input-output Economics for Industrial Ecology. Eco-Efficiency in Industry and Science*, Volume 23, Springer. http://www.springer.com/earth+sciences/geostatistics/book/978-1-4020-4083-2?detailsPage=toc.

WRI and WBCSD (2009) *GHG Protocol Initiative for a Product and Supply Chain Accounting and Reporting Standard (ongoing).* World Resources Institute (WRI) and World Business Council for Sustainable Development (WBCSD). http://www.ghgprotocol.org/standards/product-and-supply-chain-standard.

WWF (2008) *EU Consumption, Global Pollution*. A report written by WWF's Trade and Investment Programme and the Industrial Ecology Programme at the Norwegian University of Science and Technology, WWF International, Gland, Switzerland. http://assets.panda.org/downloads/eu_consumption_global_pollution.pdf.

Yamakawa, A. and Peters, G. (2008) Environmental Input-Output Analysis, Structural Decomposition Analysis and Uncertainty. International Input-Output Meeting on Managing the Environment, 9-11 July 2008. Seville, Spain. http://www.upo.es/econ/IIOMME08/index.php.

Yamano, N. and Ahmad, N. (2006) *The OECD's Input-Output Database - 2006 Edition*. STI Working Paper 2006/8 (DSTI/DOC(2006)8). Organisation for Economic Co-operation and Development (OECD), Directorate for Science, Technology and Industry, Economic Analysis and Statistics Division, Paris, France. http://www.oecd.org/sti/working-papers.

Yamano, N. and Ahmad, N. (2007) Development of the OECD Input-Output database 2006 edition and the applications of harmonised international tables. 16th International Input-Output Conference of the International Input-Output Association (IIOA), 2-6 July 2007. Istanbul, Turkey. http://www.iioa.org/Conference/16th-downable%20paper.html, http://www.io2007.itu.edu.tr.

Yi, I., Itsubo, N., Inaba, A. and Matsumoto, K. (2007) Development of the interregional I/O based LCA method considering region-specifics of indirect effects in regional evaluation. *International Journal of Life Cycle Assessment* 12(6): 353-364. http://dx.doi.org/10.1065/lca2007.06.339.

skep network

www.skep-network.eu

an international research platform for environmental regulators