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Evaluation of the Environmental Accounting Methods for the assessment of global environmental impacts of traded goods and services

IMEA Project

IMports Environmental Accounting

www.imea-eu.org
www.skep-network.eu

ERA-NET SKEP Project IMEA – IMports Environmental Accounting www.imea-eu.org

EVALUATION OF THE ENVIRONMENTAL ACCOUNTING METHODS FOR THE ASSESSMENT OF GLOBAL ENVIRONMENTAL IMPACTS OF TRADED GOODS AND SERVICES

FINAL REPORT

SEPTEMBER 2010

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Abbreviations

ALD	Actual Land Demand
BOP	Balance of Payment
BPS	Balance of Payments Statistics
CPA	Classification of Products by Activities
DALYs	Disability Adjusted Life Years
DMC	Domestic Material Consumption
DMI	Direct Material Input
DPSIR	Driving Forces Pressure State Impact Responses
EAM	Environmental Accounting Method
EE IO Analysis	Extended Environmental Input Output Analysis
EF	Ecological Footprint
ESA	European System of Accounts
EW-MFA	Economy-wide Material Flow Account
FTS	Foreign Trade Statistics
GTAP	Global Trade Analysis Project
HANPP	Human Appropriation of Net Primary Production
IOA	Input-Output Analysis
IOT	Input-Output Tables
IPP	Integrated Product Policy
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
MFA	Material Flow Analysis
MR EE IO	Multi Regional Extended Environmental-Input Output
SCP	Sustainable Consumption and Production
SNA	System of National Accounts

SUT	Supply and Use Table
TMR	Total Material Requirement

Partners

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Executive Summary

Context

Environmental accounting methods (EAM) are currently getting a strong interest from political entities, multinational corporations and citizens. EAMs are applied to a large range of socio-techno-economic activities for monitoring and managing their environmental performance over time: at macro-level to implement the environmental pillar of sustainable development, at meso-level for companies reporting and at micro-level for comparing the environmental footprints of products.

A number of Environmental Accounting Methods (EAM) have been developed so far: the differences in methodologies and data sets reflect the diversity of objectives and scales of analysis in environmental accounting. Each EAM has specificities resulting in its own strengths and weaknesses. All EAMs are nevertheless currently facing the same new challenges from the globalization of the economy. Analyses of environmental sustainability demands an interregional analytical framework: sustainability anywhere is linked, directly and indirectly, to sustainability elsewhere. Similarly, all EAMs face the same societal expectations including the provision of an adequate coverage of environmental preoccupations with scientifically valid indicators that can be further used in existing tools for decision-making.

The challenge of globalization advocates for the adoption of a so-called “true” global vision. This vision acknowledges that a sound development requires more than the straightforward extension of existing environmental assessments, e.g. of products or nations, to consider foreign impacts with a proper modelling of imports. Sustainable development is explicitly concerned with defining social welfare goals, and these goals are global as shown by the adoption of the United Nations Millennium Declaration. A straightforward extension would only be equivalent to implicitly adopting an importing country perspective, e.g. a European-centred perspective in the case of Europe. This appears inappropriate in a global vision because it does not put emphasis on local environmental problems which are often the first consequences of the production of traded goods. On the contrary, a global vision leads, for example, to recognizing that the acuteness of environmental issues differs according to local environmental conditions and existing local policies. Consequently, this vision questions the choice of a particular EAM: is this EAM applicable and relevant to a particular scope, scale, or location, etc. This vision also questions the feasibility and wish of obtaining valid assessments at worldwide scale for each of the existing EAMs considering the large costs of data collection and processing as well as modelling issues.

Providing an answer to this questioning is difficult today and requires a better understanding of the abilities of EAMs.

IMEA objectives & approach

IMEA project (IMports Environmental Accounting) is a SKEP-Era-net project (Scientific Knowledge for Environmental Protection) aiming at assessing the potential of EAMs to consider the challenges from globalization and environmental impacts linked to international trade. It was lead by MINES ParisTech/ARMINES with partners from the Institute of Social Ecology, Vienna, TNO, University of Oulu, and VITO, carried out between June 2008 and September 2009.

The global aim of IMEA is to provide elements to answer the following question: “Does a given EAM meet societal expectations and how does it cope with new challenges from globalization?”

To ensure a structured and comprehensive coverage of the issues, a detailed questionnaire has first been developed and filled for each of the EAMs based on expert knowledge and literature reviews at the beginning of the project. The questionnaire was based on 55 questions combined in seven categories. Results have then been discussed in a workshop with other experts from statistical offices and environmental agencies, researchers and environmental accounting specialists, held in Paris, on March 20th, 2009.

Analyses have been performed with this first analytical framework for the following EAMs: Life Cycle Assessment methodologies (LCA), Environmentally Extended Input Output Analysis (EE IOA), Material Flow Accounts (MFA) and Environmental footprints (land and water assessments).

Life Cycle Assessment (LCA) considers the entire life cycle of a product, from raw material extraction and acquisition, through energy and material production and manufacturing, distribution to use and end of life treatments (re-use, recycling, incineration and final disposal). Material Flow Accounting and Analysis (MFA) refers to the monitoring and analysis of physical flows of materials into, through and out of a given economic system, a national economy, a region or an industry. Environmental footprints assess the land and water usage related to human activities. Environmentally Extended Input Output Analysis (EE IOA) is the main approach used for environmental assessments at macro and meso-scales. EE IOA is based on a detailed description of the domestic production processes and transactions within an economy that can be extended by any type of environmental extension, e.g. resources uses or pollutants.

Four needs have been highlighted:

1. The need for a systematic assessment of EAMs based on a common framework enabling comprehensive assessments. Based on scientific and societal objectives, this framework should show when and how EAMs can be used or should be replaced by other EAMs providing similar indicators. This framework is based on an archetypical EAM workflow to understand how EAMs are structured and how they meet expectations and challenges along their steps. This framework is then detailed in a grid to allow for the analysis of any EAM.

2. The need for additional development to handle globalization with respect of data and methodologies including the combination of these methodologies to foster strengths and reduce weaknesses since each method has strengths as well as limitations. Existing methodologies are very different from one another and provide, for most of them, only a partial answer to the fairly extensive needs of decision-makers. The largely different levels of satisfaction in meeting expectations and challenges reveal their different orientations, the youth of these methods as well as the low cross-fertilization in their developments, each community developing its own ways of tackling issues.

3. The need to consider challenges from globalization from a “true” global perspective and not only from a technical one, through the extension of existing EAMs with a capacity to deal with imports. This issue has not really been dealt with yet.

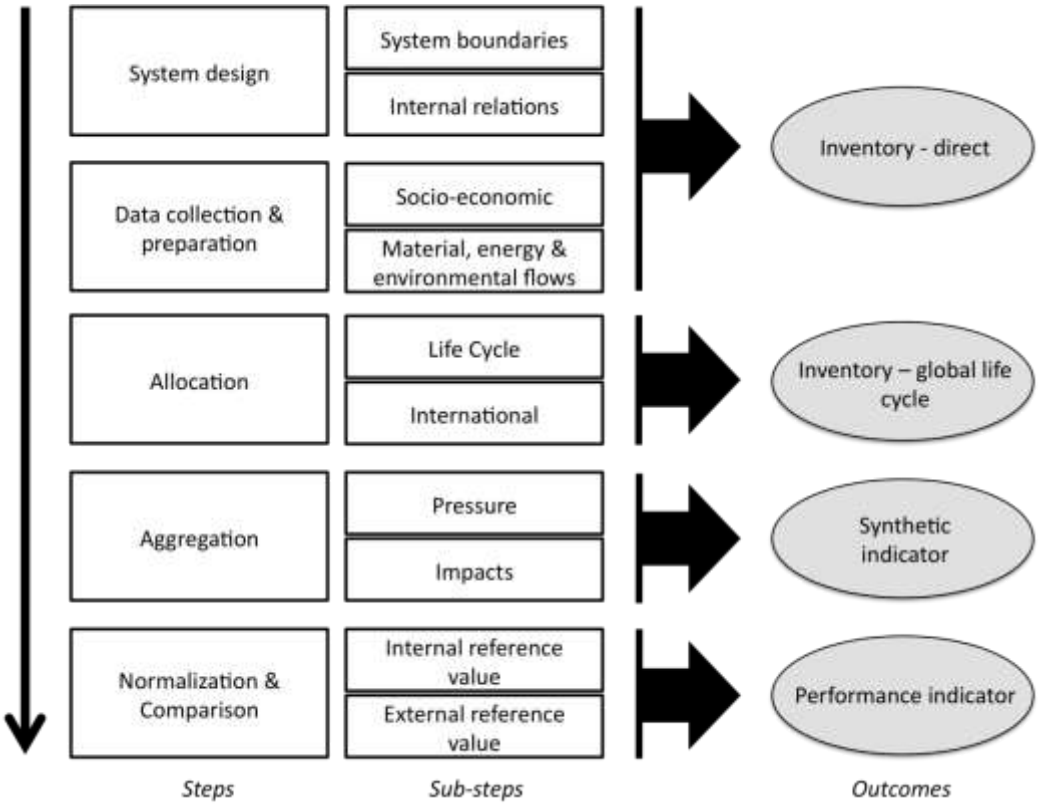
4. Finally the need for systematic methodological guidelines for all EAMs dealing specifically with identified key issues since environmental accounting is and will remain strongly based on assumptions, which need to be accepted and transparent to users.

Outcomes & Results

IMEA has focused on the analysis of these challenges based on what EAMs "are", "how" they function and the use of their results in decision-making by the means of an **archetypical workflow** and an **analytical framework**.

The archetypical workflow

An archetypical workflow has been elaborated for EAMS, including the four possible outcomes of EAMs, resulting from the explicit or implicit application of five steps (figure below). The first outcome is an "inventory – direct". This inventory is a collection of heterogeneous flows of the "direct" type, i.e. a classical inventory by source. This inventory is completed once the "system design" (step 1) and the "data collection and preparation" (step 2) are completed. Information from this inventory can then be re-allocated along global production-consumption chains in step 3 "Allocation" based on internal relations from the system. This results in a global inventory with a life cycle perspective (outcome 2 "Inventory - global life cycle"). In order to reduce the complexity and heterogeneity of the available information, one or several "synthetic indicator" can be generated by aggregating flows at the level of Pressure or Impacts (step 4). Eventually, the aggregated indicator is compared to reference values in the last step "normalization & comparison" (step 5), resulting in a "performance indicator" to ease decision-making.



Archetypical EAM workflow

The general fulfilment of societal expectations by EAMs and how they cope with the challenges from globalization has been performed for the most known EAMs[1], including some hybrid approaches. This analysis classified by outcome, clearly demonstrates a heterogeneous coverage of the outcomes by EAMs and obvious difficulties in meeting expectations and challenges.

The analytical framework

The work presented within this report has established the societal expectations and challenges from globalization faced by EAMs based on what they "are" and what they "do". Exploiting the conclusions of the IMEA workshop[2] and assessments of several EAMs, a comprehensive analytical framework has been proposed. This analytical framework is a balanced methodology-policy alternative to the RACER, proposed by the European Commission (European Commission, 2005) and applied by Best *et al*. in (2008) and Lutter and Giljum (2008), which has a strong policy orientation. This framework contributes to an objective analysis of the strengths and weaknesses of any EAM with respect to the mentioned issues as well as additional issues related to the use of results in decision-making as recommended by the workshop. This framework is structured along three axes: environmental accounting abilities, decision-making abilities and improvement potential. The first two axes are split into three dimensions, and each dimension provides an answer to specific issues:

Axis #1 Environmental accounting ability

1. Are the inherent qualities of the approach adequate to provide a sound coverage of the environmental issues globally?
2. Is the approach mature and auditable?
3. How are challenges from globalization tackled?

Axis #2 Decision-making ability

4. Is the approach usable?
5. Does the method provide a strong analytical potential?
6. Is the approach compatible or can be integrated with existing systems of indicators?

Axis #3 Improvement potential

7. How could be improved each of the first two dimensions?

Each dimension are then further decomposed into several characteristics, which are presented in the following table:

[1] Life Cycle Assessment (LCA), Economy-Wide Material Flow Analysis (EW-MFA), Physical Input Output Tables (PIOT), Material Inputs Per Service Unit (MIPS), Environmentally Extended Input-Output Analysis (EEIO), land use indicators like the Human Appropriation of Net Primary Production (HANPP), the Actual Land Demand (ALD) or the Ecological Footprint (EF), the Water Footprint (WF), and the so-called “Corporate Carbon Footprints” (CCF) based on the GHG protocol

[2] March 2009 in Paris – www.imea-eu.org

Objectives	Dimensions	Issues
Environmental accounting ability	Inherent qualities	Exclusive or best coverage of environmental issues
		Theoretical soundness
		Global life cycle perspective
		Explicit linkage between socio-economic activities and environment
	Maturity and auditability	Overall methodological consistency
		Methodological soundness : - System design - Data preparation - Allocation - Aggregation - Comparison
		Data sets reliability and completeness
		Transparency
	Adaptation to global challenges	Overall methodological consistency
		Methodological soundness : - System design - Data preparation - Allocation - Aggregation - Comparison
		Data sets extension, reliability and completeness
Decision-making ability	Usability	Intelligibility, univocity, acceptance
		Ease of use
	Analytical potential	Causal and structural analysis
	Comparability, compatibility, integration potential	Comparability and compatibility with other indicators (social, economic, environment)
		Compatibility and integration with existing accountings systems, international statistics and other reporting standards
Improvement potential	Improvements in environmental accounting	Inherent qualities
		Maturity and auditability
		Adaptation to global challenges
	Improvements in decision-making	Usability
		Analytical potential
		Comparability, compatibility, integration

Results & Recommendations

Based on this comprehensive analytical framework, the following EAMs. have been assessed in detail: Life Cycle Assessment, Economy-Wide Material Flow Analysis, Physical Input Output Tables, Environmentally Extended Input-Output Analysis, land use indicators like the Human Appropriation of Net Primary Production, the Actual Land Demand or the Ecological Footprint, and the Water Footprint.

The overall result is that a fully coherent global multi-scale and multi-criteria picture reflecting societal needs cannot be achieved currently because EAMs are still facing some un-resolved classical challenges and have only started dealing with challenges linked to globalization.

Life Cycle Assessment (LCA) considering the entire life cycle of a product, all upstream and downstream processes that can provide insight into trade flows (on a micro-scale) can be taken into account. The environmental indicators resulting from an LCA provide information on the magnitude of the impacts. They do not provide however use regional data for these assessments and do not report on the location of impacts.

LCA & the globalization challenge: improving regionalization

1. Identifying what level of regionalization is needed

   Regionalization is recognized as an important step towards improving the accuracy and precision of LCA-results with the inclusion of regional impacts, thereby increasing their discriminatory power for comparative assessments among different scenarios. Global impact categories have consequences that are independent of the emission location, such as global warming and ozone layer depletion. Other types of consequences, such as acidification or (eco-)toxicological impacts on humans and ecosystems, often occur as regional or local impacts, making the emission location an important factor. Clear guidelines should be developed that give an indication when regionalization in LCA-studies improve the quality and the uncertainty of the results in order to make sure that complex and regional-specific LCA-studies are only performed in cases that this has added value.

2. Developing guidelines and solutions for data gathering for Life Cycle Inventories (LCI) and development of situation-dependent and geographically differentiated characterization factors for the regionally- and locally-dependent impact categories (Life Cycle Impact Assessment, LCIA).

   Regionalization in LCA has two sides:

   1. Input flows: Materials and products that are imported from other regions and countries need to be taken into account. At this moment LCA common practice is limited to accounting the transport and to some extent foreign electricity production. The bottlenecks in this regard are the lack or limited availability of LCI-data for foreign production.

   2. Output flows: Emissions to air, water and soil contribute to environmental impact categories, that can be of global, e.g. climate change, regional or local nature (e.g. acidification, eco-toxicity). Characterization factors in LCA are usually global in nature and as such create an uncertainty in the LCA results for those impact categories that are not global in nature. Accounting the regional impacts of emissions needs regional characterization factors (CFs). Research projects focus on the development of such regional characterization factors, but until now such CFs are still under development.

3. Extending Database for Developing countries

   This aspect relates to data availability for foreign production. Numerous materials are extracted in developing countries (e.g. Africa) and the import of materials/products from e.g. China is booming rapidly. To include the regional environmental effect of e.g. extraction of minerals in Africa and production of steel in China, data for these processes are needed. LCI-databases focus on industrialized countries, and there is a need to include also LCI-data from developing or emerging countries.

LCA is a method that focuses on the life cycle phases and that is not compatible with national accounts. LCA is a systemic analysis enabling identification of trade-offs between scenarios. The LCA method is widely used across the world, but its applications are mainly limited to a micro level (product level) and to a lesser extent a meso level (sector level).

Coupling of LCA with import and export statistics is difficult and not common practice. One important opportunity of LCA is the link with EE-IO analysis in what is called ‘hybrid analysis’. This would offer a lot of potential with regard to extending the current environmental analysis at a micro scale to a meso and macro level.

LCA could allow a life cycle based analysis of trade issues as well as trans-boundary issues, however at this moment limited data availability and the absence of generally accepted regional characterization and normalization factors restrict its application. The availability of both data for foreign production and regional characterization factors is a prerequisite to include imports and trans-boundary issues in LCA-results.

Material Flow Accounting and Analysis (MFA) using uniform basic physical quantities, mass units, entails a clear interpretation and enables the ease of use of MFA indicators. However the drawback is that mass unit does not provide any qualitative differences between the material flows. MFA indicators inform thus on a **generic environmental pressure** of the material flows. Eurostat collects economy-wide MFA time-series, where primary raw materials are classified in detail, but fabricated products are classified very roughly. Information on imported goods should be developed.

EW-MFA & the globalization challenge: developing an open database for environmental accounts of imports

- For the EU as a whole and for each of its member countries the time series of imports and exports collected and maintained by Foreign Trade Statistics (Cometex) in monetary and mass units, can be used as a basis to complement Eurostat datasets with information on trade.

- For raw material imports, LCA-type estimates of rucksack coefficients should be developed at detailed product classification level for both products produced in EU countries and for products produced outside EU. The coefficients represent the indirect use of used and unused extraction.
- For fabricated products not included in raw materials, information should be collected from input-output studies, e.g. from the European project EXIOPOL[3], when the results will be available. Indirect resource use coefficients should be converted from kg/€ units into kg/kg units.
- For fuel purchases of international transports and for tourism consumption abroad, there is no information yet. Pilot studies should be started in order to develop appropriate estimation methods and to produce first rough estimates.
- Harmonized estimation practices for indirect resource use of imports and exports of services should be developed

Environmental footprints generate a great interest, demonstrated by the widespread adoption of the Ecological Footprint (EF). Despite this interest, each of the methods has strengths and weaknesses, and further work must be done before they can be reliably used to assess traded flows.The methods described in this report have enabled great progress in the assessment of land use. However, the central question of measuring environmental pressures, or, yet more challenging, impacts, associated with land use remains. Actual land demand (ALD) and the EF do not measure pressures; The Human Appropriation of Net Primary Production (HANPP) measures a specific pressure. In terms of the micro-meso-macro scale, all of these methods can only account for national average pressures: for instance, there is no differentiation between impacts associated with traded products from conventional and organic agriculture.

[3] EXIOPOL is developing a new environmental accounting framework using externality data and input-output tools for policy analysis http://www.feem-project.net/exiopol/index.php

Environmental footprints & the globalization challenge: coupling indicators with IO methodologies

Both the EF and HANPP can improve their treatment of traded products by:

- allocating traded goods to their country of origin,
- applying upstream factors which relate to the production conditions in that country (rather than global factors, or in the case of the EF, using upstream CO_2 emissions as the only relevant factor in traded goods). The water footprint and ALD already do this.

This process is already performed by the water footprint and ALD would involve using bilateral trade data, which is data intensive (and not always reliable, since exports and imports don't balance at the global level). The most important development for land use indicators is the systematic use of bilateral trade data, along with appropriate national conversion factors.

Establishing national-level factors for the EF might prove extremely challenging, since even at the global level these factors are far from certain. This is related to the insistence of the EF of adapting non-land use phenomena (such as fossil-fuel emissions or nuclear power) to hectare equivalents: such factors are, per definitionem, impossible to measure accurately, since they do not correspond to occurring physical processes. Moreover, these factors are dynamic, since the terrestrial sink capacity is affected by land use history, such as deforestation.

All environmental footprints methods would benefit from a combination with Input-Output approaches, to:

- assess immaterial transactions, like services, which have upstream environmental implications,
- accomplish structural analysis or causal chain analysis.

Hybrid methods or cross-checks with Input-Output and LCA may also be desirable. One central challenge (common to many methods) is the "re-export effect" or "harbor effect", where the country of export and the country of origin of a traded product are not the same. The land use and water use methods are relevant to the country of origin, but trade data records the country of export. Multi-Region Input-Output (MRIO) may be one approach to dealing with this issue.

Environmentally Extended Input Output Analysis (EE IOA) can be extended by any type of environmental extension, e.g. resources uses or pollutants.

EE IO & the globalization challenge: develop a global database

A Multi-Regional EE IO approach is probably one of the best approaches to take impacts of imports into account:

1. It uses a global perspective, and takes into account issues like that components of products made in another country themselves can come from another country
2. It shows not only the pollution embodied in imports, but also *which countries* suffer most environmental impacts by consumption by other countries;
3. The approach is inherently comprehensive: the total global environmental impacts are a starting point, and distributed over the final consumption in the world, wherever it occurs;
4. Provided that a comprehensive set of environmental extensions is included, a great variety of indicators can be supported, including LCIA, ecological footprint, and material flow indicators.

Yet, the main problem is there are significant limitations in existing data sources. Key problems in the current data sources are that most provide Supply and Use tables (SUT) and Input Output Tables (IOT) for single countries, without trade links. Sector and product detail is not as good as it ought to be. Environmental extensions are often lacking or include only a few types of emissions and primary resource uses.

At present, only the GTAP[4] (Global Trade Analysis Project) database comes a bit in the direction of the ideal, but is hindered by the fact that it was never built for environmental purposes and does not contain environmental extensions. Individual practitioners have added some emissions to their versions of the GTAP database for analytical purposes. For the future, the EXIOPOL project may result in a fairly comprehensive and detailed database for MR EE IO analyses, with data for one base year but a potential for updates.

Fundamentally, one cannot expect even in future that the sector detail of an MR EE IO will be more than 100+ sectors per country. This implies that MR EE IO in all cases only can be a supplementary tool at micro level (individual products). Further, in its present form MR EE IO inherently uses economic allocation of impacts, which may deviated from physical allocation. Also this may be a problem, again most prominent at micro level.

For the future, the EXIOPOL project may result in a fairly comprehensive database for MR EE IO analyses, with data for one base year.

The approach has however a number of inherent limitations:

- It is not realistic to expect that IOT or SUT will become available on a global scale with a much higher sector or product resolution than 100-150;
- The basis of EE IO is economic accounting; which implies that all impacts are economically allocated to final consumption and other economic activities, rather than on the basis of physical causality or other ways. Simply said, the price-quantity relationship may differ between uses of the output of a product or sector;
- Even when the data situation is improved, time lags may occur with regard to data reporting;
- The practical data situation is far from ideal, and probably the greatest bottleneck;
- There is a number of technical problems due to the fact that inherently a global database always will be based on certain assumptions; a main problem probably is the estimation of transport margins (including transport modality) and insurance margins on trade flows, and particularly the allocation of such margins to the country that delivers the transport or insurance service. This is a special case of the problem that statistics on trade in services (e.g. next to trade and insurance services also tourism) tend to be less reliable than of product trade.

Combining EAMS: the hybridization opportunities & challenges

The still recent but increasing trend toward the combination of EAMs, called hybridization, encourages exchanges and should help in the achievement of expectations and challenges. Hybrid methods shows better fulfilment of both expectations and challenges than the original methods. The main form of hybridization is a combination of EAMs with input-output tables.

[4] https://www.gtap.agecon.purdue.edu/

Provided that the limitations expressed earlier are dealt with, the full trade Input Output Analysis solution, based on Multi-Regional Input-Output (MRIO) models with enough sectors, appears to be an essential part of any solution that will be designed in the future. This recommendation is also identified with the orientation proposed by SKEP EIPOT project (Wiedmann et all, 2009):

- Firstly, additional research and data development should be performed to deal with issues like the bridge between price and quantities, exchange rates and the rapidly economic and technology structures.
- Secondly, the environmental extensions considered should cover issues that are relevant in each region. IOA is however not accurate enough for decision-making at micro and lower-meso-scales where it can only provide a first approximation. It should therefore be complemented by additional bottom-up methodologies, either on an individual basis or through the development of additional hybrid approaches. Such types of hybridization are however still in development stage and require additional development before a potential implementation on a large scale.

. Five ways of combination have been identified:

1. **IOA is combined with bottom-up approaches** to extend system boundaries and get more detailed results, i.e. in the tiered hybrid analysis, Input-Output based hybrid analysis and integrated hybrid analysis.
2. **Input-output tables are extended with additional direct environmental requirements**, e.g. material or water use, to ease the computation of indicators, to get a life cycle perspective, or to deal with the challenges from globalization.
3. **Already computed indicators are combined with IOA to extend results to additional scales,** e.g. to the meso-scale, or to translate results into consumer activities as in the EF approach with Consumption Land Use Matrices.
4. **IOA is used to compute conversion coefficients that are later used in the EAM**, e.g. indirect material use of products in MFA.
5. **EE-IOA are combined with aggregation methods, like LCIA, generating synthetic indicators**.

A benefit from the integration within an input-output framework is the increased comparability of results with socio-economic indicators developed within the System of National Accounts (SNA) (United Nations, 1993). The downside of such practice is however that IOA is subject to large biases because it cannot always adequately represent the underlying physical nature of flows. IOA performs all computations, including allocation, in monetary units and convert results, in a last step, in physical units with the help of environmental factors, for example CO_2 emissions per dollar. The extension of an existing EAM with IOA is thus potentially weakening the robustness of results generally previously based on physical rationales.

Methodological guidelines for EAMs

The effectiveness of future databases and methodological development in answering these needs and tackling challenges in a cost-effective way could be potentially improved in three ways:

i) establishing profiles of goods and of regions to better define which data is needed in which context

ii) optimizing the methodological and data collection effort by concentrating on the few relevant solutions and geo-localized data in each context, rather than aiming at developing catch-all applicable solutions and databases, and

iii) speeding up the access to adequate EAMs by adopting a modular view of EAMs to take the best solutions in existing methodologies and improve these elements through cross-methodology research groups focusing on specific issues.

1 Introduction

1.1 Background and IMEA Challenges

Human activities influence the environment, the magnitude of changes being locally-dependent. There is a need to quantify this influence in order to support decision processes in policy-making, in corporations and for citizens. Environmental accounting is a means to measure these interactions between the environment and the socio-economic sphere, such as the quantities of energy, matter and water used, climate change or impacts of pollutants on ecosystems, for all scales relevant in a decision-making process.

A number of Environmental Accounting Methods (EAM) has been developed so far: the differences in methodologies and data sets reflect the diversity of objectives and scales of analysis in environmental accounting. Each EAM has specificities resulting in its own strengths and weaknesses. All EAMs are nevertheless currently facing the same new challenges from the globalization of the economy. Analyses of environmental sustainability demands an interregional analytical framework (Kissinger & Rees, 2009): sustainability anywhere is linked, directly and indirectly, to sustainability elsewhere. Similarly, all EAMs face the same societal expectations including the provision of an adequate coverage of environmental preoccupations with scientifically valid indicators that can be further used in existing tools for decision-making.

The challenge of globalization advocates for the adoption of a so-called “true” global vision. This vision acknowledges that a sound development requires more than the straightforward extension of existing environmental assessments, e.g. of products or nations, to consider foreign impacts with a proper modelling of imports. Sustainable development is explicitly concerned with defining social welfare goals (Ekins et al., 2008) and these goals are global as shown by the adoption of the United Nations Millennium Declaration (United Nations, 2009). A straightforward extension would only be equivalent to implicitly adopting an importing country perspective, e.g. a European-centred perspective in the case of Europe. This appears inappropriate in a global vision because it does not put emphasis on local environmental problems even though these problems are among the first consequences of the production of traded goods. On the contrary, a global vision leads, for example, to recognizing that the acuteness of environmental issues differs according to local environmental conditions and socioeconomics conditions. Consequently, this vision questions the choice of a particular EAM: is this EAM applicable and relevant to a particular scope, scale, or location, etc. This vision also questions the feasibility and wish of obtaining valid assessments at worldwide scale for each of the existing EAMs considering the large costs of data collection and processing as well as modelling issues. Providing an answer to this questioning is difficult today and requires a better understanding of the abilities of EAMs.

1.2 Objectives of the project

This study is attempting to bring answers to the following questions:

1. What is currently achievable with existing EAM and data sets and what are the methodological and data improvements required to get consistent information for:

   a. Accounting and reporting with respect to identified environmental issues

   b. Potential of analysis related to the socio-economic system

2. Which methodologies or combination of methodologies are most suited to account for trade and trans-boundary issues ?

3. Can we combine existing methodologies to consider the diversity of issues with respect to locations and products environmental profiles?

A comprehensive, global environmental accounting framework capable of assessing the impacts of EU imports will require the combination within a common framework of the existing inventory and impact methodologies to determine what has to be assessed, what is the best way to do it and which methodological progress and data set are required.

The IMEA objectives therefore are :

- A comprehensive critical analysis of several environmental accounting approach and the study of each separate methodology as well as their hybrid uses.

- A coherent framework and guidelines for an integrated methodology for assessing the environmental burden of imports. The framework considers strengths and weaknesses of each methodology, its recommended field of applications (product and country coverage) and the existing quality and availability of data to determine the potential role of each approach. We have considered whether they can be combined in a unique modeling framework or if parallel assessments are required to cover the extent of environmental issues pertinent to imports. The link with existing state-of-the-art projects have been made and concrete guidance for their improvement for application to imports are now emphasized. This framework has been presented and discussed during a workshop organized in Paris in March 2009 with other experts from statistical offices and environmental agencies, researchers and environmental accounting specialists.

- Formulate recommendations for research and policy-makers towards developing a robust environmental assessment of European imports. The proposal, taking into account environmental and political priorities, both in Europe and in main trade partners countries, will consider both the further methodological and data research needs. The recommendations are based both on results of the project and on discussions with funding agencies at the workshop and subsequently.

1.3 Structure of this report along IMEA approach

The global aim of IMEA project is to provide elements to answer the following question: “Does a given EAM meet societal expectations and how does it cope with new challenges from globalization?” One possible answer to the question would have been to perform a detailed analysis of each EAM separately. We have opted here for a more synthetic analytic approach.

We firstly detail the expectations and challenges faced by EAMs (section 2.1). These expectations and challenges affect EAMs at each step of their workflow realisation; consequently, we have performed a meta-analysis of current EAMs and subsequently, identified the main characteristics of EAMs with respect of “what” they are (section 2.2) and “how” they work (section 2.3).

For each characteristic, we identify the various answers brought to expectations and challenges and their level of satisfaction. We obtain a descriptive framework that brings a structured answer to how the identified expectations are met and challenges are tackled for any EAM. This framework is used in section 2.4 to perform a global analysis of several EAMs and conclude on the general fulfilment of expectations by EAMs and how they cope with challenges from globalization.

We propose then an analytical grid for reporting on these aspects for any EAM in chapter 3. This grid is built around three axes: accounting abilities, decision-making abilities, and improvement potential. Our work is a meta-evaluation of the performance of EAMs, as defined and applied for example to sustainability indicators by Ramos & Caeiro (2009). This work complements, with an analytical perspective, the current development of environmental accounting methods towards the inclusion of non-domestic environmental impacts with a proper modelling of imports like in multi-regional approaches (Hertwich & Peters, 2009; Tukker *et al.*, 2009) or towards combining different EAMs (Kytzia, 2009; S. Suh *et al.*, 2004; T. Wiedmann, 2009) to go beyond known limitations of current EAMs.

To ensure a structured and comprehensive coverage of the issues, a detailed questionnaire has first been developed and filled for each of the EAM based on expert knowledge and literature reviews at the beginning of the project (Appendix 2) and filled on each of the EAM studied in IMEA project (Appendix 3, 4 & 5). The questionnaire was based on 55 questions combined in seven categories.

Results have then been discussed in a workshop with other experts from statistical offices and environmental agencies, researchers and environmental accounting specialists, held in Paris, March 20th 2009.

The description and discussion of EAMs along this first analytical framework have been performed and are reported for Life Cycle Assessment methodologies in chapter 4, Environmentally Extended Input Output Analysis in Chapter 5, Material Flow Accounts in Chapter 6 and Environmental footprints (land and water assessments) in Chapter 7.

The archetypical workflow and the analytical framework contribute to IMEA results as well as the recommendations for additional development to handle trade with respect of data and methodologies (Chapter 8).

2 How are EAMs meeting societal expectations and challenges in a global economy?

2.1 Constraints from societal expectations and challenges from globalization

2.1.1 Societal expectations

Societal expectations towards EAMs are framed by expectations towards environmental assessments, themselves framed by the concept of sustainable development. This concept states that the three dimensions (environment, social and economic) of society should be considered of equal importance and that a coherent vision considering them individually, and in their interactions, should be aimed at (World Commission on Environment and Development, 1987) although integration remains a medium- to long-term objective.

The first set of expectations and of subsequent operational constraints results from the search for coherence in the implementation of this concept. A coherent vision calls for integrated, or at least compatible, accounting frameworks allowing a comparison of indicators calculated in the three dimensions. Accounting frameworks should also evidence interactions between these dimensions (Ness *et al.*, 2007). The linkage between human activities and environmental impacts has, for example, been explicitly modelled by the DPSIR model adopted by the European Environment Agency (EEA, 1997). Based on a chain of causality, it links human Driving-Forces to Pressure on the environment, changes of environmental State, resulting Impacts on ecosystems, individuals or communities and eventually human Responses to correct the situation. Svarstad *et al.* (2008) show the limits of this framework used to provide and communicate knowledge on the state and causal factors regarding environmental issues.

The modelling of linkages is also desirable in socio-economic activities. A systemic view like a life cycle perspective helps in better estimating impacts of entities, activities and products. Lenzen *et al.* (2007) show how this view can provide different schemes to attribute responsibilities. The European Union is, for example, increasingly adopting plans and policies based on such perspective, e.g. the Sustainable Consumption and Production and Sustainable Industrial Policy (SCP/SIP) Action Plan (European Commission, 2008). A life cycle perspective allows the quantification of the total environmental load of a socio-economic activity by accounting for the direct, upstream and downstream environmental loads along the whole production-consumption chain of an activity (ISO, 2006a). This perspective is unusual for socio-economic indicators which leads to difficulties for comparing indicators between dimensions.

Coherence is also attained by measuring environmental pressures using multiples measures at multiple scales, as reflected in the definition of environmental accounting by the United Nations Statistics Division. The United Nations (1997) describe environmental accounting as physical and monetary accounts at the national and corporate levels. The EPA (Spitzer & Elwood, 1995) or the BSI (2008) extend this definition further in order to deal with other objects, such as products and services. Environmental Accounting is however only one of the several strategies followed for assessing the environmental dimension of sustainable development. These strategies differ in the degree of comparability between their indicators but all recognize the need for multiple environmental measures covering energy, material, water and

pollutant flows. Assessments range from sets of heterogeneous indicators on key environmental issues, e.g. the EEA core set of indicators (EEA, 2005) or the United Nations indicators of sustainable development (UNCSD, 2001) to approaches incorporating environment aspects into existing economic assessments to deliver a unique indicator, like the green GDP or the Genuine Progress Indicator (Daly & John B. Cobb, 1989; Dasgupta, 2009). Semi-integrated accounting frameworks, like the Integrated and Economic and Environmental Accounting (SEEA) (United Nations, 2003) represent the middle way: they extend existing economic accounts with satellite accounts sharing the same structure. Mayer (2008) and Singh *et al.* (2009) review a large number of sustainability assessment methodologies, broader than the environmental dimension. Bebbington et al. (2007) describe approaches in monetary terms like the Sustainability Assessment Models.

The second set of expectations comes from the objectives of accounting frameworks to provide valid indicators (Nardo *et al.*, 2008) and the abilities of the latter to undergo further analyses. Environmental accounting frameworks are expected to provide a theoretically sound and synthetic view of the high number of environmental flows induced by the socio-economic sphere. The overall methodological soundness of an EAM, *i.e.* the scientific validity of its principles and methodological steps underlying the construction of a final indicator as well as its acceptance by the scientific community, are thus crucial societal expectations. Beyond their use as a “descriptive […] structured body of information that describes a system”, EAMs are also expected to extend this neutral representation of past facts with additional assumptions for delivering analytical tools for decision-making (M. de Haan, 2001; Peskin, 1998). Pedersen & de Haan (2006) show how physical flow accounts based on national accounts can provide analytical advantages. The ability of EAM results to undergo further analyses like causal analysis, path analysis (Fernandez-Vazquez *et al.*, 2008) or structural decomposition (Wier, 1998) permits to reveal the main components of, and the causes behind, an aggregated indicator describing a complex system, increasing the potential for decision-making.

Finally, expectations are expressed on the usability of an indicator for decision-making. An indicator is of practical use for decision-making if it is relevant with respect to objectives, intelligible, delivering a clear message and accepted. In addition, results should be reproducible according to common guidelines by statistical offices, timely and cost-effective (Nardo *et al.*, 2008; Thomas Wiedmann *et al.*, 2009). Intelligibility means that an indicator can be understood without difficulty by decision-makers, citizens and consumers; it is related to the message of the indicator and to its units. Univocity is a characteristic related to the clarity of the message delivered by an EAM to decision-makers. A message is clear when the message can be interpreted as good or not good. An unclear message can be due e.g., to multiple indicators showing contradictory signals in the case of multi-criteria assessments, or indicators not related to any reference value. Univocity is thus here traded-off against a larger coverage of environmental issues represented by multiple indicators: univocity may mask the true complexity of environmental challenges. The acceptance of an indicator helps its implementation and its establishment as a reference. Acceptance is here measured with respect to the acceptance by the political, economic and social actors. Ease of use is an essential characteristic since EAMs are based on a complex workflow for computing one or several final indicators. This implementation is expected to be feasible by public bodies in order to ensure their involvement and therefore the indicators effectiveness. This implementation should not rely on scientists only, in order to fully implement the passage from science to application and ensuring a large dissemination.

These three sets of societal expectations (sustainable development, accounting and decision-making) comprise nine societal expectations summarized in Table 1 (left part). These nine expectations are labelled *exp. 1* to *exp. 9* in the rest of the report. In regard of the expectations, this table lists also the

challenges from globalization that are discussed hereafter. These expectations and challenges represent the constraints faced by assessment methodologies to achieve the purposes of sustainability assessments as defined by Kates *et al*. (2001): " the evaluation of global to local integrated nature-society systems" (Singh *et al.*, 2009).

		Societal expectations	Main challenges from globalisation
SD	1	Comparability -> integration with indicators and accounting frameworks	Comparability within an interregional accounting framework
	2	Explicit linkage between socio-economic activities and the environment	Cross-boundary pollutant transfers & regional impact computation
	3	Life Cycle perspective	Global chains
	4	Multi-criteria/indicators perspective	Regional significance of criteria, new criteria (e.g. water)
	5	Multi-scale perspective	Relevance of scales & bridging between scales
Accounting	6	Soundness (theory, models and data)	Soundness of imports assessment (production and trade)
	7	Analytical capabilities	New analytical capacities to answer globalisation issues
Decision-Making	8	Usability of indicators	Cost-effectiveness of global indicators
	9	Relevance to objectives	Europeo-centered or 'local in global' perspective

Table 1 Summary table of main societal expectations and challenges from globalization faced by EAMs.

SD stands for Sustainable Development.

2.1.2 Challenges from globalization

Challenges from globalization –labelled C1 to C9 hereafter, are affecting EAMs in their ability to report on sustainable development, accounting and decision-making capabilities. As the world economy evolves towards more integration, production-consumption chains are becoming international and even global due to the dynamics of relocation (off-shoring) and reorganization (outsourcing) of activities (Abonyi, 2006). This integration results in a parallel shift of environmental impacts. Ghertner & Fripp (2007) evidence, for example, the shift associated with the goods consumed in the USA to other countries through trade. Consequently, there is a need for an interregional accounting framework and a life cycle perspective in this context must be global and should consider this geographic fragmentation (C3).

Kissinger & Rees (2009) identify the needs to quantify inter-regional relationships: *i)* the volume of material exchange between regions, *ii)* the quantities of physical inputs employed to produce goods for trade and *iii*) the direct & indirect negative ecological impacts on the producer and exporter. We generalise these needs as needs for a proper modelling of international transport, international trade in goods and services, and regional production structures with their inputs and outputs flows. A large amount of data and new models are thus required. Due to their global reach, these data and models differ in availability and in quality, affecting the robustness of EAMs results. This is the challenge C6 "soundness of imports assessment". The computation of the relevant ecological impacts is the challenge C4. As mentioned in the introduction, globalization implies the development of indicators which were not crucial in a European context but are crucial for some new trading partners, like water footprints, which are currently entering into a first phase of normalisation (Chapagain & Hoekstra, 2008). This computation requires, for some EAMs, to handle two more key features: the cross-boundary transfer of environmental flows through environmental media (air, water and soil) and through additional pathways like food products, as well as the foreign/regional characteristics of the regions of impact (C2). Jolliet *et al*. (2008) show that the magnitude of global pollutant transfers through food is comparable to air transfer for some pollutants. Huijbregts (1998) and Potting & Hauschild (2006) describe that methodological variations and local specificities result in up to three order of magnitude for acidification and eutrophication between European

regions. Globalisation thus requires regional information. Some EAMs, like the Human Appropriation of Net Primary Production (HANPP) are inherently regional since they are partly built on geo-referenced data sets (Haberl *et al.*, 2007) but most of them require specific developments, which are still in infancy. Mutel & Hellweg (2009) show how to regionalise life cycle assessments with existing data sets based on available geographic information. Raugei & Ulgiati (2009) show an example of accounting with a global perspective for Life Cycle Assessment (LCA) and Material Flow Analysis (MFA) but however without location-dependant data. Finally, though not only originating from globalization, an essential challenge (C1) is the compatibility and comparability of indicators from this interregional accounting framework with existing indicators.

Reporting is intrinsically linked to objectives and underlying values since 'indicators arise from values and create values' (Meadows *et al.*, 1972). The definition of these objectives and the implementation of a "true" global vision is a challenge for decision-makers, particularly in western economies, but also for the developers of EAMs. Should European-centered indicators be designed or should a truly global perspective be adopted (C9)? Should methodologies be modified to allow evaluating and reporting on these locally important environmental issues even if they are not perceived as key issue when looking at aggregate measures? How to model and represent this so-called "local in global" perspective? De Haan (2002), proposes an overview of indicators designed to measure the indirect requirements of a national economy including cross-boundary transfers of environmental flows, as well as a comprehensive 'environmental balance of trade' of the Netherlands.

