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

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

Draft Final Report

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

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

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

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

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

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1 Introduction

1.1 Background

Issues related to environmental consequences of intensifying international trade have gained significant 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 e.g. Nash 2009).

Products are increasingly produced in one part of the world, taken into another country and then redistributed to their final country of consumption. In order to promote and understand sustainable consumption and production, there is a need to capture the whole life cycle costs of products and services (in terms of emissions, water use, material flows, etc), in order to be able to fully quantify the environmental impacts of consumption and trade. However, there is an absence of an accepted approach towards quantifying and assessing the trans-national impacts of consumption. Many existing methodologies such as life-cycle assessment (LCA), resource flow and material flow analysis rely on average or out-dated data and do not easily allow assessing the local 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 spans across several national boundaries.

The SKEP network aims at developing a suitable methodology to assess such trans-national environmental impacts and has funded the EIPOT Project ("**e**nvironmental **i**m**p**acts **o**f **t**rade")[1]. This project brings together existing knowledge and ongoing research on the assessment of global environmental impacts of traded goods and services. Its purpose is to review past and current accounting methodologies and to identify, specify and develop a suitable integrated approach, which can be applied by SKEP member states and other countries.

1.2 Project scope and goal

The main objective of the EIPOT Project is to develop and specify an environmental accounting methodology which allows quantifying and assessing the trans-national environmental impacts of traded goods and services.

More specifically, this project aims to:

- review and comparatively evaluate a large number of existing environmental accounting techniques that allow to illustrate trans-national impacts of traded goods and services,
- identify the most suitable methodology and develop it further into an accounting approach, which can be applied by all SKEP member states,
- specify the (theoretical) framework and define criteria for environmental accounting methodologies to be suitable for the assessment of environmental impacts of imported and exported goods and services,
- identify data requirements and suggest possible date sources for the improved methodology, and

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

- elaborate the roles of different regulatory authorities in providing required data and advice on the practical implementation of the methodology.

1.3 Project approach

In the EIPOT project, an approach called "RACER" was adapted for the specific research questions in this project (Lutter and Giljum 2008). RACER is a methodology, based on a DG ENV project, for the evaluation of methodologies and indicators using five major evaluation categories specified with sub-categories for the application in EIPOT. Thereby, RACER stands for

- **R**elevant – i.e. closely linked to the objectives to be reached
- **A**ccepted – e.g. by staff and stakeholders
- **C**redible for non experts, unambiguous and easy to interpret
- **E**asy to monitor (e.g. data collection should be possible at low cost)
- **R**obust – e.g. against manipulation

In EIPOT, the evaluation of the specific methods was carried out on three levels, from 0 to 2. This kind of scoring enabled to judge if a methodology does not fulfil a criterion at all, does fulfil it but only partly, or is perfectly appropriate to answer the criterion’s question. Then, for each RACER category (R-A-C-E-R) the mean score was calculated. These category mean values of each methodology were compared, instead of the total mean values, in order to produce a more comprehensive picture of the differences between the methodologies. The evaluations were reviewed by all the other project partners, in order to ensure completeness and integrity. The results of this RACER evaluation has been described in a separate report (Lutter et al. 2008). Chapter 3 gives a summarising overview of the advantages and drawbacks of the methods that were assessed in relation to the trade aspect.

On the basis of the assessments of the different methodologies and approaches, EIPOT makes recommendations concerning the set up of a method able to fulfil the projects aim of assessing trans-national environmental impacts of traded goods and products. Rather than focussing on one (existing) approach and its possible further development, the suggested way forward is described in Chapter 456 as a methodology incorporating various elements of different tools which have proven to be successful (as confirmed by the RACER analysis) and the identification of future development and completion needs, in order to safeguard the composition of an effective and applicable tool.

Having identified the most useful components of the future methodology, EIPOT also discusses related data issues, such as data availability, accuracy, etc. Here, valuable experiences from project partners working on the compilation of different types of data sets on a regular basis were incorporated. The results of this discussion are explained in Chapter 65.

Finally, in EIPOT it was elaborated on the necessary steps for further development and implementation of the suggested methodology. Necessary measures to be taken on behalf of international as well as national statistical institutes were identified (see Chapter 6).

2 Policy Context – Relevant methodological dimensions

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

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

On the *macro* level the impacts of *total trade flows* of a country comes into consideration. Key political questions that have arisen in this context are for example: How much greenhouse gas 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 relevant for policy and decision making. It has been recognised that the adoption of such a consumption-based perspective – in addition to the traditional approach of territorial emissions accounting – opens up the possibility of extending the range of policy and research applications considerably and provides several new opportunities to climate policy (CP/RAC 2008). One opportunity, for example, is to readdress the problem of carbon leakage and to 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, the 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 on climate policy that emerge from the possibility of using a consumption-based approach have been well presented in (Peters 2008a), (Peters and Hertwich 2008a) or (Peters et al. 2009). The question how trade may affect climate policy and specifically the effects of imposing carbon tariffs has been 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, clothes manufacturing etc, 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 and increasingly questions are asked about the environmental sustainability of supply chains spanning across 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 next to meat and clothing 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 analysis (LCA) of a particular product requires the assessment of all relevant production processes and due to globalisation these processes 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 certainly the most challenging task for any methodology. Standards for LCA (ISO 2006a), (ISO 2006b) and carbon footprint of products (BSI 2008) have attempted to address this problem[2], but the data situation remains difficult, especially on internationally applicable or comparable data.

A range of methodological approaches exist that cover all economic levels (Lutter et al. 2008). Figure 1 relates the methods to policies and applications. The choice of methods will depend on the policy/research question and application.[3] Currently, there is not one single method that would cover all levels from macro to micro. At the macro and meso level, *trade flows* are analysed; *products* only appear on the micro level. This may seem subtle, but is important. Analyzing a traded product is performing an LCA of that particular product.[4] Concepts such as emissions embodied in trade or traded product groups, on the other side, imply some form of aggregation.

The broad scope of the objective of this study ("to develop and specify an environmental accounting methodology which allows quantifying and assessing the trans-national environmental impacts of traded goods and services") has been interpreted to mean that the 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.

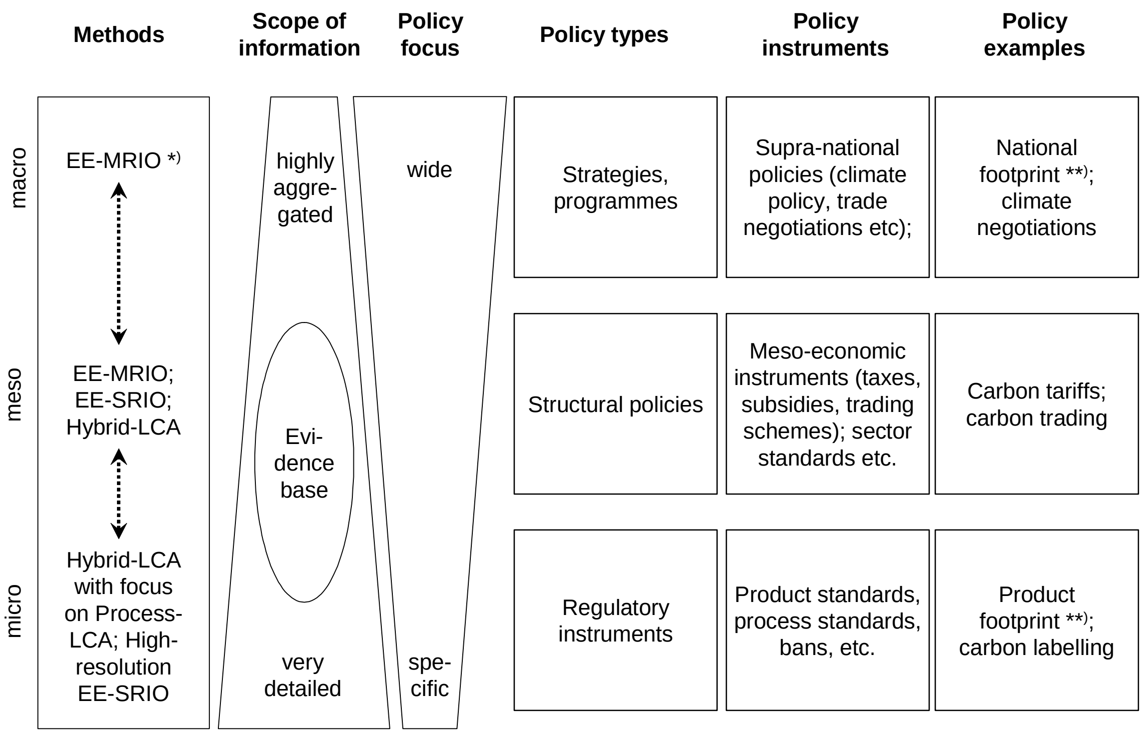
The concepts emissions embodied in trade, implies some form of aggregation. By thinking in terms of flows of aggregated product groups and not individual products the methodological question becomes easier, from the point of both, data and policy. Also, when looking at the entire traded flows, the connection to national policy becomes easier to trace. The national accounts system is designed to separate the production from the final demand; consisting of private consumption, public consumption, investments and exports. The boundary of economic activities has proven to be of use in order to show how the environmental impact is connected to the economic actors, be they producers or consumers.

However, there are links between the methods at the various levels, e.g. high-resolution input-output models can always be aggregated to the meso level, and macro level 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.

2 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).

3 See also (Finnveden and Moberg 2005) for overview of environmental systems analysis tools as well as (Heijungs R. et al. 2007, p.38) for a schematic of LCA tools.

