Environmental Impact of the use of Natural Resources and Products

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Executive Summary

The general aim of the Strategy on Sustainable Use of Natural Resources is "to develop a framework and measures that allow resources to be used in a sustainable way without further harming the environment", while achieving the objectives of the Lisbon strategy (3% economic growth). A key issue in this matter is the development of an aggregated impact indicator to follow progress on the decoupling road: an indicator that is expected to show the impact of environmental pressures related to resource use and economic development on the state of the environment in an aggregated manner.

The overall aim of this project, in accordance with the Technical Annex and the project proposal, is to make recommendations for the use of an aggregated environmental impact indicator, or set of indicators, at the Eurostat Datacenter for Natural Resources. The indicator(s) should be based on Environmental Accounting methods and existing statistical data, and should enable establishing clear links to other pillars of sustainable development.

Various indicators have been considered, all have their own strong points as well as drawbacks. No indicator has yet been put forward that has a general acceptance. Best et al. (2008) have suggested to start with a basket of indicators, together covering the total scope of resource use and impacts. One of those indicators is the Environmentally weighed Materials Consumption (EMC). A second aim of this project is to make recommendations on the improvement of EMC, as well as delivering updated time series for this indicator. In the meantime, its appropriate place in a comprehensive indicator framework, or a basket of indicators, is explored together with a number of other indicators. Besides EMC, we included the indicators out of the basket as proposed by Best et al. (2008): HANPP, Ecological Footprint (EF), and DMC. In addition we included Environmentally Extended Input Output tables (EE IO). EE IO is not an indicator but a framework which can be used to derive a number of indicators. We took the NAMEA type of EE IO as a starting point: specifying emissions from economic sectors and subjecting those to an aggregation procedure borrowed from LCA. We also included TMC as a variant of DMC, and finally we included "Environmental Policy Themes" which basically is an inventory of emissions in a country, which are translated into contributions to certain environmental impact categories.

A general framework for the characterisation of indicators is summarised in the table below. Decoupling is measured generally in two dimensions: economic growth (generally indicated by GDP) and environmental impacts or pressure. The latter is the subject here: the indicators in the basket all refer to the environmental dimension of decoupling. An aggregate is therefore needed of all pressures or impacts on the environment, or a variable indicative thereof. In theory, this would be sufficient, however in practice there are some other considerations. In the first place, it is stated in the Resource Strategy that decoupling in the EU should not be at the expense of environmental deterioration elsewhere. Therefore, foreign impacts should in some manner be included in the indicator. Also, the policy supportive power of the indicator grows when a linkage can be established between the environmental pressures or impacts , and the economic activities, sectors, products or resources causing them. In the table below, we inventarised also the description or specification of the economic system in the various indicators, as well as the nature of the description of the environmental interventions: the interface between economy and environment. Finally, it is stressed that in order to arrive at an aggregate indicator for environmental pressure or impacts, some sort of aggregation procedure is needed in all cases. Within this procedure, there always is a subjective step, which in some cases is not apparent but hidden in the procedure. This, too, is shown in the table.

Summary description of indicator characteristics

	description economy	interface	environ-mental impacts	aggregation to single indicator	reference	subjective element	foreign impacts included
HANPP	-	extraction biomass land use	reduction NPP for nature	adding kg	NPP for nature	reference	no
EE IO	IOTs	emissions (air) (extrctions)	LCIA impact categories	characteris ation (+ weighting)	- (targets)	weighting impact categories	yes
EF	material flows	extractions (biomass) emissions (CO_2) land use	global hectares	adding ha	biocapacity	translation into global hectares; reference	yes
DMC	material flows	extractions	-	adding kg	-	weighting by kg	no
TMC	material flows	extractions	-	adding kg	-	weighting by kg	yes
EMC	material flows + process trees	extractions emissions land use	LCIA impact categories	characteris ation (+ weighting)	- (targets)	weighting impact categories	yes
environ-mental policy themes	-	emissions (from emission inventory)	LCIA impact categories	characteris ation (+ weighting)	- (targets)	weighting impact categories	no

A crucial issue where indicators differ appears to be the inclusion of foreign impacts. Indicators with a consumption oriented or life-cycle based systems definition generally include those impacts, while more production or region oriented indicators do not. This can be an important criterion for the selection of such an indicator.

The indicators have been subjected to an assessment based on four criteria:

- scientific soundness

- communicative power
- indicator behaviour
- data requirement, availability and quality.

With regard to scientific soundness, all of the indicators appear to rely on fairly consistent methodologies. Question marks in this respect can be placed at the Ecological Footprint, where a consumption-based system for biomass resources is combined with a production/region based system for CO_2-emissions, and at EMC where one should be aware of the risk for double counting. With regard to the communicative power, this really depends on the user. For a user who wants information to support policy, the more encompassing and detailed indicators have the most added value: EMC and EE IO. These can be decomposed in various ways, thereby showing insight in the causes for its behaviour. For the general public, the EF and to some extent DMC are probably most appealing: simple, easily understandable indicators with a clear message.

Since the indicators have been subjected to assessments before, we have mainly focused on the third criterion, indicator behaviour. In f.e. the RACER assessment this criterion is not represented. Nevertheless it is important to know how the indicators deal with certain changes and whether they are able to detect decoupling, if this indeed would happen. For this reason we defined a number of hypothetical case studies and assessed how the indicators actually reacted. The case studies include changes in society, which in fact would change a country's environmental profile. Production with higher efficiency, changes in waste management, relocating processes from inside to outside the EU, substituting one material by another are measures included in the case studies. A summary table shows the indicator behaviour. The "Expected result" indicates the actually expected changes in environmental impacts supposing the case; "Up" means the environmental impact is expected to go up, while "Down" implies the impact to be reduced. Ideally the indicators should go up and down in the same manner.

Performance of indicators in the hypothetical case studies

	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7	Case 8	Case 9	Case 10	Case 11
Expected result	**Up**	**Neutral**	**Down**	**Down**	**?**	**Down**	**Neutral**	**Up**	**Down**	**Down**	**Down**
HANPP	Down	Down	Down	Up	Neutral	Neutral	Neutral	Neutral	Neutral	Down	Neutral
EE IO	Neutral	Neutral	Neutral	Down	?	Down	Down	Neutral	Down	Neutral	Down
EF	Neutral	Neutral	Down	Down	Down	Down	Up	Up	Neutral	Down	Down
DMC	Down	Down	Down	Up	Down	Down	Down	Down	Up	Neutral	Down
EMC	Neutral	Neutral	Neutral	Down	?	Neutral	Neutral	Neutral	Up	Neutral	Down

The perfect indicator does not exist, is the main message of this table. Generally, when there is a change in the actual environmental impact but the indicator shows a "neutral", it implies that the indicator is insensitive to the change. The indicator may not be sufficiently detailed; it may suffer from fixed technological coefficients; the economic activities, sectors or flows addressed may not be included; or the environmental pressures or impacts may not be included. When the indicator actually points the wrong way, e.g. it indicates an improvement when there is actually a deterioration, this is usually because it is a multiple impact and the indicator sees part of it. Either this is because of a partial inclusion of economic activities or impacts, or it is because of a system boundary that does not allow for detection of burden shifting to other countries.