As a result of the large amount of additional data and models needed, the cost-effectiveness of EAMs is an important issue (C8). Recognising that not all indicators are relevant in each region at each scale, some thinking seems to be required on the identification of the complementarities and redundancies between existing EAMs as well as on the scope of relevance (scale and region) of each EAM (C5). Best *et al.* (2008) compare, for example, the existing indicators of land use for the European Commission. In other words: should everything be measured everywhere at every scale or should assessments be adapted to local conditions, scales and goods specificities, hence to local and good environmental profiles? In addition, is it possible to reduce data needs by establishing bridges between scales to re-use existing databases or results from studies?

Eventually the question of the capacity of existing analytical tools provided by EAMs to answer these questions and others in a context of globalization should be asked (C7). Should new solutions be developed in addition to data sets and models to be able to tackle the challenges from globalization or are existing ones adequate? New approaches are apparently needed in some EAMS: Peters & Hertwich (2006) propose a path analysis on Multi-Regional Input-Output models to provide linkages between the global production networks linking consumption and production. Friot & Antille (2009) propose an underlying flow decomposition to analyse the structural causes of emissions within an MRIO model.

2.2 Environmental Accounting Methods: What they are

Environmental Accounting Methods (EAMs) are not defined in a formal way. We propose here a definition based on the discussion on expectations from the previous section. EAMs are defined as any accounting methodology allowing quantifying, synthesizing, analyzing, comparing and communicating the environmental performance, expressed in physical terms, of any activity, or group of activities, according to a life cycle perspective in a way that is suitable for decision-making. We describe now what EAMs "are" and their subjects with three properties relevant to our purpose: the scale of their final indicators, the methodology design of socio-economic entities and activities, and the environmental focus.

The scale of final indicators depends on the main objective for which an EAM has been initially designed. Environmental accounting methods are applied for monitoring and managing the environmental performance over time of a large range of subjects: entities and the outcomes of their activities, e.g. products and services. We group these entities into three categories: political entities bounded by geographic boundaries, economic entities and social groups. Each category is split into three scales: the macro-scale, the "upper-meso-scale" and the "lower-meso-scale". The macro-scale consists of nations, domestic economies and populations; the upper-meso-scale consists of regions, sectors and sub-populations groups, while the lower-meso-scale consists of smaller regions or cities, companies or sites and people or households, as shown in Table 2. We reserve the "upper-micro-scale" to describe production processes. Outcomes such as products, products services, and tertiary sectors services are at the "lower-micro-scale".

	Socio-economic entities			**Activities outcomes**
	Political	**Economic**	**Social groups**	
Macro	Nation	Domestic economy	Population	
Upper-meso	Region	Sector or industry	Sub-population	
Lower-meso	Small region	Company / site	Individual / household	
Upper-micro		Production processes		
Lower-micro				Products, products services, tertiary sector services

Table 2: Classification of subjects of EAMs, grouped by type (entities and outcomes) and scale.

The methodology design of socio-economic entities and activities in EAMs takes two ways: top-down and bottom-up, meaning a way downward or upward in scale. Top-down approaches begin at the highest level, formulating first an overview of the system, specifying but not detailing any first-level sub-systems. Each sub-system is considered as a "black box" which can be refined in greater details. Due their high level of aggregation, these approaches are mainly applied to describe large entities, at macro- or meso-scales and in the case of the description of an entire system, can provide assessments characterized by completeness. The coherence when dealing with lower scales is ensured through the availability of macro-scale totals. Bottom-up approaches are taking the opposite approach. They piece together detailed

systems to give rise to larger ones; the original systems become sub-systems of the emergent system. Very detailed and accurate if based on reliable data sets, these approaches are however incomplete by essence since a limit has to be set, with a cut-off rule, on what to include in the analysis, leaving out some elements. The difficulty to guaranty the coherence of an assessment performed by adding results based on bottom-up approaches is a well know issue. Lenzen (2008) lists a number of policy and decision-making frameworks that make use of life cycle techniques, where this double-counting error is highly undesirable and proposes a potential solution to this double-counting problem.

Entities and activities generate environmental flows subject of the “environmental focus” property. These flows are numerous and multiple classifications exist. OECD (2008a) proposes a usual two-categories classification: “resources-oriented” and “pollutants-oriented”. We extend this classification by splitting resources-oriented approaches into three categories: “mineral and fossil fuels resources”, “land and biomass” and “water”. We also include specifically carbon emissions by adding a fifth category, that we call “global warming-oriented”. All five categories bring complementary information in multi-criteria assessments. Pollutant-oriented approaches deal with flows of substances, e.g. chemicals or heavy metals, into air, water and soil. Global warming-oriented approaches account for greenhouse gases and their global warming potential: they are currently the most used approaches.

We propose a classification of the most used EAMs using the three properties (scale of final indicators, methodology design and environmental focus) and comment on insights that can be earned from this classification regarding expectations and challenges faced by EAMs. The analysed EAMs are listed in Table 3. Included are Life Cycle Assessment, Economy-Wide Material Flow Analysis, Physical Input Output Tables, Material Inputs Per Service Unit, Environmentally Extended Input-Output Analysis, land use indicators like the Human Appropriation of Net Primary Production, the Actual Land Demand or the Ecological Footprint, the Water Footprint, and the so-called “Corporate Carbon Footprints” based on GHG accounting. Finnveden & Moberg (2005) propose another classification of most of these EAMs based on their characteristics, the type of impacts included, their object of study and whether these studies are descriptive or change-orientated. We do not include here any EAM based on the combination of EAMS, also called hybrid methodologies, developed to overcome EAMs limitations.

Acronym	Full name
LCA	Life Cycle Assessment
EW-MFA	Economy-Wide Material Flow Analysis
PIOT	Physical Input Output Tables
MIPS	Material Inputs Per Service Unit
EE-IOA	Environmentally Extended Input-Output Analysis
HANPP	Human Appropriation of Net Primary Production
ALD	Actual Land Demand
EF	Ecological Footprint
WF	Water Footprint
CCF	Corporate Carbon Footprints

Table 3: List of the EAMs analysed with acronym.

The results of the classification are reported in Table 4. For each cell, we indicate which EAMs have been designed for the specific values taken by each of the three properties: scale of the final indicator, methodology design and environmental focus. The literature reports applications of EAMs at scales close to those for which they were initially designed; in that case, it is assumed that the original assumptions hold though less accurate and consequently, the use of such EAMs is still valid. These cases are indicated by small-scale italics. Grey cells indicate the absence of specifically-designed EAMs.

		Mineral and fossil fuels resources	**Land & biomass**	**Water**	**Global Warming**	**Pollutants**
Top-Down	macro	EE-IOA, EW-MFA, PIOT	EW-MFA, EF, HANPP, ADL	WF	EE-IOA, EF	EE-IOA
	upper-meso	EE-IOA, PIOT	EF, HANPP		EE-IOA	EE-IOA
	lower- meso	*EE-IOA*			*EE-IOA*	*EE-IOA*
	upper-micro					
	lower-micro					
Bottom-Up	macro		*EF*	*WF*		
	upper-meso		*EF*	*WF*	CCF	
	lower- meso	*LCA, MIPS*	*EF*	*WF*	CCF, *LCA*	*LCA*
	upper-micro	LCA, MIPS	LCA, *EF*	LCA, WF	LCA	LCA
	lower-micro	LCA, MIPS	LCA, *EF*	LCA, WF	LCA	LCA

Table 4: Classification of EAMs based on the three properties

scale of the final indicator, methodology design and environmental focus. Small-scale italics indicate applications of EAMs found in the literature that are at scales for which they were not initially defined. Grey cells indicate the absence of specifically-designed EAMs.

The large number of grey cells in Table 4 shows a lack of adequate coverage for some environmental issues at several scales: a fully coherent multi-criteria multi-scale perspective is not achieved by any EAM neither by the ensemble of EAMs.

A second observation arising from this classification is that none of the EAM except for the Ecological (EF) and Water Footprints (WF) has been designed for assessments from upper-micro- to macro-scale. These two applications have however been recognised as lacking robustness and are being replaced by top-down approaches for assessments at macro-scale (Hoekstra, 2009). Among the top-down EAMs, only EE-IOA and PIOT are effectively top-down since providing indicators at several scales. EW-MFA and land use indicators could be extended to lower scales by combining them with EAMs providing an internal description of socio-techno-economic relations like EE-IOA like in (Giljum *et al.*, 2008) and in (Turner *et*

al., 2007). LCA also include such a detailed description of a system within a bottom-up approach. Both EE-IOA and LCA can be applied at different scales and be complemented with any type of environmental flows: material, land, water, carbon or pollutants. While LCA is already including many of these flows, this is still not the case for EE-IOA, except in some countries like the USA (S. Suh, 2005) but development is undergoing (Tukker *et al.*, 2009). Considering the environmental factors used in EAMs, rather than the description of socio-economic economic entities and activities, provide however another picture. The EF and MIPS use national factors at the "bottom-up" levels and are thus not truly bottom up, but in fact top down applied to smaller scales. LCA is similar for some processes like electricity mixes. Indeed, none of the methods except HANPP use regionally appropriate information and can thus be applied at the regional level based on regional data.

A third observation is that the lower-meso-scale, i.e. the scale of companies, is not the original focus of any of the methodologies except for Corporate Carbon Footprints. This reflects the complexity of making an assessment with a life cycle perspective at company level and the lack of interest, up to recently, for methodology development at this scale (T. Wiedmann *et al.*, 2009). The only standardised and robust Corporate Carbon Footprints (CCF) are focusing on direct emissions (except for electricity) only (WRI & WBCSD, 2004). Schaltegger & Burritt (2000) describe concepts and issues of environmental accounting at the corporate level.

While some bridges can be established to overcome the lack of data at given scales, for example between macro- and upper-meso-scales in the case of top-down approach, or between lower- and upper-micro-scales in the case of bottom-up approach, the bridge with lower-meso-scale cannot be achieved in any case without strong assumptions. Bottom-up approaches are often used for the description of specific products and services. Going upwards in scale requires designing generic groups of products at lower-meso-scale and identifying a representative specific product for each of them. This generalization of specific results can however be inaccurate unless the specific goods described are close to the expected average of the groups. Top-down approaches face the opposite problem: they can deliver information up to a generic group of products but the linkage with specific products is difficult because of the diversity of products included within a group, even with very detailed top-down approaches (Tukker *et al.*, 2006).

A last observation is that several scales and environmental focus are dealt with by more than one EAM in table 4. While this classification could be refined in this purpose, it shows which EAMs may compete with each other since they deal with the same type of flows: substitutions between these EAMs may be further researched. On the contrary, others EAMs should probably be used together in a basket of indicators since they provide complementary information.

2.3 Environmental Accounting Methods: How they work

We concentrate now on the characteristics of “how" EAMs work and how they meet expectations and challenges with the help of an archetypical EAM workflow covering all steps required from EAMs to meet these expectations. This workflow, shown in Figure 1, draws on, and extends, the description of a Life Cycle Assessment (ISO, 2006a) and the approach by Mayer (2008) to analyse issues of sustainability indices.

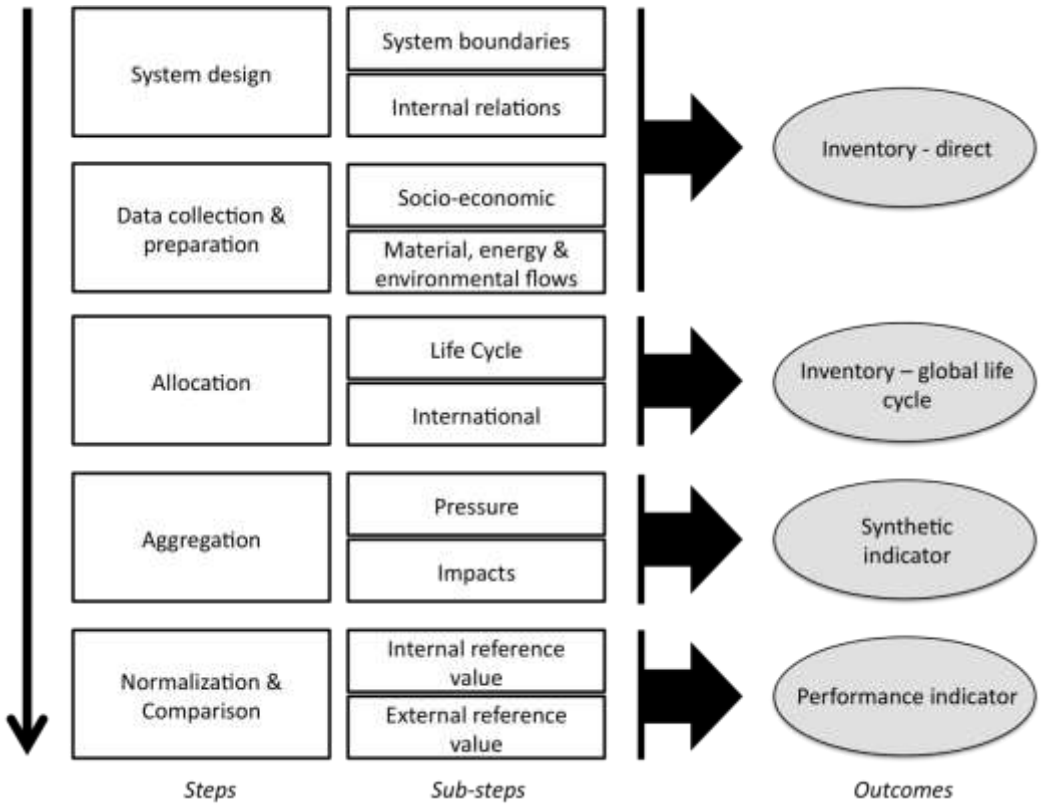


Figure 1 Archetypical EAM workflow.

Steps and sub-steps are described on the left part of the scheme and the resulting outcomes on the right.

Four possible outcomes of EAMs, resulting from the explicit or implicit application of five steps, are considered. The first outcome is an “inventory – direct”. This inventory is a collection of heterogeneous flows of the “direct” type, i.e. a classical inventory by source. This inventory is completed once the “system design” (step 1) and the “data collection and preparation” (step 2) are completed. Information from this inventory can then be re-allocated along global production-consumption chains in step 3 “Allocation” based on internal relations from the system. This results in a global inventory with a life cycle perspective (outcome 2 “Inventory - global life cycle”). In order to reduce the complexity and heterogeneity of the available information, one or several “synthetic indicator” can be generated by aggregating flows at the level of Pressure or Impacts (step 4). Eventually, the aggregated indicator is compared to reference values in the last step “normalization & comparison” (step 5), resulting in a “performance indicator” to ease decision-making.

2.3.1 System design

"System design" consists in describing the socio-economic system considered in the assessment of an entity or the outcome of an activity. The system boundaries must consider environmental-society interfaces and boundaries between societies. Setting the boundaries of a socio-economic system determines the type of environmental flows that should theoretically be included in an inventory to eventually compute an indicator that is assumed representative of the system described. The relations within a socio-economic system describe how the components of a system are connected through their inputs and outputs.

System design plays a key role since it influences the rest of the EAMs steps, and thus their capacity to meet expectations. Expectations of soundness (exp.6 in Table 1) and comparability (exp.1) in a modelling context, i.e. a context characterized by simplification and truncation are described here. The expectations of a life cycle perspective (exp. 3) and analytical capacities (exp. 9), also strongly influenced by the system design are described in other steps.

A review of the problems of setting boundaries is provided for LCA and Input-Output Analysis by Reap (2008a). We add here additional elements related to the type of rationales applied to set boundaries between socio-techno-economic activities and issues linked to boundaries between these activities and the environment.

Two types of rationales can be applied to set boundaries: physical and socio-economic rationales. Physical rationales are usually established specifically for environmental assessments, e.g. in the ISO 14044:2006(E) for LCA (ISO, 2006b). Suh *et al.* (2004) recommend to set cut-off criteria depending on the importance of the expected contribution of an activity to the total environmental load, mass or energy within a system. The cut-off is thus applied, at the "end" of production chains (upstream or downstream). On the contrary, socio-economic rationales used in approaches like IOA have other original aims: since their original goal was a representation of the economic system alone, the environmental relevance of their system boundary must be considered. In IOA for example, boundaries are set between the activities of economic and non-economic agents or between observed and non-observed economy, i.e. underground, illegal or informal activities (OECD, 2002).If a large informal economy is not included, the level of truncation of the modelled system may therefore be large and not be environmentally relevant. In a context of globalization, where underground activities can be a large part of some developing economies, and thus of related environmental flows, this aspect increases in importance. This issue adds to the challenge of setting proper geographic boundaries in top-down approaches that Lenzen (2001) qualifies as potentially as important as issues linked to cut-off in bottom-up approaches.

Comparability between indicators is possible when the indicators cover the same underlying reality: their system boundaries with respect of socio-techno-economic activities are consistent with one another. Indicators at macro- and upper-meso-scale can be compared between studies because boundaries of socio-economic nature are based on an internationally agreed framework, the System of National Accounts (SNA) (United Nations, 1993). The potential for comparisons at upper-meso-scale is however reduced for two reasons. First, the implementation of this framework varies between countries: the international classification of sectors ISIC is, for example, regionalised differently in the EU (NACE classification) and in the USA (NAICS classification) resulting in potential inconsistencies between studies based on these classifications. Second, even in the case of countries using the same classification, like NACE in Europe, similar activities are classified differently since economic structures are different: the degree of vertical integration of sectors influences, for example, this classification (Eurostat, 2001).

International comparisons with monetary values also face the well-know issues of dealing with market exchange rates and purchasing power parities (Eurostat & OECD, 2006; G. P. Peters & Hertwich, 2007). In bottom-up studies, system boundaries which may be similar in theory are implemented on a case-by-case basis and comparability between different studies and with socio-economic indicators is thus strongly reduced.

The second type of boundaries, between activities and the environment is of importance when assessing the compatibility of resource-oriented accounting frameworks with economic frameworks. Several environmental resources are economic primary inputs and are thus accounted both in economic and environmental approaches. In the SNA, the limit between the national economy and the natural environment is defined by a distinction between produced assets, belonging to the national economy, and non-produced assets, part of the national environment. According to ESA (ESA 6.06) (European Communities, 1996), vineyards, orchards and any growing crops are thus produced assets: they are however considered as part of environmental flows by some resource-oriented EAMs like MFA, leading to potential inconsistencies.

2.3.2 Data collection & adaptation

The “data collection & preparation” step consists in collecting data on socio-economic activities and the related environmental flows, and adapting it to conform to the system description, to eventually generate the final data sets used for the assessment. Data sets can be generated for one or multiple periods. A reliable and complete final data set is a clear expectation for generating sound results with an EAM (exp. 6). Challenges from globalization question the usability of indicators (exp. 8) due to the already mentioned very large data needs. The reliance on few trade data sets of questionable reliability is also a challenge to overcome.

Final data sets are always an approximation resulting from multiple computations steps like the application of conversion factors, e.g. for the conversion from dry to wet biotic resources in MFA, or the matching between different classifications to join data sets, e.g. to go from categories of environmental requirements by source to categories related to socio-economic activities, or the use of proxies in case of missing data (Eurostat, 2003). The reliability and completeness, without gaps, of collected data as well as the robustness of preparation steps and their assumptions determine thus the reliability and completeness of the final data sets. Since these preparation steps are usually performed before practitioners use data, their documentation is important for evaluating the soundness of an indicator. The full documentation of these steps, including limitations, is however not current practice even if guidelines exist for some EAMs and some data sets include uncertainties. Some methods have been proposed to assess data quality, like the data quality matrix proposed by Weidema for LCA (1998) that could be used for this purpose. Björklund (2002) surveys approaches to improve reliability in LCA with uncertainty analysis and this survey is valid for other EAMs. The application of these methods is however not a current practice according to the literature and further developments are required to ensure that users have a proper understanding of the limitations of the indicators from EAMs.

A global perspective set new challenges for delivering such data sets by extending their spatial, temporal and technological coverage with respect of socio-economic activities and extending the type of flows included to better represent environmental concerns in developing countries. An extensive spatial coverage has two advantages. First, establishing assessments from the viewpoints of a large number of countries, and second a better modelling of traded goods by considering the characteristics of each country of origin along production chains. An extensive temporal coverage means a possible identification

of time trends or up-to-date data sets through frequent updates. A frequent update is crucial for the evaluation of countries experiencing rapid structural, energetic or legal changes, or production activities based on emerging or fast evolving technologies like genomics or nano-technologies. A low spatial and temporal coverage may be compensated through modelling of missing data with detailed knowledge of the different technologies and their inputs, for example energy sources, and their outputs. An extensive spatial and temporal coverage is not yet the rule for both bottom-up and top-down approaches even if large efforts have been pursued in this direction for the last few years. Data is also lacking for many technologies, particularly new ones.

Reliability is particularly an issue in an international context because of the quality of trade data, an essential element of any top-down model. Trade data is among the oldest and better-collected data for custom taxes reasons. The development of bilateral trade matrices using databases from the OECD or the United Nations is however still a challenge. Inconsistencies are linked to the treatment of re-exports, inconsistent mirror trade, the conversion from product classifications to industry classifications, unallocated trade data (second-hand goods, waste), or issues related to the measurement of international trade in services as well as differences of definitions in compiling trade statistics (Gou *et al.*, 2009). Some autors like Feenstra *et al.* (2005) have thus developed harmonised data sets that are freely available. Oosterhaven *et al.* (2008) and Bouwmeester & Oosterhaven (2008) developed a methodology to link these data sets to input-output frameworks. Few harmonised data sets are however available. As a result, all indicators including these data sets face the same, potentially important, limitations. In addition, an adequate treatment of some key issues, like the end-of-life stage or packaging, with global models is currently not possible. Dietzenbacher (2005) explains, for example, the limitations of waste treatement in monetary input-output models compared to physical input-output models.

2.3.3 Allocation

The allocation step aims at applying a global, or at least international, life cycle perspective to a direct inventory to compute the total, i.e. direct and indirect, environmental requirements of some selected components within a system. Information on the direct inputs (e.g. use of materials, energy) and direct outputs (e.g. emissions) by the components of a system is here aggregated along global production-consumption chains by using the information on relations between these components.

This step is a direct implementation of the expectation of a life cycle perspective (exp. 3) and questions occur with respect of the expectation of soundness (exp. 6). We split the allocation step in two sub-steps to describe separately the capacity for implementing a life cycle perspective (Allocation – life cycle) and the capacity for tackling the challenges of considering production chains on a global scale (Allocation – global). Challenges from globalization are related to the soundness (exp. 6) of models and to the pivot role of goods and services for assessments at any scale (exp. 5).

Two types of allocations can be performed in this step: the virtual allocation of the embodied environmental requirements along a production chain (Ahmad & Wyckoff, 2003) and the effective transmission of the embedded, i.e. contained in a good, requirements along a production chain, like, plastic in a TV set or dioxin in prepared food products for example. The allocation of the embodied requirements represents the typical use of allocation, which is to compute the environmental load along a production chain up to a stage, e.g. resources requirements for producing a TV set.

Allocation – life cycle

The capacity for implementing a life cycle perspective depends on the necessary availability of the information on relations within a system, as mentioned under system design, and on the robustness of the so-called "allocation rules". A large stream of discussion has been undergoing in the life cycle assessment community on this type of allocation, summarised by Reap *et al.* (2008a).

A distinction between EAMs can thus be established on these two elements, the availability of relations and the robustness of allocation rules. First, some EAMs can integrate an allocation while other cannot. Macro-scale approaches do not model internal relations unless they are also designed for the upper-meso-scale. They can thus provide only a simplified life cycle perspective, distinguishing between direct and indirect environmental flows when data has been collected as such. Micro approaches, built-up around relations between elements are meant to provide a life cycle perspective, but may entail large extrapolation errors when their results are applied at a macro scale. Second, we propose to evaluate the robustness of the allocation, when it is feasible, by looking at the rationales used for splitting information at one point of a chain into the subsequent different downstream production chains. Two types of rationales can be used: physical or monetary rules. These rules are required each time an activity, e.g. cattle breeding, produces several products: milk, meat and skins in this case. In the case of embedded requirements, allocation should clearly follow a physical causality. On the contrary, several strategies using non-causal relationships based on physical and monetary rationales can be applied to allocate the virtual embodied requirements, resulting in different causal chains and responsibilities. Ekvall & Finnveden (2001) analyse these non-causal relationships for LCA and find that they do"…not accurately reflect the effects of actions".

Both physical and monetary rationales are currently used for allocating embedded and embodied environmental requirements. While physical rationales are usually preferred to monetary ones since they reflect the underlying physical flows better, monetary allocations are common for two reasons. First, they are adequate in the case of a co-production where the co-product is produced only because of the production of a main product having the main economic value. Second, they simplify the allocation procedure when monetary information is easily available. In the allocation of embedded requirements, monetary allocations are based on the strong assumption that they mimic physical relations. This is not always the case and is particularly inadequate when dealing with parts of production chains having a very low price, e.g. waste and goods for recycling. The same comment can be made when allocating embodied requirements with a monetary allocation unless the assumption is clearly made that causality and responsibility are well expressed by economic value. In our viewpoint, the choice of an allocation scheme is clearly subjective and linked to an objective. Since various objectives can be pursued, there is a need to inform on the objective since results can vary largely between allocation schemes.

Allocation – international

Globalization entails new allocation challenges, often at the lower-micro scale.

The robustness of international allocation depends on the availability and quality of data and models for estimating the embodied and embedded environmental requirements of imports. These estimates, as described in section one, are based on the modelling of foreign production structures and related flows, and on the modelling of trade, both of which present challenges.

At macro- and upper-meso scales, different strategies have been applied to overcome the lack of data with respect to foreign production structures when estimating the total requirements of imports; they differ

in the amount of data used and in their robustness (Figure 2). Wiedmann *et al.* (2007) and Peters *et al.* (2007) provide a review of the different types of strategies, based on IOA, used in this purpose. We draw on these descriptions here. The simplest strategy is to assume a similarity between foreign and domestic production and emissions structures (case 1 in Figure 2). This can be acceptable in the case of a large economy producing most of its inputs and for some type of assessments but is inadequate for a largely open economy where several extraction and industrial activities do not occur. Recent studies have shown that this strategy is inadequate when performing an assessment at the level of impacts even for large economies with a low openness to trade. The three other strategies differentiate foreign production and emissions structures but differ in the way trade is considered: partial trade (case 2 and 3), and full trade (case 4). In the second strategy, production chains are purely domestic and the environmental requirements of exchanges are based on environmental trade balances. In the third strategy, international productions chains are partially modelled but only on a bilateral basis: this solution is adequate when the trade partners of the economy of interest are not trading a lot together and in a world without global production chains. The fourth strategy considers global production chains and is the most appropriate. Due to the increasing amount of data required from strategy one to four, the first ones have been largely privileged so far. Only few models (Multi-Regional Input Output models) are now considering global productions chains, listed in (Tukker *et al.*, 2009). These models are however relying on monetary rationales: limitations with respect of robustness previously mentioned apply thus here with some additional ones. First, these assessments are subject to the high variability of exchange rates. Second, the necessary use of nominal exchanges rates rather than purchaser power parities in these models renders even more apparent the potential inadequacy of a monetary allocation in an international context.

The modelling of trade is, in addition, still inadequate in this type of models because of the lack of information on the use of imported goods and services within an economy. Imports are usually allocated to industries by assuming a hypothesis of similarity between the products of different origins (Tukker *et al.*, 2009). Each sector importing the same good is thus importing the same modelled product which is a weighted sum of the different origins. The fact that industries are rather importing from a region rather than from another is therefore levelled out. The robustness of the whole international allocation is thus to be questioned and would benefit from studies on different countries and sectors. The lack of robustness of this allocation is particularly critical in some cases, for example when estimating the embedded transfer of pollutants through the food chain, requiring causal relationships, for an assessment at the level of impacts with a global perspective.

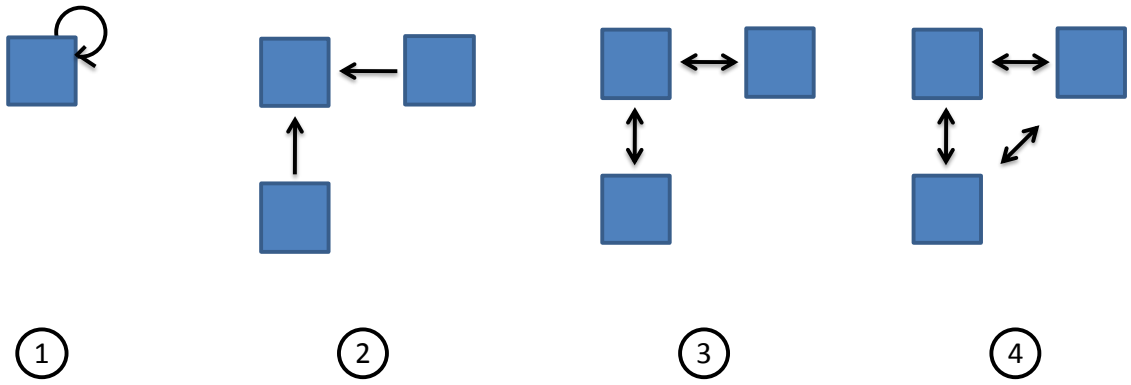


Figure 2 Four strategies of modelling global production chains.

Boxes represent countries and arrows represent trade.

At micro-scale, the situation is not better because only few studies consider the global dimension explicitly, and only up to the second strategy in figure 2. In the first strategy, which is common practice, the same technology is assumed everywhere and the supply chain of foreign processes is similar to the domestic one. In the second strategy, different technologies are assumed but the full production chain of each of the inputs is thought of in terms of origin only: there are no international production chains. These international chains are introduced partially in strategy 3, and fully in strategy 4, which tremendously increase the amount of data required. As a result, while bottom-up studies are judged being more accurate than top-down approaches, this accuracy is however lowered in an international context with tightly integrated global production chains because of their large data needs which are usually not satisfied (Sangwon Suh & Huppes, 2005).

Interestingly, the extension of a life cycle perspective to a global scale is introducing a lower-micro-scale into macro-studies since the assessment of exchanges between countries requires the estimating the total environmental requirements of traded goods and services. The modelling of traded goods and services affect thus the assessments at all scales. The consequence for purely macro approaches is that the robustness of the allocation mechanism they adopt influences the overall robustness of the method, particularly for originally physical based methods adopting an international allocation based on a monetary method like IOA which is the dominant one.

2.3.4 Aggregation: Pressure & impacts

The aggregation step aims at reducing complexity by aggregating the heterogeneous environmental flows from an inventory to provide a synthetic indicator for decision-making (exp. 8). Most EAMs are designed to synthesize information from inventories through an aggregation of input and/or outputs into a reduced number of categories. This aggregation, whether implicit or explicit, is mostly performed with a weighted average of the various values as shown by (Singh *et al.*, 2009) in their overview of sustainability assessment methodologies. The robustness (exp. 6) of weighting schemes is the first concern (Nardo *et al.*, 2008). We propose to classify weighting schemes based on the categories from the DPSIR framework and on hypotheses of similarity. Challenges from globalization are linked to the capacity to deliver indicators at the level of impact in an international context.

Two different categories of the DPSIR framework, Pressure and Impacts, are applied to define two types of aggregations. The first one, so-called “aggregation – pressure” contains two sub-types using either a similarity of physical units or similarity of potential effects hypothesis. This aggregation can be applied to resource oriented and pollutant-oriented approaches. The second type of aggregation is the so-called “aggregation – impacts” mainly used for pollutant-oriented approaches. It assumes a weighting based on a hypothesis of the similarity of potential damages on some areas of protection like human health or ecosystems (Olivier Jolliet *et al.*, 2003).

Pressure categories differ from Impact categories by only describing environmental flows without specifying the exact environmental influence these flows entail. Impact categories attempt to go one step further and describe the specific environmental consequences of certain flows (a process which is inherently uncertain and incomplete, since far from all environmental influences are understood or well quantified). Since some environmental impacts in turn influence the socio-economic system, the impact category may thus provide additional insights on indirect environment-society relations and existing and potential feedbacks. Beyond the fact that several existing aggregations schemes rely on scientifically disputed assumptions, the more they are aggregated down the chain of the DPSIR, the less accurate and

less robust the assessments.. End-points categories have thus higher levels of uncertainty than the mid-points categories in Life Cycle Impact Assessment (LCIA) (UNEP, 2003). Some scientific aggregation scheme, such as the aggregation of greenhouse gases effect based on their radiative properties, are available but others are still lacking standardisation (Udo de Haes *et al.*, 2002). Blanc *et al.* (2008) show the interest of applying such a scientific scheme in the case of sustainable environmental indices. Non-scientific weighting schemes are also used based on explicit or implicit societal preferences, for example when using measures of willingness to pay (Reap *et al.*, 2008b), trading off robustness with societal objectives.

The robustness of aggregation in an international context depends on the use of additional information in pollutant-oriented approaches: the availability and quality of data and models for estimating the effective cross-boundary transfer of pollutants through environmental media (air, water and soil) and information on local conditions. Models like EMEP in Europe have shown that a large part of the pollutants deposited in Germany are, for example, of foreign origin (Klein *et al.*, 2007). Only few models are available for modelling the transfer of the large number of existing pollutants and even fewer for the long-range modelling. Damage factors are also scarce outside Europe and nonexistent for large numbers of widely used substances. Reap *et al.* (2008b) review extensively the limitations of life cycle impact assessment among which the selection of impact categories, the data gaps with toxicity-related impact categories or the spatial variations and locations uniqueness.

2.3.5 Comparison & normalisation

The “comparison & normalisation” step aims at delivering a performance indicator to inform decision makers of the performance of the synthetic indicator compared to a reference value. References values can be internal, i.e. calculated within the EAM, like the sum of impacts or a threshold, or external, e.g. legal limits, targets, or an indicator from another dimension of Sustainable Development. These references have an influence on the overall soundness of the results (exp. 6). Challenges from globalization are related to the change of perspective discussed in section 1, the so-called “local in global” perspective and the way of representing it.

Internal reference values are used in two different ways: for normalizing results in order to compare the performance of different indicators, e.g. in LCA, and for comparing a synthetic indicator to limits computed within an EAM, e.g. in the EF. The validity of the performance indicator is obviously dependent on the validity of the internal reference value, which itself can be based on different data sets and methods than the previously computed synthetic indicator. Internal references values have however the advantage of being submitted to the same scientific validations procedures applied to EAMs while this is less current for external reference values which are not necessarily resulting from a scientific process. External reference values have the advantage of being not subject to EAM limitations in terms of calculations. Some comparisons with external references value are however clearly not possible due to different system boundaries, resulting in meaningless performance indicators. The use of EAMs in decision-making would clearly gain from further research and guidelines on the choice and soundness of potential internal and external reference values to ensure the soundness and better use of performance indicators.

Reference values are clearly linked to the objectives of an assessment. These objectives are challenged by a global view as mentioned in the first section. From an environmental point of view, a truly international perspective should acknowledge the different environmental profiles of regions. A final indicator should report on the environmental issues that are priorities in each region along a supply chain even if they are not dominant from a global perspective. Normalization should therefore be specific to

each region and indicators should report specifically on each of them to know where corrective action is the most needed. None of the approaches surveyed are applying such principle yet and it is unclear that it will be applied since the choice of a reference basis is intimately linked to a policy focus.

2.4 Meeting societal expectations and global challenges: an overview for some EAMs

This section discusses the general fulfilment of expectations by a non-exhaustive list of EAMs and how they cope with the challenges from globalization. An overview of results is presented, classified by outcome, in Table 5. These results complement the first results and issues presented in Table 4 with respect to scale, environmental focus and methodology design.

The list of EAMs presented here differs from the list presented in Table 4. The LCA approach is split into two components: a Life Cycle Inventory (LCI) and Life Cycle Impact Assessment (LCIA). Three versions of the IOA approach are proposed following the discussion in “Allocation – international”: a single country EE-IOA, a partial trade EE-IOA and a full trade EE-IOA.

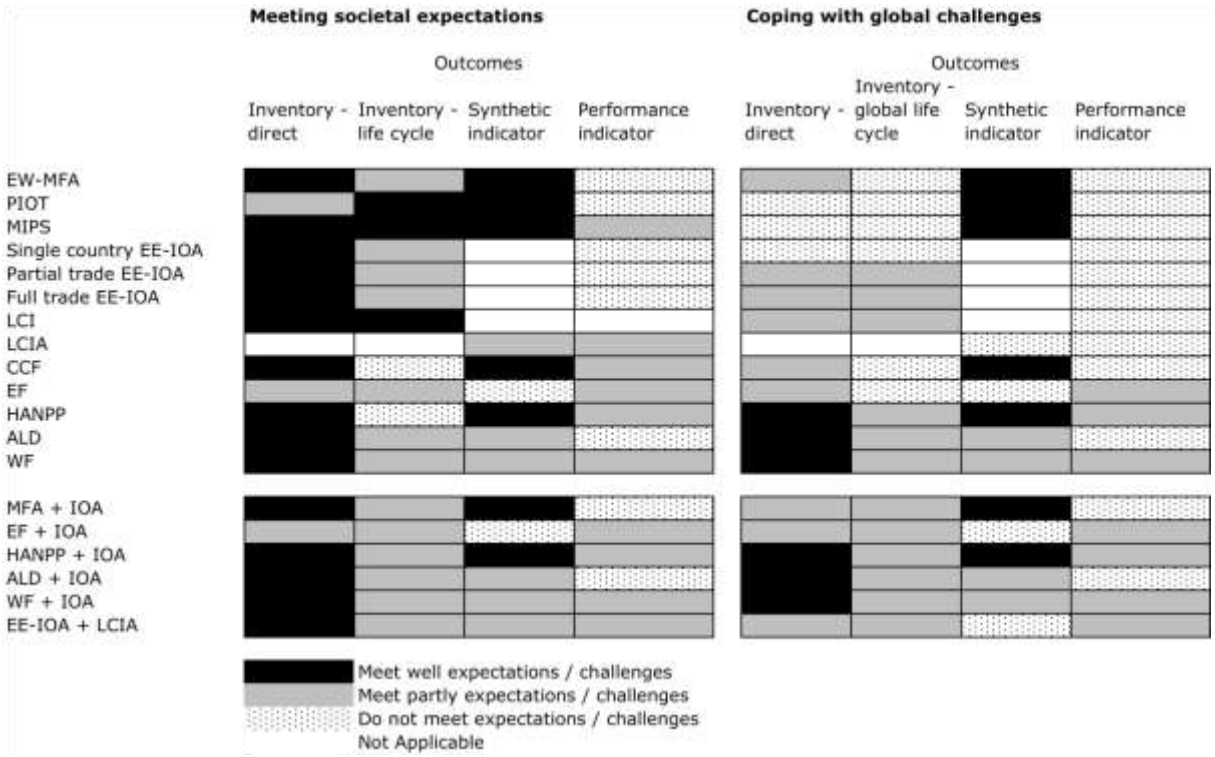


Table 5: General fulfilments of expectations, classified by outcomes, by several EAMs and how the EAMs cope with challenges of globalization.

Table 5 clearly demonstrate a heterogeneous coverage of the outcomes by EAMs and obvious difficulties in meeting expectations and challenges. Existing methodologies are very different from one another and provide, for most of them, only a partial answer to the fairly extensive needs of decision-makers. The largely different levels of satisfaction in meeting expectations and challenges reveal their different orientations, their relatively recent development (for the EF or the ALD), as well as the low cross-fertilization in their developments, each community developing its own tools and own ways of tackling issues. The widespread use of EAMs plays also a role: PIOT and MIPS are not much developed or used. Their capacity to meet the new challenges from globalization appears thus reduced.

The still recent but increasing trend toward the combination of EAMs, called hybridization, encourages exchanges and should help in the achievement of expectations and challenges. This is evidenced in Table 5. The lower part deals with hybrid methods and shows better fulfilment of both expectations and challenges than the upper part dealing with the original methods. For example, EE-IOA + LCIA appears to meet at least partly all societal expectations and all challenges, except for “synthetic indicator”.

The main form of hybridization is a combination of EAMs with input-output tables. Five ways of combination have been identified. In the first way, IOA is combined with bottom-up approaches to extend system boundaries and get more detailed results, i.e. in the tiered hybrid analysis, Input-Output based hybrid analysis and integrated hybrid analysis described by Suh & Huppes (2005). In the second way, input-output tables are extended with additional direct environmental requirements, e.g. material or water use, to ease the computation of indicators, to get a life cycle perspective, or to deal with the challenges from globalization. In the third way, already computed indicators are combined with IOA to extend results to additional scales, e.g. to the meso-scale, or to translate results into consumer activities as in the EF approach with Consumption Land Use Matrices (Thomas Wiedmann *et al.*, 2006). In a fourth way, IOA is used to compute conversion coefficients that are later used in the EAM, e.g. indirect material use of products in MFA. In the fifth way, the combination with aggregation methods, like LCIA, aims at generating synthetic indicators from EE-IOA results. An additional benefit from the integration within an input-output framework is the increased comparability of results with socio-economic indicators developed within the System of National Accounts (SNA) (United Nations, 1993). The downside of such practice is however that IOA is subject to large biases because it cannot always adequately represent the underlying physical nature of flows. IOA performs all computations, including allocation, in monetary units and convert results, in a last step, in physical units with the help of environmental factors, for example CO_2 emissions per dollar. The extension of an existing EAM with IOA is thus potentially weakening the robustness of results generally previously based on physical rationales.

The elaboration of a direct inventory is the most common outcome of environmental assessments (Table 5). The system design step is well dealt with by most EAMs but the availability of data is an issue for several of them, even in Europe (MIPS, PIOT, IOA). The transformation of input data is lacking scientific validity in the case of the EF (Piguet *et al.*, 2007). The ALD is assumed adequate but further research is needed since no critical peer review has been identified. Approaches that can be based on GIS data like HANPP and international data sets like the EF have a much better coverage and are more adapted to the challenges of globalization from an inventory view. The EF is however relying also on global factors for product consumption, which are very uncertain and not locally appropriate. While EW-MFA data is already available for a large number of countries, data is lacking for both partial and full trade EE-IOA but large projects such as EXOPIOL are currently overcoming this limitation (Tukker *et al.*, 2009). The challenge of

globalization is also tackled in LCA with the development of regional LCI databases under an international coordination within the UNEP-SETAC life cycle initiative. However development appears to be very slow.

Achieving a global life cycle is a key challenge for EAMs: few methods are able to deliver a life cycle perspective; data and models of international trade are subject to many limitations or simplifications, e.g. trade balances. The elaboration of an inventory with a life cycle perspective is soundly dealt with by approaches like LCI or PIOT while the quality of the IOA is limited by its monetary nature. The macro approaches (EW-MFA, EF, WF and ALD) provide only some rough life cycle perspective, distinguishing at best direct from indirect environmental requirements in aggregates. HANPP also includes a life cycle perspective for upstream biomass flows through "embodied HANPP," which includes traded biomass flows and their upstream components. The Corporate Carbon Footprint (CCF) covers direct and indirect emissions from electricity only (scope 2 of the GHG protocol) but other upstream and downward chains are usually not computed or only very roughly (scope 3). The future GHG protocol, currently under elaboration, should provide guidelines to remediate to this issue in 2010. The EF integrates an international view since its inception. Its implementation is however weak since imports are computed with world average factors rather than country-specific ones and trade balance are used. Among the three types of IOA presented, the single country solution is clearly not adapted to an international context but it is nevertheless currently the most used solution. The full trade IOA approach represents the most advanced solution among all EAMs and is, as such, currently the centre of the research focus in this area (Thomas Wiedmann *et al.*, 2009).