4 Since LCA covers the whole life cycle, impacts from trade should automatically be included, and are therefore normally not discussed explicitly in LCA methodology papers. Some case studies describe details, e.g. (Engström et al. 2007).



*) EE = environmentally extended, i.e. incl. environmental pressure data such as emissions, energy, materials, land use, water EF, etc.
**) carbon, water, ecological

Figure 1: EIPOT-Methods in relation to policy demands on different economic levels (adapted from (Femia and Moll 2005) and (Wiedmann et al. 2006))

All of the methods can be extended with environmental pressure or impact data, such as greenhouse gas emissions, material flows, water use, land use, bioproductivity use (Ecological Footprint) etc. The second dimension that needs therefore to be considered is *environmental impact* or *environmental pressure.* It should be noted that most methodologies 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[5]) 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 LCA. The RACER evaluation therefore considered LCA 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 eco-systems & biodiversity. Again, the environmental impact indicators cover a range of specific policy questions. They can for example be related to different environmental compartments (atmosphere, biosphere, hydrosphere, soils, etc.) as well as economic and health considerations. The choice of indicators is partly a separate question from the one that determines the methods. This report focuses on the methods.

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

The third dimension is *geography*, which considers the spatial aspect. 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 resolution of countries and sectors is therefore an important factor in the evaluation of EIPOT methods. Furthermore, the methodology should provide possibilities to assess environmental pressures that cannot be allocated directly to countries, e.g. the emissions of international transport by water and air.

Although the original focus of the EIPOT project was to build a methodology 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.

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.[6] The methods shown in Figure 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 already 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 objective is to anticipate possible future impacts or to test the effect of specific policies (e.g. taxation, trade tariffs, carbon trading, government spending, etc) then 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).

The fifth dimension concerns another system boundary aspect, viz. the *life-cycle* stages of traded goods, When performing a life cycle analysis of a product, not only upstream production impacts during the 'cradle-to-gate' or 'cradle-to-shelf' phase need to be included, but also downstream impacts during the use and disposal phase ('cradle-to-grave'). When comparing products on their environmental impacts, impacts in all life-cycle stages should be considered. The lifetime of a product hence becomes important in its use phase and methods need to attribute impacts accordingly. With regard to trade the use phase and/or the disposal phase may be (partly) abroad, e.g. the impacts of tourists or the export of waste to developing countries.

[6] Compare to the categorisation of tools for sustainability assessment by (Ness et al. 2007).

3 Results of RACER Evaluation

In order to receive insights in the pros and cons of different methods with respect to environmental impacts of trade an evaluation of these methods was carried out. The assessment was undertaken with the RACER evaluation framework, based on criteria specified by the European Commission DG ENV project[7]. This chapter briefly discusses the evaluation framework and presents an overview of the evaluation results for different types of methods concerning the environmental impacts of trade. Detailed results have been presented in the Interim Report of the EIPOT project (Lutter et al. 2008). The adaptation of the RACER evaluation framework for this project has been described in a work package report (Lutter and Giljum 2008).

3.1 RACER evaluation criteria

For the evaluation of methodologies 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. RACER stands for **R**elevant, **A**ccepted, **C**redible, **E**asy and **R**obust.

The RACER criteria can be applied to assess the value of scientific tools, like indicators, for use in policy making. Best et al. (2008) showed the value of using the broad RACER criteria in a DG ENV project by specifying them and making them operational for methodologies for the first time.

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

Relevant	• Linkage 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

[7] (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.

Easy	• Data availability • Technical feasibility • Integration
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

The proposed evaluation framework enables an analysis of methods both in a qualitative as well as a quantitative way. The qualitative step of the analysis provides, for each sub-criterion, a description of the advantages and disadvantages for methodologies that are assessed. In the second step of the analysis these descriptions are quantified per method by allocating numerical scores to each of the sub-criteria. In the EIPOT project, the range of scores was on a three-level scale between 0 and 2. This kind of scoring enables to judge if a methodology does not fulfil a criterion at all (score 0), fulfils it but only partly (score 1), or is appropriate to answer the criterion's question (score 2).

Then, for each of the five main RACER criteria, an average score was calculated per method. These average values of each methodology were compared, instead of the total average values, in order to produce a more comprehensive picture of the differences between the methodologies. Presenting the average scores in radar diagrams provides an easily-readable overview of the evaluation. An overall un-weighted RACER score for each of the methods was not calculated, as the aggregation of major categories (which contain very different numbers of sub-categories and related scores) was regarded too ambiguous.

The average scores for the five RACER criteria were not weighted either, although not all criteria are of equal importance for decision making. If decision-making is to be based on correct information, then credibility and robustness may be better indicators for correctness than acceptance. So, the criteria 'Relevance', 'Credibility' and 'Robustness' may be higher ranked than the criteria 'Easy' and 'Acceptance'. The fact that a method is accepted does not necessarily mean it is the best way to support decisions. Often, a method becomes accepted because the proponents are better marketers, have more resources for dissemination, are better connected, etc. If a method is chosen that is credible and robust, it can be made 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.

Given the qualitative and minor quantitative (3-scale score) character of the RACER framework it must be seen as a tool for providing insights in 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 hard selection mechanism for selecting the ideal methodology, but it is a structured way to show differences between methods.

3.3 Results of RACER evaluation

For the assessment of the environmental impacts of products and resource use, a great variety of approaches and related indicators has been developed. Among them are life cycle assessment, material flow analysis, environmentally extended input output analyses, and Water and Ecological Footprint accounts as well as hybrid, econometric and dynamic approaches. The RACER assessment has been carried out for the following method-indicator combinations:

- **Life Cycle Analysis / Resource Accounting**
  - LCA
  - MFA-LCA (MIPS)
  - National Ecological Footprint Accounts and variant methods
  - Water Footprint
- **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
  - Multi-Region IOA; emissions, energy, materials and land use
  - Multi-Region IOA; Ecological Footprint
- **Hybrid approaches**
  - Hybrid LCA (hybrid of IOA and process analysis)
- **Dynamic Models**
  - Econometric Models
  - Dynamic Ecological Footprint

In the EIPOT project, the RACER evaluation was undertaken by dividing the method-indicator combinations over the project team members. Each combination was assessed by one project team member, partly by doing a study of literature, and, in order to avoid bias and subjectivity, each evaluation was reviewed by all other members from the project team to cross-check both the verbal explanations and the scoring. Subsequently, three external experts reviewed the evaluation procedure and results, providing useful comments for minor revisions.

However, the subjective nature of the evaluation process could not be fully removed, as the assessment illustrated that different authors have different opinions with regard to the scores. Even if the wording of the argument was similar, authors sometimes allocated different score numbers. Cross-reading of evaluations undertaken by other partners helped avoiding clear biases, but evaluations of this type always retain some subjectivity.

The results at the detailed level are presented in the interim report on the evaluations (Lutter et al. 2008). This also includes narrative summaries of the main method-indicator combinations that were assessed. The following section gives an overview of the outcomes of the assessment by summarizing the outcomes per method-indicator combination for all sub-criteria in global descriptions for four main methodologies: LCA/process analysis, SRIO, MRIO and hybrid analysis. The scores for these four main methods were determined by using the individual scores per indicator. The scores for the main RACER categories per method are depicted in a radar diagram.

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

Table 1: Summary of results from RACER evaluation

Key Advantages	Key Disadvantages
Life Cycle Analysis / Resource Accounting	
– Life cycle thinking is regarded 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) Suitable for the 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 indicators that puts human demand of biocapacity in relation to supply of biocapacity by global ecosystems;	– LCA: Static account of the past or status-quo at best ; – due to subjective assumptions and choices, the outcomes of similar LCA's may differ strongly; – performing an LCA for each specific traded commodity requires the collection of large amounts of data; lack of appropriate 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; concerning the industrial and domestic sector, only the sectoral, national and international level are covered; missing time series of data. – Embodied impacts of services are not modelled at all in National Footprint Accounts; built-up land area is also assumed not to be 'traded'; especially for Footprints embodied in trade, the concept is not defensible; indirect impacts are only partly covered due to data restrictions.
Single- Region Input-Output Analysis	

Key Advantages	Key Disadvantages
– IO-framework is widely accepted for environmental accounting with relation to environmental impacts of production and trade; – SRIO calculation scheme is simple and extendable to forecasting and modelling applications in exploring 'what-if' questions; – outcomes of SRIO applications are comparable with outcomes of MRIO studies; – allows analysing implications for natural resource use of structural changes of the economy, as well as of 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 which can be used as tools for economic planning. – SRIO of material flows enables opening up the "black box" of economy-wide MFAs and thus providing information on branch and product-specific developments of resource flows and resource productivity.	– does not enable a regional breakdown of the environmental impacts of goods and services; 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: PIOTs have only been compiled for a very small number of countries; allocating material inputs with a MIOT, a PIOT or a hybrid model delivers significantly different results, in particular with regard to the calculation of trade balances; regarding the huge data requirements 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 style would help with data availability/consistency.
Multi-Region Input-Output Analysis; Partial and Full	
– Enables analysis of the environmental implications of trade with different countries; – gives insights in the environmental consequences of relocation of industries in foreign countries; – can be extended to forecasting and modelling applications and could be used as a basis for econometric or dynamic CGE models; – More comprehensive data collection is underway in an EU projects aimed at MRIO analyses for EU member states; – integration of MRIO and LCA is possible; – good comparability due to system completeness; – A full MRIO provides more detail on exports and allows for the quantification of 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 huge amounts of data; large time gap for some IO data, i.e. detailed MRIO data concerning the year 2000/2005 is expected to be available only in 2010. – A partial MRIO only allows for a uni-directional analysis; does not cover all trade between the regions and therefore cannot consider impacts from certain higher-order international supply chains spanning across several regions/countries. – Full MRIO has higher data requirements than partial MRIO.
Hybrid approaches; Hybrid LCA	

Key Advantages	**Key Disadvantages**
– Hybrid methods combine advantages of LCA (accurate and specific data) with those of IO (ready available, complete and consistent data); – less 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 specific traded commodity still requires a large amount of data compilation.
Dynamic models	
– Econometric models: Capacity to design and quantify (policy-oriented) scenarios; potential of covering any environmental category of interest; endorsed by SKEP stakeholders; 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, greenhouse gas 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 can be linked to GIS models	– EM require huge infrastructure; high level of expert knowledge is needed to understand the structure of the model and be able to interpret system-internal effects; assigning indirect impacts to particular upstream-production processes would require additional work steps. – Dynamic EF: in terms of trade embodiments the approach is rather coarse as it does not have a 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 on a 3-scale level. The radar diagram below depicts the more aggregated scores for the main RACER criteria for four main methods.