With regard to the data issue, a special effort was made for EMC. We investigated whether it would be possible to calculate EMC entirely from EU-managed statistics and databases. We concluded that in principle, suitable databases are available: Europroms and the Agricultural Balances at Eurostat, to calculate apparent material consumption, and the ILCD database at JRC, to calculate the impact factors. However the gaps in these databases are presently so large that no meaningful result can be obtained. When EMC has to be calculated and published on short notice, it will have to rely on other databases, such as FAOSTAT, the MFA accounts and available LCA databases such as Ecoinvent 2.0. In that respect, it does not differ from the other indicators.

Not just for EMC, but also for the other indicators the data situation was reviewed. The table below shows this. All indicators have a large data requirement – which is not surprising if they are to indicate overall environmental impacts. Basic data for four of the five indicators are statistical. Only HANPP relies completely on non-statistical data. In the table, it is also indicated what Eurostat could do to start using the indicator immediately, and what Eurostat could do to improve the data situation of the indicator over the next 3 – 5 years, if they decide to start calculating and publishing the indicator regularly.

Data demands and availability per indicator

	Data needed	**Available at Eurostat**	**What needs Eurostat to do to use the indicator now**	**What can Eurostat improve in the next 3-5 years**
HANPP	NNPo (Net Primary Production of potential vegetation) Remaining NPP after harvest	No, developed by research institutes	Contract research institutes	If HANPP is considered as a priority indicator, Eurostat and other members of the Group of Four, particularly EEA, could consider to set up HANPP accounts themselves.
EE IO	SUT/IOT NAMEAS as time series	Yes, but incomplete. For most EU27 MS, gaps are being filled in projects on NAMEAs on air, resources, water, energy, waste	Create capacity to aggregate SUT/IOT of the 27 MS to an integrated EU27 SUT/IOT	EUROSTAT could consider building a partner network with key non EU trade partners to produce harmonized NAMEAs. This is realistic since many countries work on NAMEAs and have projects on pollution embodied in trade. Additionally, EUROSTAT could consider approaches to enhance sector detail[1]
EF	Agricultural balances, ProdSTAT, COMTRADE database and other	Agricultural, forestry and fishery data available in statistics. CO_2 data are available in	EUROSTAT has no insight in some propriatry data to calculate EF, nor energy/CO_2 embodied in	EUROSTAT could set up a statistical base allowing to calculate EF independent of the GFN. Ideally, this would imply getting insights in energy/CO_2 embodied in imports to the EU27 (see also under EE IO)

[1] This goes beyound pure accounting, but the activities of EUROSTAT with regard to the Data Centres on Products and Resources allow EUROSTAT to provide to some extent modelled but useful data there.

		NAMEAs. Yield and equivalency factors only at GFN.	traded products. EUROSTAT would need to engage GFN to solve these deficiencies	
DMC	PRODCOM/Comtrade/production statistics mining/agriculture	Yes, MFA accounting is (or will be) a standard Eurostat activity	Make MFA accounts obligatory for MS.	Extend MFA in the direction of PIOTs to enable breaking down into resources. Use TMC instead of DMC.
EMC	Europroms/Agricultural balances for finished materials, LCI data for impact factors	Yes for agricultural data, partly for other materials. ILCD not available yet,	Use other reliable data sources for apparent consumption: FAOSTAT, MFA accounts. Use available LCI database	Improve supply balance sheets agricultural products, develop supply-balance sheets for non-agricultural products. Establish EU-accepted LCI database or certification scheme for LCI databases.

A first conclusion is that some issues come back for all indicators. One major challenge is the translation of the – by necessity – large dataset into one single value for environmental pressure or impacts. Different indicators have taken this up differently as well, by using elaborate procedures (such as the LCIA which is used for EMC and EE IO-based indicators), by expression in a single unit (such as the DMC and EF) or by taking a limited scope (EF and especially HANPP). For the indicators that use an LCIA-type impact assessment, a weighting between impact categories is an explicit part of the procedure. This is a controversial step but unavoidable when the aim is to have a single indicator. It is important to note that all such aggregate indicators have to take this step, via explicit weighting procedures or otherwise.

A second conclusion is, that all indicators have limitations, which have consequences for their use as decoupling indicators:

- HANPP has a limited scope which makes it insensitive for impacts other than those related to land use change, and cannot show burden shifting to other areas
- DMC does not include impacts but uses material flows as a proxy, which implies that sometimes impacts are overstated, but mostly they are understated, and it does not show burden shifting to other regions. Using TMC instead of DMC may solve the second problem.
- EF does not include any emissions besides CO_2, therefore is blind to burden shifting to other impact categories, and excludes large parts of the economic system by not including non-renewable resources. Due to its dual nature, burden shifting abroad is also not always visible.
- EMC in principle shows impacts, side-effects and displacement abroad, but in its present shape is insensitive for technological improvements, sometimes in non-obvious ways, due to the inflexibility of the impact factors
- EE IO also in principle shows impacts, side-effects and discplacement abroad, but presently includes a very limited list of emissions, sometimes suffers from lack of detail in the sector classification, and assumes foreign technology to be identical to domestic technology.

From the above, it has become clear that some of these limitations are inherent to the indicators. Especially HANPP and DMC seem to be constrained and therefore not very useful as general decoupling indicators. For the other three, improvement options could be defined, making them more flexible and sensitive. For EE IO, a larger scope of environmental interventions would be helpful, as well as a more detailed sector classification, and a differentiation between technologies in various countries. Developments are presently ongoing, especially in the EXIOPOL project, to realise this. EMC would benefit by more detail in the materials included, a regular update of LCA-based impact factors and a region-specific definition of impact factors. For the EF, the inclusion of other emissions besides CO_2 would be a major challenge, not just in the data but also in the translation to global hectares.

A final summing up of the indicators leads to the following conclusions:

HANPP is a very specific indicator, that is not designed, nor can be used as a general indicator for environmental pressure in a decoupling context. Its scope is limited, it is not based in statistics, the link to the economic system is absent, and it does not show burden shifting. It does, however, offer specific information that none of the other indicators does. Therefore, it can be used in addition to those, to highlight NPP appropriation as an indicator of pressure on land.

The Ecological Footprint has been designed as a general indicator for environmental pressure. It, too, focuses on land, but it uses hectares as a measure for pressure rather than commenting on land use itself. It is a very appealing indicator, and the only one that has a sustainability threshold. Nevertheless, it is also limited: it encompasses renewable (biomass) resources and CO_2-emissions, and therefore is blind to many changes in the environmental performance of societies. It's original set-up is consumption oriented, which allows to detect burden shifting. However, with the addition of CO_2, this clearcut focus has been abandoned to some extent, and the relevance of the globally available hectares has become questionable with this step. Extending the EF with other emissions would be possible in theory, however, there is a serious risk for further loss of meaning of global hectares as a relevant measure if this were to be done. Although as an indicator for the general public EF may point in the right direction in many cases and raise awareness of the impacts of consumption patterns, as a general decoupling indicator to support policy, the EF presently has a too limited and not easily expandable scope.