The quality of the synthetic indicators delivered by EAMs depends on the robustness of the weighting schemes, which are closely related to the stage of the EAM within the DPSIR model. The MIPS, PIOT, EW-MFA, HANPP provide a robust assessment at the level of Pressure. The quality of the EF is however lowered by a lack of a full scientific validation on the energy conversion into the common global hectare unit, and since the agricultural EF can be lowered simply by intensification (raising yields). The WF and ALD would benefit from further validations and a more widespread implementation. The quality of the WF and ALD are also lowered because of a lack of scientific validation. The LCIA approach attempts to go beyond Pressure to the Impact level, resulting in indicators more (mid-points like acidification) or less robust (end-points like human-health). Several authors have applied LCIA to resource-oriented approaches extending them to an aggregation based on a similarity of damages. Globalization is a challenge for the approaches adopting a regional perspective. The EF integrates it since its inception but LCIA is still at the beginning of developments for regional impact factors and international transfers of pollutants.

Table 5 clearly establishes that indicators of performance are a weak point of EAMs. Five approaches (EF, ALD, LCIA, HANPP and WF) propose a comparison with internal or external references values but the meaning of the references is not always clear in policy terms. Besides the obvious fact that less resource use and fewer emissions are better, there is rarely a fixed threshold that can be used as a policy goal. However, each of these methods does allow for robust monitoring, thus measuring improvements or worsening in terms of their domain. The multiple indicators provided by LCIA, or a variety of methods, may be more representative of the system's complexity and its tradeoffs, but also reduce the clarity of the message with potentially mixed signals. The lack of scientific validation of the threshold in the EF approach is an important issue. The OECD synthesis report (OECD, 2008b) on material flows mention the need to complement indicators with references values and propose some generic examples. It is not clear, however, that every environmental issue or measure is associated with a clear threshold. EE-IOA indicators and the hybrid approaches based on IOA have a large potential of comparison with other indicators from the SNA but the life cycle perspective is an issue and clear performance indicators are still

missing. The potential of comparison of bottom-up studies like LCA is much lower since results are strongly dependant on the system design that is varying between studies. Several initiatives, like (BSI, 2008) are however establishing guidelines for the labelling of products that would allow for such comparison. Globalization is adding specific challenges to all EAMs through the questioning of the objectives underlying the measurement of performances and the relevance of applying the so-called “local in global” view. None of them has dealt with this issue yet.

Provided that the limitations expressed earlier (monetary allocation and approximate modelling of the use of imports) and additional ones are dealt with, the full trade IOA solution, based on Multi-Regional Input-Output (MRIO) models with enough sectors, appears to be an essential part of any solution that will be designed in the future. Firstly, additional research and data development should be performed to deal with issues like the bridge between price and quantities, exchange rates and rapidly changing economic and technology structures. Secondly, the environmental extensions considered should cover issues that are relevant in each region. IOA is however not accurate enough for decision-making at micro and lower-meso-scales where it can only provide a first approximation. It should therefore be complemented by additional bottom-up methodologies, either on an individual basis or through the development of additional hybrid approaches. Such types of hybridization are however still in development stage and require additional development before a potential implementation on a large scale.

The effectiveness of future databases and methodological development in answering these needs and tackling challenges in a cost-effective way could be potentially improved in three ways: *i)* establishing profiles of goods and of regions to better define which data is needed in which context *ii)* optimizing the methodological and data collection effort by concentrating on the few relevant solutions and geo-localized data in each context, rather than aiming at developing catch-all applicable solutions and databases, and *iii)* speeding up the access to adequate EAMs by adopting a modular view of EAMs to take the best solutions in existing methodologies and improve these elements through cross-methodology research groups focusing on specific issues

3 First version of the IMEA Analytical Framework

Having established classical and globalization-linked issues faced by EAMs based on what they "are" and what they "do", we now turn to the inclusion of these aspects into a more general framework including additional issues related to the use of EAMs’ results for decision-making. The structure proposed here aims at providing a comprehensive analytical framework for the analysis of the strengths and weaknesses of any EAM. Several EAMS have then been assessed and analysed according to this analytical framework (Chapters 4, 5, 6 and 7). The framework is structured along two axes: environmental accounting and decision-making abilities each split into three dimensions, each dimension providing an answer to a specific issue:

Environmental accounting ability

1. Are the inherent qualities of the approach adequate to provide a sound coverage of the environmental issues globally?
2. Is the approach mature and auditable?
3. What is the potential for improving the approach?

Decision-making ability

4. Is the approach usable?
5. Does the method provide a strong analytical potential?
6. Can the approach be integrated within existing systems of indicators?

Each question is further decomposed into several characteristics (18 in total) presented in Table 6.

Objectives	Dimensions	Characteristics
Environmental Accounting Ability	Inherent qualities	Exclusive or Best coverage of environmental issues Theoretical Soundness Global Life Cycle Perspective Adaptability of indicators to products and location environmental priorities
	Maturity & Auditability	Extensive coverage Classical issues: data reliability & completeness Classical issues: methodological consistency & soundness
		Global issues: data reliability & completeness:
		Global issues: methodological consistency & soundness
		Transparency
	Improvement Potential	Data perfection, extension & hybridation
		Methodology perfection, extension & hybridation
Decision-making Ability	Usability	Intelligibility, Univocity & Acceptance Clarity of Use
	Analytical Potential	Comparability & Additivity Causal and Structural analysis
	Integration Potential	Compatibility with system of National Accounts & International statistics Compatibility with Norms, Standards & Voluntary agreements

Table 6: Analytical framework with EAMs key issues (Version 1)

3.1 Dimension1: Inherent qualities of the approach

The inherent qualities of the approach are the key expectations EAMs are facing. The first characteristic is the capacity to report on environmental issues recognized as key from a scientific perspective. This reporting should provide additional information and insights compared to other EAMs. The second characteristic is the overall methodological soundness of the approach. Methodological soundness deals both with the scientific validity of the principles and methodological steps underlying the construction of a final indicator as well as their acceptance by the scientific community (applicable to all steps of the workflow).

The third characteristic is the capacity to consider the total environmental load from a good or an activity, i.e. accounting for the direct and upstream load along the whole production-consumption chains, including its domestic and international parts (see System design). The fourth characteristic is the capacity to consider the environmental profiles of goods and regions in order that the final indicator reports on the environmental issues that are priorities in each region along a supply chain or for a specific good (see Comparison & Normalisation).

3.2 Dimension 2: Maturity & Auditability

The ability of EAMs to provide valid indicators, and comparisons of products or regions over space and time, is assessed within the maturity and auditability dimension. Maturity is defined as the state or quality of being fully grown or developed. A mature EAM is first expected to deliver accurate, i.e. in exact correspondence with facts or events, and reproducible results. A high degree of maturity implies first using reliable, complete, and specific data covering spatial, temporal or technological peculiarities. It implies then a consistent use, i.e. a homogeneous treatment across methodological steps, of robust methodologies. Auditability is defined as the possibility to establish whether a method is functioning properly and, thereafter, that it has worked properly. The requirement for auditability is the transparency of a system and of its internal controls.

Classical maturity and auditability issues are separated from issues linked to globalisation (trade and trans-boundary issues) for more clarity. Each of the steps of the workflow should be considered specifically, paying particular attention to allocation, cut-off, conversion, weighting and normalization rules.

3.3 Dimension 3: Improvement Potential

The potential for delivering better data and methodologies in the future is assessed in three ways: perfection, extension or hybridization. Each of the identified weak point in the workflow should be described here if improvement is feasible. Both feasibility and potential costs should be reported on.

Perfection is the improvement of existing datasets, e.g. completing missing values or getting more accurate data. Extension is the development of new data and methods. Datasets can be extended to cover missing areas, scales or environmental issues. Methodologies can be extended to consider specificities of new locations, to adequately integrate the consequences of rapid technological changes and flexible production chains (see Allocation - Life cycle) or to improve the treatment of trans-boundary issues (see Allocation - international). Hybridizations are possible by combining methodologies or data sets together.

3.4 Dimension 4: Usability

An indicator is of practical use for decision-making if it is intelligible, delivering a clear message and accepted. Scientists and statisticians remain responsible for the data gathering and compilation, but the end result must be comprehensible to decision-makers.

The intelligibility criterion assesses if the indicator can be understood by decision-makers, by citizens and by consumers. Intelligibility is related to the message of the indicator and to its units. Univocity is a characteristic related to the clarity of the message delivered by an EAM to decision-makers. A message is clear when the message can be interpreted as good or not good. An unclear message can be due to multiple indicators showing contradictory signals in the case of multi-criteria assessments – however, this may be a necessary evil when dealing with complex environmental issues with no silver bullet solutions. Univocity is here traded-off against a larger coverage of environmental issues. Unclear messages are also, for example, due to indicators not related to any reference or target value. In many cases, even without target values, robust EAMs may be able to measure progress or deterioration over time and between countries.

The acceptance of an indicator helps its implementation and its establishment as a reference. Acceptance is here measured with respect to the acceptance by the political, economic and social actors but not by the academia (dealt with in the point on theoretical soundness). Clarity and transparency of use are essential characteristics, since EAM are based on a complex workflow for computing final indicators. The goal of a robust methodology is its systematic implementation by diverse reporting bodies: the effective transfer to statistical agencies rather than academic bodies.

3.5 Dimension 5: Analytical Potential

Two outputs of EAMs are mainly used in analyses: final indicators and structural information. Final indicators should be additive so that aggregated values can be calculated, and so that coherent assessments from micro to macro-scale are feasible, as in economic or financial accounting. Final indicators should be comparable with existing environmental, social or economic indicators for allowing a coherent basket of indicators or new indicators based on ratios like the eco-efficiency. Structural information provides additional insights on where to act to reduce the magnitude of environmental issues (see System design).

3.6 Dimension 6: Integration Potential

The integration of environmental assessments into the basic toolbox of decision-makers requires the compatibility of EAMs with existing legally binding or voluntary accounting frameworks, norms and standards at national, corporate and products levels. Discussions towards providing integrated accounts have been held for decades at national level (SEEA), and since a few years at corporate level. All EAMs are however not covered in these discussions and information should be provided on the compatibility of EAMs methods and data sets with existing data sets and rules.

4 Life Cycle Assessment Methodologies

4.1 Review of existing frameworks

NB: The text in this section is referring to a specific bibliography related to LCA to be found after the general REFERENCES

A Life Cycle Assessment analyses the environmental impact of a product or a system over the entire life cycle, starting from the extraction and production of the raw materials and ending at the end-of-life stage (waste treatment). According to the ISO guidelines an LCA must be performed in 4 steps (see Figure 3):

- Goal and scope definition;
- Inventory Analysis;
- Impact Assessment;
- Interpretation.

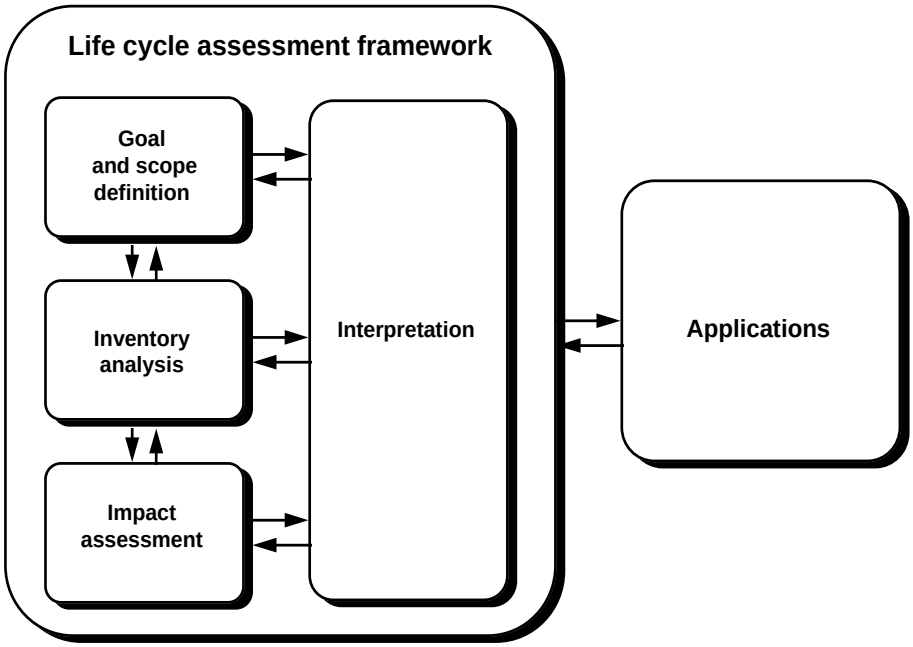


Figure 3 Methodological framework of an LCA (ISO, 2006)

In the goal and scope definition the intended use of the LCA (the goal) and the breadth and depth of the study (the scope) are clearly defined. The scope definition has to be consistent with the goal of the study. One important aspect that forms the basis for the analysis is the definition of the functional unit. The function(s) that are fulfilled by the product/system should be clearly defined. The functional unit measures the performance of the system and provides a reference to which the input and output data will be

normalized. In comparative LCAs, comparisons can only be made on the basis of equivalent functions, i.e. LCA-data can only be compared if they are related to the same functional unit.

The inventory analysis involves data collection and calculation procedures to quantify the inputs and outputs that are associated with the product/system. This includes use of resources, releases to air, water and land. Procedures of data collection and calculation should be consistent with the goal and the scope of the study. Input and output data have to be collected for each process that is included in the system boundaries. After collection, the data for the different processes have to be related to the functional unit and aggregated. This corresponds to a calculation of all inputs and outputs referenced to the functional unit, which is the final result of the inventory analysis.

The life cycle impact assessment phase (LCIA phase) is the third phase of LCA. The purpose of LCIA is to provide additional information to help assess a product system's LCI results so as to better understand their environmental significance. In the impact assessment (LCIA), the results of the inventory analysis (LCI) are linked to specific environmental impact (or damage). The elements of the LCIA phase are illustrated in Figure 4.

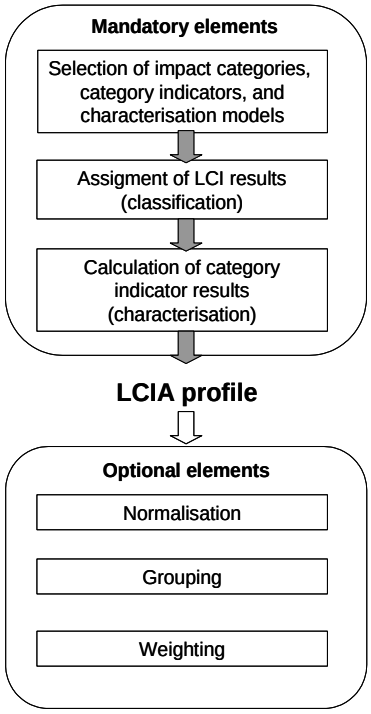


Figure 4: Elements of the LCIA (pp15 of ISO 14040)

The impact assessment according to the ISO 14040/44 (ISO, 2006) consists of the following elements:

- damage (or impact) category definition: definition of the damage (impact) categories that will be addressed;
- classification: assignment of inventory data to damage (impact) categories;

- characterization: modelling of inventory data within damage categories to express the damages in terms of a numerical indicator;
- technical analysis of significance: analysis of the significance of the numerical indicators, e.g. by relating them to total anthropogenic contribution (normalisation), by performing sensitivity analyses, etc.;
- valuation: weighting and possibly aggregation of different damage categories involving subjective value judgments.

The first three elements are mandatory, the last two are optional.

Environmental damage (or impact) categories that are commonly assessed in LCA are:

- Resource consumption (minerals and fossil fuels);
- Land use;
- Climate change;
- Stratospheric ozone layer depletion;
- Human toxicity;
- Aquatic ecotoxicity;
- Terrestrial ecotoxicity;
- Photo-oxidant formation;
- Acidification;
- Eutrophication;
- Ionizing radiation;
- Impacts on ecosystems and biodiversity;
- Respiratory effects caused by inorganics;
- Non-renewable energy
- Mineral extraction;
- Water use.

The life cycle interpretation is the final phase of LCA, in which the results of the LCI and LCIA are summarized and discussed as a basis for conclusions, recommendations and decision-support in accordance with the goal and scope definition.

A detailed discussion of the LCA-methodology, including an extensive summary of LCIA-methods, is included in Appendix 1.

4.2 Environmental Accounting Ability

4.2.1 Inherent quality of the approach

One of the advantages of LCA is that it covers a broad range of environmental issues, as discussed in the previous paragraphs. However human health impacts are mostly considered at a global scale and not on a local or individual level. A complete LCA usually assesses all global environmental impacts from a product system at micro- or meso level (product/ sector). Aspects that are not standard included in LCA are noise, soil erosion and indoor air quality.

LCA methodology was and still is thoroughly studied. This resulted in the ISO standards for LCA, ISO 14040 and 14044. Recent research on LCA methodology focuses on extensions of the methodology, e.g.

with social impacts (social LCA) and with the inclusion of location-specific impacts. As such LCA is considered to be a methodological sound method, that is still being improved. Life cycle thinking is regarded as an important tool with regard to EU environmental policy preparation.

LCA considers the entire life cycle of a product, from raw material extraction and acquisition, through energy and material production and manufacturing, distribution to use and end of life treatments (re-use, recycling, incineration and final disposal). All upstream and downstream processes are taken into account which can provide insight into trade flows (on a micro or meso level). Through such a systematic overview and perspective, the shifting of a potential environmental burden between life cycle stages or individual processes due to improvement options can be identified and possibly avoided. However the environmental indicators resulting from an LCA often provide information on the magnitude of the impacts, not on the location and exchanges.

One of the aspects of LCA that needs further research and methodological improvement is the ability to account for location-specific impacts. Most impact assessment methods currently used in LCA consider the environmental impact on a global scale which is correct for some global environmental effects (like climate change), but may lead to increased uncertainty for what regards the regional or even more local environmental impacts (like human or ecotoxicity). Seppälä, J. et al., 2008 has shown that site-specific approaches can offer a very different view about the environmental impacts of regional and global environmental problems caused by a national economy compared with the situation in which only site-generic characterisation factors are used. Yi et al. concluded in their study “Development of the Interregional I/O based LCA method considering region-specifics of indirect effects in regional evaluation” that it is especially necessary to construct inventory and damage factors for site dependent environmental burdens such as heavy metals and chemicals in order to evaluate regional characteristics more consistently.

On top of the methodological issue with regard to location-specific environmental impacts there is also another aspect of importance, being the data availability. In theory it is possible to cover all the world regions with LCA. However in practice due to data-availability there is a focus on industrialized countries (at world level there does not exist a complete regional or country specific LCA-database). The geographical coverage of LCA-data is very case-specific: the scope can be set for a region, a land or a company. As Europe is the cradle of LCA, European LCI data are quite well reported and documented, as is the case for most industrialized regions. The most widely used LCA-databases are however not covering developing countries. As many of these countries supply resources to developed countries, there is increasingly the recognition that LCI databases need to include the materials and processes from developing countries as well.

4.2.2 Maturity & Auditability

The geographical coverage in LCA is case-specific in the sense that the scope can be set for a region, land or company. In theory LCA can cover all world regions, in practice however LCA focuses on industrialized countries, due to data-availability. As Europe is the cradle of LCA, European LCI **data** are quite well reported and documented. The most widely used LCA-databases are not covering developing countries, with the exception of some extraction of raw materials in developing countries which are incorporated in the LCA-databases. Several initiatives, the UNEP Life Cycle Initiative and the European Platform on LCA being the most important, are ongoing to overcome this lack of data, especially for

developing countries, but also more in general. These initiatives focus on speeding up and coordinating the collection process and inventorying all LCI-databases worldwide. The frequency of database updates depends on the database provider e.g. the European platform on LCA aims at updating the ELCD every 4 year. So the frequency of updates in LCA databases is typically lower than the monthly/yearly import/export statistics. This is understandable due to the burden of collecting data for huge numbers of materials and processes. For certain sectors a higher update frequency is desirable, in particular for emerging or fast evolving technologies.

LCA-databases are built up from a mixture of data available in literature and data supplied by sectors or individual companies. Completeness issues cover the range of unit processes themselves, as well as the output flows:

- Unit processes : Data gaps are always clearly indicated. As there exist a wide range of materials an LCA-database can never cover all existing materials. Moreover there are always new developments of materials of which the data only become available after a delay of several years (market introduction). For example data for nano-materials and biopolymers are only recently taken up in the databases.
- Output flows within unit processes: an extensive range of outputs (several hundred) are reported, but often data are missing regarding water, indoor pollution, biodiversity issues.

The level of data uncertainty is addressed in LCA-databases and is documented by a data quality indicator (DQI) as suggested in the ISO-standards.

With regard to data sources on exchanges and trans-boundary issues it is important to note that life cycles of goods and services are generally global in nature, crossing national and geographic borders particularly in terms of raw materials and energy supplies (trade). In many cases the location of emission sources or resource use is unknown and may vary. This also reflected in the fact that most of the impact assessment methods and factors in LCA are focussed on global issues. Inventories, characterized by elementary flows (materials / emissions or energy exchanged between the system and the environment), generally do not contain information on where the elementary flows are emitted. This holds especially true for the output side (trans-boundary). On the input side (trade) some data providers create inventories with country specific resource extraction elementary flows due to different physical and chemical properties, e.g. crude oil from Venezuela.

LCA **methodology** is considered to be mature, as ISO-standards are developed. The standards prescribe that any LCA-study needs a clear and transparent definition of the system under study and its system boundaries in an initial phase of the study. This is expressed in the functional unit and in a rigorous definition of the system boundaries. The functional unit expresses a quantified performance of a product system for use as a reference unit. The ISO standards also provide clear guidance for allocation choices and cut-off rules. Life cycle impact assessment methods are also in generic terms discussed in ISO. Characterization factors are based on a scientific consensus, which is nonetheless less grounded for environmental effects like toxicity and land use. Although characterization factors in LCA are scientifically based, the impact of for instance acidifying emissions can be location-specific but is not commonly treated as such. A scientifically grounded normalization method is developed for LCA, however normalization data are limited by data-availability and as such results are highly dependent on the choice of these normalization values. At this moment no generally accepted and scientifically based weighting factors exist. In case weighting is needed, weighting factors will be selected case-specific. The European Platform on LCA is doing work on defining regional weighting factors.

Since there is a clear and transparent definition of the methodology and guidelines given in the ISO standards 14040/14044, the reproducibility of a well performed LCA study is high. However the repeatability in the sense of independent LCA practitioners performing the same project, coming to identical results is much less as results can easily differ 10-20% on impact assessment level, depending on the choices of datasets, system boundaries,…but the differences can be explained due to the importance given to transparency in the ISO standards.

4.2.3 Improvement potential

The limited data availability and methodological issues (characterization and normalisation factors) of LCA to account for trade and trans-boundary issues can be overcome by additional research and coordinated efforts with regard to data inventory. It is hard to define the feasibility (in terms of costs) of the efforts that are required and very much dependent on the scope of the study and the associated improvements.

Combining process-based LCA and Environmental Input Output Analysis (EE-IO), better known as hybrid analysis, can yield a result that has the advantages of both methods (i.e. both detail and completeness). It is often useful to develop hybrid LCAs which combine the ease and broad perspective of EE-IO with the specificity of information for a single product or process of a process-based LCA. For example, one could use process-based LCA to model the impacts of the production processes at a given facility, but use EE-IO to model the supply chain impacts of the electricity purchased by the facility. Alternatively, if specific data about a facility is known, one could disaggregate an industry sector within an EE-IO model into two sectors: one representing the specific facility and one representing the rest of the industry.

4.3 Decision-support ability

4.3.1 Usability

LCA is recognised by policy makers as a tool that delivers output useful as a basis for decision support for environmental policy for e.g. packaging and energy-using products, as is the case for the European Commission. When LCA-results are reported in a clear way, in principle the interpretation per impact category is intelligible. But when the results of comparative assertions are communicated to a broader public, results per impact category sometimes are not fully understandable to a non-LCA expert. Quite often the message is that there is no single overall winner in all impact categories and quite often the question which option is the best was the starting point for the LCA project. To support decision making weighting of the importance of impact categories can be performed but requires subjective elements. For this reason weighting of the different impact categories is not allowed for comparative assertions among competing products disclosed to the public according to ISO, but weighting is an option to enhance the intelligibility of the environmental indicator if the LCA-results are intended for internal purposes. Evidently there is a need for consensus for weighting factors which might differ at country, regional and European level. This need for consensus is not specific for LCA only , for any EAM the same consensus would be needed.

4.3.2 Analytical potential

The analytical potential for a standard LCA is good for its intended application with the known limitation that LCA due to integration and aggregation is not time and space specific. Certain information on time and space coverage might be available at the lower LCI level but usually this is far from complete. If the lowest unit process in the used database does not specify the exact time and space coverage, the information is simply not there.

Imagining the ideal situation that LCA databases would be complete at the world level, having all data available for all continents, countries and regions, and updated at a yearly frequency, in principle specific import issues could be handled with the LCA methodology, assuming that also agreement exists on regional specific impact categories and factors. Nevertheless one should realise that the data handling would become a time consuming task and also clear allocation rules should be applied consistently across the full system analysis avoiding double counting etc.

In general the more data to be included and handled, the higher the analytical potential but the “import question” to be answered is fundamental to choose the right tool.

4.3.3 Integration potential

The basic data used for environmental assessments (product life cycle inventory data) can be found in many different LCI-databases and software. Despite standardising work by EC-JRC (European Platform on LCA) and UNEP LCA initiative, commercial databases and software still can use different formats for storing and presenting the data, making data difficult to exchange and compare.

The LCA methodology as such nonetheless does allow for integration with other approaches like input-output modelling.

4.4 Strength and weaknesses of LCAs approaches according to IMEA grid

STRENGTHS

Environmental accounting ability

An important advantage of LCA is the fact that LCA covers a large spectrum of environmental impacts, as, from a life cycle perspective. The method does not focus only on one specific environmental problem, but allows to have a quite “complete” view of the environmental impact. LCA focuses not only on the production site, but enables to include all upstream and downstream phases of the life cycle of a product or system.

Geo-localised reporting is partially possible within LCA, with regard to transportation distances and electricity grids, but need to be implemented with a specific procedure.

The ISO-standards for LCA ensure a high quality and reliability of LCA as a method, keeping in mind that these standards focus on the methodology as such (procedures) and don’t apply for LCI-databases. However, numerous initiatives defined recommendations for LCI-databases.

LCA could allow a life cycle based analysis of trade issues as well as trans-boundary issues, however at this moment limited data availability and the absence of generally accepted regional characterization and normalization factors restrict the application of this.

Decision-support ability

As an LCA is based on a functional unit, it is fully related to a functional analysis in a life cycle perspective and is as such compatible with other methods. One important opportunity of LCA is the link with EE-IO analysis in what is called 'hybrid analysis'. This would offer a lot of potential with regard to extending the current environmental analysis at a micro scale to a meso and macro level.

The LCA method is widely used across the world, but its applications are mainly limited to a micro level (product level) and to a lesser extent a meso level (sector level). Due to its large implementation and recognition, life cycle thinking is regarded as an important cornerstone of EU environmental policy.

LCA is a systemic analysis enabling identification of trade-offs between scenarios.

WEAKNESSES

Environmental accounting ability

The 'traditional' ISO-LCA methodology is not designed for macro level studies. Consolidation of LCAs at macro level is inducing an additivity issue with a risk for double-counting some impacts.

Most of the LCI-databases focus on industrial countries, data on production processes in developing countries are still lacking or only very limited available. At this moment LCI-data and LCA-studies are limited to a fraction of products and sectors.

To include trade and trans-boundary issues the LCA methodology needs to be refined with a focus on location-specific characterization factors for the relevant environmental effects and efforts need to be put in increasing the data availability for developing countries.

Decision-support ability

LCA is a method that focuses on the life cycle phases and that is not compatible with national accounts. Coupling of LCA with import and export statistics is difficult and not common practice.

The inclusion of trans-boundary issues and regionalization of environmental impacts is possible, providing that all LCI-data are available and that regional characterization factors are developed for the relevant environmental impact categories. This requires an extensive data collection and GIS-integration.

Objectives	Dimensions	Characteristics	Strengths	Weaknesses
Environmental Accounting Ability	Inherent qualities of the approach	Exclusive or Best coverage of environmental issues	- Large coverage of Env . issues - Geo-localised reporting is partially possible (transport and energy mix) but need to be implemented with specific procedure - Life cycle perspective	- Standard LCA is not designed for Macro level and consolidation of LCAs at macro level is inducing an additivity issue (double-counting).
		Theoretical Soundness	- ISO Standard: for methodology (procedure), not for databases	
		Global Life Cycle Perspective	- Fully related to a functional analysis in a life cycle perspective	
		Adaptability of indicators to products and location environmental priorities		
	Maturity & Auditability	Extensive coverage		- Databases focused on industrial countries, - Data and studies limited to a fraction of products and sectors
		Data reliability & completeness		- Large uncertainty for database - Update frequency: typical 1-5 years for technological data in DB
		Methodological consistency & soundness		
		Trade and trans-boundary issues: data reliability & completeness:		- No current specific development
		Trade and trans-boundary issues: methodological consistency & soundness:		- Requires extensive data collection, GIS integration and specific regional characterization factors for some env. issues.
		Transparency	ISO requirement	
	Improvement Potential	Data perfection, extension & hybridation		
		Methodology perfection, extension & hybridation		

Decision-making Ability		Intelligibility, Univocity & Acceptance		
	Usability	Ease of Use	- Wide use of LCA across the world	- limited to micro-level (and meso-level)
	Analytical Potential	Comparability & Additivity	- Opportunities in using hybrid approach (IO-LCA)	- Consolidation of LCAs at macro level is inducing an additivity issue (double-counting)
		Causal and Structural analysis	- Systemic analysis enabling identification of trade-offs between scenarios - Through an LCI all Pressures are inventoried. In the impact assessment step LCIA continues the DPSIR Framework, but directly jumping to the Impacts from DPSIR. The State (Physical, chemical, biological) of for instance the different compartments (Water, air, land) are typically not described by LCA indicators.	
	Integration Potential	Compatibility with system of National Accounts & International statistics		- No compatibility with NA, no coupling with import/export statistics
		Compatibility with Norms, Standards & Voluntary agreements		

Table 7: LCA strengths & weaknesses

4.5 Proposals for overcoming current limitations of LCAs

Efforts related to improving regionalization in LCA should focus on:

- Identifying what level of regionalization is needed

  The life cycles of goods and services are generally global in nature, crossing national and geographic borders particularly in terms of raw materials and energy supplies. In many cases the location of emission sources or resource use is unknown and may vary. That also is reflected in the fact that most of the impact assessment methods and factors are focussed on global issues. Further distinction in e.g. emission scenarios and geographical or political boundaries can have added value, provided that life cycle inventory and unit process data are available. The additional collection and use of such specific inventory/unit process data and impact assessment factors is justified when this will reduce the uncertainty associated with a life cycle study.

  Regionalization is recognized as an important step towards improving the accuracy and precision of LCA-results, thereby increasing their discriminatory power for comparative assessments among different scenarios. Global impact categories have consequences that are independent of the emission location, such as global warming and ozone layer depletion. Other types of consequences, such as acidification or (eco-)toxicological impacts on humans and ecosystems, often occur as regional or local impacts, making the emission location an important factor. By regionalizing such impacts, decision-makers can have a higher confidence in the non-global impacts presented in the LCA.

  Spatial differentiation or regionalization can thus improve the uncertainty of the LCA-results, depending on the impact category. However, regionalization is not always needed and depends on the goal and scope and system boundaries of the LCA study. In some cases, regionalization is needed, e.g. when:

  - the LCA uses life cycle inventories differentiating emissions from different countries;
  - assessing specific key processes dominating the overall life cycle impacts, for which the exact emission location is known;
  - for further application such as cost-benefit analysis, environmental justice or environmental impact assessment.

  Clear guidelines should be developed that give an indication when regionalization in LCA-studies improve the quality and the uncertainty of the results in order to make sure that complex and regional-specific LCA-studies are only performed in cases that this has added value.

- Developing guidelines and solutions for data gathering (LCI) and development of situation dependent and geographically differentiated characterization factors (LCIA) for the regionally- and locally-dependent impact categories.

  Regionalization in LCA has two sides:

1. Input flows: Materials and products that are imported from other regions and countries need to be taken into account. At this moment in LCA common practice this is limited to accounting the transport and to some extent foreign electricity production. The bottleneck in this regard are the lack or limited availability of LCI-data for foreign production.

2. Output flows: Emissions to air, water and soil contribute to environmental impact categories, that can be of global (e.g. climate change), regional or local nature (e.g. acidification, eco-toxicity). Characterization factors in LCA are usually global in nature and as such create an uncertainty in the LCA results for those impact categories that are not global in nature. Accounting the regional impacts of emissions needs regional characterization factors. Research projects focus on the development of such regional characterization factors, but until now such CFs are still under development.

The availability of both data for foreign production and regional characterization factors is a prerequisite to include imports and transboundary issues in LCA-results.

- Developing countries

This aspect relates to data availability for foreign production. Numerous materials are extracted in developing countries (e.g. Africa) and the import of materials/products from e.g. China is booming rapidly. To include the regional environmental effect of e.g. extraction of minerals in Africa and production of steel in China, data for these processes are needed. LCI-databases focus on industrialized countries, and there is a need to include also LCI-data from developing or emerging countries.

5 Environmentally Extended Input Output (EE IO) Analysis

5.1 Review of existing frameworks

5.1.1 Introduction

NB: The text in this section is referring to a specific bibliography related to EE IO to be found after the general REFERENCES

Environmentally Extended Input Output (EE IO) Analysis is the main approach used for environmental assessments at macro and meso-scales. EE IO is based on a detailed description of the domestic production processes and transactions within an economy that can be extended by any type of environmental extension, e.g. resources uses or pollutants. This chapter will discuss the basics of Environmentally Extended Input Output Analysis

5.1.2 Environmental Extended Input Output of individual countries

5.1.2.1 Input output tables

Supply and Use Tables (SUT) and Input-Output Tables (IOT) are a component of the System of National Accounts (SNA; United Nations 1993) and European System of Accounts (ESA95; European Communities 1996).

The supply table shows the supply of goods and services by product and industry, distinguishing between domestic industries and imports (hence it is a product-by-industry table). The use table shows the use of goods, services and value-added by product and by type of use, such as, intermediate consumption (industry) and final consumption (hence it is a product-by-industry table). The SUT are a central component of the ESA95 as they show the flows of money through an economy and are used for both statistical and analytical purposes.

An input-output table gives a detailed description of the domestic production processes and transactions within an economy. The IOT is constructed by merging the supply table and the use table into one single table and is expressed as either a product-by-product or industry-by-industry table. The central part of an IOT is thus square (it contains the same number of rows and columns) and symmetric (the items indicated by the rows and columns are the same: both are products or both are industries). The abbreviation SIOT is sometimes used to refer to a square and/or symmetric IOT.

The merging of the SUT into a single table requires assumptions – hence loss of information – but the IOT is the standard framework for a detailed structural analysis of economic activity (input-output analysis, IOA). The SUT itself requires no (or fewer) assumptions, therefore it is the preferred accounting framework for SNA and ESA95. We will not discuss in detail the well-known approaches for transforming

SUT into SIOT here; reference is made to the standard literature on this matter (e.g. Miller and Blair, 1985; Ten Raa, 2005), and others (e.g. Rueda Cantuche et al., 2007)[5].

5.1.2.2 Environmental extensions

The System of Integrated Environmental and Economic Accounts – SEEA 2003 (United Nations et al. 2003) provides the conceptual foundation for environmental extensions to SNA-based IO and SU. Broadly two main types of extensions can be distinguished (see UN et al., 2003 p. 30):

1. *Natural Resources* cover mineral and energy resources, water and biological resources (in addition land use can be considered). Natural resources flow mainly from the national environment into the national economy.
2. *Residuals* are the incidental and undesired outputs from the economy without economic value and are discharged into the environment. Usually, it concerns emissions to air, water and soil[6].

Such extensions can be attached to both frameworks, SUT and IOT. For attaching environmental extensions to a SUT or IOT several options exist. The most usual one is to apply a satellite approach. The monetary SUT or SIOT remains as it is and the non-monetary environmental extensions are attached in form of separate accounts underneath the monetary accounts[7].

The satellite accounts of environmental extensions are rather simple. There is an input-matrix of environmental extensions and an output-matrix. Inputs are primary natural resources ('gifts from nature'). The output matrix of environmental extensions comprises the various emissions. The simplified EE-SIOT scheme in Figure 5 does not consider controlled landfill sites and the natural environment since they are usually not part of the monetary SIOT. As a consequence the total of residual inputs in the EE-satellite does not equal the total of residual outputs.

[5] In brief, with usually Supply tables in basic and Use tables in purchaser prices, a set of valuation matrices has to be available or constructed to express the Use table in basic prices. Similarly, an import matrix needs to be available or constructed to separate use of domestic production and imports. Once the supply- and use table are in basic prices, one has to decide if a product by product or industry by industry IOT best serves the analytical questions posed. To transform SUT into IOT assumptions about by-products in the Supply table have to be made; the two most usual are the so-called Industry technology and the Product technology assumption.

[6] Note that by-products used in the economic system, waste that is recycled, or waste that is treated, all form still flows in the economy and hence have a place in the SUT or IOT. Only a final emission or the final land use occupation of a landfill can be included as an extension.

[7] It is also thinkable to merge monetary and physical flows into one symmetric system arriving at so-called hybrid tables.

5.1.2.3 Review and potential applications

Figure 5 gives as an example how an (industry by industry) EE IO table of an individual country usually is structured. In case of an industry by industry table, the central block gives the purchases and sales of industries to and from other industries. The final use block contains domestic (household and government) consumption, gross capital formation, and exports. The value added block gives per industry insight in the compensation of employees, taxes less subsidies, investment/deprecation, and other operating profits. The value added plus the purchases of an industry as given in the central block is by definition equal to the monetary value of the output of an industry. Adding the imports to this gives the total *supply* of products in a country, which by definition must be equal to the *final use.* The figure furthermore shows the environmental extensions as a satellite account, representing 2 vectors per industry: the input vector of primary resources consumed (e.g. water, land, ores, extracted fossil fuels) or emissions discarded (which could in principle be a list of a few hundred substances to air, water and soil).

The interesting thing now about organising economic and environmental data in the way as depicted in Figure 5 is that all kind of analyses become possible with regard to identifying the root cause of specific emissions. Again, we refer to standard literature on this issue for a detailed discussion (e.g. Miller and Blair, 1985) but in laymen's terms a key analysis works as follows.

- The table in Figure 5 allows to calculate the emissions and resource use per monetary unit turnover of an industry.
- The central inter-industry block in the table allows calculating for how much value, in economic terms, each industry sector has contributed to an output that a sector provides to the final consumption block.
- By multiplying the emission intensity of each sector with the fraction and industry sector contributes to the value of an output for final consumption, and estimate of the total emissions and resource use can be made that has to be allocated to this specific final consumption expenditure output.

The elegance of the calculation is that it must be inherently complete. Usually, the Environmental Extensions in Figure 5 equal the total environmental impacts or emissions of a country (just as the total economic output in the table is equal to the GNP). The procedure above merely re-allocates the total environmental pressure, usually related to industries, to what really drives impacts: final consumption expenditure.

The shortcoming of the approach, however, is also clear. There is an import row in the table. Quite often studies assume that such imports are made with domestic technology, to avoid further complications. Yet, the resource use and emission intensities of such imports may differ considerably from the domestic industry. We will discuss the approaches that were developed in the EE IO field to deal with this issue in the next section.

	Industries	Sub-total	**Final use**			**Total use (basic prices)**
			Final consum-ption	Gross capital formation	Exports, f.o.b.	
Industries	**Industry by industry transactions in basic prices**		**By house-holds, NPISH, government**	**Gross fixed capital forma-tion and changes in inven-tories**	**Intra- and extra EU**	
Subtotal (1)	Total intermediate consumption by industry		Total final use by type			**Total use**
Tax less subsidies (2)	Net tax on production [??]					
Total (1)+(2)	Total intermediate consumption in purchasers's prices [where are transport margins?]					
Compensation of employees Other net taxes on production Consumption of fixed capital Operating surplus, net	**Components of value added by industry**					
Subtotal (3)	Value added					
Total (1)(2)(3)	**Output by industry at basic prices**					
Imports	Imports cif					
Total supply	**Supply in basic prices**					

Input (natural resources: land, fossil fuels, minerals, etc.)	Resource use per type and industry		Idem, per consumption activity					Total
Output (emissions)	Emission per type and industry		Idem, per consumption activity					Total

Figure 5: A typical IO table with Environmental Extensions

5.1.3 Trade in EE IO and practical applications

5.1.3.1 Trade in EE IO: towards Multi Regional EE IO databases

Practitioners have sought to resolve this problem of imports in EE IO tables in a number of ways. Ideally, one would of course have a global database with comprehensive EE IO tables for most countries, and map the trade flows between countries. Because of the daunting data requirements, most studies have simplified this approach[8]. Approaches include:

1. A practitioner may use LCA or other data sources to estimate the impacts in the life cycle of imported products.
2. A practitioner may identify the main trading partners of a country, make available EE I-O tables for these countries or country groups, and calculate the embedded pollution and resource use in bilateral trade (see e.g. Weidema et al. (2005, Denmark); Peters and Hertwich (2006b; Norway), Nijdam and Wilting (2003; Netherlands), Weber and Matthews (2007, US) and Norman et al (2007, Canadian-US trade). **A common feature of all these approaches is that only bilateral trade is considered and trade with other countries is ignored**.
3. More comprehensively, a practitioner could apply a truly multi-regional approach, in which economies of the rest of the world are presented together with the country of interest in a multi-regional input-output table with environmental extensions (MR EE IO). One example is Wiedmann et al. (2008), who used Nijdam and Wilting's (2003) data for the EU and other OECD and non-OECD countries and developed them as a true MR EE IO consisting of the UK and 3 other regions. The difference with the former approach is that also bilateral trade between the 3 regions is estimated. This can be relevant, since with the ever globalising production chains, e.g. computers assembled in China may actually consist of components from other countries with e.g. at totally different energy system, etc. Other practitioners recently went even further, and used certain available databases to develop a so-called Multi Regional EE IO database consisting of a dozen or more regions.

The last most comprehensive approach would lead to a set of linked country IOTs, each with its own environmental extensions.

5.1.3.2 Applications of trade linked EE IO databases

The (static) applications of trade linked EE IO databases are very similar to the applications of EE IO databases as described earlier. It is again possible to calculate which industry contributes which fraction of the added value of a final consumption expenditure category. But the main 'extra' in a trade linked EE IO database is that now the country or region of origin is also specified. If, on top of this, region or country specific emission and resource use intensities play a role in the multi-region/country EE IO database, on ends up with much richer and precise information.

[8] For instance, if we would discern the world as 50 regions/countries each represented by a 60x60 IOT, one would end up with a 3000 by 3000 matrix with close to 9 million potential trade flows that have to be mapped.