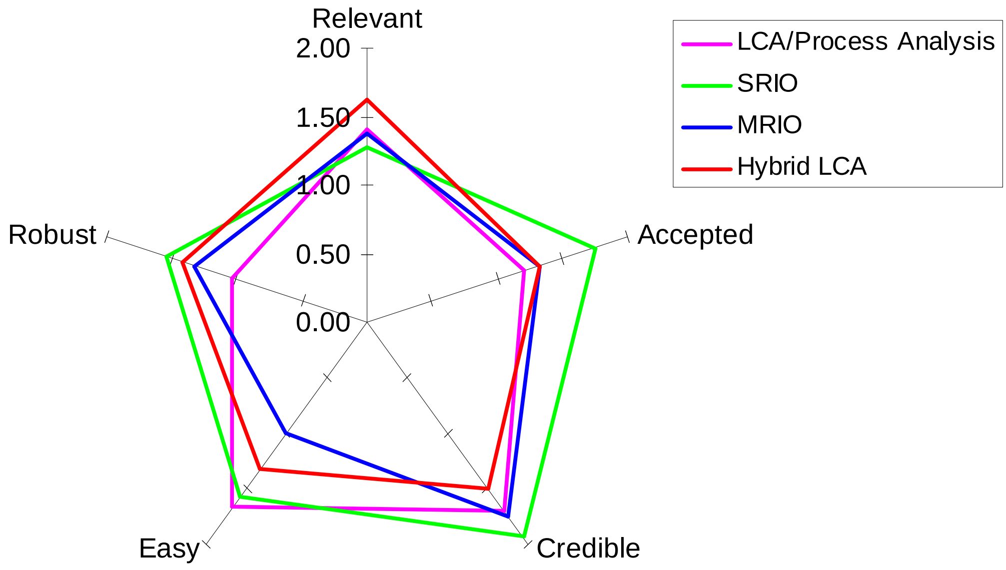


Figure 2: Average un-weighted scores of four main methods by each RACER criterion

Some further information is required to help interpreting this radar diagram.

Relevance:

- The differences in the scores are small. Hybrid LCA scores high at the scale level of economic activity (micro/meso/macro). However, a qualification would be justified as hybrid methods starting from LCA are better suited for the micro level and hybrid methods 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 scores higher than partial MRIO due to the possibilities to analyse supply chains.
- National footprint methods, which are categorized under process analysis, score higher on the identification of trends which is due to the availability of time series for some underlying data.

Acceptance:

- SRIO is a method with a long(er) tradition. It has been used in many studies and it is recognized as a useful tool by stakeholders, e.g. in policy making. The concept has been described in theoretical terms and published 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 be made accepted through good published information.

Credibility:

- Since SRIO calculation have been more often repeated by other researchers, SRIO scores higher on repeatability. The opposite holds for hybrid LCA.
- (Hybrid) LCA may have subjective assumptions and choices, so that the outcomes aren't objective (and therefore less credible).

Easy:

- SRIO scores higher due to data availability mainly and required software.
- SRIO and LCA are the basic methods; hybrid LCA and MRIO are extensions on these basic methods and therefore more sophisticated with larger data requirements.
- The difficulty of a method does not allow a judgement about its usefulness for policy making. If the best method for decision-making is difficult, then it just means it has to be supported by experts. It would not be advisable to replace these with a lest suitable but 'easier' method.

Robust:

- MRIO takes into account differences in production, but has assumptions on trade flows.
- Hybrid LCA more complete than LCA, but uses less official data than IO.
- SRIO and LCA more reliable than 'improved' methods?
- SRIO has high scores on consistency with SEEA and other methods and classifications.
- By its nature, the RACER ranking is rather coarse. For example, Process LCA was scored with a "1" for indirect effects, and Partial MRIO as well, the latter only because feedback effects aren't dealt with. With regards to truncation errors, however, there are worlds between Process LCA and Partial MRIO.

Obviously, each of the investigated methodologies has its strengths, but also weaknesses. There is no single methodology which 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 is providing 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, which are produced 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.
- SRIO: Requires extension to a multi-regional model (in one form or another), in order to reflect technological differences and differences in output mix between regions.
- MRIO models have a comprehensive geographical coverage and trace intersectoral and interregional interlinkages, but in general have a high level of aggregation regarding sectors and product groups (and still lack regularly updated data). A combination 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 also more laborious than the individual methods. However, a combination with MRIO modelling would be a useful extension.

Furthermore, dynamic, e.g. econometric, models are a valuable extension, in order to convert the methodology into an early warning and forecasting tool. Dynamic models can be based on all types of methods discussed.

In order to comprehensively calculate the environmental impacts brought about by the trade of materials, products and services, the most promising way forward seems to be to combine various methods and to synthesise best-suited elements from different existing approaches. The RACER analysis of the different existing methods carried out in this project showed to be an effective way to identify these best-suited elements.

4 Recommendations on Methodology

4.1 General conceptual design

A great variety of approaches and related indicators has been developed for the assessment of environmental impacts of products and resource use. Among them are life cycle assessment of products (Process LCA), economy-wide material flow analysis (EW-MFA), environmentally extended input-output analysis (EE-IOA) and Ecological Footprint (EF) analysis. As discussed in the previous chapter, the most promising way forward seems to be a combination of various available or emerging methods. By contrast, the parallel use of e.g. three detached methods does not appear to be very effective and not easily practicable either.

To set up a reasonable, reliable, and applicable accounting framework, the main question asked in the beginning is what exactly the purpose of the framework and the derived indicators shall be. The main objective of EIPOT (as discussed in Chapter 2) is *to develop and specify an environmental accounting methodology which allows quantifying and assessing the trans-national environmental impacts of traded goods and services*. As mentioned earlier, throughout the project, taking into account feedback by external experts as well as discussions at the stakeholder workshop, it became clear that the focus in EIPOT shall be set on trade flows between different economies as a whole and specific production sectors within them, and 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 best suited for micro-economic problems.

Life cycle analysis originating from engineering and input-output analysis originating from economics have several conceptual differences. They differ by their data inputs and the set of documents that describe how to collect these data (ISO standards versus SNA). Since both methodologies consider complete production chains, they should in theory generate the same outcomes in analysing the same question. However, due to their conceptual differences their applicability is not similar. The environmental impact of one specific (traded) product, for instance, is probably quantified best using an LCA approach. LCA as such 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 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. In case of the availability of detailed IO data the quantification of the impacts of traded product groups is possible, but the applicability to specific products seems far away.

Since EIPOT's main objective is 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 appears to be a desirable and practical compromise that still allows the distinction of high-impact sectors while at the same time keeps data and computational requirements at a manageable level. Further details will be discussed below.

We therefore regard EE-IOA in connection with the SEEA framework as an ideal basis for a suitable EIPOT methodology. The RACER analysis proved that EE-IOA is a generally accepted, credible and robust methodology. EE-IOA is a methodology which is commonly used to derive the direct and indirect environmental pressures associated with the final use of products and services in a given national economy. With the help of EE-IOA all environmental pressures are summed up which arise along the production chain of a given product. The environmental extensions, such as e.g. the use of raw materials or the emissions of air pollutants can be linearly linked to the input-output framework. However, differing production technologies in different countries can only be modelled in a multi-region IO model which requires substantial resources to set up.

Process- and product-specific, bottom-up methodologies have an important role to play, too. Even at the meso level, pure top-down approaches reach limitations on precision and the uncertainty in individual sectors can be high (see Chapter 5.3). Process-specific information is very valuable in these cases to reduce uncertainty and to extend the range of policy and research questions towards 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, the lack of detail. However, so far, there does not exist a method or approach which has the necessary detail to separate specific factories or companies in the supply chain. The challenge already lies in coming down to the sectoral level – projects as EXIOPOL[8] or FORWAST[9] prove feasibility and considerable mathematical effort at the same time (see, for instance, Tukker 2007; Tukker et al. 2009). Any disaggregation of sectors will, however, 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 specific characteristics of the 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 utilising 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 a wide range from macro to micro level. In addition to specifying the conceptual design for a method covering the macro and meso level (the main EIPOT purpose), we therefore also provide a tentative outlook of emerging approaches that promise an increased coverage of micro-level questions.