The DMC is a clearcut indicator that in its own way, i.e. counting the material flows, is encompassing. It has two drawbacks in light of its use as a general indicator for decoupling. The first is the regional scope, which does not allow for detecting burden shifting to other countries. This can be circumvented by using TMC instead of DMC: TMC includes "embodied kilograms". The second drawback is the fact that kilograms of materials use is not really a relevant indicator for environmental pressure. Although at a general level there is a certain correlation between material consumption and environmental pressure, DMC dometimes points in the wrong direction if it comes to detecting certain changes in society's pressure on the environment. DMC (or TMC) however can be used to measure decoupling of economic growth from resource use, which none of the other indicators is able to do. It therefore can play a specific role to support a resource policy.

EMC is designed to overcome the limitations of DMC: it has a consumption chain oriented approach, thereby enabling to detect burden shifting abroad, and it adds environmental impact factors to the kilograms of material, thereby adding environmental relevance. In its coverage of emissions and impacts, EMC presently is by far the most comprehensive indicator. It misses the inherent comprehensiveness of DMC in the description of the economy, however: being as complete as possible is a constant point of attention. Another point of attention is the risk for double-counting of impacts. Because of its focus on materials, it seems a very useful indicator to support resource policies. It is less adequate in detecting changes related to technological improvements or waste management, due to the fixed impact factors. EMC can be improved further by expanding the scope of materials included, and by frequently updating the impact factors.

EE-IO, finally, theoretically seems to be the best candidate to deliver a general decoupling indicator. It is encompassing and allows to include a great many environmental interventions. It also allows for a sufficiently detailed distinction of sectors to enable detecting most changes, technologically or throughput-wise. It includes the embodied environmental pressure of imports and corrects for those of the exports, which makes it suitable to detect problem shifting to foreign countries. However, at present, EE-IO falls short of its potential: NAMEAs composed by some EU countries include only a limited amount of pollutants, mainly emissions to air, its sectors are defined at a high aggregation level, and foreign production is assumed to be similar to domestic production. In ongoing projects a more sophisticated and comprehensive EE-IO approach is being developed, however, this is not available yet and it remains to be seen whether this approach can in fact be maintained by countries and updated frequently.

It seems, therefore, that the different indicators may serve different purposes. As concluded above, EE-IO may provide the best framework for a general decoupling indicator. For more specific policy areas, such as policies aimed at resources, products or waste, it would be less suitable. Since EE-IO inherently works via monetary exchanges of sectors, the link to resources, materials, products and waste cannot be made directly. To some extent even this could be included in the IO-framework. Relevant to be mentioned are the NAMEA-waste accounts that are being reported in a number of EU countries. In the EIPRO project, a link of EE-IO to product groups has been established, allowing a prioritisation among product groups. EIPRO however is a huge effort to repeat frequently, and relies on many shortcuts that will not be discussed here. In the EXIOPOL project, links are also made to resource extractions. The EE-IO framework therefore seems to be the most versatile and generally applicable one. On the other hand, it will not be able to supply resource, waste or product policies with sufficient information or sufficiently targeted indicators.

To start with a policy on resources: for this, it is imperative to have the resources and resource flows visible in the indicator, rather than have them added as multiplyers to sectors based on their monetary throughput. Resource flows themselves are captured in the DMC or TMC indicator, based on MFA accounts. The EMC seems most suitable to add the environmental dimension. EMC captures many environmental impact categories. Land use is included in EMC, however, the land use data for renewables in the EF are of a better quality. A recommendation could be to try and combine the two indicators. They both have resources rather than sectors as a starting point, and their system boundaries are rather similar. The EF then could supply the land use data for renewables and the EMC the emissions, including CO_2. Land use data for non-renewables should be added, however, these would be minor in comparison to the renewables land requirement. EE-IO would add little to this set. If PIOTs were produced for a wide number of materials, the added value would be considerable: this would allow for a more sophisticated assessment of the pathways of resources through the economic system. In the absence of PIOTs, specific Substance Flow Analysis studies could be done with regard to certain priority materials with the same results.

For a waste policy, the NAMEA waste accounts could be a valuable starting point. Most likely, more information is required here as well. Impacts of waste trade, of different waste treatment options and of various forms of recycling are very important and may not be sufficiently included in an EE-IO framework. Additional information is also required on specific hazardous waste streams and their treatment. For waste prevention, it is important to have insight in the origins of waste streams. Links must be established with resources and products, for which it is uncertain that the road via monetary exchanges of sectors is the best one to follow.

A product policy could benefit greatly from an EIPRO-like approach. This may be the only way to get a perspective on all combined products in a national economy. A product policy obviously should be supplemented by product studies for priority product groups based on detailed LCAs. Without these, it would not be possible to do eco-labelling or provide guidelines for product design – be it ecodesign, design for recycling or otherwise. However, the individual products are too numerous to keep track of all of them: instead of roughly a hundred materials, there are tens of thousands of different products to keep track of. A certain amount of aggregation therefore is inevitable, and to do this via EE-IO seems a sensible road to take.

1 Introduction

The 6th Environmental Action Plan clearly states the objectives to ensure that the consumption of resources and their associated impacts do not exceed the carrying capacity of the environment and breaking the linkages between economic growth and resource use. The general aim of the Strategy on Sustainable Use of Natural Resources is "to develop a framework and measures that allow resources to be used in a sustainable way without further harming the environment", while achieving the objectives of the Lisbon strategy (3% economic growth).

In relation, in June 2006 the European Council adopted its revised Sustainable Development Strategy that contained amongst others as key priority the topic of Sustainable Consumption and Production (SCP). The Commission was asked to develop an SCP Action Plan. This Plan should build upon and combine existing initiatives like Integrated Product Policy (IPP), the Environmental Technologies Action Plan (ETAP), ecolabelling activities, etc.

Recognising the importance of the issues presented above, and that such policies need to be based on factual evidence and data, Eurostat together with DG Environment (DG ENV), the European Environment Agency (EEA) and the Joint Research Centre (JRC) signed a Technical Arrangement (hereafter named Group of Four -G04) establishing 10 Data Centres: Natural Resources, Products (IPP), Waste, Soil, Forestry, Air, Climate Change, Water, Biodiversity, and Land Use. Eurostat was given responsibility for the Data Centres for Natural Resources, Products and Waste. The main purpose of these Data Centres is to improve knowledge about the relationship between economic growth, resource use and environmental impacts. A key issue in this matter is the development of an aggregated impact indicator: an indicator that is expected to show the impact of environmental pressures related to resource use and economic development on the state of the environment in an aggregated manner.