One can analyse and take into account:

- Differences in emission and resource use intensities between regions and countries, so that *where* production takes place becomes a relevant issue;
- In which country and region the impacts caused by consumption in another region take place. This, indeed, is the central question in the IMEA project: to understand the pollution embodied in trade, and which impacts are embodied in imports to Europe.

5.2 Environmental Accounting Ability

5.2.1 Inherent quality of the approach

Trade linked EE IO tables are excellently suited to assess environmental issues related to account the environmental burden of Europe with a worldwide trans-boundary perspective. The only 'but' is the current lack of data, harmonization and trade linking. From a theoretical perspective, MR EE IO is probably one of the most powerful approaches:

1. It uses a global perspective, and takes into account issues like that components of products made in another country themselves can come from another country
2. It shows not only the pollution embodied in imports, but also *which countries* suffer most environmental impacts by consumption by other countries;
3. The approach is inherently comprehensive: the total global environmental impacts are a starting point, and distributed over the final consumption in the world, wherever it occurs;
4. Provided that a comprehensive set of environmental extensions is included, a great variety of indicators can be supported, including LCIA, ecological footprint, and material flow indicators.

5.2.2 Maturity & Auditability

The concept of (MR) EE IO is very powerful, but as always, data availability is key to the success of the approach.

Most EU member states produce IO tables, albeit in different formats and sector resolution. The European System of Accounts (ESA95) requires EU member states to transmit in a standardized format SUT (annually) and IOT (five yearly). The big advantage of this material is that it is available in a harmonized sector and product classification. Sixty industry sectors and related product groups are discerned, corresponding with the NACE 1.1. and CPA 1.1 level 3. Tables are however not yet available for all EU15 (let alone the EU27) countries, and therefore the DG JRC IPTS decided to work out on the basis of the ESA95 tables a full set of tables for the EU27 (which hence include estimates and assumptions) (Rueda Cantuche et al., 2007).

For other countries in the world, (sometimes detailed) SUT or IOT are available covering a significant part of the global economy (e.g. the US, Japan). Yet, since most National Statistical Insitutes (NSIs) make own choices about sector/product detail and – classification, there is a lack of harmonization. The OECD has

taken the initiative to produce a harmonized set of industry by industry IOTs. Their third edition, published in 2006, discerns 48 sectors and 39 countries responsible for over 90% of the Global GDP (Yamano and Ahmad, 2006).

The Global Trade Analysis Project (GTAP) produces a multi-regional I-O table for the world economy that discerns a fair amount of sectors (about 60) and regions (about 90), and links such data also to energy use. The great achievement of GTAP is that they managed to produce the only global trade linked IOT existing to date. Yet, transparency about how this database is constructed is not optimal and environmental extensions lack (Dimaranan, 2006). Various data sets had to be constructed making rather crude assumptions. One of the problems in constructing trade linked IOTs is the assessment of transport and insurance margins on trade flows, and particularly which country delivers such services.

Furthermore, there have been individual studies that on an ad-hoc basis produce trade linked IOTs between a group of countries. An example is the work of Oosterhaven et al. (2008) on a non-survey Multi-Regional IOT for 10 Asian countries.

Many developed countries have some sort of an emission inventory system, but for EE IO purposes, these emissions must be strictly allocated according to the sector classification of the IO table. The same applies for various comprehensive data sets on resource extraction per country (e.g. Giljum et al., 2008). In most cases, this allocation is not straightforward.

On a voluntary basis, individual EU member states report National Account Matrices including Environmental Accounts (NAMEAs) with some 10-15 emissions to air (Eurostat, 2005), at best covering the GWP, ODP and acidifying emissions.

For most other countries in the world, no such NAMEA type of data is available. Individual research groups have combined IO data for countries with emission data, and hence created their own (sometimes very detailed an extensive) NAMEAs. For instance, Suh (2004) combined US emission data with the US Bureau of Economic Analysis (BEA) IOT, resulting in a 500 x 500 sector IOT with over a few hundred emissions as extensions for the US.

The use of a complete MRIO model offers a number of options for determining the specific causes of impacts (Peters and Hertwich, 2006, Peters, 2007) and allocating impacts to producers or consumers (Lenzen et al., 2007). Due to the daunting data requirements, however, just a few authors have tried to construct such MR EE IO models at global scale. No formal MR EE IOTs exist, and the main attempts to construct these have been done by individual research institutes or practitioners. Some examples are listed below.

Peters (2007) and Friot et al. (2007) used the GTAP MRIO database with various individual emissions as a basis for their modelling efforts. Peters (2007) was the first to perform an MR EE IO study using the complete GTAP database, whereas Friot used aggregated regions. Yet, in both cases the emissions covered were rather limited, usually covering CO2 and similar substances only.
The Global Resource Accounting Model of Giljum et al. (2008b) uses OECD IO and trade data extended by material extraction to calculate indirect material flows of traded products.
Wiedmann et al. (2008)) used Nijdam and Wilting's (2003) data for the EU and other OECD and non-OECD countries and developed them as a true MR EE IO consisting of the UK and 3 other regions, focusing on emissions related to climate change. The interesting point, though, is that Nijdam and Wilting developed EE IO tables for EU, other OECD and non OECD that included a fairly large amount of

extensions, including issues such as land use, fish consumption, etc. The drawback of the Nijdam and Wilting data is that their IO tables for these regions have fairly limited resolution of about 3 dozen sectors.

The description above shows that for practical applications, the data situation today is quite prohibitive to perform comprehensive environmental-economic assessments using MR EE IO:

- First, country IOTs are often not harmonized
- Second, of the harmonized data sets available, only the GTAP database forms a true MR IOT where countries are linked via trade. This is not the case for e.g. the OECD and ESA95 harmonized IOTs
- Third, various studies including EIPRO (Tukker et al., 2006a, Weidema et al., 2005) showed that a much higher resolution of at least 100-150 sectors or more is essential for allocating sustainability impacts in a meaningful way to sectors, products, and final consumption activities. When typical 60x60 sector or product tables are used, the following sectors and products which are highly relevant from an environmental perspective are too aggregated:
    - Agriculture: often just 1-2 sectors are discerned, where the impacts of production of various crops, and livestock differ greatly.
    - Mining and processing of ores: often just one mining sector and one metal processing is discerned, where the impacts of mining and processing of different metals differ greatly;
    - Energy extraction and –transformation: often just one energy extraction and one electricity producing sector is discerned, where the impacts of extraction of and production of electricity with different fossil fuels differ highly.
    - Fourth, the environmental interventions gathered via NAMEAs are just enough to analyse impacts related to global warming and maybe Acidification, but are insufficient to calculate other important sustainability indicators (e.g. external costs, Total Material Requirement, or the Ecological Footprint). And such NAMEAs are just available in the EU, in general not in other countries.

Additional issues are linked to the fact that Relations in the production-consumption chains are described in economic terms only, and not in physical terms. For instance, it is possible to assess the *value* of the contribution of the steel industry to car manufacturing (and use this as a proxy for steel consumption), but it is not possible to calculate the exact amount of steel used for cars. In theory, this problem could be solved by adding physical information to IO tables (and create PIOTs), but thus far this has only been done in a few pilot studies for a few countries (e.g. Germany).

The specific issues are placed in Table 8 and related to the problem this causes for studies at micro, meso and macro level.

- The lack of sector detail is obviously a problem for assessment at micro level, i.e. individual products. Here product LCA is the tool of choice. Such product LCAs obviously should take into account the specific technologies in countries of production. EE IO can have a supplementary role to compensate errors that may occur due to the fact that LCAs inevitably have cut-offs (hybrid LCA). At meso or macro level this problem is much less prominent.
- The fact that EE IO inherently implies an economic allocation may be problematic in specific cases. A specific example is e.g. the use of steel in different products. In EE IO, the use of iron ore will be allocated to final products on the basis of the economic value of the steel used in the product. Since steel quality will play a role prices may differ, and even for similar steel types prices in different markets may differ. In such cases, the allocation will not reflect the factual weight of steel (and hence the primary extraction of iron ore) used for the product. Again, at the micro level

this problem may be more prominent than at meso or macro level, since at aggregated levels price differences and other factors leading to errors may be ironed out.

- Time lags with regard to updates. In many cases, there is a time lag of a few years before SUT / IOT data, trade data, and data on emissions and resource uses are reported. Particularly in the case of fast growing economies, this may imply that an MR EE IO dataset works with rather outdated data. The obvious example in the last decade is China, for which trade relations with other countries changed dramatically (often with 10% or more per year).

Table 8: Specific problems with regard to MR EE IO in dealing with pollution embodied in trade

EE IO	**Sector detail limited to about 100 sectors**	**Economic rather than physical allocation of impacts**	**Only rough estimates of transport margins possible**	**Current data availability limited (solvable over time)**	**Time lags**
Micro level	Problematic: individual products cannot be discerned, like in LCA	May sometimes be problematic, if other allocation methods are fairer. Problem more prominent at micro level	Problematic where transport costs and impacts are high compared to other life cycle impacts	Problematic	Problematic in case of fast growing economies
Meso level	Minor problem	See above	See above	Problematic	Problematic in case of fast growing economies
Macro level	Minor problem	See above	See above	Problematic	Problematic in case of fast growing economies

- The limited data availability is a problem for all applications. As discussed earlier, there are just a few data sets with a large number of extensions, specified by industry and region.
- The estimation of transport margins and the country that delivers such transport services is problematic for those trade flows, where
    - International trade transport may cause a significant portion of the life cycle impacts of a final consumption category (for most products this is not the case)
    - And, on top of this: the specific transport modality is uncertain, or the impact intensity of the transport service depends highly on the country delivering that transport services

5.2.3 Improvement potential

The problems which can be solved are hence harmonizing IO tables (or SUT), detailing them to a suitable level, extending the availability of environmental extensions in the right sector format, and trade linking country tables. With regard to these issues, the following ongoing activities may be supportive:

- Harmonizing IOT/SUT: GTAP and OECD will most probably continue their work on providing harmonized IOTs for a great number of countries.
- Environmental extensions: EUROSTAT launched a call for tender to complete NAMEAs on resources, water, and air emissions, and one may hope that the data situation will be brighter in a few years from now, at least in Europe (EUROSTAT, 2008).

These efforts, however, will keep the issues of sector detail, availability of extensions, and linked country tables (the latter with the exception of GTAP) untouched. Probably the most ambitious effort to solve these problems, at least for a single base year, is the EU FP6 funded EXIOPOL project. In the period between 2007 and 2011, the project aims to:

- Develop harmonized SUT for the 43 most important economies globally, with a sector resolution of about 130;
- Provide extensions covering a few dozen resources and a few dozen emissions, sufficient to calculate the LCIA indicators GWP, ODP, and AC; MFA indicators, the Ecological Footprint, and externalties;
- Link the country tables via trade.

In principle the EXIOPOL project should provide a data set that allows calculating the pollution embodied in trade in a meaningful way via an MR EEIO approach. The project however will result in data for just one year, although it is suggested that the database should be taken over by a formal institution for updates and maintenance.

A few remaining issues need further attention. These include

- Solving the sector detail problem by hybrid modelling
- Options for analysing price-quantity relationships (rather than blindly using economic allocation)
- In relation to the issues above: data updates and potential for inclusion of physical flows
- Imports and exports of services (particularly related to international transport margins, but also related to tourism, etc.)

5.3 Decision-making ability

The usability of results from IOA depends on the type of environmental extensions. MRIOA adds however a specific issue which is the complexity of grasping the results due to the large amount of information provided by the analysis.

An EE IO framework may have other benefits over various other approaches (e.g. LCA based ones). If in due time time series of EE IO tables come available, burden shifting (export of polluting industries) can be made very clear. It also will become possible to analyse the effect of structural changes in an economy, and what structural changes occur, as well as how they contribute to changes in environmental impacts. In

this respect, one could imagine that a MR EE IO system that is filled with sufficient data, and has sufficient time series, could support indicators such as:

- Burden shifting: to what extent take the impacts related to final consumption in a country take place in that country, or abroad?
- Decoupling from a consumption perspective: are impacts related to final consumption de-linked from a growth in final consumption or not (whereas traditionally, de-linking indicators are defined from a territorial perspective)

As discussed, IO tables provide insight in the economic transactions between industry sectors. Environmental Extensions (also called NAMEAs) give per sector insight in the primary extraction of resources and emissions . IO/NAMEAs hence form an internally fully consistent and comprehensive picture of the economic and environmental characteristics of an economy in a specific country. The IO part even allows specifying (environmental and other) taxes and subsidies, and this IO core is excellently suited to be used in dynamic (e.g. CGE) models used for impact assessment of e.g. fiscal policies. It allows analysing the environmental impacts related to products/final consumption, resources, and industry sectors with the same basic dataset.

Table 9: Summary of IOA assessment

Objectives	Dimensions	Characteristics	Single country IOA	Partial MRIOA	Full MRIOA
Environmental Accounting Ability	**Inherent qualities of the approach**	Exclusive or Best coverage of environmental issues	- No exclusive coverage since it is mainly an allocation mechanism that can be extended with environmental data sets from other EAMs.		
		Theoretical Soundness	- Yes if applied to the domestic case only	- Yes if main trade partners are included	- Yes, both from a domestic and global perspective
		Global Life Cycle Perspective	- Life Cycle Perspective: yes - No global view since trade linkages are not considered.	- Life Cycle Perspective: yes - No global chains since only bilateral trade.	- Life Cycle Perspective: yes - Full global life cycle perspective.
		Adaptability of indicators to products and locations' environmental priorities	- Can be applied but not done yet.		
	Maturity & Auditability	Extensive coverage	- Spatial: extensive coverage wrt economic data but low coverage wrt environmental extensions - Temporal: time series at 5-10 years interval - Technology: only average technology and only few technologies		
		Data reliability & completeness	- Varying quality of economic data - Adequate quality of environmental data when it is available		
		Methodological consistency & soundness	- Yes, large scientific community		
		Global issues: data reliability & completeness	- Complete data but of medium quality for some countries		
		Global issues: methodological consistency & soundness	- Use of imports by importing sectors is based on rough assumptions - Transport & trade margins are difficult to estimate		
		Transparency	- Full disclosure		
	Improvement Potential	Data perfection, extension & hybridation	- Need for environmental extensions for additional countries		
		Methodology perfection, extension & hybridation	- Large hybridation potential since can be used with any type of environmental extension - Issue to solve: Price-Quantity bridge		
Decision-making Ability	**Usability**	Intelligibility, Univocity & Acceptance	- Depending on the aggregation methodologies combined to IOA - The high quantity of information provided by a full MRIOA analysis means that results are complex to grasp		
		Ease of Use	- High	- Medium	- Low because a large set of data has to be gathered and combined in a coherent system.
	Analytical Potential	Comparability & Additivity	- High due to top-down nature and the link with National Accounts		
		Causal and Structural analysis	- Feasible. - Few linkages with upstream socio-economic activities (unless connecting to behavioural models, e.g. econometric models).		
	Integration Potential	Compatibility with system of National Accounts & International statistics	- Perfect match		
		Compatibility with Norms, Standards & Voluntary agreements	- Can provide average industrial data potentially usable as proxy		

5.4 Strength and weaknesses of EE IO approaches

An MR EE IOT approach is probably one of the best approaches to take impacts of imports into account. Yet, the main problem is there are significant limitations in existing data sources. One can compare this probably with the tool of LCA in the mid 1990s, with most impact assessment methodologies having matured considerably, but still just limited databases with process related environmental data available that hindered deploying the full potential of the tool.

Key problems in the current data sources are that most provide SUT and IOT for single countries, without trade links. Sector and product detail is not as good as it ought to be. Environmental extensions are often lacking or include only a few types of emissions and primary resource uses.

At present, only the GTAP database comes a bit in the direction of the ideal, but is hindered by the fact that it was never built for environmental purposes and does not contain environmental extensions. Individual practitioners have added some emissions to their versions of the GTAP database for analytical purposes. For the future, the EXIOPOL project may result in a fairly comprehensive and detailed database for MR EE IO analyses, with data for one base year but a potential for updates. Some existing data sets (e.g. the Nijdam and Wilting, 2005 set) can help on a provisional basis, thanks to its considerable number of extensions to an as such limited sector detail for global regions clustered in OECD and non OECD countries.

Fundamentally, one cannot expect even in future that the sector detail of an MR EE IO will be more than 100+ sectors per country. This implies that MR EE IO in all cases only can be a supplementary tool at micro level (individual products). Further, in its present form MR EE IO inherently uses economic allocation of impacts, which may deviated from physical allocation. Also this may be a problem, again most prominent at micro level.

For the future, the EXIOPOL project may result in a fairly comprehensive database for MR EE IO analyses, with data for one base year.

A practical approach in the existing data situation may be the following. A practitioner could develop an EE IO table for a country of interest, and link this to e.g. the EE IO table for the US of Suh (2004) and/or the EU-OECD, other OECD and non OECD tables of Nijdam and Wilting (2003) to create some sort of an MR EE IO (with a central country and 3 regions with imports). The data sets mentioned have in any case the advantage of covering a large number of extensions, supportive to a broad set of indicators. The Nijdam and Wilting data set has the advantage that it covers estimates for non OECD countries, where industries tend to have a different environmental profile as in the OECD countries. Yet, as indicated, the sector resolution is limited.

The approach has however a number of inherent limitations, as has been discussed before.

- It is not realistic to expect that IOT or SUT will become available on a global scale with a much higher sector or product resolution than 100-150;
- The basis of EE IO is economic accounting; which implies that all impacts are economically allocated to final consumption and other economic activities, rather than on the basis of physical causality or other ways. Simply said, the price-quantity relationship may differ between uses of the output of a product or sector;
- Even when the data situation is improved, time lags may occur with regard to data reporting;
- The practical data situation is far from ideal, and probably the greatest bottleneck;

- There is a number of technical problems due to the fact that inherently a global database always will be based on certain assumptions; a main problem probably is the estimation of transport margins (including transport modality) and insurance margins on trade flows, and particularly the allocation of such margins to the country that delivers the transport or insurance service. This is a special case of the problem that statistics on trade in services (e.g. next to trade and insurance services also tourism) tend to be less reliable than of product trade.

6 Material Flow Accounts

6.1 Review of existing frameworks

6.1.1 Definition of material flow concepts

NB: The text in this section is referring to a specific bibliography related to MFA to be found after the general REFERENCES

Material Flow Accounting and Analysis (MFA) refer to the monitoring and analysis of physical flows of materials into, through and out of a given economic system, a national economy, a region or a product. MFA is generally based on organised accounts of material flows measured in mass units (kilograms or metric tons). Usually the main interest in MFA is in the total material flows even if division into different material groups is often presented also.

MFA can be used at different levels of economic activity:

- At macro level, Economy-wide MFAs are usually presented as time-series compilations of overall material inputs and outputs at national or regional level.[9] Macro-level indicators of material use per capita or material productivity can be derived from these time-series for monitoring and international comparison purposes. Material inputs consist of two main types material categories: domestic extraction and imported materials. Materials can also be divided into main categories: biomass, fossil fuels, metals, industrial minerals, construction minerals. The development of the share of imports on material use is an indicator of the globalisation of the economy. The other important indicator related to foreign trade is the physical trade balance or material content of exports minus material content of imports.

- At meso level, material flows are divided according to branches of production. The most comprehensive type of accounts at meso level are Physical Input-Output Tables (PIOTs).[10] PIOTs include the material flows between the production branches and the flows from production to domestic final demand inside the economy. The meso level approach can, however, be achieved also by means of environmentally extended input-output model (EE-IO), where only the primary inputs from nature to the extracting industries and material content of imports are measured in mass units while product flows inside the economy are in monetary units.[11] EE-IO include usually other environmental quantities than material

[9] The basic concept of the modern MFA has been first developed at Wuppertal Institute. The worldwide recognition of the approach were reached by the World Resources Institute report "Resource flows - Material basis of industrial economies" (Adriaanse et.al. 1997), where material use time series of four industrial countries, Germany, Japan, Netherlands and United States were compiled and analysed. Since then economy-wide time series have been compiled for several countries. In EU Eurostat have been further developed and harmonized the conceptual and methodological basis of EW-MFA by manuals (Eurostat 2001, Weisz et al 2007). OECD has also advanced the adoption of MFA among others by a series of manuals (OECD 2008).

[10] The concepts and structure of PIOT is described e.g. in SEEA2003 (United Nations et al 2003, Chapter 3, and in OECD manuals (OECD 2008).

[11] Examples of one country EE-IO with material flows are Moll & Acosta (2006) and Seppälä et.al. (2009). Examples of multi-regional world EE-IO accounting models are GRAM model of SERI (Giljum et al 2008) and ongoing project EXIOPOL (2008).

flows such as emissions into air and water, too. EE-IO model can further be extended into simulation models including dynamic behavioural relationships.[12]

- At micro level, the MIPS (Material Input Per Service unit) indicator is used to measure the life cycle material requirements of products when products are measured in terms of a service unit they provide (e.g. passenger kilometres in transportation, using one month of a phone). The MIPS approach underlines that the same service could be provided by different kind of products and thus MIPS is used as an indicator to compare the material efficiency of different service production methods or processes.[13]

The main material flow categories in EW-MFA are depicted in Figure 6

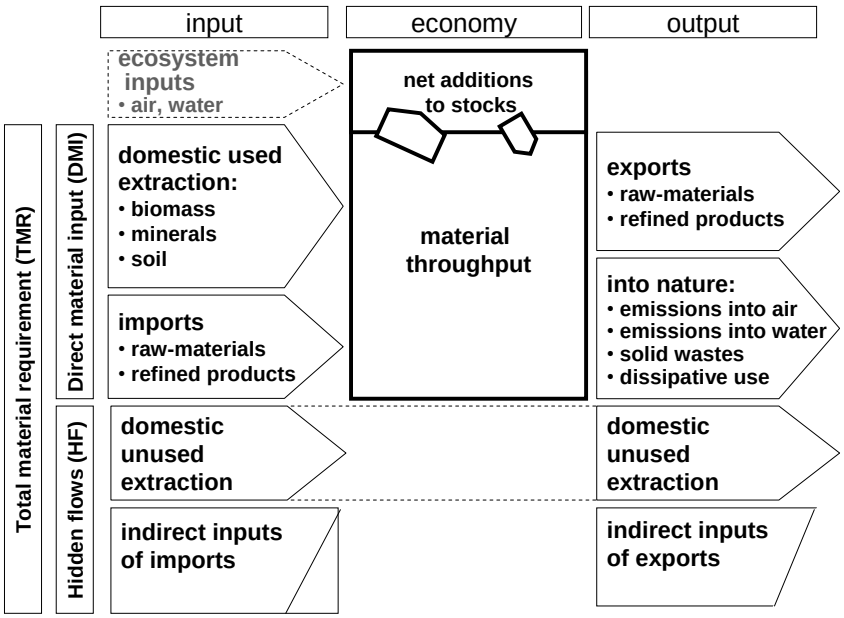


Figure 6: Main categories in economy-wide material flow balance

The Direct Material Input (DMI) is the mass of materials entering the economy. It consists of domestic used extraction and direct mass of imported products. A part of the DMI is tied by the economy as net addition to stocks, a part is exported into other economies and the rest ends up into nature as emissions into air and water, as solid wastes or as dissipative use.

Ecosystem inputs[14] consists mainly on oxygen of air for combustion and biological metabolism of humans and domestic animals and on water bounded in products by production processes and drinking water of humans and

[12] GINFORS model of SERI (Lutz et.al 2005) is an example of EE-IO simulation model

[13] MIPS concept has been first introduced at Wuppertal Institute (Weizsäcker et al 1997) and the inventory methods have been further elaborated by Rithoff et al. (2002).

[14] The term ecosystem inputs has been introduced in SEEA2003 (United Nations et al 2003)

domestic animals. In Figure 6, the box of ecosystem inputs is drawn by dashed line, because in economy-wide time-series they are generally omitted.

Domestic extraction can be completed by unused extraction that is with the part of nature mobilized in the extraction but not further processed in the economy. Discarded catch in fishing, unused logging residues in forestry, waste rock in mining and unused soil excavation in construction are typical examples of unused extraction.

The imported products are converted into the natural resource use of imports by adding indirect material inputs used abroad in producing the imported products. Indirect inputs also called as ecological rucksacks. Adding of indirect material use into the direct mass of imports converts the imports into primary materials from the nature or into the same logical level of measurement as the domestic extraction.

The unused domestic extraction and indirect inputs of imports are together called as hidden flows (HF) because there are mostly not seen in domestic production statistics or foreign trade statistics.

The sum of DMI and HF is called as Total Material Requirement (TMR). TMR may be considered as an extension of the concept of DMI. They have, however, different meanings and purposes:

- DMI measures the total mass of materials entering the economy.
- TMR measures the total mass of materials of nature mobilised by the economy – or global natural resource use attributable to the economy.

The indirect inputs of imports could be constrained only into used extraction abroad. In this case the direct imports + indirect used extraction of imports are called as Raw Material Equivalent (RME) of imports. The RME concept of imports is thus analogous to the domestic used extraction (DE). Then the sum DE + RME would give a third kind of total flow measure between DMI and TMR. The name for this indicator is, however, not fixed yet in the literature. Let us call it in the following as Raw Material Requirement (RMR).

The direct material flows of the output side of the material balance are divided into exports of products into other economies and residues and dissipative use of products into nature. The dissipative use of products includes deliberate spreading of products into nature, such as highway sanding and use of fertilizers.

The unused extraction is left by definition straight into nature. In general their environmental impacts are minor. However, e.g. the discarded catch of fishing affects the fish stocks of the waters, the logging residues of forestry are included in the national greenhouse gas inventories as a part of the man-made changes in the estimates of the net sink effects of forests and waste rock has been included in the EU legislation on mining and quarrying waste.

In the discussion of production vs. consumption side indicators the DMI and TMR are production side indicators. They measure how much resources are used by the production system of the economy. The corresponding consumption side indicators are:

- Domestic Material Consumption (DMC) = DMI – direct exports.
- Total Material Consumption (TMC) = TMR – (direct + indirect exports).

Again the concepts differ in their inherent meaning. As in DMC only the direct exports are deduced, the indirect material use of exported products are left in the DMC indicator. Thus DMC does not measure the material

content of the domestically used products. However, instead it measures the mass of materials either bounded into net addition to stocks or released into nature by the economy.

In TMC the indirect material use of exports are also subtracted and thus TMC is an unbiased estimate of the total material requirement of the domestic final use of products. Similar unbiased consumption oriented indicator could be also established by means of RME concepts of imports and exports.

For foreign trade following balance indicators can be established:

- Direct Physical Trade Balance (DTB): direct imports - direct exports.
- Total Physical Trade Balance (TTB): TMR of imports – TMR of exports.

The DMI, TMR and derived consumption oriented and foreign trade indicators are introduced for the macro level EW-MFA. They are also equally suitable for meso level approaches. Instead at the micro level MIPS indicators only calculations analogous to the TMR concept are applied without separation into domestic and foreign origin.

6.1.2 Existing datasets

The basic concept of the modern MFA has been first developed at Wuppertal Institute. The worldwide recognition of the approach were reached by the World Resources Institute report “Resource flows - Material basis of industrial economies” (Adriaanse et.al. 1997), where material use time series of four industrial countries, Germany, Japan, Netherlands and United States were compiled and analysed. Since then economy-wide time series have been compiled for several countries. In EU Eurostat have been further developed and harmonized the conceptual and methodological basis of EW-MFA by manuals (Eurostat 2001, Weisz et al 2007) and afforded unified MFA time series for EU countries (Bringezu & Schütz 2001a, Weisz et al 2002, Weisz et al 2008). OECD has also advanced the adoption of MFA among others by a series of manuals (OECD 2008)

Since then several national and European Union level compilations and analysis with different level of comprehensiveness have been made.

Eurostat started in 2007 a detailed enquiry among national statistical offices of the all EU 27 countries in order to then compile national time series for the years 2000 – 2006 and update them yearly in the future. Individual country reports are currently being harmonised and completed by Eurostat. The Eurostat enquiry only includes data on direct material inputs and exports.

So far, indirect material use of imports and unused extraction has only been included in relatively few MFA studies. The Wuppertal Institute published such a study for the European Union for the years 1980 – 1997 (Bringezu & Schütz 2001) and regularly updated national time series exist for Finland (Statistics Finland 2008), Germany (Schütz & Bringezu 2008) and Great Britain (Gazley & Francis 2005).

In 2008, SERI published an on-line world wide dataset of domestic used and unused extraction by country 1980 – 2005, classified into 12 subgroups of materials (Luter 2008).

Meso level comprehensive and fully balanced PIOTs have been compiled as yet only for three countries, Germany (Stahmer et al 2008), Denmark (Pedersen 1999) and Finland (Mäenpää 2005). The NAMEA type material use tables are compiled and used with monetary EE-IO analysis in several studies - e.g. Moll & Acosta

(2006) and Seppälä et.al. (2009) - although the regular compilation of NAMEA tables for material use is still not widespread : the Austrian statistical agency is the only one we know of which publishes these regularly[15].

The wider collections of estimated MIPS of different kind of products and services can be found at the internet pages of the Wuppertal Institute[16] and the Finnish Association for Nature Conservation[17]. In general MIPS studies do not distinguish between domestic and imported material flows.

6.1.3 System boundary issues

In system of national accounts (SNA) the national economy is defined in terms of transactions of resident units, especially "These units, known as resident units may or may not be present on the economic territory of the country at the time they carry out a transaction." (Eurostat and European Commission 2005, Paragraph 2.04) This residence principle means that the system boundary of SNA is not the geographical territory or administrative border of the nation. In MFA the difference between the system boundary of the economy and geographical territory is usually neglected. In MFA important cases where system boundary of economic activities differs from territory borders are:

- Fishing of domestic fishing vessels should be included in the domestic extraction even if it is taking place in international waters.
- Fuel purchases of domestic airplanes and vessels at foreign ports should be included in imports. Consequently at the output side the emissions of domestic vehicles in international transports should be included in the emissions of the domestic economy.
- Consumption expenditures of domestic tourists abroad should be accounted as imports as well as consumption expenditures of foreign tourists should be included in exports.

The second important system boundary issue is the boundary between national economy and environment. In SNA this boundary is defined by distinction between produced and non-produced tangible assets (Eurostat and European Commission 2005, Paragraph 6.06). Non-produced assets include land (soil covering and surface water), subsoil mineral assets and groundwater and non-cultivated biological resources. The plant cultivation is included in the system boundary of the economy.

In MFA the crops of cultivated plants are accounted as inputs from nature in the economy. Consequently the used seeds and fertilizers are registered as dissipative use in the nature. In SNA the crops are products of economic activity which uses seeds and fertilizers as intermediate inputs. Especially when MFA data is applied in EE-IO models, the material content of seed and fertilizers are also included in the indirect resource use of food products which contradicts the system boundary definition of MFA. This problem of biological resources has been elicited e.g. in SEEA 2003 (United Nations et al 2003, Ch. 3.D.3), the practical solution of the discrepancy has not yet been presented, however.

6.1.4 Issues in material use of imports

The main content of the direct material use of imports can be compiled using Foreign Trade Statistics. For EU countries uniform classifications of products and compilation methods for intra- and extra-EU trade are established for FTS of each country. Eurostat maintains the conversion tables by means of which the foreign

[15] http://www.statistik.at/web_de/statistiken/energie_und_umwelt/umwelt/namea/index.html#index2

[16] http://www.wupperinst.org/de/projekte/themen_online/mips/index.html

[17] http://www.sll.fi/luontojaymparisto/kestava/mips-online-in-english

trade product classification can be changed into classifications applied in national accounts. In FTS the imported products are classified furthermore by country of origin. Thus integration of the direct material flows of imported goods into economic models such as input-output models are relatively easy. Also analysis of imports by country or country groups is possible.

The main issues concern the estimation of indirect resource use of imports. In estimation of indirect resource flows of imports it has to be noticed that there is also one immaterial goods in FTS, electricity, for which, however, the indirect material flows are important. Also services, whose imports and exports are not included at all in FTS, have indirect material resource use.

Imports and exports of services in monetary values are included in the Balance of Payments Statistics of National Accounts and also in the monetary Supply, Use and Input-Output Tables.

Indirect primary material use of imported products can be estimated by LCA-based methods. A base work for this was done by the Wuppertal Institute in the 1990s (Bringezu & Schütz 2001b). The existing estimates of indirect resource use – or so called rucksack coefficients - are mainly restricted to raw-materials and semi-finished goods. Available MIPS studies can also be used to extend the collection of rucksack coefficients. Currently available MIPS estimates covers also variety of refined products and are available online at Wuppertal Institute and The Finnish natural Conservation Associations (2009).

Input-output models can be used to estimate the indirect resource use of imports especially for fabricated goods and services. The easiest way of doing this is to assume that indirect flows of imported product groups are the same as those of products produced domestically (e.g. Moll et al 2006). This method may be very biased especially with respect to those raw-materials which are not extracted domestically at all. The second and more developed method – applied in the ENVIMAT model (Seppälä et al 2009) - would be as follows. Assume that we have estimates of indirect flows mainly for raw-materials and semi-finished goods. Then we divide the imports into two parts: to products, for which we have estimated indirect flows and to those goods and services for which we have no estimates. Then we can create an input-output model in which the information on indirect flows of the first group of products is utilized when using domestic technology assumption only in estimation of indirect flows for the second set of products.

More developed input-output modelling would be multi-country or multi-region world models, in which the estimation of indirect resource use of imports for each country or region only requires the domestic used and unused extraction of each country. One example of this possibility is provided by the Exiopol project (Exiopol 2008). The problem with multi-region world models is that they have had a rather aggregate industry classification. E.g. different metals embody very different amounts of indirect flows caused by the very large differences in their typical ore grades. In input-output models the so called aggregation bias especially in metals and metal based products can become large.

6.2 Environmental Accounting Ability

In the following mainly macro level EW MFA is evaluated; meso level and micro level approaches are evaluated only in specific circumstances. EW MFA is further divided into two parts: DMI (and derived) indicators and TMR (and derived indicators).

6.2.1 Inherent quality of the approach

In MFA material flows are measured in basic physical quantities, in mass units, and thus product or location specific issues are not relevant, the main interest is in the total mass of material flows. The DMI indicators take into account only the material inputs directly entering the economic system under study. In TMR indicators the upstream material use of products or indirect inputs are included, too. Location specific issues arise in TMR indicators as e.g. indirect inputs of metal concentrates from different mines may vary considerable.

In MFA the main focus is in the input side of the material flows. In DMI indicators the domestic extraction is covered but the indirect material flows of imports are left aside. TMR indicators include the whole production chain of imports, too.

In EW MFA material balances the inputs into and outputs from the economy are accounted, but the economy itself is left as black boxes. The meso level approaches, PIOT and EE-IO open the inner production chain structures of the economy. Similarly in the micro level MIPS approach the whole production, use and disposal chain of the product is taken into account.

In MFA the material flows are measured unified in basic physical quantities, mass units. Then the basic law of chemistry, conservation of mass, gives sound basis for compilation of material balances.

6.2.2 Maturity & Auditability

In the field of MFA general methodological manuals have been delivered for all three levels: macro, meso and micro.

In EW MFA the DMI indicators are widely applied and thus they have the relative coverage. The quality and reliability of DMI indicators are based on the fact that data for their compilation can be found mostly from established national and international statistical sources. In TMR indicators statistical data for domestic unused extraction is more widely lagging and rough estimation method have to be used. Particularly data for estimation of indirect material use is deficient for refined goods and services.

Direct material input of imported goods can be compiled from Foreign Trade Statistics (FTS). From FTS the country origin of imported products can be picked up, too. However, especially for refined products the ultimate country origin of the primary raw materials cannot be cleared out. Multi-regional input-output world models are needed to analyse the whole international production chains.

In imports of services the most important sector is international transport services. Especially for these the location based issues are problematic.

6.2.3 Improvement potential

Most important improvement potential DMI datasets are including fuel purchases abroad of resident international transportation. In TMR datasets the development of harmonised estimates for indirect resource use of imports of refined goods, services and tourism are needed.

In methodological development the measurement of material input or biological resources in consistency with the system boundary between economy and environment in national accounts is necessary.

6.3 Decision-making ability

6.3.1 Usability

The uniform use of basic physical quantities, mass units, entails clear interpretation and ease of use of MFA indicators.

The drawback is that mass unit does not tell anything about qualitative differences between different types of material flows. Thus MFA indicators could be interpreted to give only a generic environmental pressure of the material flows.

6.3.2 Analytical potential

The uniform use of basic physical quantities, mass units, implies also that the material flows are additive such that analysis may be carried out in different levels of aggregation. The international comparisons of countries or regions or sectors of production and comparisons of economic sectors inside a country or region are easy to carry out.

Causal and structural analysis can be carried out by PIOT and EE-IO models.

6.3.3 Integration potential

MFA in macro and macro levels is aimed to be in conformity with national accounts (SNA) even if some discrepancies still exists. Most important data sources in domestic extraction and foreign trade are even the same as in national accounts.

Main problems in consistency between MFA and SNA are system boundary issues between nature and economy and between domestic economy and rest of the world which, however, could be solved.

6.4 Methodological proposals for overcoming current limitations of MFA

As a part of developing an open database for environmental accounts of imports for EU and its member countries, the following are recommended for MFA of imports:

- For EU as a whole and for each of its member countries the time series of imports and exports are collected and maintained from Foreign Trade Statistics (Cometex) in monetary and mass units, classified in conformity with the product classification applied in SUIOT's of EU countries (2-digit level of CPA) and divided by intra- and extra-EU trade. This datasets completes the economy-wide MFA time-series collected by Eurostat, where primary raw materials are classified in detail level, but fabricated products are classified very roughly.

- For raw material imports, LCA type estimates for rucksack coefficients of indirect use of used and unused extraction should be developed at detailed product classification level for both products produced in EU countries and for products produced outside EU. Raw materials include products under the CPA headings A (agricultural and forestry products), B (fishery products), C (products of mining and quarrying), DF (coke, oil products, nuclear fuel) and 27 (basic metals).

- Indirect resource use coefficients for fabricated products not included in raw materials should be collected from input-output studies – from Exiopol, when the results are available – and should be converted from kg/€ units into kg/kg units.

- For fuel purchases of international transports and for tourism consumption abroad pilot studies should be started in order to develop appropriate estimation methods and to produce first rough estimates.

- Harmonized estimation practices for indirect resource use of imports and exports of services should be developed.

7 Environmental footprints: Land & water use assessments

7.1 Review of existing frameworks and methodological issues

NB: The text in this section is referring to a specific bibliography related to Environmental Footprints to be found after the general REFERENCES

- Environmental footprints, which assess land use, are of great and increasing interest, as evidenced by the widespread popularity of the Ecological Footprint (EF). A series of methods currently exist (EF, HANPP, ADL) which allow the assessment of the impact of consumption on terrestrial ecosystems. They all need adaptation to address issues of trade more explicitly: this is the focus of this chapter.
- Imports of raw materials and goods are associated with land use, and thus with the environmental impacts which result from land use in the exporting countries. Environmentally, the most significant link between trade flows and land use is the area requirement to produce biomass-based products. These products are significant for several important trade partners of the EU (e.g. the USA, Canada and Brazil).
- Unsustainable water use, water scarcity and pollution are important environmental issues in many countries which are EU trade partners. Currently, no agreed-upon international methodology accounting for water usage exists.
- In this chapter, three environmental accounting methods related to land use are reviewed: the Ecological Footprint (EF), Human Appropriation of Net Primary Production (HANPP) and Actual Land Demand (ALD). A method for measuring water use through the concept of virtual water use, the Water Footprint, is also assessed.

The ecological footprint (EF)

The basic concept of the EF is to quantify if and by what order of magnitude human consumption of resources is exceeding the biosphere's regenerative capacity. (Wackernagel et al., 1999, Wackernagel et al., 2002). The EF calculations assess how much biologically productive area is needed to produce the yearly resource flows consumed by the population of a region (a city, a country, or the world), to absorb wastes or emissions (especially carbon dioxide), and to host the built infrastructure in this region. EF accounts standardize resource consumption to units of global biological production, expressed in area equivalents: in "global hectare" units.

Human Appropriation of Net Primary Production (HANPP)

Most human uses of land are dependent upon the land's biological productivity, i.e. its net primary production (NPP) per unit area. HANPP measures the changes in the amount of potential ecosystem NPP resulting from human land use activities (Vitousek et al., 1986). HANPP is defined as the difference between the NPP of the potential natural vegetation and the NPP remaining in the ecosystem after harvest or land use changes such as urbanization (Haberl et al., 2004; Haberl et al., 2007a). The principal indicator of this method is the ratio of the NPP appropriated by human activities (HANPP) to the potential natural vegetation's NPP, as a percentage.

Actual Land Demand (ALD)

ALD approaches, as their name indicates, calculate area demand as a function of two factors, consumption and yield per hectare (Erb, 2004). In general, only biomass flows are considered, although sometimes non-renewable resource consumption is also considered through CO_2 absorption (following the EF approach).

Water footprint: virtual water

The water footprint combines national data on apparent consumption of water in industry and households and water used in agriculture (Hoekstra and Hung, 2005; Hoekstra, 2009). Its main indicator is water use volume per year.

7.2 Environmental Accounting Ability

7.2.1 Inherent quality of the approach

The ecological footprint (EF)

Two approaches of EF assessments can be discerned: A system approach (compound approach) calculates EFs of a region or nation, a bottom-up approach (component based approach) calculates the EF of a product, groups of products, or (industrial) processes (Simmons et al., 2000; Wackernagel et al., 2005). The product-level applications follow the basic scheme of Life Cycle Assessments and are quite heterogeneous. In this study, we focus on the system approach, which is currently subjected to standardization efforts by the Global Footprint Network (GFN).

The EF uses data on the built-up land, the consumption of crops, pasture, forestry and energy to derive land area equivalents (Wackernagel et al., 2005; Monfreda et al., 2004). The method for translation to area is not uniform: it is done through global yield factors for the biomass products, estimates for terrestrial CO_2 sequestration for fossil fuel CO_2 emissions, and equivalent CO_2 emissions for replacing nuclear power by fossil generation. The hypothetical terrestrial sequestration of CO_2 is conceptually problematic (in fact, roughly half the CO_2 emitted accumulates in the atmosphere and the other half is sequestered in the oceans, very little is sequestered on land) and entails large uncertainties (Watson et al., 2000; van den Bergh and Verbruggen, 1999). The result mixes real land required for the built environment and biomass production and hypothetical land for CO_2 sequestration or alternative energy production.

The EF claims to account for the most important pressures of human activity on the biosphere, but does not account for many important activities (such as mining or extraction, or acidifying pollution or ozone damage, for example). An all-encompassing indicator of the planetary carrying capacity is an unrealistic dream, in any case, but the popularity of the EF may masks the factors which are missing from it (Fiala, 2008).

Imported products are treated through upstream land use and energy requirements and their resulting CO_2 emissions, with no specification of the location of origin (global average). These emission factors have recently

been shown to be uncertain in comparison with factors derived from MR-IO (Wiedmann, 2009). The spatial resolution is limited to the national level, with results related to global yield averages.

Human Appropriation of Net Primary Production (HANPP)

HANPP is measured at a local level, using harvested biomass, unused biomass residues, land use and actual biological productivity of the land. The goal is the comparison of actual productivity with potential productivity in the absence of human intervention: the potential natural vegetation productivity is obtained through modeling vegetation (DGVM). HANPP thus focuses only on biomass flows and built-up land. HANPP results are spatially explicit at the global scale (5 arc-minute resolution) and do not rely on global averages (Imhoff et al., 2004; Haberl et al., 2007a).