4.2 Environmentally extended MRIO as methodological basis

Generally, the SEEA scheme (including the NAMEA tables), being a satellite account of the System of National Accounts (SNA, United Nations 1993), constitutes a solid conceptual fundament for EE-IOA (United Nations 2003a). As stated in the RACER interim report, the SEEA consistently links economic statistics and environmental statistics, identifying in how far different economic sectors and different actors (producers, final consumers) are contributing 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 (EW-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 trans-national environmental impacts of trade flows of goods and services. The full version of MRIO analysis

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

9 http://forwast.brgm.fr

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 e.g. (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.

Over the last decade in particular there has been a tremendous increase in applications of analytical, and indeed forecasting, models based on environmentally extended input-output techniques. Besides being scientifically well described and established, 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 etc 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 provides the following advantages:

- A MRIO framework is consistent with existing UN Accounting Standards (United Nations 2003b) and it is desirable to develop it in parallel with the ongoing standardisation of the Footprint methodology. This will underpin and lend credibility to a Footprint accounting standard. Attention should also be paid to retaining commodity classification as disaggregated and relevant for the Footprint as possible.
- Using a model with a high sector disaggregation also would allow for the tracking of international supply chains. Structural Path Analysis (SPA), an analytical technique that allows for the quantification of 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 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 also 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. Thus it can be tested and elaborated which policy strategies and instruments are best capable of reconciling competing policy goals in economic, social and environmental policies.

It is reasonable to use the above described SEEA/NAMEA structure as a starting point for the construction of an EE-MRIO. In general, the SEEA framework has been implemented in many countries; especially in Europe where the system is fairly detailed and multidimensional. Nonetheless, for many other countries no data sets are available yet. Here, on the one hand, considerable work will be necessary to compile these data sets, and on the other hand, where the respective data is 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[10] 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 would be a desirable level but perhaps too ambitious for data provision to be sustained).
- Detailed, bilateral trade datasets for goods and services in monetary (and possibly physical) units (e.g. from UN, OECD or WTO, 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 the (partly already existing and partly conceptually foreseen) maximum number of relevant environmental extensions: material flows, energy use, land use, water use, air emissions, waste production, LCA impact categories, etc.
- Comprehensive process-based LCA data for the more detailed questions on particular sectoral systems, such as e.g. waste management practices, used in a hybrid-type approach (see below). This type of data will assist in detailing existing input-output tables and filling gaps in current NAMEA tables.

4.3 Options for hybridisation

4.3.1 Hybridisation between monetary and physical data

Three basic approaches for constructing environmentally-relevant IO tables can be distinguished. Models can use a monetary IO table (MIOT) extended by additional 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 all other sectors remain in monetary units.

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 with regard to PIOTs is still very limited and that detailed PIOTs have only been compiled for a very small number of countries (Giljum and Hubacek 2008; Weisz and Duchin 2006). Furthermore, the debate on how to apply IO analysis based on PIOT models is still ongoing (Dietzenbacher 2005).

It is also important to note that, by using a MIOT as the core matrix, one can illustrate the economic *responsibilities*, which agents hold for inducing certain environmental pressures. Monetary IO analysis has been used several times to attribute responsibilities for greenhouse gas emissions or ecological footprints to both producers and consumers, either 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).

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 delivers significantly different results, in particular with regard to 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

[10] Since all of the 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.

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 that pure monetary IO tables are extended into hybrid tables, which better reflect the physical supply and use structure of different industries and thus avoid distortions in results resulting from the assumption that monetary structures are a proxy of the 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 both from a mass balance perspective and relative to the monetary supply-use tables.

The EU project FORWAST[9] aims at constructing 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

For a brief description of input-output analysis (IOA) and process-based LCA we refer to the EIPOT Interim Report (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 (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 utilises 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 from of 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 input-output analysis and tiered Hybrid LCA.

Compared to Process LCA, the main differences of hybrid life cycle methods is that they can overcome system boundary problems by using sectoral data from environmental input-output analysis as an additional source of secondary data, where no primary or secondary process level data is available. This way data gaps in the LCA system can be filled with much less effort than it would require to obtain specific 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, (e.g. steel, plastics and glass) and the main assembly Process LCA data are available and used in the analysis. For some minor materials, assembly processes (e.g. electric components), capital goods, trade storage, etc 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 2: 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 can be combined with data from MRIO models. Such a method would especially be suited for complex commodities.

From a statistical point of view, Process-LCA data play three roles: firstly, to provide "disaggregation factors" that allow to represent NAMEA data at a lower aggregation level than allowed by the confidentiality restrictions on the original NAMEA data, and even at lower levels than possible from the way the NAMEA data are collected. Secondly, process-specific emission factors can help to replace or qualify average emission intensities of IO sectors. And thirdly, LCA data provide impact factors for impact categories.

In the following we provide several examples of recent Hybrid-LCA studies[11] in order to demonstrate the principal feasibility and usefulness of such approaches, even if they do not explicitly deal with traded goods and services.

(Benders et al. 2001) develop 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 (e.g. 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, etc.

Similar tiered hybrid analyses have been presented by (Kofoworola and Gheewala 2008) the environmental life cycle assessment of a commercial 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* has so far not been dealt with satisfactorily in MRIO modelling and is therefore an important area for tiered hybrid analysis using specific process data. The main question in this context is how to assign the emissions originating from the combustion of fuels from bunkers for international aviation and shipping. From a production perspective (e.g. 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 passenger is 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 required requiring the following information:

Air transport:

- statistics on the movement of passengers and freight by origin, destination and distance,

[11] The selection is non-exhaustive.

- 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.

A life cycle analysis (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 which has been compiled by the Ministry of Economy, Trade and Industry in Japan). The authors create an 'Expanded Inter-regional Input Output Method' (EIOM) which efficiently combines prefecture-specific emission databases and technology matrices with the inter-regional trade flows presented by the 9-region MRIO. This allows for results to be more specific to the lowest spatial level. The 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, p. 329-330) 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 I-O 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 also again by (Strømman and Solli 2008) – is that only a 1^{st}-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 with it.

Another problem that can arise especially with tiered hybrid analysis 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.[12] (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 very useful tool in several regards. Not only can it quantify and

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

help to unravel specific 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 allows for 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, e.g. in consumption (footprint) studies where embodied emissions (impacts) in trade to final consumption (EEC) of a nation is considered, a full multi-region IO analysis becomes necessary.[13] 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 considering a reasonable number of countries to be included in the accounting framework, it seems reasonable to set up certain criteria in response to which countries would have to 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 allow analysing the impact of EU policies on countries highly depending on trade with the EU. Yet, this would imply that a lot of small countries, mainly in Africa, would have to be included.

The first three criteria lead to roughly the same country sets in EXIOPOL[14], allowing coverage of over 90% of the global GDP and over 80% of the imports to the EU27 with just 16 additional EU trading partner countries, for which, additionally, in most cases reasonable data is available for recent years.

Choosing a much smaller country set, on the one hand certainly has the advantage of smaller workload and complexity; on the other hand, there is the strategic advantage to come up with a trustworthy data set when concentrating on a limited number of countries with good data.

In the present, globalising world all countries are more or less interconnected. In order to capture the impacts in all countries, including the countries not in the selected data set, a region 'Rest of the world' should be defined in the framework. The data for this residual category might be based on other countries.

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

[14] 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 an individual country will have another set of relevant countries.

4.4.2 Sectors

Several studies illustrated 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 however differ considerably per sub-sector. Hence, a much higher resolution of at least 100-150 sectors is essential for allocating sustainability impacts in a meaningful way to sectors, products, etc. (Tukker et al. 2006), (Weidema et al. 2005).

Generally, in the ESA95, 60 products and sectors are discerned. In the repeatedly mentioned EXIOPOL project the attempt is therefore made 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. Of course, there is the issue of data availability and effort to be put into further disaggregation. In the EXIOPOL project as well as in the FORWAST project this level of detail is applied for the first time – implications from the experiences made in these projects will certainly help to make future work more effective.

In many cases, a higher resolution of industries and products can be obtained from supply and use tables (SUTs) directly produced by NSI. 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 1199x1199 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 United Kingdom 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) therefore also use the supply and use tables directly (see discussion in 5, Section 5.1.1).

4.5 Relevance for different environmental categories

One of the advantages of the above mentioned structure of a possible accounting framework is its ability to link any kind of environmental impact category to the monetary economic information given in the MRIO tables, in order to enable integrated environmental and economic model calculations. This is done via environmental extensions – environmentally relevant parameters in physical units.

A reasonable way of arranging the environmental extension parameters is to do it external to the balanced monetary SUT-scheme via so-called satellite accounts. Satellite accounts are external vectors and/or matrices which are simply 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 the following Chapter 5 on data requirements).

Consequently, whatever physical information available in terms of environmental impact categories can be linked to economic transactions – be it data on material use, emission data, data on water consumption, or waste production. This is an enormous advantage as the effect of different environmental policy options can be modelled.

Generalising IO frameworks with **emissions** data is in most cases straight forward as emissions to air, in particular of greenhouse gases, is an area well covered in national environmental accounting. Because of the remarkable interest in climate change related research many single- and multi-region input-output models extended with GHG accounts have been constructed and applied to empirical research (for a review see e.g. Wiedmann et al. 2007a).

In addition to the NAMEA tables, recording the environmental pressures and impacts, also **material flows** are of great relevance for the purpose of EIPOT. According to the London Group on Environmental Accounting (2008), in the new SEEA-MFA manual, economy-wide MFA (EW-MFA) will be designed as a fully integrated sub-module. While in EW-MFA the flows within the economy in general are treated as a black box (no information about flows within an economy), the EW-MFA shows, in a breakdown by type of material, the interaction of the economy with other countries and world regions. The flows of material within the economy are the focus of other sub-modules, such as physical IO tables (PIOT).