The overall aim of this project, in accordance with the Technical Annex and the project proposal, is to make recommendations for the use of an aggregated environmental impact indicator, or set of indicators, at the Eurostat Datacenter for Natural Resources. The indicator(s) should be based on Environmental Accounting methods and existing statistical data, and should enable establishing clear links to other pillars of sustainable development.

This report contains a proposal for a framework to collect and store data needed to support the frequent publication of aggregate indicators to measure progress on the decoupling road. Such indicators, in line with the Resource Strategy, should give insight in a double decoupling: economic growth from resource use, and resource use from environmental impacts. DG Env has commissioned several studies to develop and assess such indicators (COWI, 2002; Moll et al., 2003; van der Voet et al., 2005; Best et al., 2008). Not only decoupling, but also the displacement of impacts to outside the EU borders is considered of importance. This implies that such indicators should have a life-cycle approach, and that it must be possible to make a distinction between impacts within and outside EU.

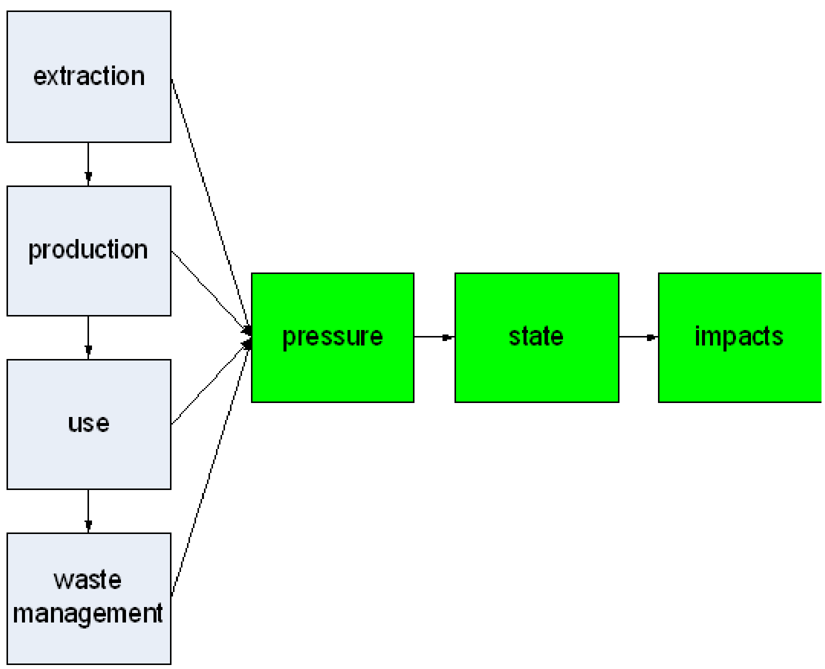
Various indicators have been considered, all have their own strong points as well as drawbacks. No indicator has yet been put forward that has a general acceptance. Nevertheless, there is a great pressure on Eurostat to start delivering time series indicators quite soon. Best et al. (2008) have suggested to start with a basket of indicators, together covering the total scope of resource use and impacts. One of those indicators is the Environmentally weighed Materials Consumption (EMC). Although its development is not yet finalised and data are not yet harmonised, it can at least be applied. A second aim of this project is to make recommendations on the improvement of EMC, as well as delivering updated time series for this indicator. In the meatime, its appropriate place in a comprehensive indicator framework, or a basket of indicators, will be explored together with a number of other indicators.

In Chapter 2, a general framework for indicators is presented, together with some specific choices to be made. Chapter 3 contains a description of a number of specific indicators and positions them in the general framework. Also, their data requirements are specified. In Chapter 4 these indicators are put to the test: what is their informative power and how do they behave under certain changes in society? This test is important as a means to assess the ability of the indicators to actually measure decoupling. In Chapter 5, an overall assessment of the indicators is provided. Chapter 6 is dedicated to EMC. It contains updated time series and also a description of how, ideally, the EMC could be developed and supported in the EU data institutes. In Chapter 7, finally, conclusions are drawn and recommendations are made with respect to the general framework, the assessed indicators and the development of EMC.

2 Indicator framework

2.1 General framework

The field we are discussing when addressing decoupling is broad: all of society as well as all of the environment. This means a general framework for indicator development and assessment also has to be braod: a comprehensive description of the economy, where the extraction of resources and the subsequent use of products is visible, and which can be linked to some sort of a comprehensive assessment of environmental impacts. For this, a starting point is the generally applicable DPSIR (Driving Forces-Pressures-State-Impacts-Responses) framework, which can be adapted to the purpose. To explicitly address double decoupling, the economic growth can be separated from the use of resources by applying D to the physical economy and detailing it into the various stages of the life cycle, as pictured below.



The extraction of resources, their processing into materials and products and the subsequent use and discarding of the products is visible in the extended Driving force-part of the DPSIR framework. This picture emphasizes the coherence of the production-consumption chain and illustrates that resources, products and waste all form an entry into the same system. Environmental interventions (emissions, extractions and the use of land) occur at all stages of the life-cycle.

This framework is still very general and can be elaborated still in different ways. In the literature, we find different answers to the following questions:

- how is the description of the D, or the economic system (physical / monetary)
- what is included in P, or what are the interfaces between economy and environment
- how is the translation from P into S and I, or how are environmental impacts specified?

These issues are treated in general terms in the next sections and will come back in the review of existing literature in further chapters. Each of the indicators included in this report has a different way to handle these three issues. However, they all draw from a limited number of options that can be distinguished in general, and form different combinations of those. These general options are described here in Chapter 2, and come back in Chapter 3 where the indicators are described in more detail.

The description of the economy can be in monetary terms, for example in the shape of input-output tables (describing mutual deliveries of producing sectors in more or less detail) or supply-use tables (describing purchases and sales of producing sectors), or in terms of the national GNP (describing the monetary turnover of a country in more or less detail). The description can also be in physical terms, such as Material Flow Accounts (MFA, describing inputs and outputs of national economies in terms of tonnes of materials), physical input-output tables (describing mutual deliveries of producing sectors in terms of tonnes, Joules and other physical quantities), or detailed process tree descriptions such as used in Life Cycle Assessments (describing detailed technical production processes in terms of physical inputs and outputs).

The description of the economy-environment interface is usually in physical terms, i.e. resources extracted, emissions to the environment, or land being used for a certain purpose. In LCA-terms this is called "environmental interventions". Not all indicators use such a description of the interface, especially the indicators that translate environmental goods into monetary terms.

The impact assessment varies widely among indicators. Some indicators describe impacts at the endpoint-level, as it is labelled in LCA, of damage to health, ecosystems, biodiversity or societal structures or values. Impacts are also described at the midpoint-level of established environmental problems (or impact categories), such as global warming, acidification or depletion of resources. A major challenge is to put all types of different interventions or impacts into one indicator. Most of the indicators do this by finding a common unit to translate into. Mass based indicators do not bother to assess the environment but add all inputs or outputs in terms of tonnes. An indicator like the Ecological Footprint translates all interventions in terms of occupied land, while the HANPP uses the (naturally occurring) primary production of biomass as its reference. Some indicators describe the environment in terms of money – either the value of goods and services provided, or the damage costs as a result of impacts on the environment. Some translate the interventions in terms of money as "avoidance costs": what would it cost to prevent the intervention?