Traded biomass products are allocated upstream HANPP factors corresponding to the country-specific potential productivity (Erb et al., 2009; Haberl et al., 2009).

Actual Land Demand (ALD)

ALD approaches calculate area demand as a function of two factors, consumption level and patterns, and yield per hectare per product. ALD approaches quantify area requirements related to domestic extraction (harvest), imports and exports, separately (Erb, 2004; Wackernagel et al., 2004). Currently, no standardized methods of ALD exist. However, due to the absence of weighting schemes (the accounts refer to actual areas under use), and because all studies are based on simple assumptions, the reproducibility and comparability of these studies is guaranteed.

In general, only biomass flows are considered. Non-renewable resource consumption sometimes complements ALD studies, following e.g. the global-hectare approach of EF for energy consumption (absorption area), which may create consistency problems.

Imports are treated through yield factors of the country of origin (not the country of last export), thus global averages are not used.

Water footprint: virtual water

The water footprint estimates the fresh water required for different functions: agricultural, domestic and industrial through blue and green water footprints (Hoekstra and Chapagain, 2008). The blue water footprint is the volume of freshwater that evaporated from the global blue water resources (surface water and ground water) to produce the goods and services consumed by the individual or community. The green water footprint is the volume of water evaporated from the global green water resources (rainwater stored in the soil as soil moisture).

Grey water is the (hypothetical) fresh water quantity required to dilute aquatic pollution. The dilution factors are obviously subject to large uncertainties. The water footprint thus combines actual water use with hypothetical water use, much like the EF combines real land use with hypothetical land required for CO_2 sequestration.

Unlike the land-use methods, the water footprint methodology has always had a trans-boundary focus, through the concept of virtual water trade (Hoekstra and Hung, 2005). Traded products are explicitly linked to their countries are origin and destination. Imports are assigned upstream requirements based on the national factors of their country of origin (Chapagain and Hoekstra, 2008).

7.2.2 Maturity & Auditability

Land use methods, and to some extent the water footprint, all rely on international data on biomass use and trade, such as the Food and Agriculture Organisation (FAO) and the UN Comtrade database or the corresponding national agricultural, land use and trade statistics. From a global perspective the overall quality of this data can be ranked as follows: Primary data on agriculture and energy tends to be of the highest quality. Forestry data is at most of medium quality, whereas livestock is medium-to-poor quality. Indeed, all of the land use methods suffer from a lack of reliable data for livestock production and feed use. Livestock is fed through a combination of grain, fodder crops, crop residues and grazing, and some of these have practically no international data coverage (Wirsenius, 2003; Eurostat, 2007, Krausmann et al. 2008).

The ecological footprint (EF)

The EF is the most mature and accepted of the land use methods, with yearly diffusion through the WWF Living Planet reports (e.g. Hails et al., 2008; Loh et al., 1998). The Global Footprint Network represents an interactive user community with the goal of dissemination of the method (Wackernagel et al., 2005; Kitzes et al., 2007; Kitzes, 2009) The data basis comes from publicly available sources, whereas the EF results themselves are proprietary through the GFN. Models are used to cover data gaps on livestock feed demand and LCA analysis is used for estimating upstream energy in trade. Moreover, there are significant uncertainties stemming from the conversion factors to global hectares.

Trade could be better addressed by the EF through the use of bilateral trade matrices detailing the country of export (Moran et al., 2009; Wiedmann, 2009). However, even with country-specific import data, the use of global conversion factors masks large international differences.

Human Appropriation of Net Primary Production (HANPP)

HANPP is still in a development stage, although the first global dataset for 2000 has been published (Haberl et al., 2007a) and the approach has been applied in several national case studies (Krausmann, 2001, O'Neill et al., 2007, Erb et al. 2009). It is associated with the research community of the Global Land Project.

Models are used to cover data gaps on livestock feed demand, soil degradation, irrigation, vegetation fires, the influence of fertilizers and the potential ecosystem productivity (Haberl et al. 2007; Haberl et al., 2007b). However, since no weighting factors are used, the uncertainty in HANPP should be smaller than that of the EF. Moreover, the HANPP results aggregate at all scales and thus undergo consistency cross-checks.

Recently, a first empirical assessment of HANPP associated to traded products has been published (Erb. Et al. 2009, Haberl et al. 2009) but there is research need to develop a sufficiently detailed set of consistent coefficients for the conversion of agricultural products into HANP equivalents. Trade could be better addressed by HANPP through the use of bilateral trade matrices detailing the country of export..

Actual Land Demand (ALD)

ALD is also in a development stage but probably the most straightforward approach. Many required data (Bilateral trade data, crop yields) are available at reasonable accuracy. A set of consistent coefficients for the conversion of agricultural products into area equivalent needs to be developed .

Water footprint: virtual water

The water footprint is a maturing concept, in an ongoing process of harmonization and standardization (Hoekstra and Chapagain, 2008; Chapagain and Hoekstra, 2008). It is partly based on global water flow models, which have uncertainties associated with them. Its treatment of traded products is among the most developed of this chapter's methods, since it was explicitly designed to account for trade.

7.2.3 Improvement potential

Both the EF and HANPP can improve their treatment of traded products by allocating traded goods to their country of origin, and applying upstream factors which relate to the production conditions in that country (rather than global factors, or in the case of the EF, using upstream CO_2 emissions as the only relevant factor in traded goods). The water footprint and ALD already do this. This process would involve using bilateral trade data, which is data intensive (and not always reliable, since exports and imports don't balance at the global level).

Establishing national-level factors for the EF might prove extremely challenging, since even at the global level these factors are far from certain. This is related to the insistence of the EF of adapting non-land use phenomena (such as fossil-fuel emissions or nuclear power) to hectare equivalents: such factors are, per definitionem, impossible to measure accurately, since they do not correspond to occuring physical processes. Moreover, these factors are dynamic, since the terrestrial sink capacity is affected by land use history, such as deforestation.

Even immaterial transactions, like services, have upstream environmental implications. Coupling the land use and water use indicators with Input-Output methodologies could assess these upstream requirements. This has already been demonstrated for GHG emissions and the EF (e.g. Lenzen and Murray, 2001; Wiedmann et al., 2008; Turner et al., 2007; Tolmasquim and Machado, 2003; Haberl et al., 2009).

Although the international trade data and input-output methodologies exist and have been applied to land and water use indicators at the case study level, their systematic application will require a sustained effort, both at the research and statistical agency level.

7.3 Decision-making ability

7.3.1 Usability

The ecological footprint (EF)

The EF is by far the easiest indicator to communicate to policy makers and a wider public, which has contributed to its immense popularity, since global hectares are, by definition, limited to the terrestrial surface of the planet. It is also widely accepted and has been adopted by a variety of governmental and non-governmental bodies, the most prominent of which is the WWF (Hails, 2008). It is also being considered in the "basket of indicators of the EEA. The policy implications of the EF are, however, far from obvious, since not all the phenomena it assesses are really related to terrestrial land, and the EF's "conservative approach" assumes that ongoing land use levels are sustainable (Wackernagel et al., 2002, Monfreda et al., 2004, Kitzes et al., 2009; Fiala, 2008). The use of global conversion factors masks local advantage or disadvantage in land use: some countries are superior places to grow certain crops.

From a continuity perspective, the EF depends on current harvests for the global hectare yield levels, which may or may not be sustainable. The sequestration capacity of terrestrial carbon sinks is dynamic, since it depends on land use changes, but currently treated as static in the EF.

Human Appropriation of Net Primary Production (HANPP)

HANPP is currently accepted in land use academic circles and being considered by the EEA as part of its "basket of indicators". A larger HANPP indicates a larger human appropriation of biomass which would otherwise be available for use by ecosystems, but there is no consensus on what level of HANPP is sustainable (Haberl, 2004). HANPP is an indicator both of quantity and quality of the intensity of land use. HANPP is robust in time series, and thus can be used for monitoring (Haberl, 2007).

Actual Land Demand (ALD)

ALD results are straightforward and have a univocal interpretion, but, like HANPP, have no sustainability threshold. Also like HANPP, ALD is robust over time (Erb et al. 2004).

Water footprint: virtual water

The water footprint method yields straightforward results, with a univocal interpretation. Despite the availability of a threshold indicator, the sustainability interpretation of the results is not so clear. Over time, technological change and changes in water demand due to changes in land management might not be reflected in the indicator, since the water footprint relies on local, but static, conversion factors (Gerbens-Leenes et al., 2009).

7.3.2 Analytical potential

All of the methods described in this chapter have a global, international perspective. As a result, an indicator measured in one country is comparable with one measured in another, and can be aggregated up to a global scale. This constitutes a particular strength of these approaches.

The EF uses global factors to convert energy and other flows to global hectares. If a more localized approach is pursued, with nationally-appropriate factors, the comparison to global hectares may also become more problematic. The other methods use national conversion factors.

In the absence of combination with Input-Output approaches, none of these models can accomplish structural analysis or causal chain analysis

7.3.3 Integration potential

All of these methods are based on international and national statistical accounts. Their integration into national and international frameworks is easily conceivable.

However, by themselves, they may not be a good basis for setting norms or standards. They are all too aggregated to be relevant to individual products. At most, they indicate average values for a country's exports at the level of a family of products. Moreover, the EF does not distinguish between sustainable and unsustainable land use (the current yield level defines the potential), which makes its use problematic as a norm for land use.

7.4 Strength and weaknesses of Environmental Footprints approaches according to IMEA grid

There exists a great interest in land and water use indicators, demonstrated by the widespread adoption of the EF and references to water footprints. These methods relate environmental indicators directly to human activities on land and water use. Despite this interest, each method has strengths and weaknesses, and further work must be done before they can be reliably used to assess traded flows.

The methods described in this chapter have enabled great progress in the assessment of land use. However, the central question of measuring environmental pressures, or, yet more challenging, impacts, associated with land use remains. Actual land demand and the EF do not measure pressures; HANPP measures a specific pressure.

In terms of the micro-meso-macro scale, all of these methods can only account for national average pressures: for instance, there is no differentiation between impacts associated with traded products from conventional and organic agriculture. The typical problems encountered in LCA also exist for these methods, in particular allocation issues of environmental pressures to products and byproducts of agriculture.

The ecological footprint (EF)

The EF has an advantage of simplicity in concept and communication, but may in fact distort and oversimplify a more complex reality in the process. The approach is not currently suited to national specificities, which may in turn bring complexity to reporting and comparing footprints. The time evolution aspect is complicated by the change in important processes (intensity of land use) and weighting factors (terrestrial carbon sink capacity). There may also be issues of double counting (common to LCA) in the inclusion of traded goods.

Human Appropriation of Net Primary Production (HANPP)

HANPP relates to the quality of land use, since it measures the intensity of human influence on natural productivity levels. Its other strengths are its global spatial resolution, robustness over time for monitoring, focus on land use activities, and use as an indicator of human tampering with ecosystem functioning. Thus it can be related directly to pressures on biodiversity (Haberl, 2007). HANPP is more difficult to communicate than the EF, since it is conceptually based on ecosystem processes rather than terrestrial surfaces per se.

Actual Land Demand (ALD)

The ALD is perhaps the least developed or deployed of these methods. It is quite data intensive, but could be applied more widely with a dedicated research effort. Its advantage compared to the EF is that it measures real hectares being used. Its weakness may be that hectares alone tell only part of the story: an ecosystem perspective such as HANPP's may be necessary to understand the implications of land use.

Water footprint: virtual water

The water footprint refers to actual water use, with no weighting involved. It is conceptually robust and aggregates at all scales. Of all the methods described in this chapter, it is the one with the most evolved integration of trade issues. The use of static conversion factors hampers its use for monitoring purposes.

7.5 Proposals for overcoming current limitations of Environmental Footprints

The most important development for land use indicators is the systematic use of bilateral trade data, along with appropriate national conversion factors: from traded material flows into area equivalents, at a variety of potential levels of disaggregation. Hybrid methods or cross-checks with Input-Output and LCA may also be desirable. One central challenge (common to many methods) is the "re-export effect" or "harbor effect", where the country of export and the country of origin of a traded product are not the same. The land use and water use methods are relevant to the country of origin, but trade data records the country of export. Multi-Region Input-Output may be one approach to dealing with this issue.

In the future, the product level may be addressed by a combination of methods: product-level LCA compared to national averages, for instance.

8 Conclusions & Recommendations

EAMs are used by a large number of actors for assessing environmental performances. Since each EAM is based upon a specific system definition and was developed with a specific goal, they have a diverse potential in terms of their ability to treat issues related to trade. In one way or another, however, they are all facing the challenges of integrating international trade issues.

We have proposed a description of these challenges based on what EAMs "are", "how" they function and the use of their results in decision-making by the means of an archetypical workflow and an analytical framework. Four current needs are highlighted:

1. The need to define an archetypical EAM workflow to understand how EAMs are structured and how they meet expectations and challenges along its steps.

2. The need for a reference framework common to all EAMs enabling comprehensive assessments, based on scientific and societal objectives, to show when and how they can be used or should be replaced by other EAMs providing similar indicators. A second and final version of such reference framework is proposed following the analysis performed on several EAMs performed throughout IMEA project.

3. The need for additional development to handle globalization with respect of data and methodologies including the combination of these methodologies to foster strengths and reduce weaknesses since each method has strengths as well as limitations.

4. Finally the need for systematic methodological guidelines for all EAMs dealing specifically with identified key issues since environmental accounting is and will remain strongly based on assumptions which need to be accepted and transparent to users.

8.1 EAMs assessment along an archetypical workflow

An archetypical workflow has been elaborated for EAMS based on four possible outcomes of EAMs, resulting from the explicit or implicit application of five steps (Figure 1). The first outcome is an "inventory – direct". This inventory is a collection of heterogeneous flows of the "direct" type, i.e. a classical inventory by source. This inventory is completed once the "system design" (step 1) and the "data collection and preparation" (step 2) are completed. Information from this inventory can then be re-allocated along global production-consumption chains in step 3 "Allocation" based on internal relations from the system. This results in a global inventory with a life cycle perspective (outcome 2 "Inventory - global life cycle"). In order to reduce the complexity and heterogeneity of the available information, one or several "synthetic indicator" can be generated by aggregating flows at the level of Pressure or Impacts based on hypotheses of similarity (step 4). Eventually, the aggregated indicator is compared to reference values in the last step "normalization & comparison" (step 5), resulting in a "performance indicator" to ease decision-making.

Outcome 1: Direct inventory

The elaboration of a direct inventory is the most common outcome of environmental assessments. The system design step is well dealt with by most EAMs but the availability of data is an issue for several of them, even in Europe (MIPS, PIOT, IOA). The transformation of input data is lacking scientific validity in the case of the EF (Piguet *et al.*, 2007). The ALD is assumed adequate but further research is needed since no critical peer review has been identified. Approaches that can be based on GIS data like HANPP and international data sets like the EF have a much better coverage and are more adapted to the challenges of globalization from an inventory view. The EF is however relying also on global factors for product consumption, which are very uncertain and not locally appropriate. While EW-MFA data is already available for a large number of countries, data is lacking for both partial and full trade EE-IOA but large projects such as EXOPIOL are currently overcoming this limitation (Tukker *et al.*, 2009). The challenge of globalization is also tackled in LCA with the development of regional LCI databases under an international coordination within the UNEP-SETAC life cycle initiative. However development appears to be very slow.

Outcome 2: Global life cycle Inventory

Achieving a global life cycle is a key challenge for EAMs: few methods are able to deliver a life cycle perspective; data and models of international trade are subject to many limitations or simplifications, e.g. trade balances. The elaboration of an inventory with a life cycle perspective is soundly dealt with by approaches like LCI or PIOT while the quality of the IOA is limited by its monetary nature. The macro approaches (EW-MFA, EF, WF and ALD) provide only some rough life cycle perspective, distinguishing at best direct from indirect environmental requirements in aggregates. HANPP also includes a life cycle perspective for upstream biomass flows through "embodied HANPP," which includes traded biomass flows and their upstream components. The Corporate Carbon Footprint (CCF) covers direct and indirect emissions from electricity only (scope 2 of the GHG protocol) but other upstream and downward chains are usually not computed or only very roughly (scope 3). The future GHG protocol, currently under elaboration, should provide guidelines to remediate to this issue in 2010. The EF integrates an international view since its inception. Its implementation is however weak since imports are computed with world average factors rather than country-specific ones and trade balance are used. Among the three types of IOA presented, the single country solution is clearly not adapted to an international context but it is nevertheless currently the most used solution. The full trade IOA approach represents the most advanced solution among all EAMs and is, as such, currently the centre of the research focus in this area (Thomas Wiedmann *et al.*, 2009).

Outcome 3: Synthetic indicator

The quality of the synthetic indicators delivered by EAMs depends on the robustness of the weighting schemes, which are closely related to the stage of the EAM within the DPSIR model. The MIPS, PIOT, EW-MFA, HANPP provide a robust assessment at the level of Pressure. The quality of the EF is however lowered by a lack of a full scientific validation on the energy conversion into the common global hectare unit, since the agricultural EF can be lowered simply by intensification (raising yields). The WF and ALD would benefit from further validations and a more widespread implementation. The quality of the WF and ALD are also lowered because of a lack of scientific validation. The LCIA approach attempts to go beyond Pressure to the Impact level, resulting in indicators more (mid-points like acidification) or less robust (end-points like human-health). Several authors have applied LCIA to resource-oriented approaches extending them to an aggregation based on a similarity of damages. Globalization is a challenge for the approaches adopting a regional perspective. The EF integrates it since its inception but LCIA is still at the beginning of developments for regional impact factors and international transfers of pollutants.

Outcome 4: Performance indicator

Table 5 clearly establishes that indicators of performance are a weak point of EAMs. Five approaches (EF, ALD, LCIA, HANPP and WF) propose a comparison with internal or external references values but the meaning of the references is not always clear in policy terms. Besides the obvious fact that less resource use and fewer emissions are better, there is rarely a fixed threshold that can be used as a policy goal. However, each of these methods does allow for robust monitoring, thus measuring improvements or worsening in terms of their domain. The multiple indicators provided by LCIA, or a variety of methods, may be more representative of the system's complexity and its tradeoffs, but also reduce the clarity of the message with potentially mixed signals. The lack of scientific validation of the threshold in the EF approach is an important issue. The OECD synthesis report (OECD, 2008b) on material flows mention the need to complement indicators with references values and propose some generic examples. It is not clear, however, that every environmental issue or measure is associated with a clear threshold. EE-IOA indicators and the hybrid approaches based on IOA have a large potential of comparison with other indicators from the SNA but the life cycle perspective is an issue and clear performance indicators are still missing. The potential of comparison of bottom-up studies like LCA is much lower since results are strongly dependant on the system design that is varying between studies. Several initiatives, like (BSI, 2008) are however establishing guidelines for the labelling of products that would allow for such comparison. Globalization is adding specific challenges to all EAMs through the questioning of the objectives underlying the measurement of performances and the relevance of applying the so-called “local in global” view. None of them has dealt with this issue yet.

8.2 Proposal for an analytical reference framework enabling comprehensive assessments of EAMs

The work presented within this report has established the societal expectations and challenges from globalization faced by EAMs based on what they "are" and what they "do". By exploiting this work as well as the conclusion of the IMEA workshop[18] and assessments of several EAMs, we are now in a good position to propose a comprehensive analytical framework. This analytical framework is a balanced methodology-policy alternative to the RACER, proposed by the European Commission (European Commission, 2005) and applied by Best *et al*. in (2008) and Lutter and Giljum (2008), which has a strong policy orientation. This framework will permit an objective analysis of the strengths and weaknesses of any EAM with respect to the mentioned issues as well as additional issues related to the use of results in decision-making as recommended by the workshop. This framework is structured along three axes: environmental accounting abilities, decision-making abilities and improvement potential. Its structure slightly differs from the one proposed in chapter 3. The first two axes are split into three dimensions, and each dimension provides an answer to specific issues:

Axis #1 Environmental accounting ability

1. Are the inherent qualities of the approach adequate to provide a sound coverage of the environmental issues globally?
2. Is the approach mature and auditable?
3. How are challenges from globalization tackled?

[18] March 2009 in Paris – www.imea-eu.org

Axis #2 Decision-making ability

4. Is the approach usable?
5. Does the method provide a strong analytical potential?
6. Is the approach compatible or can be integrated with existing systems of indicators?

Axis #3 Improvement potential

7. How could be improved each of the first two dimensions?

Each dimension can be further decomposed into several characteristics, which are presented in Table 10 and described below.

Objectives	Dimensions	Issues
Environmental accounting ability	Inherent qualities	Exclusive or best coverage of environmental issues
		Theoretical soundness
		Global life cycle perspective
		Explicit linkage between socio-economic activities and environment
	Maturity and auditability	Overall methodological consistency
		Methodological soundness : - System design - Data preparation - Allocation - Aggregation - Comparison
		Data sets reliability and completeness
		Transparency
	Adaptation to global challenges	Overall methodological consistency
		Methodological soundness : - System design - Data preparation - Allocation - Aggregation - Comparison
		Data sets extension, reliability and completeness
Decision-making ability	Usability	Intelligibility, univocity, acceptance
		Ease of use
	Analytical potential	Causal and structural analysis
	Comparability, compatibility, integration potential	Comparability and compatibility with other indicators (social, economic, environment)
		Compatibility and integration with existing accountings systems, international statistics and other reporting standards
Improvement potential	Improvements in environmental accounting	Inherent qualities
		Maturity and auditability
		Adaptation to global challenges
	Improvements in decision-making	Usability
		Analytical potential
		Comparability, compatibility, integration

Table 10: IMEA Analytical framework for EAM analysis (Final version)

Dimension 1: Inherent qualities of the approach

The inherent qualities of the approach are the key expectations that EAMs are facing. The first quality is the capacity to report on environmental issues recognized as important from a scientific perspective. This reporting should provide additional information and insights compared to other EAMs. The second quality is the overall theoretical soundness of the approach, i.e. the scientific validity of the principles underlying the construction of a final indicator as well as their acceptance by the scientific community. The third quality is to adopt a global life cycle perspective, i.e. the capacity to consider the total environmental load of a good or an activity by accounting for the direct and upstream load along the whole production-consumption chains, including its domestic and international parts. The fourth quality is the capacity to provide explicit linkages between the socio-economic activities and their induced environmental flows.

Dimension 2: Maturity and auditability

The ability of EAMs to provide sound indicators over space and time is assessed within the maturity and auditability dimension, without consideration to the globalization challenges. Maturity is defined as the state or quality of being fully grown or developed. A mature EAM is expected to deliver reproducible and accurate results, i.e. in exact correspondence with facts or events. A high degree of maturity implies firstly reliable, complete, and specific data sets covering spatial, temporal or technological peculiarities. It implies then a consistent use, i.e., a homogeneous treatment across methodological steps, of robust methodologies at each of the steps of the workflow. Auditability is defined as the possibility to establish whether a method is functioning properly and, thereafter, that it has worked properly. The requirement for auditability is the transparency of a system and of its internal controls.

Dimension 3: Adaptation to global challenges

The ability of EAMs to adapt to global challenges with respect of data and methods is assessed within the dimension “adaptation to global challenges dimension”. As for the faced issues, they are similar to those in the second dimension.

Dimension 4: Usability

An indicator is of practical use for decision-making if it is intelligible, delivering a clear message and accepted. Definitions are provided in section 2.1 -- Constraints from societal expectations and challenges from globalization.

Dimension 5: Analytical potential

Two outputs of EAMs are mainly used in analyses: final indicators and structural information. Causal analysis, path analysis and structural decomposition are three examples of the analyses, using structural information, that can be applied to identify and quantify the different key factors along a complex cause-effect chain going from the underlying socio-economic driving-forces to the final environmental requirements. These additional insights are crucial to know where to act to reduce the magnitude of environmental issues and to monitor the consequences of actions.

Dimension 6: Compatibility, Comparability and integration potential

The compatibility, comparability and integration potential of EAMs' assessments with existing indicators and into the basic toolbox of decision-makers requires the compatibility of EAMs with existing legally-binding or voluntary accounting frameworks, norms and standards at national, corporate and products levels. Discussions towards providing integrated accounts have been held for decades at national level and since a few years at corporate level (Jasch & Savage, 2005). All EAMs are however still not considered in these discussions.

Dimensions 7 & 8: Improvement Potential in environmental accounting and decision-making

The potential for delivering better EAMs can take three forms: perfection, extension or hybridization. Perfection is the improvement of existing data sets, e.g. completing missing values or getting more accurate data and methods. Extension is the development of new data sets and methods. Data sets can be extended to cover missing areas, scales or environmental issues. Methodologies can be extended to e.g., consider specificities of new locations, adequately integrate the consequences of rapid technological changes and flexible production chains (or improve the treatment of trans-boundary issues). Hybridizations are possible by combining methodologies or data sets together. Each of the identified weak points in the other dimensions could be described here if improvement is feasible.

8.3 Recommendations for additional development to handle trade (and imports) with respect of data and methodologies including the combination of these methodologies

Section 2.4 "Meeting societal expectations and global challenges: an overview for some EAMs" discusses the general fulfilment of expectations by a non-exhaustive list of EAMs and how they cope with the challenges from globalization. An overview of results is presented, classified by outcome, in Table 5 which clearly demonstrates a heterogeneous coverage of the outcomes by EAMs and obvious difficulties in meeting expectations and challenges. Existing methodologies are very different from one another and provide, for most of them, only a partial answer to the fairly extensive needs of decision-makers. The largely different levels of satisfaction in meeting expectations and challenges reveal their different orientations, the youth of these methods, e.g. the EF or the ALD, as well as the low cross-fertilization in their developments, each community developing its own tools and own ways of tackling issues. The liveliness of EAMs plays also a role: PIOT and MIPS are not so developed nor used. Their capacity to meet the new challenges from globalization appears thus reduced.

Life Cycle Assessment (LCA) considers the entire life cycle of a product, from raw material extraction and acquisition, through energy and material production and manufacturing, distribution to use and end of life treatments (re-use, recycling, incineration and final disposal). All upstream and downstream processes are taken into account which can provide insight into trade flows (on a micro or meso level). LCA is a systemic analysis enabling identification of trade-offs between scenarios. The LCA method is widely used across the world, but its applications are mainly limited to a micro level (product level) and to a lesser extent a meso level (sector level). Due to its large implementation and recognition, life cycle thinking is regarded as an important cornerstone of EU environmental policy. One important opportunity of LCA is the link with EE-IO analysis in what is called 'hybrid analysis'. This would offer a lot of potential with regard to extending the current environmental analysis at a micro scale to a meso and macro level. The environmental indicators resulting from an LCA often provide information on the magnitude of the impacts, not on the location and exchanges. Geo-localised reporting is partially possible within LCA, with regard to transportation distances and electricity grids, but need to be implemented with a specific procedure. LCA could allow a life cycle based analysis of trade issues as well as

trans-boundary issues, however at this moment limited data availability and the absence of generally accepted regional characterization and normalization factors restrict its application.

The inclusion of trans-boundary issues and regionalization of environmental impacts is possible, providing that all LCI-data are available and that regional characterization factors are developed for the relevant environmental impact categories. This requires an extensive data collection and GIS-integration.

Efforts related to improving regionalization in LCA should focus on:

1. Identifying what level of regionalization is needed

   The life cycles of goods and services are generally global in nature, crossing national and geographic borders particularly in terms of raw materials and energy supplies. In many cases the location of emission sources or resource use is unknown and may vary. That also is reflected in the fact that most of the impact assessment methods and factors are focussed on global issues. Regionalization is recognized as an important step towards improving the accuracy and precision of LCA-results with the inclusion of regional impacts, thereby increasing their discriminatory power for comparative assessments among different scenarios. Global impact categories have consequences that are independent of the emission location, such as global warming and ozone layer depletion. Other types of consequences, such as acidification or (eco-)toxicological impacts on humans and ecosystems, often occur as regional or local impacts, making the emission location an important factor. By regionalizing such impacts, decision-makers can have a higher confidence in the non-global impacts presented in the LCA. However, regionalization is not always needed and depends on the goal and scope and system boundaries of the LCA study. In some cases, regionalization is needed, e.g. when:

   - the LCA uses life cycle inventories differentiating emissions from different countries;
   - specific key processes are dominating the overall life cycle impacts, for which the exact emission location is known;
   - further application such as cost-benefit analysis, environmental justice or environmental impact assessment are foreseen.

   Clear guidelines should be developed that give an indication when regionalization in LCA-studies improve the quality and the uncertainty of the results in order to make sure that complex and regional-specific LCA-studies are only performed in cases that this has added value.

2. Developing guidelines and solutions for data gathering (LCI) and development of situation dependent and geographically differentiated characterization factors (LCIA) for the regionally- and locally-dependent impact categories.

   Regionalization in LCA has two sides:

   1. Input flows: Materials and products that are imported from other regions and countries need to be taken into account. At this moment LCA common practice is limited to accounting the transport and to some extent foreign electricity production. The bottleneck in this regard are the lack or limited availability of LCI-data for foreign production.
   2. Output flows: Emissions to air, water and soil contribute to environmental impact categories, that can be of global (e.g. climate change), regional or local nature (e.g. acidification, eco-toxicity).

Characterization factors in LCA are usually global in nature and as such create an uncertainty in the LCA results for those impact categories that are not global in nature. Accounting the regional impacts of emissions needs regional characterization factors (CFs). Research projects focus on the development of such regional characterization factors, but until now such CFs are still under development.

The availability of both data for foreign production and regional characterization factors is a prerequisite to include imports and trans-boundary issues in LCA-results.

3. Extending Database for Developing countries

This aspect relates to data availability for foreign production. Numerous materials are extracted in developing countries (e.g. Africa) and the import of materials/products from e.g. China is booming rapidly. To include the regional environmental effect of e.g. extraction of minerals in Africa and production of steel in China, data for these processes are needed. LCI-databases focus on industrialized countries, and there is a need to include also LCI-data from developing or emerging countries.

LCA is a method that focuses on the life cycle phases and that is not compatible with national accounts. Coupling of LCA with import and export statistics is difficult and not common practice.

Material Flow Accounting and Analysis (MFA) refer to the monitoring and analysis of physical flows of materials into, through and out of a given economic system, a national economy, a region or a product. The uniform use of basic physical quantities, mass units, entails clear interpretation and ease of use of MFA indicators. However the drawback is that mass unit does not provide any qualitative differences between the material flows. MFA indicators can only inform on a **generic environmental pressure** of the material flows and cannot provide any information related to actual nor potential environmental impacts as such.

As part of developing an open database for environmental accounts of imports for EU and its member countries, the following are recommended for MFA handling imports:

- For EU as a whole and for each of its member countries the time series of imports and exports are collected and maintained from Foreign Trade Statistics (Cometex) in monetary and mass units, classified in conformity with the product classification applied in SUIOT's of EU countries (2-digit level of CPA) and divided by intra- and extra-EU trade. This datasets completes the economy-wide MFA time-series collected by Eurostat, where primary raw materials are classified in detail level, but fabricated products are classified very roughly.

- For raw material imports, LCA type estimates for rucksack coefficients of indirect use of used and unused extraction should be developed at detailed product classification level for both products produced in EU countries and for products produced outside EU. Raw materials include products under the CPA headings A (agricultural and forestry products), B (fishery products), C (products of mining and quarrying), DF (coke, oil products, nuclear fuel) and 27 (basic metals).

- Indirect resource use coefficients for fabricated products not included in raw materials should be collected from input-output studies – from Exiopol, when the results are available – and should be converted from kg/€ units into kg/kg units.

- For fuel purchases of international transports and for tourism consumption abroad pilot studies should be started in order to develop appropriate estimation methods and to produce first rough estimates.

Harmonized estimation practices for indirect resource use of imports and exports of services should be developed. For an example, DESTATIS, the German statistical agency has recently calculated raw material equivalents of services in its last report on indicators of material input[19].

Environmental footprints relate environmental indicators directly to human activities on land and water use There exists a great interest in such use indicators, demonstrated by the widespread adoption of the Ecological Footprint (EF) and references to water footprints. Despite this interest, each method has strengths and weaknesses, and further work must be done before they can be reliably used to assess traded flows.The methods described in this report have enabled great progress in the assessment of land use. However, the central question of measuring environmental pressures, or, yet more challenging, impacts, associated with land use remains. Actual land demand and the EF do not measure pressures; HANPP measures a specific pressure. In terms of the micro-meso-macro scale, all of these methods can only account for national average pressures: for instance, there is no differentiation between impacts associated with traded products from conventional and organic agriculture.

Both the EF and HANPP can improve their treatment of traded products by allocating traded goods to their country of origin, and applying upstream factors which relate to the production conditions in that country (rather than global factors, or in the case of the EF, using upstream CO_2 emissions as the only relevant factor in traded goods). The water footprint and ALD already do this. This process would involve using bilateral trade data, which is data intensive (and not always reliable, since exports and imports don't balance at the global level).

Establishing national-level factors for the EF might prove extremely challenging, since even at the global level these factors are far from certain. This is related to the insistence of the EF of adapting non-land use phenomena (such as fossil-fuel emissions or nuclear power) to hectare equivalents: such factors are, per definitionem, impossible to measure accurately, since they do not correspond to occurring physical processes. Moreover, these factors are dynamic, since the terrestrial sink capacity is affected by land use history, such as deforestation.

Even immaterial transactions, like services, have upstream environmental implications. Coupling the land use and water use indicators with Input-Output methodologies could assess these upstream requirements. This has already been demonstrated for GHG emissions and the EF (e.g. Lenzen and Murray, 2001; Wiedmann et al., 2008; Turner et al., 2007; Tolmasquim and Machado, 2003; Haberl et al., 2009). In the absence of combination with Input-Output approaches, none of these models can accomplish structural analysis or causal chain analysis. Although the international trade data and input-output methodologies exist and have been applied to land and water use indicators at the case study level, their systematic application will require a sustained effort, both at the research and statistical agency level. The most important development for land use indicators is the systematic use of bilateral trade data, along with appropriate national conversion factors. Hybrid methods or cross-checks with Input-Output and LCA may also be desirable. One central challenge (common to many methods) is the "re-export effect" or "harbor effect", where the country of export and the country of origin of a traded product are not the same. The land use and water use methods are relevant to the country of origin, but trade data records the country of export. Multi-Region Input-Output may be one approach to dealing with this issue.

[19] http://www.destatis.de/jetspeed/portal/cms/Sites/destatis/Internet/DE/Content/Publikationen/Fachveroeffentlichungen/UmweltoekonomischeGesamtrechnungen/Materialinputindikator,property=file.pdf

Environmentally Extended Input Output Analysis (EE IOA) is the main approach used for environmental assessments at macro and meso-scales. EE IO is based on a detailed description of the domestic production processes and transactions within an economy that can be extended by any type of environmental extension, e.g. resources uses or pollutants. An MR EE IOT approach is probably one of the best approaches to take impacts of imports into account:

1. It uses a global perspective, and takes into account issues like that components of products made in another country themselves can come from another country
2. It shows not only the pollution embodied in imports, but also *which countries* suffer most environmental impacts by consumption by other countries;
3. The approach is inherently comprehensive: the total global environmental impacts are a starting point, and distributed over the final consumption in the world, wherever it occurs;
4. Provided that a comprehensive set of environmental extensions is included, a great variety of indicators can be supported, including LCIA, ecological footprint, and material flow indicators.

Yet, the main problem is there are significant limitations in existing data sources. One can compare this probably with the tool of LCA in the mid 1990s, with most impact assessment methodologies having matured considerably, but still just limited databases with process related environmental data available that hindered deploying the full potential of the tool.

Key problems in the current data sources are that most provide SUT and IOT for single countries, without trade links. Sector and product detail is not as good as it ought to be. Environmental extensions are often lacking or include only a few types of emissions and primary resource uses.

At present, only the GTAP database comes a bit in the direction of the ideal, but is hindered by the fact that it was never built for environmental purposes and does not contain environmental extensions. Individual practitioners have added some emissions to their versions of the GTAP database for analytical purposes. For the future, the EXIOPOL project (Tukker et al, 2009) may result in a fairly comprehensive and detailed database for MR EE IO analyses, with data for one base year but a potential for updates. Some existing data sets (e.g. the Nijdam and Wilting, 2005 set) can help on a provisional basis, thanks to its considerable number of extensions to an as such limited sector detail for global regions clustered in OECD and non OECD countries.

Fundamentally, one cannot expect even in future that the sector detail of an MR EE IO will be more than 100+ sectors per country. This implies that MR EE IO in all cases only can be a supplementary tool at micro level (individual products). Further, in its present form MR EE IO inherently uses economic allocation of impacts, which may deviated from physical allocation. Also this may be a problem, again most prominent at micro level.

For the future, the EXIOPOL project may result in a fairly comprehensive database for MR EE IO analyses, with data for one base year.

A practical approach in the existing data situation may be the following. A practitioner could develop an EE IO table for a country of interest, and link this to e.g. the EE IO table for the US of Suh (2004) and/or the EU-OECD, other OECD and non OECD tables of Nijdam and Wilting (2003) to create some sort of an MR EE IO (with a central country and 3 regions with imports). The data sets mentioned have in any case the advantage of covering a large number of extensions, supportive to a broad set of indicators. The Nijdam and Wilting data set has the advantage that it covers estimates for non OECD countries, where industries tend to have a different environmental profile as in the OECD countries. Yet, as indicated, the sector resolution is limited.

The approach has however a number of inherent limitations:

- It is not realistic to expect that IOT or SUT will become available on a global scale with a much higher sector or product resolution than 100-150;
- The basis of EE IO is economic accounting; which implies that all impacts are economically allocated to final consumption and other economic activities, rather than on the basis of physical causality or other ways. Simply said, the price-quantity relationship may differ between uses of the output of a product or sector;
- Even when the data situation is improved, time lags may occur with regard to data reporting;
- The practical data situation is far from ideal, and probably the greatest bottleneck;
- There is a number of technical problems due to the fact that inherently a global database always will be based on certain assumptions; a main problem probably is the estimation of transport margins (including transport modality) and insurance margins on trade flows, and particularly the allocation of such margins to the country that delivers the transport or insurance service. This is a special case of the problem that statistics on trade in services (e.g. next to trade and insurance services also tourism) tend to be less reliable than of product trade.

Combining EAMS: the hybridization opportunities & challenges

The still recent but increasing trend toward the combination of EAMs, called hybridization, encourages exchanges and should help in the achievement of expectations and challenges. Hybrid methods shows better fulfilment of both expectations and challenges than the original methods. For example, EE-IOA coupled to LCIA appears to meet at least partly all societal expectations and all challenges, except for “synthetic indicator” (See Table 5).

The main form of hybridization is a combination of EAMs with input-output tables. Five ways of combination have been identified:

1. **IOA is combined with bottom-up approaches** to extend system boundaries and get more detailed results, i.e. in the tiered hybrid analysis, Input-Output based hybrid analysis and integrated hybrid analysis described by Suh & Huppes (2005).

2. **Input-output tables are extended with additional direct environmental requirements**, e.g. material or water use, to ease the computation of indicators, to get a life cycle perspective, or to deal with the challenges from globalization. For instance, an integrated Input/Output/LCA model has been implemented in a recent project in Austria concerning raw material equivalents (Schaffartzik, et al., 2010).

3. **Already computed indicators are combined with IOA to extend results to additional scales,** e.g. to the meso-scale, or to translate results into consumer activities as in the EF approach with Consumption Land Use Matrices (Thomas Wiedmann *et al.*, 2006).

4. **IOA is used to compute conversion coefficients that are later used in the EAM**, e.g. indirect material use of products in MFA.

5. **EE-IOA are combined with aggregation methods, like LCIA, generating synthetic indicators**.

An benefit from the integration within an input-output framework is the increased comparability of results with socio-economic indicators developed within the System of National Accounts (SNA) (United Nations, 1993). The

downside of such practice is however that IOA is subject to large biases because it cannot always adequately represent the underlying physical nature of flows. IOA performs all computations, including allocation, in monetary units and convert results, in a last step, in physical units with the help of environmental factors, for example CO_2 emissions per dollar. The extension of an existing EAM with IOA is thus potentially weakening the robustness of results generally previously based on physical rationales.

8.4 Methodological guidelines for EAMs

Provided that the limitations expressed earlier (monetary allocation and approximate modelling of the use of imports) and additional ones are dealt with, the full trade IOA solution, based on Multi-Regional Input-Output (MRIO) models with enough sectors, appears to be an essential part of any solution that will be designed in the future. This recommendation is in line with the orientation proposed by SKEP EIPOT project (Wiedmann et all, 2009).

- Firstly, additional research and data development should be performed to deal with issues like the bridge between price and quantities, exchange rates and rapidly changing economic and technology structures.
- Secondly, the environmental extensions considered should cover issues that are relevant in each region. IOA is however not accurate enough for decision-making at micro and lower-meso-scales where it can only provide a first approximation. It should therefore be complemented by additional bottom-up methodologies, either on an individual basis or through the development of additional hybrid approaches. Such types of hybridization are however still in development stage and require much more work before a potential implementation on a large scale.

The effectiveness of future databases and methodological development in answering these needs and tackling challenges in a cost-effective way could be potentially improved in three ways:

i) establishing profiles of goods and of regions to better define which data is needed in which context

ii) optimizing the methodological and data collection effort by concentrating on the few relevant solutions and geo-localized data in each context, rather than aiming at developing catch-all applicable solutions and databases, and

iii) speeding up the access to adequate EAMs by adopting a modular view of EAMs to take the best solutions in existing methodologies and improve these elements through cross-methodology research groups focusing on specific issues.

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Appendix 1 : Critical review of LCI and LCIA indicators, impact and methods

Life Cycle Assessment (LCA) is a relatively young instrument and its methodology is still in a stage of development. Guidelines for carrying out LCA-studies have been published by SETAC (Society for Environmental Toxicology and Chemistry) in the so-called 'Code of Practice' (Consoli et al., 1993).

A general (conceptual) methodological framework for LCA has also been defined by ISO in its 14040 and 14044 standard (ISO, 2006). The methodological frameworks proposed by SETAC and ISO are to a large extent similar. Existing differences are mostly due to the used terminology rather than to fundamental methodological choices. In this study, the ISO terminology is used.

ISO describes LCA as follows:

"LCA addresses the environmental aspects and potential environmental impacts (e.g. use of resources and environmental consequences of releases) throughout a product's life cycle from raw material acquisition through production, use, end-of-life treatment, recycling and final disposal (i.e. cradle-to-grave)" (ISO, 2006).Products can be goods or services.

According to these ISO guidelines an LCA must be performed in 4 steps:

- Goal and scope definition;
- Inventory Analysis;
- Impact Assessment;
- Interpretation.

The relation between the different phases is illustrated in Figure 7: Methodological framework of an LCA (ISO, 2006). The figure shows that the 4 phases are not independent of each other. It also shows that the scope, the boundaries and the level of detail of an LCA depend on the intended use of the study.