Concerning the "**footprint family**", it seems essential that these approaches are further developed towards compatibility with the SEEA accounting framework and thus also to 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 need to be compiled (or transferred from already existing National Footprint Accounts which in turn 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 most appropriate approach would be a 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 with combining the input-output framework with water use data (for instance, using the virtual water concept) have demonstrated that it is an effective means to explore which economic sectors have the greatest consumption of water – directly as well as indirectly. Here, on the one hand, determining the amount of imbedded water in €1 of a product *i* water consumption in the production process *I* is covered; but on the other hand, also the water consumed in the production of the amount of each good *k* that is used as an input in process *I* and the water contained in the inputs in *k*, etc is accounted for. As with respect to other extensions, using an IO-framework, the interrelationships between different sectors in terms of water use can be determined and recommendations for political action made. Furthermore, it allows judging whether the use of water resources, which are often limited in a regional sense, for economic productivity or environmental flows is reasonable. Concerning 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).

4.6 Summary of recommendations regarding methodology

- MRIO analysis extended with environmental data based on the SEEA / NAMEA framework is the ideal basis for EIPOT related research.
- The EE-MRIO model should comprise all EU-countries plus a maximum number of EU trading partners .
- The sectoral resolution may have to depend on the application. While for specific purposes more than 100 sectors seems 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 the NAMEA data (see Chapter 5). Substantial work is still to be done both on making the 60 sector data available from more countries as well as continuing research and separate analysis with a higher resolution.

- For specific policy and research questions, data from process analysis and LCA can be used to hybridise the system (hybrid IO tables, hybrid LCA) and/or to enumerate specific processes (e.g. international transportation) and thereby increase the resolution of the analysis.
- All relevant environmental impact categories should be included in the analysis. For some issues, notably chemicals and land use there is still a need for harmonisation and methodology work.

5 Data requirements for EIPOT modelling

This chapter deals with the data requirements for analysing environmental aspects of international trade flows. In general 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 (e.g. bioproductivity, number of endangered species, waste etc.).
- 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 impact from life cycle inventories (LCI) and other technical databases for hybridisation and completion.

One important point is that a MRIO model does not need one individual data set, but a whole set of IO, trade and environmental data. All of these data sets exist already, but the challenge is to convert the available data into the MRIO format and to keep them up to date. Rather than a lack of data per se the crucial 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 institutions (NSI). The data are usually compiled further at international statistical agencies, i.e. Eurostat, UN, OECD, World Bank etc. Further important data source include projects such as EXIOPOL and GTAP as well as commercial data sources for LCA.

The main focus in this chapter is on the building blocks of economic data (SUT, SIOT), environmental data, trade data and possible refinements using process-based LCA data. The experiences from Statistics Sweden in previous work is used to make the presentation as concrete as possible. Furthermore, experiences with hybrid approaches (using process-based LCA data) from projects such as EXIOPOL will be presented in order to illustrate the viability of such approaches.

5.1 Data sources

5.1.1 Data sources for economic data

Without a doubt, the most widely available and consistent data are found in national economic accounts and trade statistics. Both are corner stones of most statistical agencies and they are more or less completely harmonized in the EU and further worldwide through the work of Eurostat, OECD, the UN, etc.

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, there exist IOT 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 that are used in the process of compiling a consistent set of accounts. This process ensures that there is 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 2-digit NACE level, which means roughly 60 products/industries. The level of detail used in the tables used for compiling the finished SUT can run up to thousands of products and well over 100 of 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 concerns.

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

The annual SUT are compiled and sent to Eurostat in the agreed 2-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 facilitate chain linking to prices in reference years. The table below shows the availability of European SUT as of 2008. The average time lag for publication is about two years.

Table 3: 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			

Constant price tables can be used in IO models for one year and in most cases for time series. However, if a structural decomposition analyses or similar analyses are to be performed then tables in constant prices are required. The Eurostat collection of SUT tables in constant prices is more sparsely populated, see Table 4.

Table 4: 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													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																										
BG	Bulgaria						/			2010										/			2010				
CZ	Czech Republic																										
DK	Denmark								x	x	x											x	x	x			
DE	Germany									x													x				
EE	Estonia						/			2009										/			2009				
IE	Ireland									2015													2015				
GR	Greece							x	x	x	x	x	x	x							x	x	x	x	x	x	x
ES	Spain								2008													2008					
FR	France																										
IT	Italy								2008													2008					
CY	Cyprus								2008		2009		2010									2008		2009		2010	
LV	Latvia						/	/	/	/	/	/	/							/	/	/	/	/	/	/	
LT	Lithuania								2012			2010										2012			2010		
LU	Luxembourg																										
HU	Hungary									x	x	x											x	x	x		
MT	Malta																										
NL	Netherlands																										
AT	Austria		/		/											/		/									
PL	Poland									2009													2009				
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							2008													2008						
SI	Slovenia						/	/	/	/										/	/	/	/				
SK	Slovakia			2008													2008										
FI	Finland																										
SE	Sweden	x	x	x	x	x									x	x	x	x	x								
UK	United Kingdom									2009													2009				
HR	Croatia																										
MK	FYR Macedonia																										
TR	Turkey																										
NO	Norway																										

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 uni-directional MRIO at least all imports to the country under investigation need to be known in matrix form, i.e. by product and by industry, for each country where imports are received from. 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, e.g. 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 techniques can be used to update them to the desired year (see Section 5.2.3 below). The national import tables often have rows with so-called non-competitive imports which are goods and services that are not produced domestically, e.g. 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 as 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.

The individual trade flow matrices by country, i.e. the off-diagonale 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, p.14). This procedure assumes that the trade coefficients are identical for all entries along a row of the total imports matrix, i.e. 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 either 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, industry-by-industry input-output tables are closer to statistical sources and actual observations. In empirical research it depends on the objectives of analysis which type of input-output table is better suited for economic analysis (Rueda-Cantuche et al. 2008).

In most cases, industries produce several different products, including by-products and auxiliary products. When constructing a SIOT, it can be assumed that products are produced either 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 e.g. (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 using different technology assumptions is rather large, although, in a factor content of trade application the of different technology assumptions didn't seem to be a decisive factor. The authors conclude that it is more important to produce SIOTs annually than the question of what compilation method to choose.

There are several pros and cons for the use of SUTs vs SIOTs; see the separate discussion of this issue further below.

The Eurostat data set

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. The table below illustrates 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. Current 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 the 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. 2008).

Table 5: Availability of Symmetric IO Tables from Eurostat in 2008

Availability of SymmetricTables, Current Prices

ESA 95 Table: 1700 Siot

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

ESA 95 Table: 1800 Domestic

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

ESA 95 Table: 1900 Imports

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

The OECD data set

The 2006 edition of IO tables published by the OECD includes 28 OECD countries (except Iceland and Luxemburg) and 9 non-OECD countries (Argentina, Brazil, China, India, Indonesia, Israel, Russia, Singapore and Taiwan) in 48 harmonised sectors (see Tables 1, 2 and 3). The latest edition of the OECD data set (2009) is due to be released in early 2009.

The tables of the 2006 edition are based around the year 2000 (Yamano and Ahmad 2006), see also (Yamano and Ahmad 2007). The underlying data are submitted to the OECD by national statistical offices, which were asked to provide data in accordance with the ISIC Rev. 3 harmonised industry structure. Furthermore, national statistical offices could submit any relevant data (e.g. supply-use tables) at the most detailed and practicable level in order to maximise compliance and to minimise costs. Against this background most countries submitted data using national industrial classification systems. The consideration of supply-use tables basically stem from the fact that IO tables are not compiled by all national statistical offices, but in this case they produce supply-use-tables. By using standard assumptions these can easily be converted into symmetric IO tables.

As Table 6 and Table 7 illustrate most of the received data as well as those submitted in earlier years need to be converted to the predefined and originally requested structure, in a way that they are consistent with the industry classification used in OECD systems and that they are using the same price basis. The harmonisation process itself is explicitly described. Table 8 provides an overview of the considered industries and discloses future potentials of disaggregation.

Table 6: 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 ar	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 7: 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.

Besides the IO tables representing total inter-industry requirements and total final demand in million US$, 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 respective country, while the other represents intermediate and final demand requirements on foreign production (import matrix).

Table 8: OECD IO Database – Industry classification and concordance with ISIC Rev. 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

The GTAP data base

GTAP (Global Trade Analysis Project) is a global network of researchers and policy makers conducting quantitative analysis of international policy issues.[15] 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 Data Base is a publicly available global data base 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).

[15] http://www.gtap.agecon.purdue.edu

Version 7, published in 2009, corresponds to the global economy in 2004 as reference year and distinguishes 57 sectors and 113 countries and world regions.[16] The GTAP Data Base is most commonly used with the GTAP Model, a static multi-region, multi-sector applied general equilibrium model.

GTAP receives IO tables from various institutions around the world and applies balancing techniques to fit them with the standard GTAP format. Both, product-by-product and industry-by-industry SIOTs are submitted and the re-balanced final tables in GTAP are therefore a mix of both, industries and commodities.

There have been criticisms about the way IO data is handled by GTAP. Amongst various issues, (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 straight-forward 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 then 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 data sets."

Input-output tables from EXIOPOL

EXIOPOL (A New Environmental Accounting Framework Using Externality Data and Input-Output Tools for Policy Analysis)[17] 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 objectives of EXIOPOL is to set up 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 for the estimation of environmental impacts and external costs of different economic sector activities, final consumption activities 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 2007a), (Tukker et al. in press):

- to synthesise and develop further estimate 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);

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

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

- to apply the results of the external cost estimates and EE IO analysis for the analysis of policy questions of importance, as well as for the evaluation of the value and 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 which has a resolution of about 130 economic sectors to which about the same amount of different categories of environmental extensions are 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.