Below, some of the more commonly used ways to describe the economy, the interface and the impacts are described in more detail. In Chapter 3, where the indicators are presented and evaluated, we will refer back to these descriptions.

2.2 Description of the economy

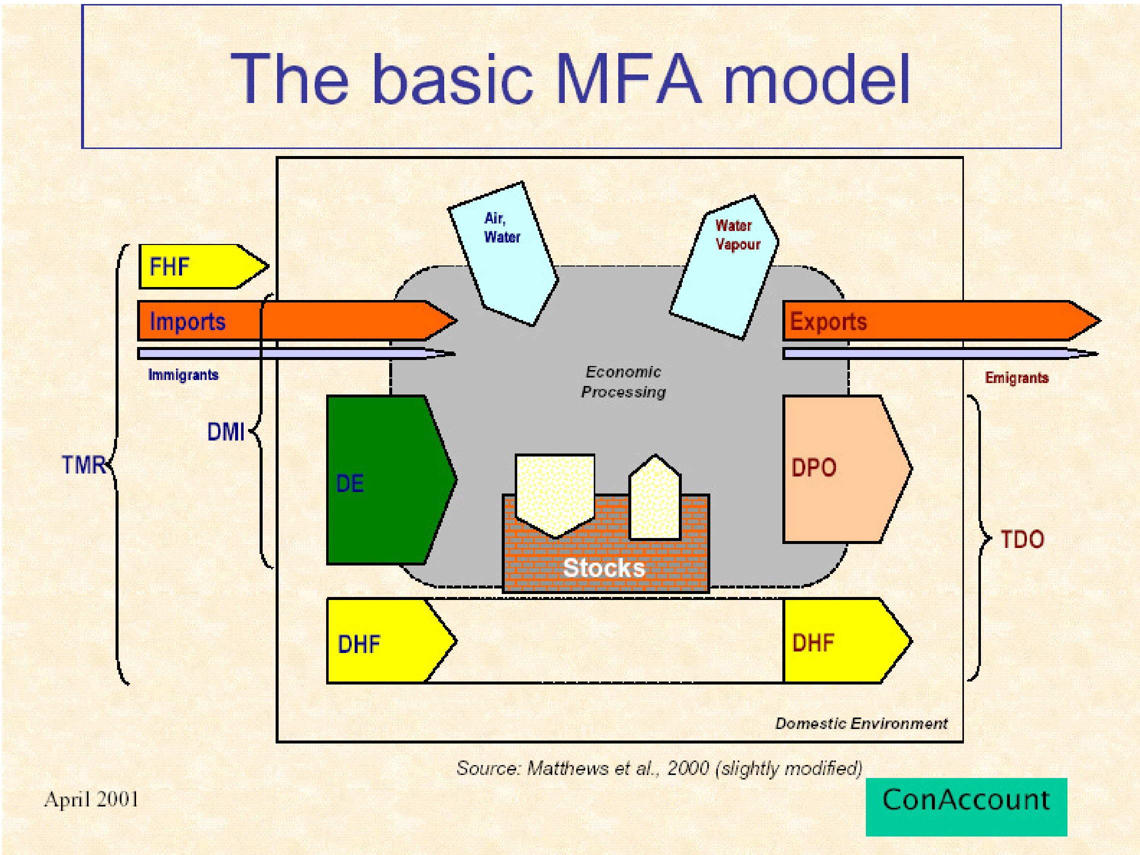
2.2.1 Material flow accounting

Material flow accounting is a description of the economy in physical terms, namely the overall input and output of a national economy in terms of kilograms. This type of accounting is developed by IFF and Wuppertal Institut, and is standardised by Eurostat in a methodology guide (Eurostat, 2001). The Eurostat guide specifies classifications and subclassifications of types of raw materials, materials and products, mainly derived from the classifications as used in trade statistics. Trade statistics is also one of the main sources of information. In addition, other statistics are used, for example agricultural production statistics (FAOSTAT) and industrial and mining production statistics. Occasionally, less standardised sources are used, for example to estimate domestic extractions of resources like sand and gravel.

Imports, exports and extractions of raw materials, finished materials, products and all kinds of intermediates are specified. The result is an overview of the total amount of kilograms of goods entering and leaving a national economy. The difference between these inputs and outputs is the Domestic Material Consumption (DMC), one of the main indicators used for measuring the size of the physical economy, which is discussed in more detail in Chapter 3.

Below, the basic MFA model is pictured in Figure 2.1:

Figure 2.1 The basic MFA model



In this model a number of aggregate flows are visible. Besides imports and exports, these are: domestic extractions (DE); domestically produced outputs (DPO) which is a total of all wastes and emissions from the economy; domestic hidden flows (DHF) indicating the extractions that do not really enter the economic system (for example, mining overburdens); foreign hidden flows (FHF) which are similar to the DHF only occurring in other countries. Then there is a stock in the economy, which can grow or decline as a result of all other flows.

The model also presents a number of aggregate MFA indicators: TMR, DMI and TDO. These are discussed in Chapter 3, together with the DMC.

The overall description of the economy in terms of the input and output of mass can be broken down into a limited number of groups of materials. Generally, 4 – 12 categories are distinguished. The most aggregate categories are fossil fuels, minerals (construction and industrial), metals and biomass. Within these categories a limited further breakdown is possible. Also, a breakdown can be made into a limited number of sectors of society, such as agriculture, mining, construction, energy generation etc.

An MFA account according to the Eurostat methodology is in principle a complete overview. However, it only describes transboundary flows: the national economy itself is a black box. This limits the analytic power of the system and also limits the options to do a systems check.

In the area of Material Flow Analysis, there are other types of methodologies that allow for more detail, although this implies at the same time the loss of comprehensiveness. Substance Flow Analysis (SFA) is a method to follow the flows and stocks of one specific substance in, out and through a societal system. SFA studies have been conducted for a number of elements (individual heavy metals, nitrogen, phosphorus, carbon, chlorine compounds) and at different scale levels (national economies, the EU, the world, but also regions and cities) (Graedel et al., 2004; van der Voet et al. (eds.), 2000; Bergbäck et al., 1997; van der Voet, 1996). In most cases, the black box of the economy is opened to see the substances flow from one industry to another, being applied in products, entering the use phase and being discarded and treated as waste. Not only accounts, but also models have been used, to capture the causal relationships between the flows and the dynamics of the systems over time. This makes it possible to simulate the effectiveness of certain developments or policies (Elshkaki, 2007; Müller et al, 2006). MFA accounts may serve as one of the databases to support these SFA studies.