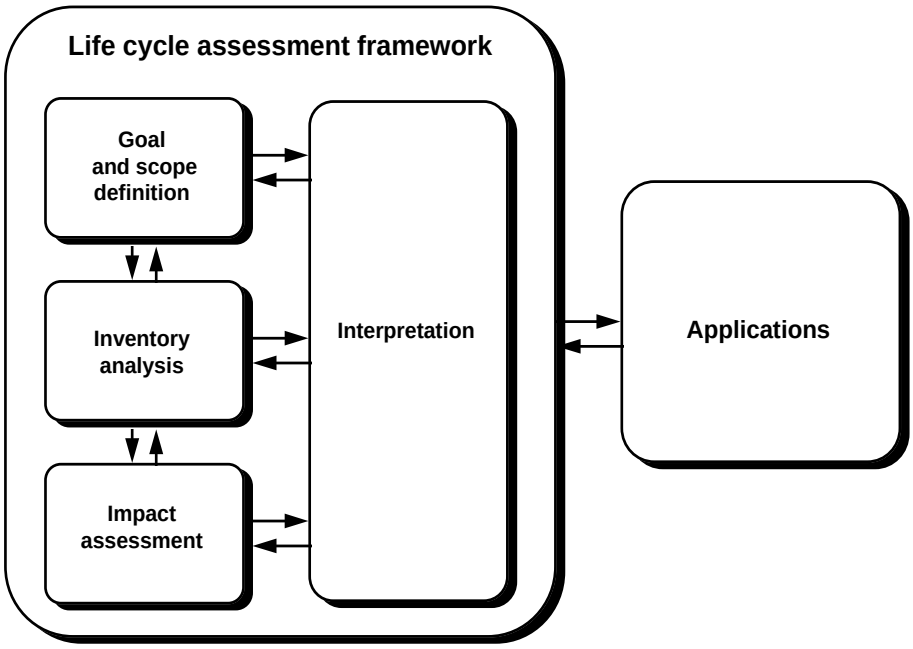

Figure 7: Methodological framework of an LCA (ISO, 2006)

Goal and scope definition

In the first phase of an LCA, the intended use of the LCA (the goal) and the breadth and depth of the study (the scope) have to be clearly defined. The scope definition has to be consistent with the goal of the study. In the following paragraphs aspects that should be clearly and unambiguous agreed upon at the start of the study are shortly discussed (ISO, 2006).

Goal of the LCA

The goal definition of an LCA includes a clear and unambiguous description of:

- the reasons for carrying out the LCA;
- the intended use of its results;
- the audience(s) to which the results are intended to be communicated.

In general, the reasons for carrying out an LCA depend on different choices:

Specific LCA:

- determining the environmental profile of ONE product system;
- finding out potentials for environmental improvement of the product system studied.

Comparative LCA

- determining the environmental profile of different existing product systems;
- comparing the different environmental profiles.

In general, an LCA-study can be aimed at:

- Internal use: the results will be used internally (remark: the impact profile can be normalized and weighted in order to obtain one final environmental index for the system studied)
- External use: commercial use of positive results for application and marketing (remark: ISO 14040 says "in the case of comparative assertions disclosed to the public, the evaluation shall be conducted in accordance with the critical review process and presented category indicator by category indicator").

Scope of the LCA

In the scope definition of an LCA, the following items should be considered and clearly described:

- the functions of the product system(s);
- the functional unit;
- the product system(s) to be studied;
- the product system(s) boundaries;
- allocation procedures;
- types of impact and methodology of impact assessment, and subsequent interpretation to be used;
- data requirements;
- data quality requirements;
- assumptions;
- limitations;
- type of critical review, if any;
- type and format of the report required for the study.

The scope should be sufficiently well-defined to ensure that the breadth, the depth and the detail of the study are compatible and sufficient to address the stated goal.

→ ***Function and functional unit***

The function(s) that are fulfilled by the system(s) under study should be clearly defined. Derived from that, the functional unit has to be defined. The functional unit measures the performance of the system and provides a reference to which the input and output data will be normalized. In comparative LCAs, comparisons can only be made on the basis of equivalent functions, i.e. LCA-data can only be compared if they are normalized to the same functional unit.

To illustrate the concept of functional unit, ISO gives the following example. For an LCA of paint systems, which provide a protective and decorative covering to a surface, the functional unit could be defined as the “unit surface area covered” by the paints under consideration. However, to include durability and different coverings, a more appropriate definition of the functional unit might be “unit surface protected for a defined period of time”.

→ ***Description of the system(s) studied***

The system that will be studied in the LCA should be clearly described. Flow diagrams can be used to show the different subsystems, processes and material flows that are part of the system model.

→ ***System boundaries***

The system boundaries of the LCA should be clearly defined. This includes a statement of:

- which processes will be included in the study;
- to which level of detail these processes will be studied;
- which releases to the environment will be evaluated;
- to which level of detail this evaluation will be made.

Ideally, all life cycle stages, from the extraction of raw materials to the final waste treatment, should be taken into consideration. In practice however, there is often not sufficient time, data or resources to conduct such a comprehensive study. Decisions have to be made regarding which life cycle stages, processes or releases to the environment can be omitted without compromising the objectives and the results of the study. Any omissions should be clearly stated and justified in the light of the defined goal of the study.

→ ***Allocation procedures***

Allocation procedures are needed when dealing with systems involving multiple products. The materials and energy flows as well as associated environmental releases shall be allocated to the different products according to clearly stated procedures, which shall be documented and justified.

→ ***Methodology***

The impact assessment phase of the LCA is aimed at evaluating the significance of potential environmental impacts using the results of the life cycle inventory analysis. In general, this process involves associating inventory data with specific environmental impacts and attempting to understand those impacts. The level of detail, choice of impacts evaluated and methodologies depends on the goal and scope of the study.

→ ***Data and data quality requirements***

It should be identified which data are needed in order to meet the goal of the study, and which level of detail is required for the different data categories. The different data sources that will be used should be stated. This may include measured data, data obtained from published sources, calculated or estimated data. The data requirements are dependent on the questions that are raised in the study. Efforts do not need to be put in the quantification of minor or negligible inputs and outputs that will not significantly change the overall results of the study.

A complete description of the required data quality includes the following parameters:

- geographical coverage;
- time period covered;
- technology coverage;
- precision, completeness and representativeness;
- consistency and reproducibility;
- sources of the data and their representativeness;
- variability and uncertainty of the information and methods.

→ ***Assumptions and limitations***

All assumptions made during the course of the project and the limitations of the study are commented on in the report. The results of the LCA are interpreted in agreement with the goal and scope.

→ ***Critical review***

A critical review is a process to verify whether an LCA has met the requirements of international (ISO) standards for methodology, data collection and reporting. Whether and how a critical review will be conducted should be specified in the scope of the study.

Three types of critical review are defined by ISO 14040/44:

- internal review, performed by an internal expert independent of the LCA study;
- expert review, performed by an external expert independent of the LCA study;
- review by interested parties, performed by a review panel chaired by an external independent expert - the panel includes interested parties that will be affected by conclusions drawn from the LCA-study, such as government agencies, non-governmental groups or competitors.

When an LCA study will be used to make a comparative assertion that is disclosed to the public, the ISO standards require a critical review by interested parties to be conducted. In all other cases, critical reviews in LCA are optional and may utilize any of the three review options mentioned above.

→ ***Type and format of the report***

The results of the LCA are fairly, completely and accurately reported to the intended audience, in keeping with ISO 14040/44.

Inventory analysis

General

The inventory analysis involves data collection and calculation procedures to quantify the inputs and outputs that are associated with the product system(s) under study. This includes use of resources, releases to air, water and land. Procedures of data collection and calculation should be consistent with the goal and the scope of the

study. The results of the inventory analysis may constitute the input for the life cycle assessment as well as an input for the interpretation phase.

Input and output data have to be collected for each process that is included in the system boundaries. After collection, the data for the different processes have to be normalized to the functional unit and aggregated. This corresponds to a calculation of all inputs and outputs referenced to the functional unit, which is the final result of the inventory analysis.

Inventory analysis is an iterative process. As data are collected and the system is better known, new data requirements or limitations may become apparent. This may require better or additional data to be collected or system boundaries to be refined.

Allocation

A special issue related to the inventory analysis is the so-called allocation problem. This refers to the allocation of environmental inputs and outputs of a process to different products. Examples of processes were allocation is needed are:

- *co-production*: processes in which two or more products are produced simultaneously; the environmental inputs and outputs of these processes need to be allocated to the different products;
- *processing of mixed waste streams*: processes in which two or more waste streams are processed simultaneously; the environmental inputs and outputs of these processes need to be allocated to the different waste streams;
- *open-loop recycling*: processes in which a discarded product from one product system is used as a raw material for another product system; the environmental inputs and outputs of these processes need to be allocated to the different product systems.

For processes where allocation is necessary (multiple input or output processes), the allocation procedure described in par. 4.3.4 of the ISO 14044 standard will be followed. The allocation procedure as defined in this standard is summarized as follows:

- Step 1: Wherever possible, allocation should be avoided or minimized by
    1. detailing multiple processes into two or more sub-processes, some of which can be located outside the system boundaries;
    2. expanding the system boundaries so that inputs/outputs remain inside the system. This is called “avoiding allocation by system expansion”.
- Step 2: Where allocation cannot be avoided, it should preferentially be based on causal relationships between the system inputs and outputs. These causal relationships between the flows into and out of the system may be based on physical or economic parameters.
- Step 3: Where causal relationships cannot be established, allocation to different products may be based on their economic value.

Impact assessment

The life cycle impact assessment phase (LCIA phase) is the third phase of the LCA. The purpose of the LCIA is to provide additional information to help assess a product system’s LCI results so as to better understand their environmental significance.

In the impact assessment (LCIA), the results of the inventory analysis (LCI) are linked to specific environmental impact (or damage) categories (e.g. CO_2 emissions are related to global warming, SO_2 emissions are related to acidification). It is important to note that the inventory results generally do not include spatial, temporal, dose-response or threshold information. Therefore, the impact assessment cannot and is not intended to identify or predict actual environmental impacts. Instead, the impact assessment predicts potential environmental damages (impacts) related to the systems under study.

The elements of the LCIA phase are illustrated in Figure 8.

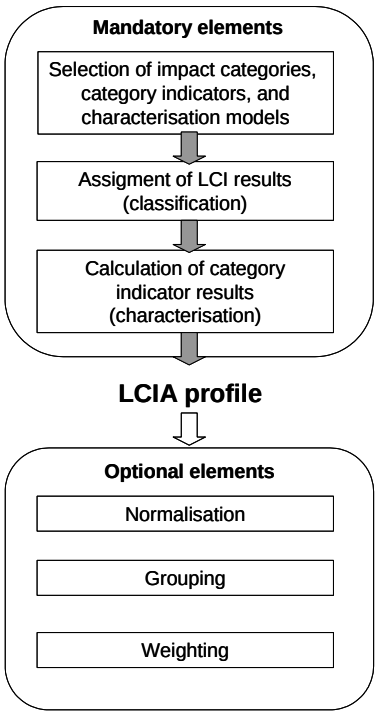

Figure 8: Elements of the LCIA phase (pp 15 of ISO 14040)

The impact assessment will be performed according to the ISO 14040/44 (ISO, 2006). The framework proposed by ISO consists of the following elements:

- damage (or impact) category definition: definition of the damage (impact) categories that will be addressed;
- classification: assignment of inventory data to damage (impact) categories;
- characterization: modelling of inventory data within damage categories to express the damages in terms of a numerical indicator;
- technical analysis of significance: analysis of the significance of the numerical indicators, e.g. by relating them to total anthropogenic contribution (normalisation), by performing sensitivity analyses, etc.;
- valuation: weighting and possibly aggregation of different damage categories involving subjective value judgments.

The first three elements are mandatory, the last two are optional. ISO 14040 states "in the case of comparative assertions disclosed to the public, the evaluation shall be conducted in accordance with the critical review process and presented category indicator by category indicator" (ISO, pp 23 of ISO 14044).

This means that the results of an LCA study, that claims to be ISO compliant, only can be published to the general public after a critical review process and at the level of the different impact categories. Weighting can be performed, however this part will then not be in line with ISO.

Category definition

During the first step of the LCIA different environmental categories addressed by the study should be selected. The selection should be consistent with the goal and scope of study. Furthermore it should be complete and shall not avoid disguise environmental issues or concerns. ISO does not prescribe the categories or indicators to be included. The choice of categories and indicators should be justified and the categories/indicators are recommended to have a scientific basis and international acceptance.

There are two generic classes of categories : midpoint (like CO_2 eq.) and endpoint (like DALY).

Classification

The classification steps comprise the assignment of inventory input and output data to the defined environmental impact categories, as selected and defined in the previous step. The assignment is based on the scientific analysis and understanding of the relevant environmental processes.

There are no generally accepted methodologies for consistently and accurately associating inventory data with specific environmental impacts. Models for impact categories are in different stages of development.

Characterisation

During characterisation, for each impact category the relative importance of the contributing substances are modelled and quantified. The result of the characterisation is the contribution to the different environmental impact categories considered in terms of equivalent amounts of emitted reference substance for each impact category (= the environmental profile of the product system studied).

Normalisation

As soon as the classification and the characterisation steps are performed and the environmental profile of a particular product system has been developed, the magnitude of the category indicator results relative to the reference information optionally can be calculated. This process is called normalisation. By normalisation, the environmental impacts of a product system are for example being related to the impact of economic activities in a certain region over a certain time period. By doing so the contributions to the different environmental impact categories are expressed as a percentage of the total environmental impacts during one year in a certain region.

Weighting

After normalisation the contributions to the different environmental impact categories can not be added up directly. There is no scientific agreement on the importance of the different impact categories amongst each other. So to reach the one-single environmental indicator weighting is unavoidable. However according to ISO 14044 (paragraph 4.1) it should be recognized that there is no scientific basis for reducing LCA results to a single overall score or number.

Various methods are in use to assess the environmental effects of products, processes and systems. Almost all methods operate with a conceptual framework in which the product's entire life cycle is analysed. To calculate one single environmental indicator all these methods need some kind of weighting principle to give weight to the different environmental aspects considered. However, to date these weighting methods are not fully scientific and objective, but need some subjective choices. According to ISO 14040/44 it must be stressed that the calculation of one single environmental indicator within a comparative LCA study disclosed to the public is not allowed.

The development of a common set of weighting factors is still under development. It consists of a value judgment that includes the social values and preferences of the society. The basis for weighting are the normalised environmental profiles. Each impact category considered should be weighted in order to allow a direct addition. Weighting factors (representing the relative seriousness of a particular impact category) may differ from country to country, or even within one country, due to differences in local conditions and values. Political views may also affect the weighting process due to different opinions concerning the relative importance of local or regional impact categories versus global issues. ISO 14040/44 does not specify any specific methodology or support the underlying value-choices used to group (weight) the impact categories. The value-choices and judgements within the grouping procedures are the sole responsibilities of the commissioner of the LCA study. So the conclusions and recommendations derived from grouping and weighting are based on value-choices.

All weighting methods and operations used shall be documented to provide transparency. Data and environmental profiles (category indicator results) or normalised indicator results reached prior to weighting should be made available to the panel. The results of the weighting procedure should be made available to the general public. This ensures that trade-offs and other information remain available to decision-makers and to others, and that users of the weighting set can appreciate the full extent and ramifications of the results.

According to ISO 14040/44 it must be stressed that the calculation of one single environmental indicator within a comparative LCA study disclosed to the public is not allowed.

Description of different commonly used methods for life cycle impact assessment (LCIA)

In the next paragraphs some of the most commonly used LCIA methods are shortly highlighted.

→ ***Eco-indicator 99***

One of the most used and widely accepted methods is the Eco-indicator 99 method (Goedkoop et al, 2000).

A general overview of the Eco-Indicator 99 method is presented in Figure 9.

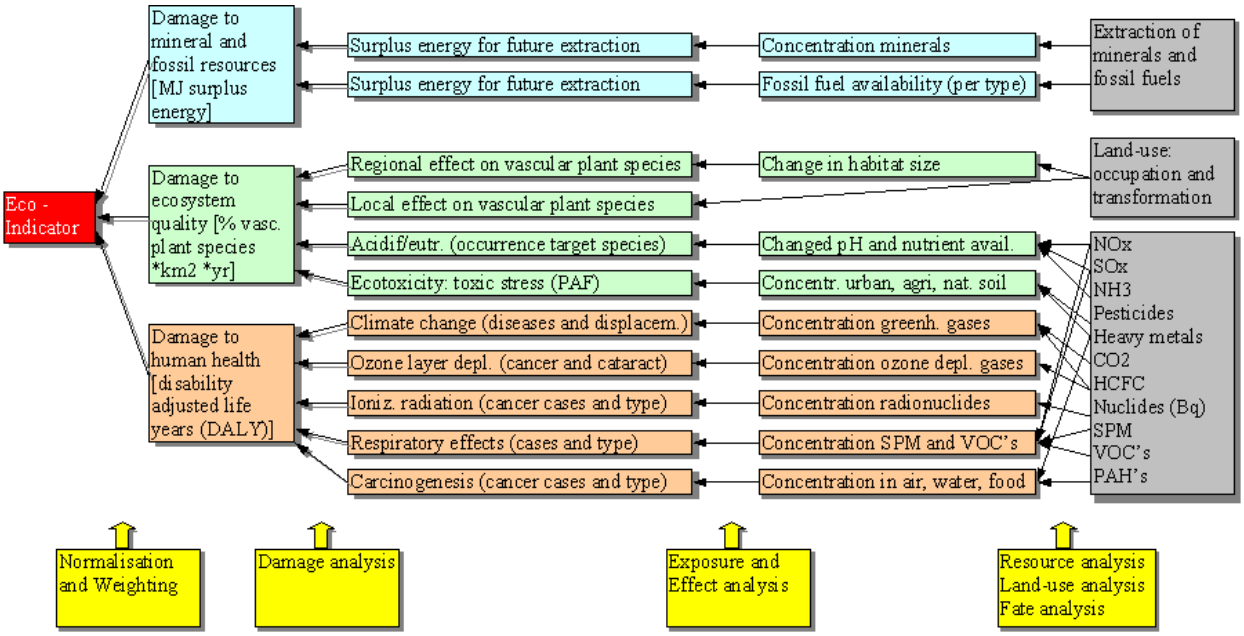

Figure 9: The Eco-Indicator 99 methodological framework (Goedkoop et al, 2000, pp. 10)

The Eco-indicator 99 method uses different procedures to establish the link between the inventory table and the potential damages. The following damage models have been established to link the inventory result with three damage categories: damages to Human Health, damages to Ecosystem Quality and Damages to Resources.

The damage category Human Health

The health of any human individual, being a member of the present or a future generation, may be damaged either by reducing its duration of life by a premature death, or by causing a temporary or permanent reduction of body functions (disabilities). According to current knowledge, the environmental sources for such damages are mainly the following:

- Infectious diseases
- cardiovascular and respiratory diseases, as well as forced displacement due to the climate change
- Cancer as a result of ionising radiation
- Cancer and eye damages due to ozone layer depletion
- Respiratory diseases and cancer due to toxic chemicals in air, drinking water and food.

These damages represent the most important damages to Human Health caused by emissions from product systems. The damage category is not complete. For instance, damage from emissions of Cd and Pb, endocrine disrupters etc. cannot yet be modelled. Furthermore health damages from allergic reactions, noise and odour cannot yet be modelled (Goedkoop et al, 2000, pp. 11).

Damages to Human Health are expressed as DALY (Disability Adjusted Life Years). Models have been developed for respiratory and carcinogenic effects, the effects of climate change, ozone layer depletion and ionising radiation. In these models for Human Health four sub steps are used:

1. Fate analysis, linking an emission (expressed as mass) to a temporary change in concentration.
2. Exposure analysis, linking this temporary concentration to a dose.

3. Effect analysis, linking the dose to a number of health effects, like the number and types of cancers.
4. Damage analysis, linking health effects to DALYs, using estimates of the number of Years Lived Disabled (YLD) and Years of Life Lost (YLL).

The damage category Ecosystem Quality

Ecosystems are very complex, and it is very difficult to determine all damages inflicted upon them. An important difference with Human Health is that less concern is given to the individual organism, plant or animal. The species diversity is used as an indicator for Ecosystem Quality.

Damages to Ecosystem Quality are expressed as the percentage of species that have disappeared in a certain area during a certain time due to the environmental load. It is expressed as the percentage of all species present in the environment living under toxic stress (Potentially Affected Fraction – PAF). This definition is not as homogeneous as the definition of Human Health. For ecosystem quality two different approaches are used:

1. Toxic emissions and emissions that change acidity and nutrients levels go through the procedure of:
   - Fate analysis, linking emissions to concentrations
   - Effect analysis, linking concentrations to toxic stress or increased nutrient or acidity levels.
   - Damage analysis, linking these effects to the increased potentially disappeared fraction for plants.

   Note:
   - Ecotoxicity is not an observable damage, a rather crude conversion factor is used to translate toxic stress into real observable damage.
   - Acidification and eutrophication are treated as a single impact category. Here the damage to target species (vascular plants) in natural areas is modelled.
2. Land-use and land transformation are modelled on the basis of empirical data on the quality of ecosystems, as a function of the land-use type and the area size. Land-use and land transformation is based on empirical data of the occurrence of vascular plants as a function of the land-use type and the area size. Both the local damage on the occupied or transformed area as well as the regional damage on ecosystems is taken into account.

The damage category Resources

In the Eco-indicator 99 methodology only mineral resources and fossil fuels are modelled. The use of agricultural and silvicultural biotic resources and the mining of resources such as sand or gravel, are considered to be adequately covered by the effects on land use. Biotic resources which are extracted directly from nature, like fish and game or wild plants, are not modelled in Eco-indicator 99 so far.

<u>Resource extraction</u> is related to a parameter that indicates the quality of the remaining mineral and fossil resources. In both cases the extraction of these resources will result in higher energy requirements for future extraction (expressed as MJ surplus energy). Resource extraction is modelled in two steps:

1. Resource analysis, which can be regarded as a similar step as the fate analysis, as it links an extraction of a resource to a decrease of the resource concentration. Instead of modelling the increase of the concentration of pollutants, the decrease of the concentration of mineral resources is modelled.
2. Damage analysis, linking lower concentration to the increased efforts to extract the resource in the future.

In the Eco-indicator 99 method weighting is simplified by:

- using just three endpoints (human health, ecosystem quality and resources); this minimizes the mental stress among panellists to take into account too many issues; and

- defining three issues as endpoints that are reasonably easy to understand.

The weighting problem has not been solved, but weighting and interpretation of results without weighting has been made easier. Other ideas in the methods are the consistent management of subjective choices using the concept of cultural perspectives. This has led to a good documentation of the choices and to the publication of three versions, each with a different set of choices. Modelling uncertainties cannot be expressed as a range: a model assumption is correct or not. In order to cope with these uncertainties, a system referred to as Cultural Theory has been used to separate three versions of the damage model. A simplified characterization of these versions is:

- Egalitarian: long time perspective (even a minimum of scientific proof justifies inclusion). Egalitarians have a strong link to the group, but a weak link to their grid. In this environment there is no internal role differentiation, relations between group members are often ambiguous and conflicts can occur easily.
- Individualist short time perspective (only proven effects are included). Individualists are both free from strong links to group and grid. In this environment all limits are provisional and subject to negotiation. Although they are relatively free of control by others, they are often engaged in controlling others.
- Hierarchist: balanced time perspective (consensus among scientist determines inclusion of effects). Hierarchists have both a strong link to group and grid. In this environment people are both controlling others and are subject of control by others. This hierarchy creates a high degree of stability in the group.

For a complete overview of the Eco-indicator 99 methodology used for impact assessment reference is made to Goedkoop et al, 2000. Table 11 gives an overview of the different environmental damage categories considered in the Eco-indicator 99.

Category	Unit
Carcinogenics	DALY
Resp. organics	DALY
Resp. inorganics	DALY
Climate change	DALY
Radiation	DALY
Ozone layer	DALY
Ecotoxicity	PAF*m².yr
Acidification/eutrophication	PDF*m².yr
Land use	PDF*m².yr
Minerals	MJ surplus
Fossil fuels	MJ surplus

Table 11: Eco-indicator 99 environmental damage categories

Link: http://www.pre.nl/eco-indicator99/

→ ***CML method***

The (Dutch) Handbook on LCA provides a stepwise `cookbook' with operational guidelines for conducting an LCA study step-by-step, justified by a scientific background document, based on the ISO Standards for LCA. The different ISO elements and requirements are made operational to be `best available practice' for each step.

The life cycle impact assessment (LCIA) methodology recommended is based on a midpoint approach covering all emission- and resource-related impacts, for which practical and acceptable characterization methods are available (Guinée et al, 2002). Best available characterization methods have been selected based on an extensive review of existing methodologies world-wide. For most impact categories a baseline and a number of alternative characterization methods is recommended and for these methods comprehensive lists of

characterization and also normalization factors are supplied. Ecotoxicity and human toxicity are modelled adopting the multi-media USES-LCA model developed by Huijbregts et al, 2000, 2001.

The spreadsheet containing the different characterisation factors and impact categories can be downloaded from the internet via:

http://www.leidenuniv.nl/cml/ssp/databases/cmlia/index.html

The CML baseline method elaborates the problem-oriented (midpoint) approach. The CML Guide provides a list of impact assessment categories grouped into

A: Obligatory impact categories (Category indicators used in most LCAs)

B: Additional impact categories (operational indicators exist, but are not often included in LCA studies)

C: Other impact categories (no operational indicators available, therefore impossible to include quantitatively in LCA)

In case several methods are available for obligatory impact categories a baseline indicator is selected, based on the principle of best available practice. These baseline indicators are category indicators at "mid-point level" (problem oriented approach)". Baseline indicators are recommended for simplified studies. The guide provides guidelines for inclusion of other methods and impact category indicators in case of detailed studies and extended studies.

Only baseline indicators are available in the CML method in the SimaPro software programme (based on CML Excel spreadsheet with characterisation and normalisation factors). The impact categories considered in the CML method are presented in Table 12.

Category	Unit
Abiotic depletion	kg Sb eq.
Global warming (GWP 100)	kg CO2 eq.
Ozone layer depletion	kg CFC-11 eq.
Human toxicity	kg 1,4-DB eq.
Fresh water aquatic ecotoxicity	kg 1,4-DB eq.
Marine aquatic ecotoxicity	kg 1,4-DB eq.
Terestrial ecotoxicity	kg 1,4-DB eq.
Photochemical oxidation	kg C2H2 eq.
Acidification	kg SO2 eq.
Eutrophication	Kg PO4--- eq.

Table 12: CML impact categories (Guinée et al, 2002)

Link: http://www.leidenuniv.nl/cml/ssp/databases/cmlia/index.html

→ ***EDIP 97***

EDIP97 is a thoroughly documented midpoint approach covering most of the emission-related impacts, resource use and working environment impacts (Wenzel et al, 1997; Hauschild et al, 1998) with normalization based on person equivalents and weighting based on political reduction targets for environmental impacts and working environment impacts, and supply horizon for resources. An updated version of the method has been published in 2004 (Schmidt et al, 2004).

The weighting factors are set to the politically set target emissions per person in the year 2000, except for resources which are based on the proven reserves per person in 1990. Presenting the EDIP method as a single score (addition) is allowed, however it is not recommended by the authors. Note that due to a different weighting method for resources (based on reserves rather than political targets), resources may never be included in a

single score. This is the reason that the weighting factor for resources is set at zero. The impact of resources are reported in a special "EDIP method only resources". Opposite to the default EDIP method, resources are given in individual impact categories, on a mass basis of the pure resource (for instance 100% metal in ore, rather than ore).

Ecotoxicity and human toxicity are modelled using a simple key-property approach where the most important fate characteristics are included in a simple modular framework requiring relatively few substance data for the calculation of the characterization factors.

The impact categories considered in the EDIP method are presented in Table 13.

Category	Unit
Global warming (GWP 100)	g CO2
Ozone layer depletion	g CFC-11
Acidification	g SO2
Eutrophication	g NO3
Photochemical smog	g C2H2
Ecotoxicity water chronic	m³
Ecotoxicity water acute	m³
Ecotoxicity soil chronic	m³
Human toxicity air	m³
Human toxicity water	m³
Human toxicity soil	m³
Bulk waste	kg
Hazardous waste	kg
Radioactive waste	kg
Slags/ashes	kg
Resources (all)	kg

Table 13: EDIP impact categories (Schmidt et al, 2004)

Link:

http://www.lca-center.dk/cms/webedit/images/cmsdoc__4/Metodeprojekt/arbejdsmiljø-uk-vejledning.pdf

http://ipt.dtu.dk/~mic/EDIP97

→ ***EPS 2000d***

The EPS 2000d impact assessment method is the default impact assessment method in the EPS system. It is developed to be used for supporting choice between two product concepts. Category indicators are chosen for this purpose, i.e., they are suitable for assigning values to impact categories. Category indicators are chosen to represent actual environmental impacts on any or several of five safeguard subjects: human health, ecosystem production capacity, biodiversity, abiotic resources and recreational and cultural values. The characterization factor is the sum of a number of pathway-specific characterization factors describing the average change in category indicator units per unit of emission, e.g. kg decrease of fish growth per kg emitted SO_2. An estimate is made of the standard deviation in the characterization factors due to real variations depending on emission location etc. and model uncertainty. This means that characterization factors are only available, where there are known and likely effects. Characterization factors are given for emissions defined by their location, size and temporal occurrence. Most factors are for global conditions 1990 and represent average emission rates. This means that many toxic substances, which mostly are present in trace amounts, have a low average impact.

Empirical, equivalency and mechanistic models are used to calculate default characterisation values. The different impact categories considered in the EPS method are presented in Table 14.

In the EPS default method, weighting is done through valuation. Weighting factors represent the willingness to pay to avoid changes. The environmental reference is the present state of the environment. The indicator unit is ELU (Environmental Load Unit).

Category	Unit
Life expectancy	person.year
Severe morbidity	person.year
Morbidity	person.year
Nuisance	person.year
Severe nuisance	person.year
Crop growth capacity	kg
Wood growth capacity	kg
Fish and meat production	kg
Soil acidification	H+ eq.
Prod. Cap. Irrigation water	kg
Prod. Cap. Drinking water	kg
Depletion of reserves	ELU
Species extinction	NEX

Table 14: EPS damage categories (Bengt Steen, 1999)

Link: http://eps.esa.chalmers.se/

→ ***Impact 2002+***

The IMPACT 2002+ life cycle impact assessment methodology proposes a feasible implementation of a combined midpoint/damage approach, linking all types of life cycle inventory results (elementary flows and other interventions) via 14 midpoint categories to four damage categories. For IMPACT 2002+ new concepts and methods have been developed, especially for the comparative assessment of human toxicity and eco-toxicity. Human Damage Factors are calculated for carcinogens and non-carcinogens, employing intake fractions, best estimates of dose-response slope factors, as well as severities. The transfer of contaminants into the human food is no more based on consumption surveys, but accounts for agricultural and livestock production levels. Indoor and outdoor air emissions can be compared and the intermittent character of rainfall is considered. Both human toxicity and ecotoxicity effect factors are based on mean responses rather than on conservative assumptions. Other midpoint categories are adapted from existing characterizing methods (Eco-indicator 99 and CML). All midpoint scores are expressed in units of a reference substance and related to the four damage categories human health, ecosystem quality, climate change, and resources. Normalization can be performed either at midpoint or at damage level. The IMPACT 2002+ method presently provides characterization factors for almost 1500 different LCI-results, which can be downloaded at http://www.epfl.ch/impact.

The different impact categories considered in the IMPACT2002+ method are presented in Table 15 .

Category	Unit
Carcinogens	kg C2H3Cl
Non-carcinogens	kg C2H3Cl
Resp. inorganics	kg PM2,5
Ionizing radiation	Bq C-14
Ozone layer depletion	kg CFC-11
Resp. organics	kg ethylene
Aquatic ecotoxicity	kg TEG water
Terrestrial ecotoxicity	kg TEG soil
Terrestrial acidification.nutrification	kg SO2
Land occupation	m2org.arable
Aquatic acidification	kg SO2
Aquatic eutrophication	kg PO4 P-lim
Global warming	kg CO2
Non-renewable energy	MJ primary
Mineral extraction	MJ surplus

Table 15: IMPACT2002+ damage categories (Jolliet et al, 2003)

Link: http://www.epfl.ch/impact

→ ***Ecopoints***

The Swiss Ecopoints 1997 (environmental scarcity) is an update of the 1990 method, based on actual pollution and on critical targets that are derived from Swiss policy (Braunschweig et al, 1998). All characterisation factors in this method are entered for the 'unspecified' subcompartment of each compartment (Raw materials, air, water, soil) and thus applicable on all subcompartments, where no specific characterisation value is specified.

The method of environmental scarcity is used, which allows a comparative weighting and aggregation of various environmental interventions by use of so-called eco-factors. This Ecopoints method (1997) updates and complements the eco-factors first published in 1990 in the BUWAL series No. 133 "*Methodik für Ökobilanzen auf der Basis ökologischer Optimierung*". It contains weighting factors for different emissions into air, water and top-soil/groundwater as well as for the use of energy resources. The eco-factors are based on the actual pollution (current flows) and on the pollution considered as critical (critical flows). Current flows are taken from the newest available data. Critical flows are deduced from the scientifically supported goals of Swiss environment policy.

Link: : http://www.e2mc.com/BUWAL297%20english.pdf

Sensitivity analyses

Finally sensitivity analyses can be performed in the impact assessment to determine the influence of a change in the inventory data on the results of the impact assessment. In fact, they determine the sensitivity of the outcome of calculations to a variation in the range within which the assumptions are considered to be valid.

Interpretation

The life cycle interpretation is the final phase of the LCA, in which the results of an LCI or an LCIA, or both, are summarized and discussed as a basis for conclusions, recommendations and decision-making in accordance with the goal and scope definition.

According to ISO 14040/44 during interpretation the results of the inventory analysis and the impact assessment are critically analyzed and interpreted. The findings of this interpretation may take the form of conclusions and recommendations to decision-makers. It may also take the form of an improvement assessment, i.e. an identification of opportunities to improve the environmental performance of the different types that will be analyzed.

Appendix 2 : IMEA *initial* analytical GRID

IMEA initial analytical Framework and its seven dimensions

IMEA project assessed the existing Environmental Accounting Methodologies (EAMs) with the support of an **analytical grid** and with a set of questions. A first version of the grid has been elaborated at the beginning of the project and supported the collection of the necessary knowledge on each EAM families by answering a series of structured questions. Answers to these key questions provided valuable knowledge for EAMs benchmarking

Answers are provided by surveying both trans-national and general characteristics[20] of EAM with the help of an analytical framework containing seven dimensions:

1. Environmental Reporting (ER)
2. Coverage (CO)
3. Quality and Reliability (QR)
4. Trans-boundary Ability (TA)
5. Integration Potential (IP)
6. Extensibility (EX)
7. Support to Policy-making (SP)

Each covers an essential characteristic of EAM, which should ideally address key environmental issues (ER), deal adequately with trans-boundary issues (TA), have a large coverage in terms of space, time and details (CO), be reliable (QR), extensible (EX) and integrated within existing assessment frameworks (IP) in a cost-effective way to effectively support policy making (SP).

The four stages of an EAM

Trans-boundary issues are considered at various stages within EAM methodologies, e.g. the availability of data or the formal integration into the modeling framework. The identification of strengths and weaknesses is therefore performed along four different EAM stages:

1. Data sources
2. System and boundaries
3. Calculation: weighting, conversion factors, normalization
4. Environmental indicator(s)

The first one relates to data, the second and third ones cover methodological aspects (system definition and calculations) and the last one describing the final output, i.e. the resulting Environmental indicator (s). These stages have been formally represented in the final IMEA workflow.

Seven Dimensions: description

[20] IMEA scope is not reduced to the only trans-national issues and questions listed below will sometimes be duplicated to handle both issues (the general one and the trans-boundary one)

(1) Environmental Reporting (ER)

The Environmental Reporting dimension assesses how EAMs cover environmental issues, including the following elements:

a) Position within existing analytical frameworks (DPSIR, others?

b) Inclusiveness of recognized environmental issues

c) Overlap, complementarity and substitutability with other EAM

d) Standardization across analytical scales and regions

The positioning of EAM into existing analytical frameworks informs on the potential uses of the final output of EAM (so-called "Environmental indicator"), and allows for a general classification of existing EAM according to their viewpoint. EAM address, for example, different steps along the DPSIR chain (Driving-forces, Pressures, State, Impact, Response)[21] . Some relate to the Pressure on the environment, e.g. kilograms of a substance used, while other relate to the Impacts in terms of damages, e.g. percentage of disappeared species. The relevant level of a measure depends on the political objectives to be assessed.

EAMs cover one or various environmental issues: to adequately deal with politically and scientifically recognized environmental issues, a combination of EAM's is probably required. The overlap and complementarity of EAMs should be assessed to understand how to enlarge coverage while reducing overlap. A selection of recognized environmental issues to be covered has been performed within the European project "Potential of the Ecological Footprint for monitoring environmental impacts from natural resource use", based on EU needs and the revised Sustainable Development Strategy as recognized by specialists. These environmental impacts are:

- Resource consumption
- Land use
- Climate change
- Stratospheric ozone depletion
- Human health impacts
- Eco-toxicity
- Photo-oxydant formation
- Acidification
- Eutrophication
- Ionizing radiation
- Impacts on ecosystems and biodiversity

We complete it with newly discussed aspects:

- Water use (depletion and degradation)

In addition, is a generic recipe enough or should the assessment report on local conditions and environmental specificities? The world is diverse both in terms of local environments (water, land, biodiversity,…), levels of GDP and induced environmental Pressures and Impacts, as well as Responses: should the appropriate set of

[21] The causal framework for describing the interactions between society and the environment adopted by the European Environment Agency: driving forces, pressures, states, impacts, responses (extension of the PSR model developed by OECD). See more on http://esl.jrc.it/envind/theory/handb_03.htm#Heading5

indicators be location specific and in which way? Could the same Environmental indicator(s) be used at each scale and is the differentiation, e.g. between two products, achievable with a unique indicator only or are multiple indicators needed?

(2). Coverage (CO)

The Coverage dimension assesses the scope of EAMs, data availability and applicability over space and time:

(a) Geographical coverage and level of resolution

(b) Temporal coverage, level of resolution, and update frequency

(c) Analytical scale and level of differentiation

(d) System analyzed and its boundaries

The geographical coverage reports on the ability of the EAM to consider the diversity of origins and the spatial resolution of data. The temporal coverage describes the ability to identify trends to report on changing production and consumption structures and the availability of up-to-date datasets. The system considered describes what is included and excluded from the analysis, providing information on the completeness of the analysis. The analytical scale is related both to the ability to provide information at one or multiple scales and to the level of differentiation, e.g. material categories for MFA, crops vs. forestry or pasture for land use, number of sectors for I-O, basic processes for LCA. Three different analytical scales are considered: the Macro level, to synthesize the situation of a whole region, usually a country, the Meso level, to characterize sub-entities, either sectors, groups of products or groups of companies, the Micro level, to provide a finer decomposition by considering the lowest building blocks, in our case products and services.

To ease the assessment, we propose to use archetype case studies between EU countries, regions, specific sector and non EU countries for example. They are:

1. Total imports by a EU country X
    a. From another EU country Y
    b. From China and/or from South Africa
2. Total imports by a sub-region of a EU country X
3. Imports by country X of toys from China
4. Imports by EU country X of a toy from a specific brand from China
5. Imports by a company Z from EU country X of a toy from China

Such cases studies could provide references cases and each EAM could be assessed according to their ability to handle these cases[22].

[22] IMEA will not handle these case studies but only consider EAM ABILITY

(3). Overall Quality and Reliability (QR)

The Overall Quality and Reliability dimension reports on the credibility of the EAM to provide scientifically valid Environmental indicators, as well as their technical feasibility. Elements specific to trans-boundary issues are not considered here but are assessed in the next section. It includes:

a) Accuracy, repeatability and robustness of the methodology

b) Completeness and uncertainty of datasets

c) Feasibility of datasets combination

d) Objectivity, sensitivity and robustness of results

The quality and reliability of the analysis is based first on the reliability of the theoretical basis and the scientific basis of the calculation (both for weighting and normalization of data and at subsequent stages). Second, reliable datasets are required (completeness, level of uncertainty) and their combination should be possible. The resulting Environmental indicator should be objectives and robust.

(4). Trans-boundaries Ability (TA)

The Trans-boundaries Ability dimension specifically assesses the way EAM consider trans-boundary issues, from a methodological and practical perspective. Both economic (trade) and natural exchanges (transfers trough the environment) are considered.

a) Accuracy, repeatability and robustness of the methodology

b) Completeness and uncertainty of datasets

c) Reporting on trans-boundary issues

Trans-boundary specific issues are related, for example, to the capacity of the environmental indicator to report on the location and magnitude of the environmental impacts. The reliance on poorly reconciled international trade datasets is also surveyed, as well as the capacity of dealing adequately with the complex international production chains resulting in multiple feedbacks between regions. Finally, the capacity of EAM to consider the differences due to standards, labels and fair trade practices is reviewed.

(5). Integration potential (IP)

The Integration Potential dimension assesses the potential for integrating EAM into current statistical collection endeavors.

a) Theoretical compatibility

b) Technical compatibility

Both the technical (at data level) and theoretical compatibility with (i) existing accounting systems (SNA93, SEC95, SEEA), (ii) norms and legislations (GHG protocol, ISO), as well as (iii) the way EAM can deal with the large changes related to the treatment of imports in the next version of the SNA (SNA 2008) and the large development of the SEEA in its next version (SEEA 2010) are of interest. The integration should be cost-effective.

(6). Extensibility (EX)

The Extensibility dimension assesses the potential of development of existing EAM:

a) Datasets extensions

b) Methodological extension

c) Easiness and cost of extensions

Datasets can be extended to cover missing areas, analytical levels or issues. Methodologies can be adapted to consider specificities of new locations, to adequately integrate the consequences of rapid technological changes and flexible production chains or to improve the treatment of trans-boundary issues. Extensions are also possible by combining methodologies together. Can methodologies be combined in a modular way? Extensions should be feasible, i.e. their implementation should be comprehensible and reproducible also for non-experts such as statisticians and cost-effective to ensure applicability on a large scale. Expert knowledge can probably be used to reduce information requirements: when and how this is feasible should be documented.

(7). Support to Policy-making (SP)

The Support to Policy-making dimension assesses the potential of EAMs to provide a relevant Environmental indicator for policy-making, as well as its potential uses according to its nature.

a) Intelligibility and Univocity
b) Maturity, Auditability and Acceptance
c) Nature (static/dynamic, absolute/relative) of the analysis

An indicator should be intelligible and provide a univocal (good/no-good) message for decision-making and for communication. It should be mature enough (fidelity) to allow comparability over space and time and the approach should be auditable, and accepted.

Various types of analysis can be performed with Environmental indicators, i.e. in a static (a comparison of levels across space or time) or dynamic (a comparison of the changes) perspective, or within an absolute or comparative framework. The legitimate types of analysis are however limited by the theoretical and practical foundations of each EAM. How can the various Environmental indicators be used?

Contribution of stages to the seven dimensions

The contribution of the four stages to the seven dimensions is shown in the following table. Data sources are analyzed with 19 questions, 21 (9+12) for the methodology, and 15 for the Environmental indicator.