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

SUTs versus SIOTs - concluding remarks on IO tables

Both, (rectangular) supply and use tables (SUTs) or balanced, symmetric IO tables (SIOTs) have advantages and disadvantages for MRIO modelling. It is possible to use SUTs directly in an MRIO framework as demonstrated by (Lenzen et al. 2004).[18] Depending on the way the supply and use tables as well as the 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 that had been compiled by assuming industry technology. SUT blocks also allow to assemble physical data under either commodities or industries or both, giving the possibility of deriving more specific multipliers depending on the research question and/or data availability. Finally, SIOTs can always be constructed from SUTs mechanically, i.e. without specific information on co-production, by using a mix of commodity and industry technology assumption (see e.g. (Konijn 1994), (Bohlin and Widell 2006)).

The following criteria will have to be considered by modellers when choosing either SUTs or SIOTs:

- <u>Frequency of publication</u>: 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.
- <u>Level of sectoral disaggregation</u>: SUTs have normally a finer sector disaggregation than SIOTs. The sector breakdown for products in particular is often considerably higher in SUTs.
- <u>Flexibility</u>: arranging data in SUT blocks in an MRIO allows for the possibility to associate physical information, such as resource use or environmental pressures, to both industries and commodities. This allows for a wider range of policy and research questions to be addressed. One important issue for hybridisation is that fact that specific information on production processes, e.g. derived from LCA, can more readily be associated with the original information on supply and use than with altered SIOT data.
- <u>Quality of information</u>: SIOTs produced by statistical offices contain superior information on co-production as they would normally have been 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.
- <u>Consistency</u>: Supra-national databases such as those from Eurostat, OECD or GTAP adhere to a standardised, consistent format which allows for uncomplicated direct comparisons. Whilst Eurostat reports in both SUT and SIOT format, OECD and GTAP report symmetric tables only.

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

In the FP-7-EU project EXIOPOL, both the SUT and IOT play a central role. While analysis is performed using SIOTs, national SUTs provide the foundation for constructing the 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. 2008).

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 a first time (e.g. in the course of the EXIOPOL project), it is far easier to repeat it to include additional years.

5.1.2 Data sources for environmental data

European data

Most environmental accounts (EA) 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 as in the national accounts 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. This means that there is consistency between energy use per fuel and the emissions to air from this fuel use. Some countries base the emissions in their EA on emission inventories directly, using different methods of allocating inventory data over industries and final demand.

The data compiled and published in the EA 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 fall of 2008. The published time series at Eurostat covers the period from 1995 up to 2005 or 2006, depending on how the national EA is compiled.

As the EA is a satellite system to the national accounts, the aim of the EA is to have the same 2-digit NACE level reporting. Some countries achieve this level while others have much more aggregated data. This is due both to confidentiality and a lack of data to facilitate an allocation over industries at that level. The same applies for time series for some countries, i.e. they don't have a yearly compilation of EA data.

Table 9 below shows the different levels of aggregations present 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 2-digit NACE level present for the same substance and year over member states. The least common denominator in terms of sectors is a 10-sector level where all countries report data, except Ireland, Polen, Slovenia and France.

Table 9: CO_2 emissions data for 2002 compiled by Eurostat

	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

In order 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, the

EU-FP-6 project EXIOPOL, as described above, is setting up a multi-regional input-output framework, where environmental interventions are taken account of via satellite accounts – so-called environmental extensions. These environmental 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 the materials are divided into various sub-categories. For all these categories extension data in EXIOPOL include used and unused extraction.

Land area was included in the EXIOPOL database with respect to the area which is used to generate biomass for economic processing using the categories 'Arable Land', 'Pasture', and 'Forest'.

With respect to *water use* in the different sectors special focus was set on the water consumption in the agricultural sector, being by far the biggest water consumer. The main data source for water use for the incorporation in the EXIOPOL data base was identified as 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 the water use data are given in yearly average numbers for 5-year periods (e.g. 1999-2003). Additionally, data from the LPJmL model (Rost et al. 2008) were used, in order to disaggregate blue (water retrieved from rivers, lakes, etc used for irrigation purposes) and green (precipitation) water consumption.

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

The *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 results in around 40 environmental extension vectors including air pollutants such as GHGs, metals, and others.

Global data sets

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 IPCC'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) has shown, 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 (see below), have to be used to further disaggregate sectoral emissions (see also 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 data set, an error concerning an overestimation of emissions in the petroleum refinery sector, and a lack in using region specific emission factors and fuel contents. Since 2009 the CO_2 emissions database for GTAP version 7 (base year 2001) is available, but it is not known yet if these data show the same differences with national CO2 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 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)[19]. The EDGAR information system stores global emission inventories of direct and indirect greenhouse gases from anthropogenic sources both 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 presently been done for 1990 and 1995. The EDGAR 3.2 Fast Track 2000 dataset is the latest version of the EDGAR data set 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, e.g. in the production of concrete, emissions allocated to non-energy use and chemical feedstock, emissions of waste processing (e.g. landfills), emissions related to biomass burning and emissions caused by tropical forest, savannah, shrubs and grassland fires. On the other hand, the sectoral level of the emissions in the EGAR database is not very detailed. The sectoral emissions are presented at the level of some 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 the sectoral data in the GTAP/EPA project.

Apart from the above mentioned data sources there are several other, more or less official sources, often built on the national data and sometimes enhanced or adjusted for specific purposes. This ties in with both EXIOPOL and GTAP.

One source that has been used in several projects at Statistics Sweden is the Climate Analysis Indicators Tool (CAIT) on-line database from the World Resources Institute[20]. In this data set, 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.

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

20 http://cait.wri.org

Table 10: 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-based analyses of environmental effects of trade, as they conform to the definitions, system boundaries etc. of the national economic accounts.

If the reporting and compilation ambitions at Eurostat succeed, with economic and environmental data for all member states published at the 2-digit NACE level, there is a great potential for analysing 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 instead. One way would be to develop LCA-based inventory data to fill the gaps (see also below). It is important that this kind of second best solution does not diminish the ambitions to make the 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 the allocation of total imports (and possibly exports) that are 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, e.g. HS, CN, SITC or versions of NACE[21]. Apart from the monetary value, physical units of traded volumes such as

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

kg, L, m2 etc are often presented. The combination of value and volume units is useful to overcome extreme price differences between countries.

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 from (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 data base includes data on trade within the EU27 as well as external trade data[22]. Furthermore, distinction is made between modes of transports and with respect 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

[22] Data can be retrieved from http://epp.eurostat.ec.europa.eu/newxtweb.

OECD trade data

The bilateral trade data (BTD) from OECD are based on the ISIC Rev. 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 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 as well as 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 both on a global scale and on a country level and in order 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)[23], 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 as China and India which will further improve the consistency of the approach. The above described approach has been applied 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 in the sense that in the case of bilateral data the trade flow reported by the importing country match with the trade flow reported by the exporting country. Several researchers and institutions are constructing more consistent datasets on trade by correcting, balancing and adjusting the 'raw' data. Examples of such 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),
- NBER, United Nations Trade Data (http://www.nber.org/data, http://cid.econ.ucdavis.edu),

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

- GTAP (https://www.gtap.agecon.purdue.edu/databases/v7/default.asp).

WTO, International Trade Statistics

The International Trade Statistics 2008 from the 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 is introduced by a highlights section that identifies the most salient trends in the data and illustrates them with numerous charts and maps. There is also a methodological chapter that explains essential concepts and definitions used in compiling the statistics, and an appendix with 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 by selected economies.

NBER, Trade dataset

The NBER UN trade database concerns 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 4-digit Standard International Trade Classification, revision 2 and are based on the United Nations 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, however, the corresponding exporter report is used instead. 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, already mentioned above, also comprises bilateral trade data. The trade data for 87 countries (version 6) has relied nearly 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 the Harmonized System (HS) classification were used, since this classification matches better with the GTAP sector classification. In case of other classification schemes or unspecified trade or partners adjustments were made (Gehlhar 1996).

5.1.4 Data sources for international transportation

Above, only international trade statistics and databases have been discussed. Another type of data that may be relevant for assessing the environmental impacts of trade concerns transport flows. International transport flow statistics report on quantities of transported weights by mode of transport (road, air, etc.) 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[24]. In general, trade flow and transport statistics are independent statistics, although there are attempts to integrate both types of data (Linders et al. 2008).

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

5.1.5 Data sources for process and LCI data

As discussed in Section 4.3.2, process-specific emission or impact factors as well as 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 research question to be investigated – additional, detailed information needs to be applied in order to quantify the associated environmental impacts.

In some cases, a straightforward multiplication with emission factors will suffice, e.g. 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, depending on the size of the engine etc. These emissions factors can be derived from disparate data sources such as national emission inventories, publications from transport statistics or LCI databases, like the Eco-invent database (Frischknecht et al. 2004), (Frischknecht et al. 2005)[25], the Franklin database[26] or the EU database ELCD[27].

If whole rows and columns in SUTs or SIOTs are to be disaggregated or newly defined (see Section 4.3.2), then 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 data sets such as the previously mentioned Ecoinvent LCI database (Frischknecht et al. 2004), (Frischknecht et al. 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. The Buwal and ETH databases are the predecessors of the Eco-invent database. The Franklin is a large well-known (American) commercial database[26]. 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.