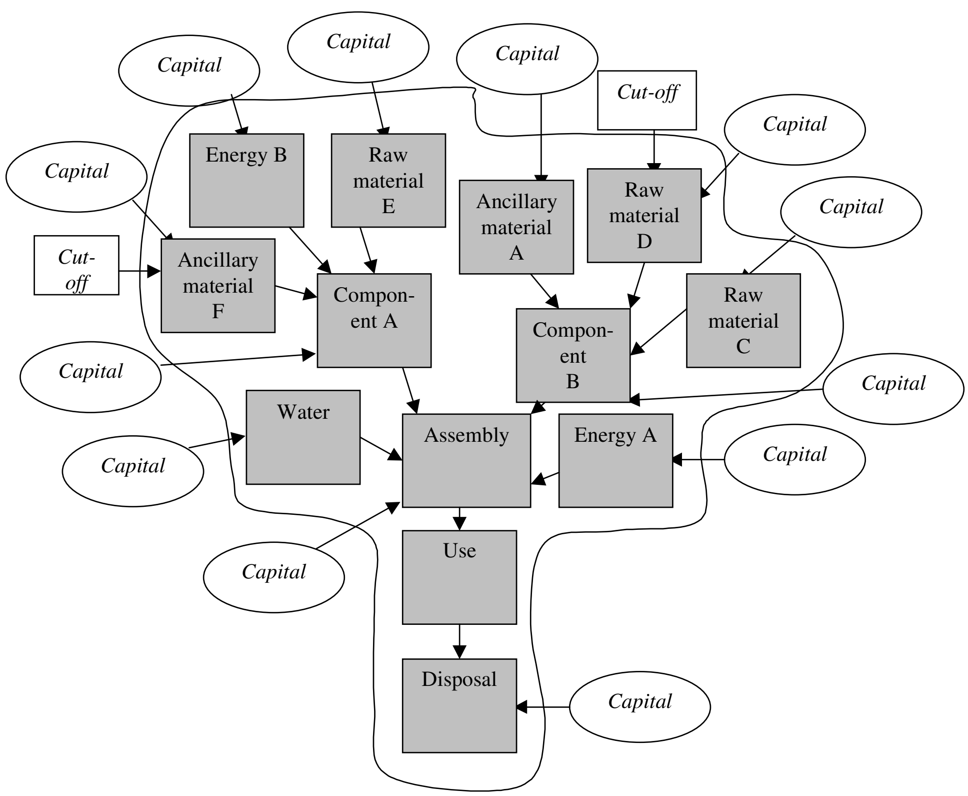
While very useful to support policies on specific resources, these methodologies are not suitable as a basis for overall indicators for environmental pressure or impacts of whole societies. The only way they may be used in that way is to establish SFAs for all materials / substances handled in a national economy. To a limited extent, this is what has been done in composing the EMC: the material balances used there can be regarded as highly simplified SFAs per material.

2.2.2 Physical process trees

Process trees is a concept used in Life-Cycle Assessment (LCA). In LCA, a so-called functional unit is chosen. That unit expresses the ‘final utility’ that is provided. This unit is the starting point for the identification of the processes in the economy that contribute to this final utility. A functional unit can for instance be: the packaging of 1000 liters of milk, or the transport for one person from A to B. The processes involved are technological processes at a very detailed level.

In traditional life cycle assessment, a process tree related to the functional unit is set up (Guinee, 2002). This process tree provides the *physical* relations between all processes needed to produce the funcational unit. For instance, for packaging 1000 liters of milk in carton packaging this would imply the use of a certain amount of trees, processing of them in the paper and pulp industry, production of carton, filling, transport to shop and home, and waste management of the discarded carton. With, of course, all the processes that contribute to this primary process tree which would imply energy production, with in turn needs mining of coal or extraction of oil, and so on. Figure 2.2 gives an example of such a process tree in LCA. The advantage of this way of describing the economy is that specific technical processes at a high level of detail are singled out, well below the level of a sector[2]. A typical problem in LCA is hence 'where to stop', since the whole economy in principle is related: In the LCA community this is known as the 'cut off' problem. Typically, in LCA one choses not to follow a process tree any further if the contribution in material, economical or energy terms is just a few percent of the total into that process. Yet, it has been shown that all these small parts that have been cut off in total still can be seizable, up to a few dozen percent (Lenzen, 2002)

Figure 2.2 Process tree in Life Cycle Assessment



This type of description of the economy allows for a high level of detail and therefore has a high explanatory power. The life-cycle approach as well as the consumption-oriented starting point is suitable and in line with the requirements of the Resource Strategy. However, where the phyiscal process tree approach to describe economic linkages is very suitable for product LCAs, this approach is probably less suitable if one is interested in developing indicators at macro level and if one wants to cover all economic processes in a country. One would have to make LCA's for virtually all products for final use in a

[2] For instance, in the dairy industry we only would look at the packaging process, since that is the only element relevant.

country, or assume that an LCA for a specific product is representative for a product group. It has been convincingly shown that this leads to drawbacks such as double counts in some cases, missing processes in other cases, and inconsistencies since most LCA's use different data sources (cf. Tukker and Jansen, 2006; Suh, 2004). it is nearly impossible to describe a total economy in that way.

One of the present challenges of the LCA community is to develop approaches where the valuable life-cycle angle is preserved, while at the same time allowing for a higher aggregation level. Present attempts include combinations with Input-Output analysis and Material Flow analysis (a.o. Tukker et al., 2006, but the challenge is broader.

2.2.3 Input Output tables

In the discipline of economics the field input output economics has developed a way of consistently describing interrelations in the economy via so-called Supply and Use Tables (SUT) and Input-Output Tables (IOT). SUT and IOT form a key component in national economic accounting systems (e.g. System of National Accounts (SNA; UN et al., 2003) and European System of Accounts ESA; European Communities 1996).

In layman terms, a Supply table shows the output value of the product groups that each industry sector produces. The Use table shows the purchases of products by industries (that use them in production) and by final consumers (households and governments). An Input-Output table (IOT) combines the information in SUTs. For instance, an industry by industry IOT describes the monetary value of purchases by an industry from each other industry (and hence the sales from an industry sector to each other industry sector). Similarly, one could also make a product by product IOT, which describes the monetary value of products that are used in the production of another product. Table 2.1 gives a SUT and Table 2.2 gives an IOT (cf. Miller and Blair, 1986; Rueda Cantuche et al., 2007; Oosterhaven, 1984; Dimaranan, 2006; Yamano and Ahmad, 2006).

Most industries of course cause emissions to the environment, and use primary resources. The magnitude of such 'environmental extensions', usually expressed in kg emission or resource use, can be listed in a 'satellite account' as attribute of an industry sector. In this way, an 'Environmentally Extended Input-Output Table' or EE IOT is created Such a table can have all kind of analytical applications. For instance, it can be calculated what value individual industries contributed to purchases by final consumers, and by allocating the emissions and resource use of each industry proportionally, the environmental impact of such purchases can be calculated.