	Data	System	Calculation	Indicator
Environmental Reporting				4
Coverage	6	3		1
Quality and Reliability	4	1	5	3
Trans-boundaries Ability	4	2	7	1
Integration Potential	2	1		2
Extensibility	3	2		
Support to Policy-making				4

INITIAL ANALYTICAL GRID

The analytical grid lists the questions to be answered for assessing existing environmental accounting methodologies. Questions are presented by EAM stage. Questions are numbered with a reference to the analytical dimensions, e.g. CO1 for question one related to the Coverage dimension.

Stage 1: Data

CO1 World regions covered? Adequate coverage of developing countries?

CO2 Spatial resolution of the data?

CO3 Availability of time-series? Period and regions covered?

CO4 Accounting period of the EAM?

CO5 Frequency of updates?

CO6 Number and description of categories existing to establish a differentiation (material categories for MFA, crops vs. forestry or pasture for land use, number of sectors for I-O, basic processes for LCA) (data requirements)?

QR1 Main data sources? Do reference databases exist and who is collecting the data?

QR2 Completeness of datasets and data gaps?

QR3 Level of data uncertainty and is it documented?

QR4 Feasibility of combining different datasets in a coherent way?

TA1 Sources of data on exchanges and trans-boundary issue? Do reference databases exist?

TA2 Completeness of datasets and data gaps?

TA3 Level of data uncertainty and is it documented?

TA4 Feasibility of combining different datasets in a coherent way?

IP1 Correspondence of classification to National Accounts and other international databases (IEA, FAO)

IP2 Format of datasets (with existing examples for Europe)

EX1 Ease of use of datasets (proprietary or public domain software packages, existing toolboxes, current examples of use communities)

EX2 Ease of extending datasets to fill data gaps, to new geographic areas and analytical levels

EX3 Feasibility (by non-experts)[23] and cost-effectiveness of data development

[23] Estimation only

Stage 2: System and boundaries

CO7 Description of the system and system boundaries?

CO8 Relation to the socio-economic system: inclusion of non-monetarized relations, informal sector activities?

CO9 Adequate consideration of (a) end of life, e.g. waste treatment, recycling, (b) trade-offs and displacements of environmental issues along a chain?

QR5 Clear expression of protocols for allocation choices and cut-off rules?

TA5 Detailed description of trans-boundary issues within the system?

TA6 Ability of the system to account for complex or international production chains with multiple feedbacks?

IP3 Compatibility of system boundaries with existing accounting frameworks, standards or legislation

Stage 3: Calculation (weighting, conversion factors, normalization)

QR6 Focus of the measure (stocks, flows, inputs, outputs)? Units of measurement?

QR7 Accuracy: Scientifically grounded weighting scheme, normalization, conversion factors for data and environmental pressures?

QR8 Is the basis of normalization an endogenous benchmark/sustainable level?

QR9 Appropriately used conversion factors (average vs. local or product-specific)?

QR10 Repeatability: Degree of harmonization of methods? Availability of recognized methodological guidelines and deciding bodies? Clear and transparent definition and documentation of the methodology?

TA7 Scientifically grounded weighting scheme, normalization and conversion factors of the integration of trans-boundary issues rely?

TA8 Appropriately used conversion factors for trans-boundary issues (average vs. local or product-specific)? Are normalizations and conversion factors using a valid denominator when dealing with trans-boundary issues?

TA9 Is the normalization basis accounting for trans-boundary issues?

TA10 Methodological issues regarding trans-boundary issues and how do they impair the quality of results?

TA11 Do recognized methodological guidelines exist for of trans-boundary issues?

TA12 Clearly defined and documented methodological steps for dealing with trans-boundary issues?

TA13	Ability to specifically consider standards and labels for traded products
EX4	Ease of extending methodologies (alone or in combination with other EAM) to answer specific needs of new geographic and analytical levels
EX5	Feasibility (cost-effectiveness) of methodological improvements

Stage 4: Environmental indicator(S)

Applicable to main (headline and intermediate if applicable) indicators

ER1 Position of the EAM within the DPSIR (or other) framework?

ER2 Inclusiveness: Adequate coverage of recognized environmental issues? Which issues are not considered?

ER3 Overlap: Unique coverage of a specific issue? How does the EAM complement or could substitute another EAM?

ER4 Standardization: Is the EAM relevant to all regions and analytical scales? If not, when and where is it particularly appropriate? Is the local context considered?

CO10 Adapted to analytical scales (micro, meso, macro)?

QR11 Objectivity: Is the resulting environmental indicator calculable without ambiguity?

QR12 Sensitivity/Robustness: Is the resulting environmental indicator (a) sensitive to small changes, and (b) robust enough against data gaps or extremes?

QR13 Is the environmental indicator largely influenced by dominant factors and which one?

TA13 Does the indicator provide information on the location and magnitude of the environmental impacts and on exchanges?

IP4 Relation to economic measures: Potential of integration into a neo-classical framework (expression in terms of preferences and utility)? Potential or established correspondence with monetary values?

IP5 Ease of integration within a needs analysis or a functional analysis?

SP1 Intelligibility of the indicator, univocity of the message (good/no good)

SP2 Maturity, auditability, acceptability

SP3 Current use by firms, governments or international bodies

SP4 Relevance of the indicator as a static (in level)/dynamic (changes) variable and relevance as an absolute or comparative value

Appendix 3: Review of existing LCA methodologies along IMEA *initial* analytical grid

Stage 1: Data

CO1: World regions covered? Adequate coverage of developing countries?

In theory it is possible to cover all the world regions with LCA. However in practice due to data-availability (there are no global LCA-data) there is a focus on industrialized countries. The geographical coverage in LCA is very case-specific: the scope can be set for a region, a land or a company.

As *Europe* is the cradle of LCA, European LCI data are quite well reported and documented. In the *United States* limited databases are available with LCI data for the USA, including cradle-to-gate or gate-to-gate data. In Japan a publicly available, reliable LCI database is developed with data for average Japanese production of a variety of materials (however only in Japanese). In Australia the Australian Life Cycle Inventory Data project developed publicly available Australian LCI data. These data sets are developed from the best Australian data available.

The most widely used LCA-databases are not covering developing countries, with the exception of some extraction of raw materials in developing countries which are incorporated in the LCA-databases. In developing countries in general, LCA capacity is low. As many of these countries supply resources to developed countries, there is increasingly the recognition that LCI databases need to include the products and services from developing countries as well.

How to overcome this lack of data for developing countries ?

- Speed the collection process – Is there any specific help planned from UNEP for example? – It would be good to enquire about strategies at the international levels,
- Develop an alternative strategy to overcome it: (1) as a first step, substitute within inventories of imported goods or intermediate goods, energy/electricity mix specific to developed countries (2) other strategies ?

CO2: Spatial resolution of the data?

In theory it is possible to have a very high spatial resolution of the data, however in practice LCA-databases are generic contain averages for example for a European sector, which can not be split up into individual production sites, or which can not be attributed to for example 2 plants in Belgium, 5 in Germany,…

An LCA study can combine generic inventories issued from databases and specific localized data. This issue is also linked to the issue of heterogeneity of the data.

CO3: Availability of time-series? Period and regions covered?

Theoretically it is possible to have time series, however in practice LCA-practitioners work with up-to-date datasets covering modern technology. In LCA current state of technology is assumed and it is current practice to work with the latest, most reliable data available. However the issue lies also within the heterogeneity of time and space within the same database. LCA is not intended to identify trends to report on changing production and consumption structures.

CO4: Accounting period of the EAM?

The accounting period can vary in function of the available data and the goal and scope of the study. It can be a snapshot of the latest state-of-the-art technology, while sometimes the LCA is constructed based on annual production figures. There is no predefined accounting period. It is up to the choice of the LCA practitioner, depending on the goal and scope of the study.

CO5: Frequency of updates?

The frequency of database updates depends on the database provider. The frequency is approximately every 1 to several years. Ecoinvent for example is updated every 3 years.

This is acceptable except for ther energy sector, CO2 intensive industries and regulated industries where yearly updates would be advisable.

CO6: Number and description of categories existing to establish a differentiation (material categories for MFA, crops vs forestry or pasture for land use, number of sectors for IO, basis processes for LCA) (data requirements)?

There are thousands of categories in LCA-database, mainly related to materials production, energy production, transportation, waste treatment (end-of-life scenarios), and processing technologies (for example surface treatment and industrial design techniques).

Specification of available datasets:

- materials (component) production: agricultural, ceramics, chemicals, construction, electronics, fuels, glass, metals, minerals, paper & board, plastics, textiles, water, wood
- energy production: biomass, cogeneration, electricity, heat, mechanical, etc.
- different transport modi
- different waste treatment technologies

Some examples of specific datarecords:

Titanium dioxide, production mix, at plant/RER U

Light clay brick, at plant/DE U

Electricity, low voltage, production UCTE, at grid/UCTE U

Transport, aircraft, passenger, Europe/RER U

Disposal, bitumen sheet, 1.5% water, to municipal incineration/CH U

QR1: Main data sources? Do reference databases exist and who is collecting the data?

LCA-data are inventoried and centralized in commercial or publicly available databases. Databases are developed on either a multi-organisational/national level (e.g. Australia), by consultants and research institutes (e.g. Switzerland, USA) or by industry (e.g. Plastics Europe). Sofar no statistical offices are collecting nor generating LCI[i] data. There is no standard as such for LCI data collection and generation.

LCA-databases are built up from a mixture of data available in literature and data supplied by industrial sector federations or individual companies.

A list of available databases is provided on the website of the European platform on LCA (http://lca.jrc.ec.europa.eu/lcainfohub/databaseList.vm) and on the website of the UNEP Life Cycle Initiative

(http://jp1.estis.net/sites/lcinit/default.asp?site=lcinit&page_id=15CFD910-956F-457D-BD0D-3EF35AB93D60).

A (public) (European) reference database is being set up by JRC in the International platform on LCA. A first version of the Commission's "European Reference Life Cycle Data System" (ELCD), v 1.0.1. is now available on the following website:

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

The database comprises - next to other sources - LCI data sets of the European Aluminium Association (EAA), the European Copper Institute (ECI), the European Confederation of Iron and Steel Industries (EUROFER), The Association of Plastics Manufacturers in Europe (PlasticsEurope, former APME), The European Federation of Corrugated Board Manufacturers (FEFCO), Groupement Ondulé (GO), and the European Container Board Organisation (ECO). All these data sets are officially provided and approved by the named association for publication in the Commission's ELCD core database.

A similar initiative is being set up in Australia and Japan by resp. ALCAS (Australia) and the Ministry of International Trade and Industry (MITI)/JEMAI (Japan). The Australian LCA Society (ALCAS) is currently developing a data collection protocol for a National LCI database which is planned to be hosted and supported by the Australian Commonwealth Scientific and Research Organisation.

QR2: Completeness of datasets and data gaps?

Completeness issues cover the range of processes themselves as well as the outputs of LCI

- Processes :Data gaps are always clearly indicated. As there exist a wide range of materials an LCA-database can never cover all existing materials. Besides this fact there are always new developments of materials of which the data only become available after a delay of several years (market introduction). For example data for nanomaterials and biopolymers are only recently taken up in the databases.
- Inventories outputs: extensive range of outputs (several hundreds) but still data are missing regarding water, indoor pollution, biodiversity issues. Other issues ??

QR3: Level of data uncertainty and is it documented?

The level of data uncertainty is addressed in LCA-databases and is documented by a data quality indicator (DQI). Databases often report data quality indicators as suggested in the ISO-standards, which comprise information on:

a) time-related coverage: age of data and the minimum length of time over which data should be collected;
b) geographical coverage: geographical area from which data for unit processes should be collected to satisfy the goal of the study;
c) technology coverage: specific technology or technology mix;
d) precision: measure of the variability of the data values for each data expressed (e.g. variance);
e) completeness: percentage of flow that is measured or estimated;
f) representativeness: qualitative assessment of the degree to which the data set reflects the true population of interest (i.e. geographical coverage, time period and technology coverage);
g) consistency: qualitative assessment of whether the study methodology is applied uniformly to the various components of the analysis;
h) reproducibility: qualitative assessment of the extent to which information about the methodology and data values would allow an independent practitioner to reproduce the results reported in the study;
i) sources of the data;uncertainty of the information (e.g. data, models and assumptions).

Recognition of large levels of uncertainties (could be as high as 200% in some cases) . May be, examples could ge given.

QR4: Feasibility of combining different datasets in a coherent way?

We could recall right at the beginning of this analysis that performing a LCA combines database data and specific data in line with the goal and scope of the study.

The criteria for such coherence combining datasets (several db and specific data) include:

- coverage issues
- Precision issue
- Completeness issue
- Consistency issue
- Reproductibility issue
- Uncertainty issue

Within one (commercial) database it is feasible to combine different datasets in a coherent way, as the same inventory principles, inventory formats and impact categories apply. So within one database, data are compatible.

Sometimes, due to incompleteness of a database, other databases are consulted which use other classifications, system boundaries and sets of impact categories. Practitioners should be aware of these restrictions.

TA1: Sources of data on exchanges and trans-boundary issues? Do reference databases exist?

Two questions :

1- Related to trade No import/export statistics are applied in LCA. One issue within IMEA is to investigate whether these statistics could be coupled to LCA and how in order to couple international trade and LCA.

2 - Related to transboundary pollution

The lack of keeping track on spatial and temporal dimensions in the LCI-result introduces uncertainty in the LCIA-results. The uncertainty varies with the spatial and temporal characteristics of each impact category (ISO 14040:2006(E))

Import of materials/components can be taken into account in an LCA by defining supply chains, however the impact of this import is limited to transport processes and energy production mixes.

Regional differentiation is already part of LCI modelling as, for example, the production of many products is assessed country-specific, e.g. by defining country-specific power grid mixes (country-specific electricity generation). Inventories, characterized by elementary flows (materials / emissions or energy exchanged between the system and the environment), generally do not contain information on where the elementary flows are emitted. This holds especially true for the output side. On the input side, some data providers create inventories with country specific resource extraction elementary flows due to different physical and chemical properties, e.g. crude oil from Venezuela.

Some inventories currently try to address the receiving compartment more specifically, e.g. copper ion to groundwater. Recently, a project for a general, valid elementary flow list has begun, initiated by the European Commission (European Platform on LCA 2007). From the inventory side, what is now needed is a comprehensive, easily manageable, and meaningful spatial differentiation of single processes within a process chain, and a documentation of the spatial aspects that is in line with data management possibilities and the extra effort (http://www.itas.fzk.de/tatup/073/seua07a.htm).

TA2: Completeness of datasets and data gaps?

Not Applicable (N.A.)

TA3: Level of data uncertainty and is it documented?

N.A.

TA4: Feasibility of combining different datasets in a coherent way?

N.A. in relation with comment CO1 on strategy to cope with this question.

IP1: Correspondence of classification to National Accounts and other international databases (IEA, FAO)

Two ISO-standards are composed with regard to LCA, ISO 14040 and 14044. Both standards give guidance to apply LCA in a correct and objective manner.

Regarding the classification of data: LCA-databases classify chemicals according to their CAS (Chemical Abstracts Service) Registry Number. For other materials no standardised classification scheme is applied.

IP2: Format of datasets (with existing examples for Europe)

The basic data used for environmental assessments (product life cycle inventory data) can be found in many different LCA-databases and software. However, practically every database and software use an own format for storing and presenting the data, making data difficult to exchange and compare. A first attempt to facilitate the exchange of LCI data was done by SPOLD (Society for the Promotion of Lifecycle Development) which worked to develop a common format for the exchange of life-cycle inventory data. In the beginning of 2000 the EcoSPOLD format was developed, starting from SPOLD 99 and the ISO/TS 14048 data reporting format. Most commercially available LCA software are able to import and export EcoSPOLD files.

EX1: Ease of use of datasets (proprietary or public domain software packages, toolboxes, current examples of use communities)

There are many providers of LCA-software. For a (non-limited) overview of European providers, one can consult the website of the European platform on LCA (http://lca.jrc.ec.europa.eu/lcainfohub/providerList.vm)

Many practitioners worldwide use LCA. Examples of user-communities are SETAC (Society of Environmental Toxicology and Chemistry), the LCA discussion list (Pré Consultants), the LCT (life cycle thinking) forum mailing list of the European platform on LCA.

EX2: Ease of extending datasets to fill data gaps, to new geographic areas and analytical levels

LCA-experts can create their own database, which can build on datasets in existing databases or can be created with own datasets. How easy to respect quality comparability with existing database ? Here we could introduce a notation level.

EX3: Feasibility (by non-experts) and cost-effectiveness of data development

Data development is not feasible for non-experts and costs can be considerable.

Stage 2: System and boundaries

CO7: Description of the system and system boundaries?

ISO standards prescribe that any LCA-study needs a clear and transparent definition of the system under study and its system boundaries in an initial phase of the study. This is expressed in the functional unit and in a rigorous definition of the system boundaries. The functional unit expresses a quantified performance of a product system for use as a reference unit.

CO8: Relation to the socio-economic system: inclusion of non-monetarized relations, informal sector activities?

N.A.

CO9: Adequate consideration of (a) end of life, e.g. waste treatment, recycling, (b) trade-offs and displacements of environmental issues along a chain?

LCA provides the perfect assessment framework for evaluation of end-of-life options, as well as considerations of trade-offs and displacements of environmental issues along a chain.

QR5: Clear expression of protocols for allocation choices and cut-off rules?

The ISO standards provide clear guidance for allocation choices and cut-off rules.

TA5: Detailed description of trans-boundary issues within the system?

In practice not included. Here propose alternative strategies and introduce future ones.

TA6: Ability of the system to account for complex or international production chains with multiple feedbacks?

In theory one can construct very complex production chains, but in practice it will be limited due to data-availability.

IP3: Compatibility of system boundaries with existing accounting frameworks, standards or legislation

The system boundaries are defined by the LCA-practitioner based on the goal and scope of the study. When combining tools, several aspects need to be considered e.g. time- and site-specificity, degree of quantification, system boundaries, type of impacts included. Differences between tools with regard to these aspects can determine if and how different tools can be used in combination.

Discussion on NAMEAS could be included here (to what extent NAMEAS initiative could help sorting the question of national environmental reporting on industrial sectors ?)

Stage 3: Calculation: weighting, conversion factors, normalization

QR6: Focus of the measure (stocks, flows, inputs, outputs)? Units of measurement?

LCA considers input-output flows of a system over its entire life cycle. Units of measurement are all available physical units depending on the type of input and output flow. For inventarisation flows, input measurements are for example mass, volume and tkm, output measurements e.g. expressed in kg emissions. For the characterization factors the units depend on the environmental impact category (e.g. CO_2-equivalent) and the impact assessment methodology.

The purpose of life cycle impact assessment (LCIA) is to assess the significance of potential environmental impacts of each elementary flow of the life cycle inventory (LCI) for each relevant impact category. The results of a LCIA are expressed through what is known as an environmental profile, where the LCI is grouped in a reduced number of indicators (impact categories). Within the conversion of LCI to LCIA, characterization factors are applied to get results with a common unit (see also ISO 14044).

Current LCIA methodologies have been developed to assess emission inventories for specific regions such as Europe (e.g., IMPACT 2002+ – Jolliet et al. 2003; Eco-indicator 99 – Goedkoop and Spriensma 2000; CML – Guinée et al. 2002; EDIP 2003 – Hauschild et al. 2006), the US (TRACI – Bare et al. 2003), Canada (LUCAS – Toffoletto et al. 2006), and Japan (LIME – Itsubo and Inaba 2003). The lack of models adapted to other regions, and especially to developing countries, is considered as a political and scientific limitation of the current impact assessment practices (Humbert et al. 2007c in http://www.itas.fzk.de/tatup/073/seua07a.htm).

QR7: Accuracy: scientifically grounded weighting scheme, normalization, conversion factors for data and environmental pressures?

May be the discussion could detail more on the different steps:

Clear separated steps within the aggregation scheme:

(1) sum of flows -> inventory

(2) flows -> impact categories (= classification) (qualitative)

(3) flows -> impact categories (=characterization) (quantitative)

(4) weighted sum -> mid-points (impacts)

(5) weighted sum -> end-points (impacts)

(6) normalization -> compared to a value of reference

(7) weighting -> unique indicator

Answer: Yes for 1-2, ~ for 3,4, ~~ for 5, yes for 6 (no if consider that for EU only), not for 7 equal weighting = abritary: worse than political or scientific weights.

6-7: Answer no in ISO norm.

6-7: Necessary to be able to make a final clear/univocal choice

A scientifically grounded normalization method is developed for LCA, however normalization data are limited by data-availability results are highly dependant on the choice of these values. Only limited so far for the EU context.

With regard to conversion factors (characterization factors) there is for most categories a scientific consensus. This scientific consensus is less grounded for some environmental impact categories like toxicity and land use.

The development of generic characterization factors (CF) in LCIA has been historically motivated by the lack of spatial and temporal information when collecting LCI data for a given product system. Though several LCA software programs do allow the inclusion of geographical information, this feature is still not always taken advantage of. The generic characterization factors are well adapted to evaluate global impacts, such as global warming and ozone layer depletion, but have some inherent limitations when assessing those impact categories that are not global in nature, such as acidification or eutrophication, which are typically regional impact categories with continental coverage. Photochemical ozone formation or respiratory effects from airborne pollutants, and resource related impact categories such as land use and water use are considered even more local (down to a few kilometres). Toxicity and ecotoxicity impact categories, however, can range from very local to global impacts, depending on the substances

(http://www.itas.fzk.de/tatup/073/seua07a.htm).

As discussed we need more information on current attempts to the development of regional weighting factors.

QR8: Is the basis of normalization an endogenous benchmark/sustainable level?

The basis for normalization is the environmental score per region/country or per person. It is definitely not a sustainable level.

QR9: Appropriately used conversion factors (average vs local or product-specific)?

Conversion factors in LCA are scientifically based, but the impact of for instance acidifying emissions can be location-specific but is not commonly treated as such.

According to the ISO 14044 standard, LCI results are first classified into impact categories. A category indicator, representing the amount of impact potential, can be located at any place between the LCI results and the category endpoint. Jolliet et al. (2004) explain the difference between midpoint and endpoint as follows:

Two types of LCIA methods exist:

a) Classical impact assessment methods (e.g. CML 2001 methodology) that stop quantitative modelling before the end of the impact pathways and link LCI results to so-defined *midpoint* categories, e.g. ozone depletion or acidification. However, depletion of the ozone layer, as expressed by a corresponding midpoint category indicator such as ozone depletion potential, is an environmental concern in itself, but the larger concern is usually the subsequent damages to humans, animals and plants.
b) Damage oriented methods (e.g. Eco-Indicator 99: Goedkoop and Spriensma 2000, EPS: Steen 1999) which aim at LCA outcomes that are more easily interpretable for further weighting, by modelling the cause-effect chain up to the environmental damages, the damages to human health, to the natural environment and to natural resources. These may be expressed for example in additional cases of human health impairment or species endangerment, enabling to reduce the number of considered *endpoints* in making different midpoints comparable. They can, however, lead to high uncertainties.

Although users may choose to work at either the midpoint or damage levels, a current tendency in LCIA method development aims at reconciling these two approaches. Both of them have their merits, and optimal solutions can be expected if the 'midpoint-oriented methods' and the 'damage-oriented methods' are fitted into a consistent framework. Certain methods of this type were recently made available (Impact 2002+: Jolliet et al. 2003a, The Japanese LIME method: Itsubo and Inaba 2003) or will soon be finalized (the Recipe project: Heijungs et al. 2003).

As discussed we need more information on current attemps to the development of regional weighting factors.

QR10: Repeatability: Degree of harmonization of methods? Availability of recognized methodological guidelines and deciding bodies? Clear and transparent definition and documentation of the methodology?

There is clear and transparent definition of the methodology and guidelines are given in the ISO standards 14040/14044. The reproducibility of a well performed LCA study is very high. However the repeatability in the

sense of 2 independent LCA practitioners performing the same project, coming to identical results is much less . Results can easily differ 10-20% on impact assessment level, depending on the choices of datasets, system boundaries (??),…

TA7: Scientifically grounded weighting scheme, normalization and conversion factors of the integration of trans-boundary issues rely?

N.A.

Impact's geo-scale

No for characterization step : need for regional specific characterization factors

- For exposure
- For impact calculation

No for normalization, need regional specific (see QR 7)

No for an indicator making clear that some issues are critical in some regions even if not dominant from an aggregated perspective (red flags/avoiding averaging of critical issues)

Needs:

Regional or world diffusion model but not only for EU

A **specific aggregation scheme** for aggregating regions together

Clearly use a new spatial dimension for reporting of emissions and impacts, but aggregation between regions will have another logic -> update ISO norm?

- Question of "is displacement of impacts an issue & when?"
  - To deal with delocalization & dematerialization

TA8: Appropriately used conversion factors for trans-boundary issues (average vs local or product-specific)? Are normalizations and conversion factors using a valid denominator when dealing with trans-boundary issues?

N.A.

TA9: Is the normalization basis accounting for trans-boundary issues?

N.A.

TA10: Methodological issues regarding trans-boundary issues and how do they impair the quality of results?

N.A.

TA11: Do recognized methodological guidelines exist for of trans-boundary issues?

N.A. No

TA12: Clearly defined and documented methodological steps for dealing with trans-boundary issues?

N.A.

TA13: Ability to specifically consider standards and labels for traded products?

Labels are often based on LCA considerations. LCA studies are the basis for many environmental labelling schemes.

EX4: Ease of extending methodologies (alone or in combination with other EAM) to answer specific needs of new geographic and analytical levels?

Combining process-based LCA and Environmental Input Output Analysis (EE-IO) has become known as “hybrid analysis”. It can yield a result that has the advantages of both methods (i.e. both detail and completeness).

It is often useful to develop hybrid LCAs which combine the ease and broad perspective of EE-IO with the specificity of information for a single product or process of a process-based LCA. For example, one could use process-based LCA to model the impacts of the production processes at a given facility, but use EE-IO to model the supply chain impacts of the electricity purchased by the facility. Alternatively, if specific data about a facility is known, one could disaggregate an industry sector within an EE-IO model into two sectors: one representing the specific facility and one representing the rest of the industry.

As discussed in the WP3 Position paper of the CALCAS project, broadening and deepening of LCA can allow to link the analysis of a product system at different governance levels (micro-meso-macro). Governance at the micro level relates to individual companies and households. On a company-level this can be achieved by connection LCA to Corporate Social Responsibility reporting (CSR), to ecodesign and to cost accounting. The next level, the meso level, relates to sectors or economic activities. The highest governance level is the macro-level, the world, world regions or national economies. A number of methods and models exist with respect to spatial and temporal dimensions. The starting point is LCA as a steady-state analysis. It is for example possible to link the LCA to EE-IO, which places specific products and technologies in an encompassing scientific framework, which allows linking the micro performance to meso and macro levels.

There is a large gap between investigations on micro and macro level (Schütz and Ritthof, 2006). Most analyses at the macro level are time specific, at the micro level not. Making LCA time specific can improve the connection

between micro and macro levels. It must also be taken into account that the level of technological development does not correspond directly to the level of environmental problems that should be addressed. Ideally all micro level questions should be answered in terms of macro level effects.

EX5: Feasibility (cost-effectiveness) of methodological improvements?

This is hard to define and very much dependent on the scope of the study and the associated improvements.

Stage 4: Environmental indicator(s)

ER1: Position of EAM in the DPSIR (or other) framework?

P, I, R optional

ER2: Inclusiveness: Adequate coverage of recognized environmental issues? Which issues are not considered?

One of the advantages of LCA is the integral assessment of environmental impact, which means that a wide range of environmental impact categories are considered, such as:

- Resource consumption (minerals and fossil fuels);
- Land use;
- Climate change;
- Stratospheric ozone depletion;
- Human health impacts;
- Eco-toxicity;
- Photo-oxidant formation;
- Acidification;
- Eutrophication;
- Ionizing radiation;
- Impacts on ecosystems and biodiversity.

All these environmental impact categories are covered in LCA methodology. However human health impacts are only considered at a global scale, and not the local/individual exposure.

It would be interesting to enlarge the scope of potential impacts. http://epi.yale.edu/Home

ER3: Overlap: Unique coverage of a specific issue? How does the EAM complement or could substitute another EAM?

LCA does not focus on one specific issue but looks at the integral environmental impact.

LCA considers the entire life cycle of a product, from raw material extraction and acquisition, through energy and material production and manufacturing, to use and end of life treatment and final disposal. Through such a systematic overview and perspective, the shifting of a potential environmental burden between life cycle stages or individual processes can be identified and possibly avoided.

LCA is not complementary to other EAM (e.g. EE-IO) with respect to other impact categories, but is regarding data-availability and the level of detail.

EE-IO advances current understandings of trade and the environment not by exploring new relationships between regulation and the environment or by including new dependent variables, but rather by providing a more comprehensive approach to using existing data for the study of environmental trends (Ghertner, D.A. and Fripp, M., 2007). As discussed before hybrid analysis (LCA/EE-IO) can yield a result that has the advantages of both methods (i.e. both detail and completeness). It is often useful to develop hybrid LCAs which combine the ease and broad perspective of EE-IO with the specificity of information for a single product or process of a process-based LCA.

LCA can complement IO. Several examples in literature specifically dealing with environmental impact of imports

Weinzettel, J. and Kovanda, J.developed an input output model with environmental extension based on a combination of domestic technology assumption for imports with equivalent domestic production and life cycle coefficients for imports with no or different domestic production technology. Emissions embodied in imports can be interpreted as the pressure exerted by the country in question on the environment of other countries, while the emissions embodied in exports can be interpreted as the environmental pressure exerted on the country in question by other countries (Weinzettel, J. and Kovanda, J., 2008).

Environmentally extended input-output (EE-IO) tables offer a basis to assess all materials flows in an economy and domestic environmental interventions (emissions, raw material extractions, land use). Furthermore, it is possible to assess environmental interventions for the imported materials, by for example using life cycle inventory databases. The impact assessment methods used in the EE-IO models are commonly based on site-generic characterisation factors of life cycle impact assessment (LCIA). Seppälä, J. et al., 2008 addresses a new procedure to assess global environmental impacts using a site-specific approach. They found that the site-specific impact results of regional and local environmental impact categories (e.g. acidification, particulate matter) related to materials imported from outside Finland differ dramatically from the results derived by commonly used site-generic characterisation factors.

Impact assessment methods used in the environmentally extended input output (EE-IO) models are commonly based on site-generic characterisation factors of life cycle impact assessment (LCIA). However, Seppälä, J. et al., 2008 has shown that the site-specific approaches can offer a very different view about the environmental impacts of regional and global environmental problems caused by a national economy compared with the situation in which only site-generic characterisation factors are used.

Yi et al. found in their study “Development of the Interregional I/O based LCA method considering region-specifics of indirect effects in regional evaluation” that it is especially necessary to construct inventory and damage factors for site dependent environmental burdens such as heavy metals and chemicals in order to evaluate regional characteristics more totally.

ER4: Standardization: Is the EAM relevant to all regions and analytical scales? If not, when and where is it particularly appropriate? Is the local context considered?

Standardization of impact categories is relatively high across LCA practitioners over the world. Yes and no if we do need to consider regional impacts within LCA to fully account for transboundary exchanges.

Some impacts are highly site specific and require specific regional definitions which are not yet available.

LCA is mainly relevant for the micro and meso level: i.e. product and sector applications.

CO10: Adapted to analytical scales (macro-meso-micro)?

The macro analytical scale is not really applicable. But many micro and meso LCAs can help answering macro studies (e.g. EIPRO study – Environmental Impacts of Products, http://ec.europa.eu/environment/ipp/pdf/eipro_report.pdf)

As discussed in the WP3 Position paper of the CALCAS project, broadening and deepening of LCA can allow to link the analysis of a product system at different governance levels (micro-meso-macro). Governance at the micro level relates to individual companies and households. On a company-level this can be achieved by connection LCA to Corporate Social Responsibility reporting (CSR), to ecodesign and to cost accounting. The next level, the meso level, relates to sectors or economic activities. The highest governance level is the macro-level, the world, world regions or national economies.

A number of methods and models exist with respect to spatial and temporal dimensions. The starting point is LCA as a steady-state analysis. It is for example possible to link the LCA to EE-IO, which places specific products and technologies in an encompassing scientific framework, which allows linking the micro performance to meso and macro levels.

There is a large gap between investigations on micro and macro level (Schütz and Ritthof, 2006). Most analyses at the macro level are time specific, at the micro level not. Making LCA time specific can improve the connection between micro and macro levels. It must also be taken into account that the level of technological development does not correspond directly to the level of environmental problems that should be addressed. Ideally all micro level questions should be answered in terms of macro level effects.

While both process LCA and EE-IO have been important decision-making tools, neither of them has been able to perform regional and state level analyses efficiently. Cicas, G. et al., 2007 wished to develop a model that indicates US regional economic and environmental effects from the production of goods and services. In turn, the regional model can be used to complement local, process based or national analyses. The REIO-LCA model will quantify regional environmental effects. The quality of data, e.g., age and level of aggregation, and the assumed linearity between sectoral outputs and environmental emissions represent the main sources of uncertainty in the model. The results show that the GSP estimates are appropriate to construct a framework for a regional economic input-output and environmental assessment model. However, further research is recommended to construct more specific state-level input-output matrices incorporating interstate commodity flows, and state environmental factors in order to mitigate the parameter uncertainties. Further, the model might be improved by updating it regularly, as more recent data become available (Cicas, G. et al., 2007).

QR11: Objectivity: Is the resulting environmental indicator calculable without ambiguity?

Due to the scientifically based conversion (characterization) factors, LCA results in unambiguous environmental indicators per impact category.

When considering the last stage (resulting) "weighting" the answer is NO when including trade-related issues since political choices are needed for.

QR12: Sensitivity/Robustness: Is the resulting environmental indicator (a) sensitive to small changes, and (b) robust enough against data gaps or extremes?

It depends on the studied system. ISO guidelines clearly state that enough sensitivity analyses[24] has to be performed to check the influence of data uncertainties and to assess the consequences on the results of different value-choices and weighting.

Sensitivity analysis (sensitivity check) tries to determine the influence of variations in assumptions, methods and data on the results. Mainly, the sensitivity of the most significant issues identified is checked. The procedure of sensitivity analysis is a comparison of the results obtained using certain given assumptions, methods or data with the results obtained using altered assumptions, methods or data. In sensitivity analyses, typically the influence on the results of varying the assumptions and data by some range (e.g. ± 25 %) is checked. Both results are then compared. Sensitivity can be expressed as the percentage of change or as the absolute deviation of the results. On this basis, significant changes in the results (e.g. larger than 10 %) can be identified. Very significant changes in the results (over 100%) when input data present high uncertainties.

QR13: Is the environmental indicator largely influenced by dominant factors and which one?

Energy (fossil fuels) always contributes substantially to the end result. Therefore most impacts on human health are to be related to Particulate Matters.

TA13: Does the indicator provide information on the location and magnitude of the environmental impacts and on exchanges?

The environmental indicators provide information on the magnitude of the environmental impacts, not on the location and exchanges, since LCA is site- and time-independent. What about knowledge about the geo-distribution of impacts ? Water stress is key for developing countries for example.

[24] systematic procedures for estimating the effects of the choices made regarding methods and data on the outcome of a study

IP4: Relation to economic measures: Potential of integration into a neo-classical framework (expression in terms of preferences and utility)? Potential or established correspondence with monetary values?

IP5: Ease of integration within a needs analysis or a functional analysis?

As long as a relation with the products or products systems under study can be established, LCA-results can be integrated in a broader needs or functional analysis.

SP1: Intelligibility of the indicator, univocity of the message (good/no good)

If results are reported in a clear way, in principle the interpretation per impact category is intelligible. But when the results of comparative assertions are communicated to a broader public, results per impact category are not fully understandable to a non-LCA expert. Most often the message is not a simple good/no good result. Weighting of the different impact categories is not compulsary according to ISO, but is an option to enhance the intelligibility of the environmental indicator if the LCA results are intended for internal purposes. There is a need for a policitical weighting recognised at the OCDE/EU (?) levels to account for regional specificties.

SP2: Maturity, auditability, acceptability

An optional critical review allows for an increased credibility.

The critical review is a process intended to ensure consistency between a life cycle assessment and the principles and requirements of the International Standards on life cycle assessment. Acceptability is increasing answering wider needs (companies decisions -eco-design, eco-efficiency, marketing, political decisions –public policies, education –on sustainable consumption issues, etc … See below

SP3: Current use by firms, governments or international bodies

LCA-results are used for many purposes, by industry as well as governmental organisations. Intended direct applications of LCA are:

- Product development and improvement;
- Strategic planning;
- Public policy making;
- Marketing;
- Other.

Further applications in the field of environmental management systems and tools include, among others:

- environmental management systems and environmental performance evaluation (ISO 14001, ISO 14004, ISO 14031 and ISO/TR 14032), for example, identification of significant environmental aspects of the products and services of an organization;
- environmental labels and declarations (ISO 14020, ISO 14021 and ISO 14025);
- integration of environmental aspects into product design and development (design for environment) (ISO/TR 14062);

- inclusion of environmental aspects in product standards (ISO Guide 64);
- environmental communication (ISO 14063);
- quantification, monitoring and reporting of entity and project emissions and removals, and validation, verification and certification of greenhouse gas emissions [ISO 14064 (all parts)].

There are a variety of potential further applications in private and public organizations. The list of techniques, methods and tools below does not indicate that they are based on LCA as such, but that the life cycle approach, principles and framework can be beneficially applied. These are, amongst others:

- environmental impact assessment (EIA);
- environmental management accounting (EMA);
- assessment of policies (models for recycling, etc.);
- sustainability assessment; economic and social aspects are not included in LCA, but the procedures and guidelines could be applied by appropriate competent parties;
- substance and material flow analysis (SFA and MFA);
- hazard and risk assessment of chemicals;
- risk analysis and risk management of facilities and plants;
- product stewardship, supply chain management;
- life cycle management (LCM);
- design briefs, life cycle thinking;
- life cycle costing (LCC).

SP4: Relevance of the indicator as a static (in level)/dynamic (changes) variable and relevance as an absolute or comparative value

The LCA environmental indicator gives a static picture due to the nature of LCA, as its main application is static.

The environmental LCA indicator has both relevance as an absolute (not systematically as it reports potential impacts and refer to “virtual” units (DALYs for example) are and comparative value (preferable)

In the current “production-based approach” national environmental accounts are used to quantify the environmental impact of production activities without differentiating between goods produced for domestic versus international consumption. Current environmental indicators thus do not account for environmental impacts embodied in traded goods (Ghertner, D.A. and Fripp, M., 2007).

To measure the full environmental impacts associated with US expenditure requires a consumption-based approach with particular attention to international trade (Rothman, 1998). The research of Ghertner, D.A. and Fripp, M. (2007) adopts such an approach using economic input– output life-cycle assessment (EIO-LCA) for four categories of environmental impact: global warming potential, energy use, toxic release, and the criteria air pollutants (carbon monoxide, particulate matter b10 µm, sulphur dioxide, nitrogen oxides, lead, and volatile organic compounds).

Appendix 4 : Review of MFA methodologies along IMEA *initial* analytical grid

DESCRIPTION OF THE EAM

Name: Material flow accounting

Existing accounting systems can be summarized to four groups:

1. Eurostat standard tables (EUST)
2. IFF series (IFF)
3. SERI domestic extraction series
4. Country specific accounting systems (Germany, United Kingdom, Denmark, Finland)
5. Special studies: applications of MFA to EU15 level and international trade analysis

Main indicators (headline and intermediate if applicable) (at Economy-wide level)

1. Direct Material Input (DMI) (domestic raw materials+ imports): all the materials of economic value that enter the domestic economy and which are processed and used within that economy (production and consumption processes)
2. Domestic Material Consumption (DMC) (domestic used extraction + imports – exports): the total amount of materials directly used in a national economy and consumed by domestic actors.
3. Total Material Consumption (TMC) (total material requirement-exports and their associated indirect flows): the total (life cycle wide) material use associated with the domestic consumption activities, including indirect flows imported but less exports and associated indirect flows.
4. Raw material equivalent (RME) = DMI + indirect flows associated to DMI
5. Total material requirement (TMR) (Direct material input + hidden flows of domestic raw materials + hidden flows of imports): the domestic resource extraction and the resource extraction associated with the supply of the imports (all primary materials except water and air).
6. Net Addition to Stock (NAS) (DMI – exports – DPO): the physical growth of the economy, i.e. the quantity (weight) of materials net added to the stock of buildings and other infrastructures, materials incorporated into new durable goods such as cars, industrial machinery, and household appliances.
7. Physical Trade Balance (PTB): the physical trade surplus or deficit of an economy.
8. Efficiency indicators:
    - Material productivity of GDP (GDP/Input or Output indicator) GDP divided by indicators values

- Resource efficiency of materials extraction (Unused/Used) Ratio of unused (hidden or indirect) to used (DMI) materials.

9. Imports and Exports

Source: Eurostat 2001, extracted from Moll, Bringezu and Schütz, 2005, and OECD 2007.

Principal environmental aim

The principal aim of MFA is not environmental as such as MFA informs on the mass of materials that flows through a system. The main indicators obtained from MFA provide more specific information on these flows. However, these indicators can however act as indicators of environmental pressure.

Brief summary of the methodology

MFA studies the flows of material that enter, accumulate in and subsequently exit a system. Materials are divided by type of flow and by type of material (see below, CO6). All flows are measured in mass units (kg, metric tons). Once the flows have been calculated, they are used to produce material flow indicators which inform about the quantities of flows within a system at different stages, from extraction to disposal.

STAGE 1: DATA

CO1 World regions covered? Adequate coverage of developing countries?

EUST: EU27

IFF: EU15

SERI: whole world by country, but only domestic extraction

Existing country specific studies outside the EU: United States, Japan, Chile, etc.

The compilation of MFA is not systematic in all countries and MFA may either be compiled on a regular basis or on an ad-hoc basis, for instance, in punctual academic studies. Only SERI time-series cover developing countries.

CO2 Spatial resolution of the data?

The national country is the standard spatial unit. Some sub-national regional applications can be found, too. In foreign trade, existing datasets have generally no spatial break-downs, Eurostat standard tables have division of intra-EU/extra-EU trade.

- Special studies on international trade: Schütz, Helmut, Moll, Stephan, and Bringezu, Stefan (2004): Globalisation and the Shifting Environmental Burden. Wuppertal: Wuppertal Institute for Climate, Environment, Energy.Wuppertal Papers No. 134e.

CO3 Availability of time-series? Period and regions covered?

Eurostat standard tables 2000 -2006

IFF-series 1980 (- 1970) -2004

SERI-series: 1980 - 2005

CO4 Accounting period of the EAM?

A year as a standard

CO5 Frequency of updates?

Eurostat standard tables: to be updated yearly

IFF series, two updates (or: original + one update)

SERI time-series, two updates (original+ one update)

CO6 Number and description of categories existing to establish a differentiation (material categories for MFA, crops vs. forestry or pasture for land use, number of sectors for I-O, basic processes for LCA) (data requirements)?

Material categories:

- domestic vs rest of the world categories
- direct vs indirect flows
- input vs output flows

Material flow categories:

1. Domestic Extraction: The annual amount of used (materials of economic value that actually cross the system border on the input side)solid, liquid and gaseous materials (except for water and air).