In the case of EIPOT, there is a likely need for trans-national 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 trans-national production (of e.g. semi-fabricates). The problem is that there are only some data for each commodity (or none) that are representative for only part of global production (e.g data on European and US steel production but none on Chinese steel production). Hence extensive data gaps exist and much work still needs to be done to fill them.

One application of LCA data in a MRIO, for instance, is for the disaggregation of environmental extensions such as energy use. This approach has been also been applied in the EU-FP6 Project EXIOPOL. In EXIOPOL, for the environmental extension data on energy use the IEA energy balances were used as main data source. These balances comprise around 60 energy commodities which is too broad for EXIOPOL requirements. Hence, these 60 commodities had to be split into 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. The main problems faced in this process were with respect to obtaining physical output data. Alternatively, auxiliary data such as employment numbers were used (Lutter et al., forthcoming).

[25] http://www.ecoinvent.ch

[26] http://www.fal.com/lifecycle.htm

[27] http://lca.jrc.ec.europa.eu/lcainfohub/datasetArea.vm

5.2 MRIO-specific data requirements

The next step in compiling an MRIO framework, after collecting all the relevant (and hopefully consistent) data, is the construction of the multi-region input-output table. There are several ways to do this, e.g. starting from the trade data or starting from the input-output data (see e.g. (Bouwmeester and Oosterhaven 2007) for a proposal of a methodology). In constructing the MRIO table, several other issues play a role like valuation, disaggregation of data, balancing, etc. These issues will be 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. Under certain limitations and assumption 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

Eq. 1
$$e_j = e_{j1} + e_{j2} = \frac{g_{j1}}{g_j} e_j + \frac{g_{j2}}{g_j} e_j$$
$$\text{with } g_j = g_{j1} + g_{j2}$$

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

Eq. 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 e.g. Druckman and Jackson 2008).

In case the detail of the input-output data is not sufficient, also data from other countries or regions can 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 a, environmentally extended IO-framework, disaggregated into about 130 sectors. As in general such detailed IO tables are not available, various transformations and estimations are necessary, to complete national data sets, reach this level of disaggregation and harmonise existing SUTs. The following list summarises the approaches used (Tukker and Heijungs 2007b):

Completing the basic data set

- 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 (assume proportional use of domestic and imported products in all sectors; or use known import matrices from 'similar' countries)
- Estimating missing and confidential data. E.g. some NSIs (e.g. the UK) '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. Scale up or down the SUT to match the base year output.
- Adjustment 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 methods 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 was undertaken that applied SDA in a national context to identify the underlying causes for changes in emissions, some of them including trade, e.g. (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 that of incomplete data. Missing matrix elements may be due to a variety of reasons such as costly and therefore 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, that is exhibiting 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 a number of 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 considering the reliability of the initial estimate;
- allow considering 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) present a new RAS variant (referred to as CRAS, Conflicting RAS) that is 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 CRAS 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, p.461-475). The basic idea of the approach is to derive input-output tables which are consistent with official macroeconomic forecasts for GDP but avoid 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 update 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 methodology 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 a high degree of automation are the main benefits of the Euro procedure. (Rueda-Cantuche et al. 2008) use the Euro method to demonstrate how a projection of an input-output table 2000 can be established for Greece on the basis of the latest available SIOT for 1998.

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 – even more important – of error margins of results is very important for the relevance and reliability of any calculation and essential for decision-making.

However, few practitioners in LCA, footprint and IO analysis are routinely undertaking a robust uncertainty analysis. Only recently, more attention has been paid to the uncertainties associated with these types of environmental analysis and modelling. One early example is the study of Wilting (1996), who investigates 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 6% and 8% for sectoral energy intensities (based on 95% confidence interval boundaries). Due to other assumptions on the uncertainties of the base data the uncertainties for 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 evaluate 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 find annual variations in both data sets and apply a regression analysis to remove trends from underlying data and estimate the uncertainty in the raw IO tables. They then calculate the emissions for various final uses and sectors to estimate the uncertainties from typical EE-IOA investigations.

There are very few empirical studies on error estimates associated with MRIO analysis so far; in particular, with 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, Table 3, p.27). SRIO models also assume that the production technology of imported goods and services is identical to the economy under investigation. The relaxation of this assumption and the 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.[28] (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 exports led only to minor corrections, the explicit modelling of Danish imports, as well as 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, Table 3, p.27) and can introduce substantial additional errors.

With their environmental MRIO used to calculate emissions embodied in US trade, Weber and Matthews (Weber and Matthews 2007) perform a sensitivity analysis by assuming the ROW is represented by the most CO_2-intensive and least CO_2-intensive countries in the data below and find considerable variation due to this uncertainty, on the order of 20% of total embodied emissions of CO_2.

Aggregation is a problem in particular 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 (for these three see Weber 2008), or aluminium and other non-ferrous metals. Lenzen et al. (Lenzen et al. 2004) analyse the error associated with aggregation by merging their 39-133 sector MRIO to 10 aggregated sectors and find significant errors, particularly due to aggregating electricity together with gas and water production.

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

The sensitivity of MRIO calculations towards the use of MER or PPP as a means to convert currencies is tested by Weber and Matthews (2007) as well as (Kanemoto and Tonooka 2009). (Weber 2008) finds that the ratio of the rates (MER/PPP) can be as high as 4.7 for China versus the US and contemplates 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, i.e. the off-diagonale elements in a full, multidirectional MRIO model, also deserve special 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 different 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, i.e. 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 modeling should also be considered, especially if the analysis only requires a few commodities to be modelled and a hybrid analysis using SPA[29] is possible."

The first comprehensive Monte-Carlo analysis of the uncertainties in a global multi-region input-output model is presented by (Wiedmann et al. 2008a), (see also Wiedmann et al. 2008b).[30] Uncertainty functions were determined for all input variables to the model, the IO tables uncertainties were estimated from constraint uncertainties and matrix balancing, 5000 Monte-Carlo 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 has been shown to be between 3.3% and 5.5%. Therefore, the estimate of total embedded emissions can be regarded as robust and reliable. The authors emphasis, however, that on an individual sector level these errors are generally higher and that the accuracy is not sufficient for a robust footprint or life cycle analysis 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.

[29] Structural Path Analysis (Defourny and Thorbecke 1984), (Treloar 1997), (Peters and Hertwich 2006), (Lenzen 2007).

[30] 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" (page 4876); but they do not carry out a Monte-Carlo analysis.

Finally, further work is currently undertaken by (Rodrigues and Domingos 2008b) to quantify the 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 supra-national 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 therefore advisable to replace data from the above mentioned supra-national 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 (countries) under investigation (e.g. IO tables for the U.S. are available with nearly 500 sectors).

In cases where this level of detail is not available, auxiliary data and estimation procedures must be used. Estimation of this additional data must be done using appropriate, consistent data, in a way that can be easily understood by the model user, and within a reasonable time frame. Also, NSI are providing 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 first priority.

To provide further detail to the data to be obtained from NSI, a number of topical datasets exist which can be used: International Energy Agency (IAE), the British Geological Survey, the US Geological Survey, and the 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 then 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 (neither 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 for the disaggregation of 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 Food and Agriculture Organization, and British Geological Survey which provide consistent data for a number of the countries included in the EXIOPOL database.
- Transparency is achieved through the use of publicly available data and data provided by national statistical institutions (NSI).

- 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 NSI 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-preferred in cases where they are less transparent than another available estimation option.

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

A too detailed disaggregation can be troublesome also in a quality sense. The uncertainty increases as the aggregates become smaller. The environmental data, as well as the energy use data, is not collected in a bottom-up fashion from all companies. That type of data collection would be too expensive for any country 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.

Driven by a different focus on the research or policy question, the various data providers / compilers place another emphasis 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 (all) – which is again an argument for a hybridisation of models – but ultimately the policy question will decide the exact features of the approach.

The following Chapter 6 will discuss the role of institutions with respect to data provision and implementation.

5.5 Summary of recommendations regarding data

- Data from the EXIOPOL project, once available, seem to be the ideal basis for a European-focussed EIPOT model and should be used in the first instance to construct the basic EE-MRIO framework.
- Data from other consistent meta-databases, such as GTAP, should be used to fill gaps in country coverage, sector data, and environmental extensions.
- SUTs, rather than SIOTs, should be used if they provide significantly more sectoral detail and are considerably more up to date.
- Bilateral trade data are essential if off-diagonale trade flow matrices have to be estimated separately. We recommend using the UN Comtrade database[31] in the first instance for consistency and world coverage.
- EXIOPOL will use process and LCA data for hybridisation; if further specification is required, additional LCI data sets should be utilised.

[31] Possibly by also using the NBER version of it (Feenstra et al. 2005).

6 General Recommendations

Specific recommendations on methodology and data have been made in Chapters 4 and 5, respectively. This chapter goes beyond those specific recommendations by looking at a possible implementation of the methodology on a wider scale and discussing the role of institutions in such a process. Future research needs and policy applications are also discussed in this Chapter.

6.1 The need for 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 (e.g. GDP). While economic growth still seems to be the aim to be strived for, a shift has been happening towards the de-coupling of economic growth from the use of natural resources; as it has been recognised that the current growth level of worldwide resource consumptions can by no means be sustained for a long time without risking the global ecological, social, and economic equilibrium.

As outlined in Chapter 2 (Policy Context), there are many facets of political and corporate decision-making from the macro to the micro scale that require appropriate models. As wide spread as the range of policy and research questions might be, there are several common elements that increase the need for a further development of existing approaches, e.g.:

- 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 which are not available in their own territory. Consequently, these countries more and more import resources from resource-rich countries with manifold consequences, among which stand out the dependency on the exporting countries as well as the environmental, social and economic consequences the exploitation has in-situ, for which the importing countries are, at least partly, responsible. But not only direct consequences, also indirect impacts, as for instance the food stuff price crisis caused by the enormous demand for agricultural products for energy consumption and resulting speculations have to be taken into account in this context.