Table 2.1 Supply table (after Eurostat, 2002)

	Industries	**Imports (c.i.f)**	**Total**	**Valuation**	**Total**
Products	**Production matrix:** Output by products and industries	**Imports** broken down by products	Supply of products at basic prices	**Valuation adjustment items by product**: + Taxes less subsidies on products +Trade and transport margins	Supply at purchasers' prices
Total	**Output by industry at basic prices**	Total Imports	Total supply at basic prices		**Total supply**

Table 2.2: Use table (after Eurostat, 2002)

	Industries	Sub-total	**Final use**					**Total**
			Final consum-ption		Gross capital formation		Exports, f.o.b.	
Products	**Intermediate consumption at purchaser's prices by product and industry**		**By house-holds, NPISH, govern-ment**		**Gross fixed capital forma-tion and changes in invent-tories**		**Intra- and extra EU**	Use at purcha-sers' prices
Subtotal (1)	Total intermediate consumption by industry		Total final use by type					**Total use**
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)+(3)	**Output by industry at basic prices**							

Table 2.3: Environmental extensions in a symmetric industry by industry Input-Output framework (EE-SIOT)

	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, govern-ment**	**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

The European System of Accounts (ESA) asks that each EU member states produces annually a SUT and five-yearly an IOT in a harmonized form, with a resolution of 60 products / sectors[3]. For each EU member state, these tables give a fully consistent and fully comprehensive picture of the economic relations in an economy. The main difference with the approach use in product LCA is:

- No cut-offs due to the comprehensiveness and consistency: all relations are accounted for.
- Relations are expressed in monetary terms rather than physical terms. The implication of this is that primary resource use and emissions are by necessity allocated on the basis of economic value, while LCA allows for other (physical) types of allocation as well[4].
- The resolution / level of detail is much lower (for instance, one cannot identify the purchasing of carton for milk packs from the paper and pulp industry by the dairy industry, but just purchases in general of the dairy industry from the paper and pulp industry)[5].

This analysis also indicates the relative strengths of each approach. If one is interested in specific products, the required detail implies that the approach of product LCA has to be followed. But if one is interested in broad trends of the environmental impacts of broad final consumption categories, an IO-based approach is superior, due to its consistency, comprehensiveness, and inherent relations with the (economic) System of National Accounts (e.g. Tukker et al., 2006a and 2006b).

Very much in the same way as monetary IOTs and SUTs are constructed, one can construct such tables in physical terms. Such 'physical' input output tables (PIOTs) and physical supply and use tables (P-SUT) express the flows in the SUT or IOT in kg material or product (e.g Schoer, 2006 and Seppälä, 2008). Such PIOTs or P-SUTs may discern different material categories and also energy flows (the latter expressed in MJ or similar).

2.2.4 Spatial descriptions

The abovementioned types of descriptions focus on the use of material resources and the processing them into materials and products at a generic level. All of them ignore the spatial aspect of production and consumption. The most direct spatial aspect is the use of

[3] The EXIOPOL project, a major Integrated Project in Input Output analysis and externalities, aims to construct similar tables for 16 trade partners of the EU, enhance resolution of the EU and non EU tables to around 130 sectors, and add a broad range of environmental extensions (FEEM and TNO, 2006)
[4] For instance: a product LCA would look at the carbon content of a discarded milk pack, and then calculate CO_2 emissions in an incinerator on the basis of this carbon content. In an IO-approach, one would would look at the total annual CO_2 emissions of the incinerator, the total turnover, and allocate CO_2 emissions to the milk pack according to the price paid for the incineration service. Hence, all CO_2 emissions of the incinerator still are accounted for, but they are differently allocated to the waste input as in the case of physical allocation.
[5] And even this is optimistic since the ESA95 tables do not discern the dairy industry, but just the 'Manufacturing of food products and beverages'.

land for economic activities. The direct land use is included in some of the LCA databases at the unit process level. In SUTs, IOTs and MFA land use is altogether ignored. The same is true, by the way, of water use[6]. These are serious hiates from the point of view of a Resource Strategy, as well as for an overall indicator of environmental impacts.

Land use and the changes therein is recognised, however, as a major sustainability issue. Land use statistics are available in many countries. Land use and land use databases and surveys often take a GIS-like approach, which is a logical starting point. However the relation with economic activities is difficult to establish: this can be done only in some cases at the most aggregate level: a distinction can be made into agriculture, nature and forestry, and built-up land. Agriculture in most cases can be broken down further into crop production and pasture / meadowland, sometimes even further to the level of crops. All industrial activities fall within the category of built-up land and can not always been distinguished from residential areas. It is therefore difficult to make the link with production and consumption. In some LCA databases, an attempt is made to define land use at the level of the unit processes. In the Ecological Footprint indicator, land is taken as the key variable and every activity is translated into square meters of land use. This is elaborated further in Chapter 3.

2.2.5 Other descriptions

Other descriptions of the economic system exist, mainly in non-physical terms. The main index over overall economic activity is the gross domestic production (GDP), which is a measure of all money earned (and spent) in a national economy. Other socio-economic variables are, for example: employment rate, education level, participation of minorities, etc. etc. These are not included in the present report. It might be interesting to use them in a decoupling setting as indicators for welfare or rather well-being.

Attempts have been made, and still are being made, to define a "green GDP" (Hueting, 1980). This would solve one of the observed shortcomings in GDP, that most environmental services are not priced through the market and hence not included in the GDP..A valuation of the scarcity of environmental services in one way or other enables correcting the GDP for the loss of such goods and services. Comparing the developments in green GDP and ordinary GDP gives an indication on the degree that decoupling is achieved.

The expression of environmental goods and services in monetary terms is discussed further in Section 2.4.5. For the purpose of measuring decoupling of economic growth from environmental impacts, the green GDP might be less preferable, since the implicit valuation of environmental scarcity clouds the actual physical process of decoupling.

[6] In the Eurostat MFA methodology the choice is made to ignore water use, as the flow of water dwarfs all other flows by comparison. In SUTs and IOTs water use is not visible. LCA process descriptions sometimes include water use, but not in all cases.

2.3 Interface: environmental interventions

Environmental interventions form the interface between the economy and the environment. The term "environmental interventions" is generally used in LCA. In the LCA methodology, it means any (physical) transgression of the economy-environment border. This transgression works both ways. On the one hand, stuff is taken out of the environment to be used. This can be raw materials, but also land that is converted from nature. On the other hand, stuff is put into the environment. This can be emissions, but also waste streams and even land that is taken out of production. There are some boundary discussions that have been there for a long time and are not solved, but put in their proper place. These will be indicated in the next sections.

2.3.1 Extractions of resources

In most cases, it is quite clear what is meant by "extraction of resources". We define it, in accordance with many others, as "taking something out of the natural environment to be processed and used in society". Extraction of ores of metals, of raw materials for construction such as sand and gravel, of fish out of the oceans and rivers, of wood from forests, and of water for use in agriculture, households and industries are undisputed.