2. Physical imports and Physical exports: All imported and exported goods. These include both imported raw materials and imported processed products.

3. Domestic Processed Output: All materials that have been used in the domestic economy before flowing to the environment: emissions to air, industrial and household wastes deposited in uncontrolled landfills, material loads in wastewater and materials dispersed into the environment as a result of product use (dissipative flows). Recycled materials flows and landfilled waste are not comprised in DPO.

4. Net Addition to Stock: The quantity of new construction materials used in buildings and other infrastructure and of materials incorporated into new durable goods. Decommissioned materials that are not recycled are also included here.

5. Input and output balancing items: Estimations of flow that occur during processing (e.g. combustion), typically the oxygen demand of combustion processes, CO2 and water vapour from respiration, water vapour from the combustion of fossils fuels etc.

Material types (input):

1. Abiotic Raw materials:

- Mineral raw materials (saleable production, e.g. sand and gravel, ores.)
- Fossil fuels (e.g. coal, oil, gas)
- Non-saleable production (e.g. over burden, gangue)
- Excavation (e.g. for construction).

2. Biotic Raw materials:

- Plant biomass from cultivation (agriculture and forestry)
- Biomass from wild harvest (e.g. fishing, hunting, gathering).

3. Soil:

All soil moved at the earth's surface (i.e. all biogeologically formed soils containing at least 2% humus, e.g. agricultural land, pastures, forest soils).

Additionally, as a role of balancing items:

4. Water (may be differentiated either according to its origin or according to its use. Analogous to the main categories I and II, water should always be accounted for after its origin):

- surface water
- groundwater
- deep groundwater

5. Air or constituents of it, if it is physically or chemically transformed:

- air for combustion
- air as raw material for chemical/ physical transformations.

(Source: Spagenberg et al. 1998, Weisz et al. 2007)

QR1 Main data sources? Do reference databases exist and who is collecting the data?

- EUST: National Statistical Offices using domestic databases, harmonized with Eurostat.

- IFF, SERI for domestic extraction: International databases: FAO (Food and Agriculture Organization of the United Nations), NewCronos (Eurostat's principal database), IEA, some material flows(e.g. construction minerals) roughly estimated

- For foreign trade series: Comext (Eurostat Database - harmonized Intra- and Extra-European Trade Data and comparable statistical database for external EU merchandise trade - and merchandise trade among EU member states), domestic Foreign Trade Statistics

QR2 Completeness of datasets and data gaps?

- Can vary from one country to another depending on methodology used
- For some countries (e.g. Finland) datasets are set up regularly, for other countries, data may only be available for certain years
- Data on direct input flows and stock flows are more documented. Indirect flows are less complete and may vary highly, often based on calculated estimates.
- Example of most often neglected direct material flows: trans-boundary movements of wastes not included in foreign trade statistics.
- Complete data gab: indirect flows of services in foreign trade.

QR3 Level of data uncertainty and is it documented?

Data uncertainty is relatively high in domestic extraction of construction minerals and in some agricultural biomass (hay and grazed biomass) and more widely in unused extraction (exception e.g. Finland where rather reliable data on construction minerals and total extraction (including unused extraction) exist).

Mass of direct flows of imports and exports have relatively reliable databases in foreign trade statistics. The indirect material use of imports is based mostly on rough estimates.

Data uncertainties are rarely documented.

QR4 Feasibility of combining different datasets in a coherent way?

In MFA, material flows are measured uniformly in mass units, kilograms or metric tones. This of course makes the combining of different datasets easy. However, datasets may differ with respect to the inclusion of material flows for which data is sparsely available and to the conversion of the dry matter of some biotic materials. The inclusion of some material flows into unused extraction varies also between

different datasets (e.g. SERI United Kingdom includes unused agricultural crop residues into unused extraction but excludes erosion, but German TMR series exclude crop residues but include erosion.

TA1 Sources of data on exchanges and trans-boundary issue? Do reference databases exist?

MFA considers flows from nature to economy, from economy to nature and product flows between economies but excludes the consideration of flows between the natures of economic territories.

The basic data source of product exchanges is the Foreign Trade Statistics (FTS). The legislation regulating the compilation of statistics on the external (Extrastat) and internal (Intrastat) trade of the European Community ensures that the statistics are based on an accurately defined set of norms applied in all the EU Member States. Furthermore, uniform definitions and methods have been issued in regulations or decisions of the Commission on the practice of compiling FTS.

FTS registers the value and quantity data on the export and import of merchandise under the subheadings country and land territory. Imports are registered according to both country of origin and country of consignment. Exports are registered according to the country of destination. The country of origin is the country in which the merchandise was produced or where the last economically most important part of the production took place. Packaging is not considered as production. For exports, the country of destination is the country to which the merchandise is intended to be exported to (exportation may be either direct or via some other country).

FTS include only material goods and electricity that cross the border of a national territory. Imports and exports of services are registered in national Balance of Payments Statistics (BPS) as harmonized by IMF. In BPS imports and exports of services are accounted only in monetary terms. Countries of origin or destination are not registered.

TA2 Completeness of datasets and data gaps?

Foreign trade statistics (FTS) give comprehensive accounts of imports and exports of goods crossing the border of a national territory. Trans-boundary waste flows for direct industrial use (waste flows that have a positive economic value) are also included in FTS. However waste flows which are going to waste treatment operations and for which the exporting country has to pay, are not included in FST, and thus generally neglected in MFA**.**

In the estimation of indirect flows of foreign trade, the indirect material use of services are generally neglected, as are fuel acquisitions of resident transport companies for international transport purposes.

TA3 Level of data uncertainty and is it documented?

Data uncertainty high, especially in indirect material flows of refined products and services. Data uncertainties are rarely documented.

TA4 Feasibility of combining different datasets in a coherent way?

The estimation of indirect flows of product exchanges can be problematic when combining datasets of goods and services together. In FTS product flows of goods are registered both in monetary and mass units (for electricity, however, in monetary and energy units) and country origin or destination are registered. However, in BPS only monetary values are used and no regional breakdowns are presented.

IP1 Correspondence of classification to National Accounts and other international databases(IEA, FAO)

The basic 8-digit level of CN classification of Foreign trade statistics has unambiguous conversion tables to different international classification systems and especially into CPA product classication used in the National Accounts of EU countries. The Eurostat standard tables include also the correspondence tables between EUST classification and CPA, ISIC, FAO and SITC.

The BPS for services is also harmonized with National accounts.

IP2 Format of datasets (with existing examples for Europe)

EX1 Ease of use of datasets (proprietary or public domain software packages, existing toolboxes, current examples of use communities)

Mostly public domain software packages

EX2 Ease of extending datasets to fill data gaps, to new geographic areas and analytical levels

Difficult to asses

EX3 Feasibility (by non-experts) and cost-effectiveness of data development

The existing data gaps in indirect flows of refined goods and services need sophisticated methods (input-output models) to be estimated.

STAGE 2: SYSTEM AND BOUNDARIES

CO7 Description of the system and system boundaries?

Economy-wide MFA include material inputs from the domestic nature (domestic extraction)and from the rest of the world (imported materials crossing the borders of the national territory). Flows of material inside the economy are generally not considered besides the net accumulation of the material stock of the economy.

CO8 Relation to the socio-economic system: inclusion of non-monetarized relations, informal sector activities?

Not relevant MFA

CO9 Adequate consideration of (a) end of life, e.g. waste treatment, recycling, (b) trade-offs and displacements of environmental issues along a chain?

a) Economy-wide MFA only includes inputs to and outputs from the economy. Thus flows inside economy, such as waste treatment and recycling, are generally not considered. However, some special studies in physical waste input-output accounts exist.

b) Pure MFA does not consider qualitative environmental issues. These can included in integrated or hybrid approaches.

QR5 Clear expression of protocols for allocation choices and cut-off rules?

Allocation choice and cut-off rules relevant only for the estimation of indirect flows. No general rules exist.

TA5 Detailed description of trans-boundary issues within the system?

TA6 Ability of the system to account for complex or international production chains with multiple feedbacks?

MFA could be relatively easily extended to include the country of origin and the destination of imported and exported products (the country of origin meaning the country in which the merchandise was produced or where the last economically most important part of the production took place).

However, problems arise for some goods, the production of which is staged and takes place in several countries (staged production and fabrication processes). In this case, the registered country of origin is the country in which the last stage of the production was completed. The problem here is that the other countries in which the production took place are left out from FTS. A multiregional world input-output model is needed to asses the ultimate international effects of these kinds of production chains.

IP3 Compatibility of system boundaries with existing accounting frameworks, standards or legislation.

In general economy-wide MFA has some discrepancies with the system boundaries of national accounts and also with some environmental accounting systems, e.g. with SEEA2003 and Greenhouse Gas Inventories.

In MFA, agricultural crops and raw wood from forests are considered as inputs from nature into the economy. However, in National Accounts, agriculture and forestry (crops and trees) are inside the system boundary of the economy. SEEA2003 states that in principle only the “ecosystem services” of agricultural and forest soil, water and air should be included as the inputs from nature in growing cops and trees.

Similarly in GHG inventories, the GHG emissions of agricultural soils resulting from, for instance, fertilizing and liming, are accounted for as man-made emissions, and not as natural emissions.

Discrepancies also exist with regards to the definition of imports and exports. MFA only takes into account the material flows that actually cross the borders of national territories. National Accounts, on the contrary, include the economic activities of the natural or legal residents of the territory irrespective of where these activities take place.

STAGE 3: CALCULATION (WEIGHTING, CONVERSION FACTORS, NORMALIZATION)

QR6 Focus of the measure (stocks, flows, inputs, outputs)? Units of measurement?

The main focuses of MFA are the input and output flows into and from the economic system under consideration (country, region).

Accumulation into stocks inside the system has sometimes been studied as well.

Material flows are measured uniformly in mass units (kg, metric tones)

QR7 Accuracy: Scientifically grounded weighting scheme, normalization, conversion factors for data and environmental pressures?

Weighting or normalization procedures are irrelevant because of uniform measurement.

QR8 Is the basis of normalization an endogenous benchmark/sustainable level?

Not Applicable

QR9 Appropriately used conversion factors (average vs. local or product-specific)?

Not applicable

QR10 Repeatability: Degree of harmonization of methods? Availability of recognized methodological guidelines and deciding bodies? Clear and transparent definition and documentation of the methodology?

Main harmonization steps taken by European Statitistical Office, Eurostat. Existence of methodological guide (2001), however countries may choose their own methodology, no deciding body. The OECD has also contributed to harmonization efforts.

TA7 Scientifically grounded weighting scheme, normalization and conversion factors of the integration of trans-boundary issues rely?

Not applicable

TA8 Appropriately used conversion factors for trans-boundary issues (average vs. local or product-specific)? Are normalizations and conversion factors using a valid denominator when dealing with trans-boundary issues?

Not applicable

TA9 Is the normalization basis accounting for trans-boundary issues?

Not applicable

TA10 Methodological issues regarding trans-boundary issues and how do they impair the quality of results?

- indirect flows of imports: estimation problems
- residence vs territory principle: accounting of services, especially tourism and transport.

TA11 Do recognized methodological guidelines exist for trans-boundary issues?

No

TA12 Clearly defined and documented methodological steps for dealing with trans-boundary issues?

No

TA13 Ability to specifically consider standards and labels for traded products

Not applicable

EX4 Ease of extending methodologies (alone or in combination with other EAM)

to answer specific needs of new geographic and analytical levels

A few studies have combined MFA and LCA approaches

Otherwise combination with monetary analysis only

EX5 Feasibility (cost-effectiveness) of methodological improvements

The assessment of the feasibility and cost effectiveness of such improvements will be dealt with and developed at later stages of the projects by WP5.

STAGE 4: ENVIRONMENTAL INDICATOR(S)

Applicable to main (headline and intermediate if applicable) indicators

ER1 Position of the EAM within the DPSIR (or other) framework?

MFA indicators can be conceived as Driving force indicators. The TMR indicator may be also interpreted as a type of pressure indicator: total mass of nature mobilized by the human economy.

ER2 Inclusiveness: Adequate coverage of recognized environmental issues? Which issues are not considered?

Not really applicable to MFA as MFA is a driving force.

ER3 Overlap: Unique coverage of a specific issue? How does the EAM complement or could substitute another EAM?

MFA, as a driving force, does not cover a specific environmental issue as it informs on mass of flows. It complements and acts as a background for other EAM. MFA does not substitute another EAM.

ER4 Standardization: Is the EAM relevant to all regions and analytical scales? If not, when and where is it particularly appropriate? Is the local context considered?

Yes

CO10 Adapted to analytical scales (micro, meso, macro)?

Yes, micro, meso and macro scale: EW-MFA, PIOT, MIPS. At scales smaller than a national economy, the system boundaries may not be the same as those mentioned above.

QR11 Objectivity: Is the resulting environmental indicator calculable without ambiguity?

Uniform measurement unit > the indicators are calculable without ambiguities.

QR12 Sensitivity/Robustness: Is the resulting environmental indicator (a) sensitive to small changes, and (b) robust enough against data gaps or extremes?

MFA indicators are robust to small changes but sensitive to data gaps/extremes (especially when data is estimated)

QR13 Is the environmental indicator largely influenced by dominant factors and which one?

Some materials, such as construction minerals (especially gravel and crushed stone) have a great share in the domestic material flows of all economies but do not generally affect time series. This may be the

consequence of the fact that usually, the time series for gravel and crushed stone are based on rough estimation methods, which often level off possible big changes.

TA13 Does the indicator provide information on the location and magnitude of the environmental impacts and on exchanges?

Yes, if foreign trade flows are divided by country of origin and destination.

IP4 Relation to economic measures: Potential of integration into a neo-classical framework (expression in terms of preferences and utility)? Potential or established correspondence with monetary values?

The question is unclear

IP5 Ease of integration within a needs analysis or a functional analysis? Unclear

SP1 Intelligibility of the indicator, univocity of the message (good/no good)

Question difficult to understand – what does "univocity" mean?

SP2 Maturity, auditability, acceptability

DMI, DMC indicators can be seen as mature, TMR, TMC indicators need further standardization.

SP3 Current use by firms, governments or international bodies

- Firms: data collected on monitored/regulated materials, to make sure that materials and energy used in the production process are used in an efficient manner (loss reduction)

- Governments: growing interest but countries are at a variety of stages in developing and using MFA.

In some countries, MFA work is now systematically integrated into national statistics. Two third of OECD countries have developed or are developing EW-MFA (Austria, Belgium, the Czech Republic, Denmark, Finland, France, Germany, Hungary, Italy, Japan, Korea, the Netherlands, Poland, Portugal, the Slovak Republic, Spain, Sweden, Switzerland, the United Kingdom, and the UnitedStates). In 12 countries, EW-MF work is a regular activity with annual updates. In 8 countries (Denmark, Hungary, Korea, the Netherlands, Poland, Portugal, Sweden, and the United States) EW-MF work has been carried out on a stand-alone or pilot basis. A few countries have not reported any plans to develop EW-MFA (Australia, Canada, Greece, Iceland, Luxembourg, Mexico, and New Zealand).

Material flow and natural resource data are used and published in national state of the environment reports or in national environmental data publications (e.g. Australia, Belgium, Finland, France, Germany, Italy, Japan, Norway, Switzerland), or in national environmental or sustainable development indicators reports (e.g. Austria, Germany, Hungary, the Slovak Republic, the United Kingdom). In countries where MF work is well advanced, partnerships are commonly established among various partners within the country as well as with international networks and with partners in other countries. Examples of international MF networks and partnerships are the ConAccount network managed by the Wuppertal Institute and the recently established International Society of Industrial Ecology (source OECD, 2007)

MFA data may be used by governments to develop environmental strategies and policies, respond to changes etc.

SP4 Relevance of the indicator as a static (in level)/dynamic (changes) variable and relevance as an absolute or comparative value

Relevant both as a static variable in international comparisons and as a dynamic time series in which case the short time changes and longer time trend directions are important.

Appendix 5 : Review of Environmental Footprints methodologies according to IMEA *initial* analytical grid

	Ecological Footprint (EF)	**Human Appropriation of Net Primary Production (HANPP)**	**Actual land demand (ALD)**	**Comments**	**Water footprint – virtual Water concept**
STAGE 1: DATA					
CO1 World regions covered? Adequate coverage of developing countries?	Global terrestrial coverage	Global terrestrial coverage, spatially explicit, aggregates at all (nations, watershed, etc.) levels	No global assessment available (yet). Imports from all countries, to specific countries (currently: Austria, Switzerland). All required data (bilateral trade matrices, item-specific yields) are available at the global level in international databases.	refers to the current standard versions of the indicators.	Global terrestrial coverage
CO2 Spatial resolution of the data?	Combines national data on apparent consumption with global yield averages. Current resolution: national level, subnational in development, requires (not easily available) data on trade.	Combines national data on apparent consumption with spatially explicit data on land use, land cover and ecosystem productivity. Current resolution at the global level: 5 arc min resolution (app. 10x10 km at the equator). For single countries, much higher resolutions possible.	National	Refers to the current standards. Transboundary application require the application of bilateral matrices; currently, no allocation of imports at subnational (or spatially explicit) level.	Combines national data on apparent consumption of water in industry and households and water used in agriculture. for the latter, national averages of agricultural yields and water-requirement per crop and area are combined. Current resolution: national level Combinations with grid-based run-off data possible
CO3 Availability of time-series? Period and regions covered?	Time series 1961 – 2003 available from the Global Footprint Network (update to 2006 currently in prep.) Country-studies exist.	Global: only 2000 Country studies with longer time frames exist.	Country studies with longer time frames exist (e.g. back to 1926)		country-case studies in time series exist (e.g. 1995 – 2005)

	Ecological Footprint (EF)	**Human Appropriation of Net Primary Production (HANPP)**	**Actual land demand (ALD)**	**Comments**	**Water footprint – virtual Water concept**
CO4 Accounting period of the EAM?	Annual	3-5 year average	Annual		Annual
CO5 Frequency of updates?	Every 2-4 years Annual updates possible, but data intensive, because requires global and national time series on land use, land cover, productivity, apparent consumption, conversion factors. Some unresolved methodological-conceptual problems concerning time series applications remain.	only one comprehensive assessment to date Annual updates possible, data intensive, because relying on data on land use (extent & intensity), land cover, apparent consumption, productivity etc.	only specific studies exist to date Annual updates possible, relatively straightforward depending on the availability of bilateral trade data.		Part of Living planet Report (WWF), biannually. Annual updates possible, relatively straightforward depending on the availability of bilateral trade data.
CO6 Number and description of categories existing to establish a differentiation (material categories for MFA, crops vs. forestry or pasture for land use, number of sectors for I-O, basic processes for LCA) (data requirements)?	6 aggregate groups: (built-up, arable land, pastures, forests, marine area, CO2 land) based on: appr. 75 cropland products, 2 pasture groups, 2-6 forest groups, CO2 according to the disaggregation of CO_2 emission statistics, embodied CO_2 in traded products applying emission coefficients	5 aggregate groups: (built-up, arable land, pastures, forests, un-used areas) based on >100 biomass products. Only accounts for impacts of biomass production and built-up area on land use (ecosystem flows).	Restricted to data availability of yields, currently refers to >100 biomass products. Only accounts for the extent of land use related to biomass production. Can be combined with global demand for energy area (similar to EF)		Distinguishes three types of water: blue, green, grey. Product-based approach blue, grey: industrial and household-consumption green water refers to water used to produce agricultural biomass Disaggregation by traded items, FAO commodities: 175 crops, 8 livestock categories. Does not include forest products Does not include water content of traded non-biomass products

	Ecological Footprint (EF)	**Human Appropriation of Net Primary Production (HANPP)**	**Actual land demand (ALD)**	**Comments**	**Water footprint – virtual Water concept**
QR1 Main data sources? Do reference databases exist and who is collecting the data?	Data sources: Land use, domestic extraction and yields of biomass: FAO, FAO/Unece (cropland, pasture), forests: FRA, TBFRA, Global Fibre Supply Study, Corine land cover Trade: UN Comtrade, FAO upstream-emission factors of imported products: assumptions of the Global Footprint Network and Stockholm Environmental Institute CO_2 emissions (terrestrial emission statistics): IEA, IPCC (CDIAC), British Petroleum NPP calculations (pasture) Casa Model (Stanford & Harvard) Reference databases: The Global Footprint Network provides global data at the national level, with yearly updates.	Data sources: Land use (consistent land use database derived from national statistics and spatial patterns from remote sensing): FAO, FRA, TBFRA. Biomass harvest and trade: FAO NPP of vegetation (potential, part of actual): Lund-Potsdam-Jena DGVM Conversion factors to calculate upstream HANPP of imported products (embodied HANPP) derived from data on national biomass production, national HANPP flow and trade flows (Currently: one individual study). Reference databases: The global HANPP data for 2000 is available online from the Institute of Social Ecology. The indicator is being considered by EEA.	Data sources: Biomass trade, yield, harvest, land use: FAO and national databases. Reference databases: None, only individual studies		Agricultural statistics Water statistics Trade statistics Evapotranspiration models Reference databases: None, only individual studies, Living Planet Report is the flagship reference.
QR2 Completeness of datasets and data gaps?	Currently, for some data gaps model assumptions are applied: livestock feed demand, grey energy	Currently, for some data gaps model assumptions are applied: livestock feed demand, soil degradation, effects of irrigation and N-fertilization on NPP,	Currently, for some data gaps model assumptions are applied: livestock feed demand	Most data sources have global coverage and are yearly updated. Some primary data sources are not annually updated (relevant for all three indicators: spatial explicit data	no data gaps, see above: product based approach, based on national statistical data and model results

	Ecological Footprint (EF)	Human Appropriation of Net Primary Production (HANPP)	Actual land demand (ALD)	Comments	Water footprint – virtual Water concept
		vegetation fires		(land use, land cover), comprehensive forestry data (e.g. FRA, TBFRA)	
QR3 Level of data uncertainty and is it documented?	not documented	not documented	not documented	Although no uncertainty is provided with these indicators, the data quality can be described as follows: primary data on agriculture and energy consumption, of high quality, forestry: medium quality, livestock medium-to-poor quality. Extensive application of conversion factors introduces a considerable amount of uncertainty (in particular relevant for EF, to a less extent ALD, even less HANPP).	not documented see comment left, evapotrans-models are not data and can not be validated virtual water content factors are results of (global) models and have thus a certain uncertainty…
QR4 Feasibility of combining different datasets in a coherent way?				Results at different scales can be combined for all three methods in a double-counting-free and consistent manner. However, heterogeneity in approaches prevails (e.g. national studies) and hampers comparability of individual case studies (applies to all 3 indicators)	comment applies
TA1 Sources of data on exchanges and trans-boundary issue? Do reference databases	Data on foreign trade with biomass and other products are based on UNComtrade or FAO	Data on foreign trade with biomass are based on UNComtrade or FAO	Data on foreign trade with biomass are based on international (FAO or		Data on foreign trade with biomass and other products are based on UNComtrade or FAO

	Ecological Footprint (EF)	**Human Appropriation of Net Primary Production (HANPP)**	**Actual land demand (ALD)**	**Comments**	**Water footprint – virtual Water concept**
exist?	Current versions of EF do not explicitly address transboundary issues (EF of imports), but the information is in the calculation sheets and can be extracted. No regional specification of countries of origin, national imports are translated to global average areas (the so-called "global hectare approach")	Global HANPP of imports calculation in preparation; currently, only aggregate biomass imports considered, no specification of countries of origin.	UNComtrade)l and national trade statistics.		designed to capture transboundary issues
TA2 Completeness of datasets and data gaps?				see QR2; The application of bilateral trade matrices would allow to capture transboundary issues with all three indicators. Upstream factors are required to convert mass flows to EF, HANPP or ALD and are certainly less developed, in particular region-specific upstream factors are not available, but would be required to reduce the uncertainty.	comment applies. upstream factors are the very heart of WF assessments
TA3 Level of data uncertainty and is it documented?				See QR3; the availability of two databases (FAO & comtrade) allows for uncertainty reduction/analyses	comment applies model uncertainty of upstream factors difficult to assess, not documented
TA4 Feasibility of combining different datasets in a coherent way?				See QR4	idem

	Ecological Footprint (EF)	**Human Appropriation of Net Primary Production (HANPP)**	**Actual land demand (ALD)**	**Comments**	**Water footprint – virtual Water concept**
IP1 Correspondence of classification to National Accounts and other international databases(IEA, FAO)	Partly based on these databases, but the result does not correspond to any of their classifications.	Partly based on these databases, but the result does not correspond to any of their classifications.	Based national and international databases, but the results do not correspond to any of their classifications.		Based national and international databases, but the results do not correspond to any of their classifications.
IP2 Format of datasets (with existing examples for Europe)				*Not sure what kind of response this question requires.*	
EX1 Ease of use of datasets (proprietary or public domain software packages, existing toolboxes, current examples of use communities)	basis data publicly available. Footprint calculation and result sheets can be obtained from GFN (proprietary) The Global Footprint Network represents an interactive user community with the goal of dissemination of the method.	basis data publicly available, aggregate results publicly available. The methodology is described in a series of journal articles, and being implemented by several academic research groups. EEA is considering the method for environmental indicators.	basis data publicly available, specific studies published in journals. No active user groups identified		basis data publicly available, aggregate results publicly available. published by LPR, UNESCO-IHE
EX2 Ease of extending datasets to fill data gaps, to new geographic areas and analytical levels	global coverage already exists. transboundary analysis requires adaptation of method to integrate bilateral trade data.	global coverage already exists. transboundary analysis requires the integration of bilateral trade data.	Can be extended to new geographic areas, data-intensive but feasible. Analytical levels high.	.	all geographic areas can be covered, analytical level: product level, sector level datasets easily extendable
EX3 Feasibility (by non-experts) and cost-effectiveness of data development	Standardization for nation accounts to be applied by non-experts in progress. TBI to be developed and requires expert knowledge	No standardization, but considered by EEA as part of the “basket of indicators” Can currently not be assessed by non-experts TBI to be developed and requires expert knowledge	No standardization yet. Could be developed in a cost-effective way for non-expert account	input data publicly available to a large extent (see above), region-specific factors and model assumptions require expert knowledge	No standardization yet. Could be developed in a cost-effective way for non-expert use.

	Ecological Footprint (EF)	Human Appropriation of Net Primary Production (HANPP)	Actual land demand (ALD)	Comments	Water footprint – virtual Water concept
STAGE 2: SYSTEM AND BOUNDARIES					
CO7 Description of the system and system boundaries?	National economy Selective national apparent consumption (DE+Imp-Exp) of biomass, fossil, hydro and nuclear energy plus built-up land. Some consumption is addressed through its inputs (biomass), others though outputs (CO2 emissions for fossils or CO2 emissions required for replacement for nuclear). The goal is the estimation of upstream (biomass) and downstream (CO2) land required by the consumption. However, the result mixes real land used for biomass production, and hypothetical land necessary for CO2 sequestration.	National economy National production and apparent consumption of biomass.	National economy (Selective) national production, imports and exports of biomass, fossil, hydro and nuclear energy plus built-up land		National economy (Selective) national production, virtual water flows related to imports and exports of agricultural biomass domestic and industrial use of water
CO8 Relation to the socio-economic system: inclusion of non-monetarized relations, informal sector activities?	Method based on physical flows, informal sector flows as covered by input data (e.g. FAO estimates subsistence fuelwood collection based on elaborate model assumptions)	Method based on physical flows, informal sector flows as covered by input data	Method based on physical flows, informal sector flows as covered by input data		Method based on physical flows, informal sector flows as covered by input data
CO9 Adequate consideration of (a) end of life, e.g. waste treatment, recycling, (b) trade-	(a) The EF attempts to address waste issues through the inclusion of CO2 emissions (real	(a) The method focuses on inputs. Biomass waste flows returned to the environment or	(a) The method focuses on inputs/land area requirement. Waste flows returned to the	System based approaches as opposed to LCA refer to the entire system unit, product chain	Waste water component included (grey water)

	Ecological Footprint (EF)	Human Appropriation of Net Primary Production (HANPP)	Actual land demand (ALD)	Comments	Water footprint – virtual Water concept
offs and displacements of environmental issues along a chain?	and hypothetical) through biomass sequestration (entirely hypotetical). (b) By considering the national economy as a whole, trade-offs within the system are automatically included. The treatment of nuclear being replaced by fossil technology represents an explicit trade-off choice. The weighing scheme between fossil energy and biomass fractions may blur the adequate consideration of trade offs.	used in the economy are estimated as part of the accounting for harvests and fodder/feed. (b) By considering the national economy as a whole, trade-offs within the land system are automatically included (e.g. more land under cultivation results in less land for forestry or wilderness). Trade-offs between fossil energy use and biomass production are neglected (HANPP can decrease due to fossil fuel inputs in agriculture)	environment or used in the economy are not considered, but the account can be complemented by CO2 emission accounts identical with EF. (b) By considering the national economy as a whole, trade-offs within the land system are automatically included. Trade-offs between fossil energy use and biomass production are neglected or only addressed with simplified assumptions (see EF)	processes are not explicitly considered	not applied for traded goods for trade, the WF follows LCA approach, see comment
QR5 Clear expression of protocols for allocation choices and cut-off rules?				See above: system approaches	clearly defined
TA5 Detailed description of trans-boundary issues within the system?	Current applications focus on apparent consumption and measures the aggregate land requirement of apparent consumption. The method, however, allows to assess transboundary issues	HANPP estimates traditionally measure the impact of domestic land use and biomass extraction on domestic terrestrial ecosystems. The method has been used to measure the domestic and global impact of apparent consumption and to explicitely quantify TBIs.	Allows to measure domestic and global impact of apparent consumption and to quantify land requirements of imports and exports		measure domestic and global water consumption related to the final consumption of biomass products and domestic water consumption in industry and households
TA6 Ability of the system to account for complex or international production chains	Imports are assigned upstream requirements based on global averages. Global averages are	Imports are assigned upstream requirements based on global averages. Could be extended to	Imports are assigned upstream requirements based on national land requirements for biomass	No specific international product chains are considered.	Imports are assigned upstream requirements based on national factors.

	Ecological Footprint (EF)	**Human Appropriation of Net Primary Production (HANPP)**	**Actual land demand (ALD)**	**Comments**	**Water footprint – virtual Water concept**
with multiple feedbacks?	at the core of the indicator, must be maintained	use specific (regional or national) upstream factors, appling bilateral trade data.	production (yields) Import data are revised in order to refer to the countries of origin, not to the last exporting country, applying simple assumptions.		explicitly accounts for countries of origin and destinantion
IP3 Compatibility of system boundaries with existing accounting frameworks, standards or legislation	Method is based on national and international accounts.	Method is based on national and international accounts.	Method is based on national and international accounts.		Method is based on national and international accounts.
STAGE 3: CALCULATION (WEIGHTING, CONVERSION FACTORS, NORMALIZATION)					
QR6 Focus of the measure (stocks, flows, inputs, outputs)? Units of measurement?	flows (production, import, export) of materials (biomass inputs, CO2 outputs) converted to share of global stocks (area) in each year [gha/yr]	flows (production, import, export) of biomass compared to potential natural (=without land use) flows [gC/m²/yr]	flows (production, import, export) of materials (biomass inputs, CO2 outputs), converted to actual area requirement for its production. [ha/yr]		flows [m³/yr]
QR7 Accuracy: Scientifically grounded weighting scheme, normalization, conversion factors for data and environmental pressures?	Calculation – weighting schemes intricate and not easily accessible (e.g. global yields on product level, equivalence factors on broader land use level, mix of local and global approaches (pasture land), application of different upstream factors of imports and exports. Normalization with global average productivity, not clearly	Normalization based on potential Net Primary Production (NPP. No weighting schemes applied (refers to actual flows) Upstream factors for imports currently only at global average available, not regionally differentiated.	No weighting schemes applied (refers to actual flows) No normalization, calculates actually used areas		No weighting schemes applied (refers to actual flows) Evaportranspiration model used to infer green water flows per crop area (m³/ha) No normalization

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	defined (NPP or agricultural potentials), weighting with factors that reflect the deviation of the productivity of a particular land use category from the global average productivity (Eqivalence factors).				
QR8 Is the basis of normalization an endogenous benchmark/sustainable level?	Globally available bioproductive area weighted according to the productivity level of the land use categories [gha] as a proxy for sustainability levels. Since productivity can be (and is) increased by intensification, the footprint "rewards" intensive land use.. Allows for quantification of overshoot. Caveat: unsustainable land use is not considered.	The basis of the calculation is the Potential Net Primary Production (NPP). Deviations from this level measures human interference in global ecosystem functioning, although the sustainability limit is not known.	No normalization or benchmarking		No normalization or benchmarking Can be combined with spatially explicit run-off models, or information on the availability of freshwater resources.
QR9 Appropriately used conversion factors (average vs. local or product-specific)?	conversion factors of mixed quality, requires in principle only global factors, but is for certain products inconsistent (category pasture land)	Country-specific conversion factors to calculate embodied HANPP in exported products, global factors for imports.	Conversion factors: yield of cultivars/products		Conversion factors: yield of cultivars/products Water requirement per crop (global) Approach may be debatable, does not account for differences in per area water demand resulting from different yield levels (same water-demand with different Leaf Area Index/biomass denstities
QR10 Repeatability: Degree of	Ongoing process of	Method development in process	No standards and		Ongoing process of

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harmonization of methods? Availability of recognized methodological guidelines and deciding bodies? Clear and transparent definition and documentation of the methodology?	harmonization and standardization. Methodological approaches subject to frequent changes. Aggregate documentation available, detailed documentation lacking	–currently, definition are not agreed upon. Guidelines, scientific descriptions of current methods available.	harmonization available. Method easily reproducible due to simple assumptions; scientific descriptions of methods available.		harmonization and standardization, advanced
TA7 Scientifically grounded weighting scheme, normalization and conversion factors of the integration of trans-boundary issues rely?	Application of different upstream factors of imports and exports, weighing scheme complex. Normalization with global average productivity, which is, however, not clearly defined (NPP or agricultural potentials), weighting intricate due to the application of factors that reflect the deviation from the global average.	Upstream factors for imports currently only at global average available, not regionally differentiated.	No weighting schemes applied (refers to actual flows) No normalization, calculates actually used areas		No weighting schemes applied (refers to actual flows) Approach may be debatable, does not account for differences in per area water demand resulting from different yield levels (same water-demand with different Leaf Area Index/biomass denstities in calculating upstream factors
TA8 Appropriately used conversion factors for trans-boundary issues (average vs. local or product-specific)? Are normalizations and conversion factors using a valid denominator when dealing with trans-boundary issues?				see QR9	
TA9 Is the normalization basis accounting for trans-boundary issues?	Due to the application of global weighting factors, imports are standardized with the same factors as production and	Normalization according to country-specific potential NPP	No normalization, not applicable		No normalization, not applicable

	Ecological Footprint (EF)	Human Appropriation of Net Primary Production (HANPP)	Actual land demand (ALD)	Comments	Water footprint – virtual Water concept
	exports; thus, no regional differentiation is possible.				
TA10 Methodological issues regarding trans-boundary issues and how do they impair the quality of results?	No standardized method to assess tb-issues developed yet. Single study-level prevails.	No standardized method to assess tb-issues developed yet. Single study-level prevails.	Methodological influence on result might not be too strong due to straightforward application of non-weighted factors and data.		Methodological influence on result might not be too strong due to straightforward application of non-weighted factors and data.
TA11 Do recognized methodological guidelines exist for of trans-boundary issues?	NO	NO	NO		NO
TA12 Clearly defined and documented methodological steps for dealing with trans-boundary issues?	NO	NO	NO	currently under development for all three indicators, only single application available	TA issues are the purpose of this EAM; Standardization in process
TA13 Ability to specifically consider standards and labels for traded products	as the EF does not differentiate between sustainable and un-sustainable land use, probably not straightforward, with the exception of a carbon footprint extension	in principle, could be incorporated in labeling systems, practically limited by the spatial resolution of the assessments and data-availability	NO		in principle, could be incorporated in labeling systems, practically limited by the spatial resolution of the assessments and data-availability Reference value (available fresh water resource) is difficult to assess, would require tracing traded products to the place of production and specification of the water-use to the local water availability/stress. National assessments available

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EX4 Ease of extending methodologies (alone or in combination with other EAM) to answer specific needs of new geographic and analytical levels	Global coverage. Analytical extension potential is given, although limited by the intricate weighting schemes. Combining EF with I-O approaches has been explored. Is not directly linkable to impacts	Global coverage. Extension potential is given, but requires incorporation of bilateral trade matrices and higher product resolution. Combining HANPP with I-O approaches have not yet been explored, but are feasible. Is directly linkable to ecosystem impacts	Measures land demand associated with imports and exports and can be linked to ecosystem impacts straightforwardly. Combining ALD with I-O approaches are feasible. Data-intensive		global coverage addresses a very specific TA issue (water demand) link to impacts (e.g. on ecosystem functioning, water cycle, etc.) difficult to establish (TA13), on national level possible i-o methods not widely explored yet, although they have been applied by Dey, Lenzen, Foran and colleagues to water use from households in Australia.
EX5 Feasibility (cost-effectiveness) of methodological improvements				difficult to assess	
STAGE 4: ENVIRONMENTAL INDICATOR(S)					
Applicable to main (headline and intermediate if applicable) indicators					
ER1 Position of the EAM within the DPSIR (or other) framework?	P	P, S, I	P, S		P, S
ER2 Inclusiveness: Adequate coverage of recognized environmental issues? Which	Broad coverage, biomass and energy Issues of energy probably	Only biomass, and through it, ecosystem functioning.	Broad coverage, biomass and energy, with focus on biomass. Energy issue questionable in		Only water only green water in traded agricultural products (no forest

	Ecological Footprint (EF)	**Human Appropriation of Net Primary Production (HANPP)**	**Actual land demand (ALD)**	**Comments**	**Water footprint – virtual Water concept**
issues are not considered?	questionable due to weighing scheme		ALD context		products) Impacts difficult to quantify, to link pressures - impacts
ER3 Overlap: Unique coverage of a specific issue? How does the EAM complement or could substitute another EAM?	Combines energy consumption and land use. Direct link to material flow analysis, but blurred by complex weighting schemes.	Land use intensity. Consistently linkable to material and energy flow analysis and vegetation carbon studies).	Directly and readily linkable to material and energy flow analysis		Water complements the other approaches; close compatibility with ALD and HANPP
ER4 Standardization: Is the EAM relevant to all regions and analytical scales? If not, when and where is it particularly appropriate? Is the local context considered?	global coverage. National scale Does not reflect unsustainable land use (e.g. degradation), nor land use intensity Makes levels of consumption comparable regardless of differences in productivity (technological, naturally induced, etc.) local level not considered	global coverage. National scale Does not take fossil energy use into account, nor other (non-biomass) products Operationalises land use intensity, referring to biological productivity. Links directly to ecosystem functions (energetics) Allows analysis of the production chain efficiencies, e.g. of food production. spatially explicit, local level considered	global coverage achievable, but not performed yet. Globally relevant. National scale Only refers to land use extent, not to quality of land use, but is readily linkable to issues related to land use quality. Assessment of imports of biomass products and the underlying area requirement for the production local level not considered		global coverage. National scale local context not considered only water considered
CO10 Adapted to analytical scales (micro, meso, macro)?	Macro, meso (break-down to sectors: agriculture, forestry, energy sectors); limited: products and services (problem	Macro, meso (break-down to sectors: agriculture, forestry, energy sectors); limited: products (problem of double	Macro, meso (break-down to sectors: agriculture, forestry, energy sectors);		Macro, meso (break-down to in principle all water-using sectors Products (biomass) specific

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	of double counting, conversion-factor based)	counting, conversion-factor based)	Products (biomass) specific		
QR11 Objectivity: Is the resulting environmental indicator calculable without ambiguity?	yes	yes	yes		yes
QR12 Sensitivity/Robustness: Is the resulting environmental indicator (a) sensitive to small changes, and (b) robust enough against data gaps or extremes?	Conservative approach: only certain flows considered. Land use effects dominated. robust, single items dominate, internal weighting schemes maybe questionable (internal consistency) Small changes may be blurred by the enhanced uncertainty due to the weighing schemes and the level of aggregation	robust Product specific applications prone to uncertainty Small changes may be blurred by the high levels of aggregation, but easily made visible with changing reference systems.	robust		Robust caveat: assumption on green-water use per crop and area are static, only yield considered, not changes in water demand per yield level. Agratechnolgical changes can not be depicted
QR13 Is the environmental indicator largely influenced by dominant factors and which one?	Fossil energy appr. 50% of overall EF in industrial countries. Selection of conversion factors and weighting factors has a high impact on the result	no	no		No
TA13 Does the indicator provide information on the location and magnitude of the environmental impacts and on exchanges?	no	yes, spatially explicit, impact on energy availability in ecosystems	location only on national scale, only area extent		location only on national scale, link to impacts difficult (what is water stress, what is the impact of water-stress? difficult to assess)

	Ecological Footprint (EF)	**Human Appropriation of Net Primary Production (HANPP)**	**Actual land demand (ALD)**	**Comments**	**Water footprint – virtual Water concept**
IP4 Relation to economic measures: Potential of integration into a neo-classical framework (expression in terms of preferences and utility)? Potential or established correspondence with monetary values?	Not elaborated	Not elaborated	Not elaborated		Not elaborated
IP5 Ease of integration within a needs analysis or a functional analysis?	Too highly aggregated, requires specific assessments	Allows to address specific ecosystem functions for society (e.g. biodiversity, provisioning services, wilderness)	Allows to address land use competition (e.g. provisioning services, wilderness)		
SP1 Intelligibility of the indicator, univocity of the message (good/no good)	At a very high level of interpretation highly intuitive, but for deriving policy options / decision making maybe too coarse, sometimes counterintuitive (land use assumed to be sustainable in any case, only quantitative measure) – in particular, not explored yet for transboundary issues. Sometimes counterintuitive if applied in time series analysis Strong threshold allows for simple messages, but its analytical/practical potential is limited	Results not straightforward to interpret (no threshold). Robust in time series, thus applicable in monitoring Interpretation requires specific assessments of the underlying components. High analytical potential as a ground for informed decision making.	Straightforward results, but no univocal interpretation (no threshold). Robust in time series, thus applicable in monitoring		Straightforward results, but no univocal interpretation (threshold available, but interpretation not straightforward). time series application might not depict technological change / changed water demand due to land management
SP2 Maturity, auditability, acceptability	concept maturing, highly accepted	development stage	development stage		concept maturing

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SP3 Current use by firms, governments or international bodies	in preparation to be implemented in EEA "basket of indicators" several applications on the firm and governmental level, in particular for communication	in preparation to be implemented in EEA "basket of indicators" mainly scientific applications	mainly scientific applications		beginning, in international bodies mainly
SP4 Relevance of the indicator as a static (in level)/dynamic (changes) variable and relevance as an absolute or comparative value	Time series analysis possible, but problematic to the intricate weighting scheme at all levels. Communicative strength Cross country comparison possible and established	Time series analysis possible, analytical strength Cross country comparison possible	Time series analysis possible, analytical strength Cross country comparison possible		time series possible, absence of weighing schemes allows for straightforward applications. Caveat: technological change / changed water demand due to land management not considered appropriately in the upstream factor generation Cross country comparison possible and established

[i] LCI : Life Cycle Inventory