Understanding and addressing these problems now and in the future requires continuing development of adequate methods and tools, in order to assess the consequences and impacts of current resource consumption, trading patterns, etc and to evaluate possible policy options in terms of their efficiency and practicability. In this report we have captured the current state-of-the-art in methods able to analyse environmental impacts of trade and have suggested a combination of some of them as a promising way forward. We have discussed data sources and availability as well as uncertainty – all of which have an influence on 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 for answering pressing questions.

The methodological framework proposed in this report 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, e.g. consumption. A detailed quantification of these impacts in terms of regions and sectors where impacts take place offers possibility for reducing the negative effects of consumption. Another possible analytical objective, for instance, may be to quantify 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. E.g. 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 between 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 specific products like meat, cotton and palm oil[32], which have high impacts on the environment or biodiversity, may support policy makers with information about the relevance of these impacts in other regions. This information may be used regarding the 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 earlier in this report and on future research needs. As in many fields, one project can not resolve all problems. There is still active research 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, definitions, etc come into consideration.

6.2 Recommendations for implementation

6.2.1 The role of data providers

Today the situation for the analysis of environment and trade is still under development and somewhat patchy. It is driven partly from the environmental policy side, where the discussion on the environmental impact of consumption is in need of some 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, as they are designed to fit just the tool that is needed. This is good news in the sense that a theoretical framework is already in place. Through the work to build a common manual for the system, a good deal of harmonisation work has already been done. For some countries the first estimations are already in place.

However, the international system is still not under way. As is discussed in the previous chapters, there are already modelling exercises that make it possible to investigate the issue in a multi-regional input-output system. However, the models are to a large extent driven by non-governmental, synthetic data put together by researchers and projects rather than statistical offices. This is not a major problem right now, as the policy debate and policy uses of the analysis are still more on a conceptual than a concrete basis. It will become a crucial issue however, once 'tough' decisions have to be made, e.g. in the context of international climate policy.

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

As has been discussed earlier, the data situation for many of the economic statistics needed for the analysis is good compared to the environmental statistics situation. In the EU, it has been suggested that a statistics regulation of the SEEA would help to improve the data situation. The plans are to make the regulation come in place in the coming year or shortly thereafter. Previously the data were provided by gentlemen's agreement, and that has not proven sufficient to obtain a good coverage for the European countries. The specific details as to what data in the system will be collected are not yet decided. Air emissions have been in focus, and discussions on energy use and on economic instruments are also among the candidates for EU priorities.

In the context of concerted action, the 'Group of Four' (Go4) – Eurostat, together with DG Environment (DG ENV), the European Environment Agency (EEA) and the Joint Research Centre (JRC) – signed a Technical Arrangement establishing 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 about the relationship between resource use, economic growth and environmental impacts. While each of these Data Centres has importance for itself, also here a very important issue is that they are attuned to one another, in order to avoid double work as well as inconsistencies.

Another policy issue is to make sure that the institutions that need the results from these types of analyses, data and methods are active in setting up the national systems to ensure that future studies can be conducted. Also in this context it is essential that the main international institutions, such as the Go4, agree on one main methodology and common standards of data compilation, in order to ensure data consistency and to enable automating of the data collection. So far, still many national statistical offices move within the required standards, but these are too loose as to guarantee uniform data structure from different countries. This is the reason why we suggest to use the SEEA and SNA as starting point for the new 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.

The alternative is to develop IO tables outside the official departments. This is done in different ways, both inside and outside national agencies and Eurostat. In an ideal case – and this is actually aspired by the 'Group of Four' (DG Environment, Eurostat, the Joint Research Centre (JRC) and the European Environment Agency (EEA)), by means of the set up of ten Environmental Data Centres – inside and outside of official departments an agreement on a certain structure of data collection as well as processing is made which enables to synchronise and unify efforts.

In this context it has also to be ensured that countries produce and report IO tables and NAMEA data regularly. At the moment, the data collection in the EU+Efta area is based on a gentlemen's agreement. Plans are being made for putting a statistical regulation in place to make it obligatory to report.

A statistical EU+Efta regulation together with the existing manuals will improve the data situation for many countries. Still, it is foreseen that the data will need to be checked and that some countries will need more time than others to report. Resources and institutional structure is needed to ensure the consistency of the data.

The data provision from countries outside of Europe also needs special attention. The continuing coordination between European institutions and the UN, OECD, WTO, etc is important to ensure consistency of data compilation. Capacity building in developing countries to construct the necessary data will be needed. Such initiatives are being made, both on a national scale and from the UN, but more such activities are necessary.

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. One basic recommendation is to align the terminology, as it is likely confusing for people outside of the modelling world.

6.2.2 Stewardship for EIPOT analysis

In order to realise the implementation of methods as suggested by the EIPOT project a common framework and adequately funded institutional backing is needed. The development of methods will be a long-term commitment as new data, methods, definitions, etc come into consideration.

If the EIPOT type of analysis is to be useful for policy making there needs to be a strong institutional link between statistics, the research and the policy arena. Which institution would be most suited to ensure this connection? What criteria does a 'steward' for EIPOT-type analyses have to fulfil?

In the context of environmental policy, it is obvious that the Sustainable Development Strategy and all other sustainability policies of the European Union need to be based on factual evidence and data. The current environmental policies are mainly formed considering the obligations of nations or actors activities within the national borders. The initiatives to extend policy beyond the national borders have largely come from non-governmental organisations. The certified products, mainly agricultural products, which are being sold in eco-labelling schemes, are the best known examples of such policies.

As a result, it is essential that official bodies like the European Commission articulate what policy questions have to be answered. The questions to be answered by EIPOT and with the methodology suggested in the present report are only some of several of high relevance. As explained in Chapter 4, the EIPOT methodology would be useful in many ways.

The European Commission as a research funding body would be well suited to provide a link between EIPOT related research and policy applications.

The above mentioned Group of Four seems to be a well suited consortium to ensure the provision of data needed for EIPOT analysis based on EE-MRIO.

The SKEP consortium itself is another institution with a dual outreach to research and policy. Member States contributing to SKEP commit to enhance environmental research across Europe and the national funding bodies have direct links to environmental policy making (e.g. Environmental Agencies, Ministries for the Environment, etc). The SKEP consortium could engage in communicating needs from national and international policy makers to the Group of Four.

On a global scale it is also conceivable that bodies such as the IPCC could get interested in getting 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

Asking about the best method for measuring the environmental impact of trade flows does not mean that other methods will cease to exist. LCA, EF, etc will be productively around for many years to come and will have an important role to play in the future. As mentioned before, different methods generally answer different types of questions and maintaining a pool of methods allows for a wider range of question to be answered.

In the following, some specific areas are listed where further research is needed. Many of them are being addressed in the EXIOPOL project but it is very important that this research is continued beyond individual and current projects.

Hybridisation – although conceptually well described for some time, hybrid models combining IOA and LCA are still rare and empirical experience is thin.

Computation – the mathematical skills and computation tasks involved in global MRIO modelling are substantial. Systems with more than 1 billion variables – which are reached by models with high (>100) resolution of countries and sectors – will require a super computer to run. There are no precedences or experiences in this field of super-modelling so far.

Currency conversion – Future research should also look into 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; Peters et al. in press) 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. It should be investigated 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.

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

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

Including land use and types of management – There is a need for more data and harmonised methods to record the linkage between land use and traded goods. Important examples include the impacts of the use 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 that we have seen over the last years is an illusion. That is, whether the reduced environmental impact is merely an effect of the production moving to other countries which has not always to be the case. At least in Sweden it is easy to point out that there are concrete environmental policies and activities that have improved the situation in many ways. Air and water pollution has decreased because the environmental management and policy has really made a difference. Still, the high consumption level does imply a certain responsibility for the environmentally polluting activities in other countries. This responsibility is only partly the consumers', as the producers are often the people with the power to change the production methods.

In some studies, the environmental trade balance has been calculated, as a way to address the question above, of emissions being exported to other countries. The trade balance has often been calculated as the difference between the emissions from the imports and the emissions from the exports, or vice versa. However, the trade flow and the environmental pressures that are connected to them are more complex than what can be captured in such a number. 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 out of it, the solution for the Swedish studies has been to go back to basics and present the imported embodied emissions as a part of the environmental pressure connected to Swedish consumption. This presentation form relates the size of the embodied emissions to the normal national environmental goals, and thus shows it in perspective to a known figure.

As stated above, in addition to direct resource use, also 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 in order to calculate environmental pressures, such as material use, emissions, etc. 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 highest potential for increasing resource efficiency respectively.[33]

6.5 Summary of general recommendations

- We suggest the establishment of a 'steward' for analyses concerning the 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 Eurostat and Go4 could back the data provision, the Commission would be well suited to initiate and participate in the dialogue of how statistics, research and policy can be adequately integrated. The SKEP consortium could provide support to the Go4 with national research and policy needs.
- Several areas of research require long-term attention, including hybridisation of models, computational problems and widening the scope and linkages to other areas of interest.
- Therefore, a long-term research strategy is needed that coordinates and links the various research activities that contribute to EIPOT analyses (as is currently being done by the EXIOPOL project).

[33] For example, research undertaken by the Wuppertal Institute (Acosta-Fernández 2007) reveals that ten production sectors account for more than 50 % 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 provoke an increase in resource efficiency.

- 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.

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