Boundary problems occur when considering agriculture. In MFA, for example, the harvesting of crops is considered an extraction, agricultural soil being part of the environment. In LCA, this is not the case: here, agricultural production is considered an economic activity with crops as its product, hence only the CO_2 fixation by the crops counts as an extraction. When combining methodologies, this needs to be kept in mind in order to keep the system consistent.

2.3.2 Emissions to the environment

Here, too, the identification of emissions to the environment in most cases will not be a problem. Emissions from industrial processes and use or consumption are undisputed, although a discussion is ongoing on CO_2 emissions from biogenic origins. In some energy analyses, these are not accounted for since they are considered to be "carbon neutral". In normal LCA procedure, they are accounted for, but so is the extraction of CO2. Worldwide, this amounts to the same. At any sub-global level it may cause differences due to the extractions occurring in different areas as the emissions. Especially when considering burden shifting to other countries, this is something to keep in mind.

A next issue concerns waste streams. Here, the economy-environment boundary is drawn in different places. While waste incincerators and recyclers are still undisputed part of the economic system, the landfill sites are not. Are landfills part of the environment, and is landfilling waste an emission to the environment, or are landfills still within the economy and therefore only the losses from landfill sites to be considered as emissions? Here, too, the system consistency needs to be guarded.

2.3.3 Land use

Another issue is the use of land. In MFA as well as in IOT and SUT, this is out of the scope. In LCA, the land use of unit processes is accounted for as an intervention. While the conversion of land from nature is an obvious extraction, the case is less clear when using land that has already been in use for a long time. This is solved by some in the LCA methodology by distinguishing "land use change" from "land use competition" as two different types of interventions.

Land use statistics and surveys, as mentioned before, do not fit easily into the perspective of the economic systems as present in MFA, LCA and IOT/SUT. Therefore a land use indicator derived from such statistics or surveys is also not easily combined with that information to one aggregate indicator of environmental pressure or impacts. There are some real problems, like the degradation of habitats and the fragmentation of natural areas, that can come out only in a spatially defined land use survey and cannot be linked directly (or: at all) to particular economic activities.

2.3.4 Other

National economies not only use nature's goods, but also its services: the so-called life support functions or regulatory functions of nature (De Groot, 1994). Free services of nature include climate stabilisation, water flow and water quality regulation, resistance against pests and diseases, pollination, regulating soil fertility etc. etc. We use these services, be it mostly unconsciously. It would be very difficult and at the least extremely costly to replace these services by man-made devices. The use of these services could also be seen as environmental interventions. These functions seem to be included at least in the EU Resource Strategy, which takes a very broad scope.

We propose not to include the use of nature's services as environmental interventions. As we see it, the use of these services does in no way impair their availability or quality: their use does not imply taking anything out of the environment. However, the environmental interventions in terms of emissions and extractions of "stuff" may cause problems in the area of loss of environmental quality or loss of biotic stocks or natural area, that may have adverse consequences for these services. We therefore include them in the specification of the impacts, rather than in the list of interventions.

2.4 Environmental impacts

The activities in our economy cause environmental interventions, which we narrowed down in the above to extractions of material resources, emissions and possibly the landfilling of waste, and the use and conversion of land. These interventions in turn lead to impacts on the environment, directly or through a chain of environmental processes.

Emissions to air and water are dispersed and deposited, leading to higher environmental concentrations and a potential loss of environmental quality. Emissions to soil may cause local pollution problems and contaminate groundwater and crops. Land use causes loss of habitat for species. All these things in the end may cause health problems, ecosystem degradation, loss of environmental services, or deregulation of the planetary ecosystem. To capture all this into one environmental indicator is a tall order. All attempts to do so must be regarded with the greatest caution. At the same time, there is a great demand for such an encompassing indicator: how else to evualuate the developments and attempts to steer society in a more sustainable direction? The indicators discussed in Chapter 3 all have done a brave attempt at composing such an encompassing indicator. In the aggregation of all the different types of impacts into the one indicator, some routes in general can be described again, which are sketched below.

2.4.1 Impact categories and areas of protection

MFA and IOTs/SUTs have not attempted to develop schemes to aggregate over all different types of impacts. In the LCA community, however, this has been a prime concern in the development of the Life Cycle Impact Assessment (LCIA). This has not resulted in one dominant approach, although harmonisation is ongoing. Basically, there are two main approaches. One is sometimes called the "midpoint approach": here, the environmental interventions are translated and added up into a limited (order of magnitude: 10) number of so-called impact categories, which refer to well-recognised environmental problems. Examples are: global warming, acidification, photochemical smog formation, and toxicity. The number of different categories is thus reduced from several hundreds to a dozen. Further aggregation can only take place by subjective weighting. The second is the "endpoint approach". Here, the philosophy is to model the environmental impact chain all the way up to the final impacts, which are then classified under some "areas of protection": human health damage, damage to nature, and damage to the human environment. Both approaches are used in the LCA community, each having its own advantages and drawbacks. The LCIA-scheme is also used outside the LCA community. It can be used in all cases where aggregation of a large number of emissions or extractions is required and a risk assessment therefore is not possible. It has been added to environmentally extended IOTs (Tukker et al., 2006; Tukker et al., 2009), and to eco-efficiency methods developed by companies (Rüdenauer et al., 2005), and therefore has a broader relevance.

The other way of adding up is by expressing all interventions into one unit. This can be a physical unit, such as kilogram, Joule or square meter. In economics, as mentioned before, there are also some approaches to assess environmental impacts or damage and translate this into monetary terms. Having a single unit enables adding up over the total of all impacts or damages.

Different aggregation methods are treated in sections 2.4.3 – 2.4.6.

2.4.2 Environmental inventories

A quite straightforward way of following the developments with regard to the state of the environment and environmental impacts, is to make frequent inventories of the environment itself. Any changes in that can be regarded as the consequence or impact of all economic activities in a country. To make these inventories is a very useful activity. It is difficult, however, to make the link with economic activities. Moreover, impacts may arise from transboundary pollution, or from production of products-to-be-exported. Therefore, an overall indicator of environmental pressure or impacts, which makes a distinction between impacts within and outside the country, cannot be based on environmental inventories only.

2.4.3 Aggregation methods: adding

Adding up is one of the most straightforward ways to arrive at an aggregate indicator. The main thing to do is then to find a common expression for the environmental interventions. For example, in the Ecological Footprint all interventions are translated into square meters, which then can be added to the total footprint. Material Flow Accounts express everything in kilograms, which can be added up easily to overall material input, output or throughput indicators. Aggregate energy or exergy accounts do something similar in terms of Joules. The problem with such indicators can be twofold: (1) the common expression may not be very relevant as an indicator for environmental impacts – this is signalled for example as a problem for mass based indicators, and (2) it may be that in order to arrive at a common expression a translation step is required which hides modelling or even weighting, making the indicator only seemingly straightforward.

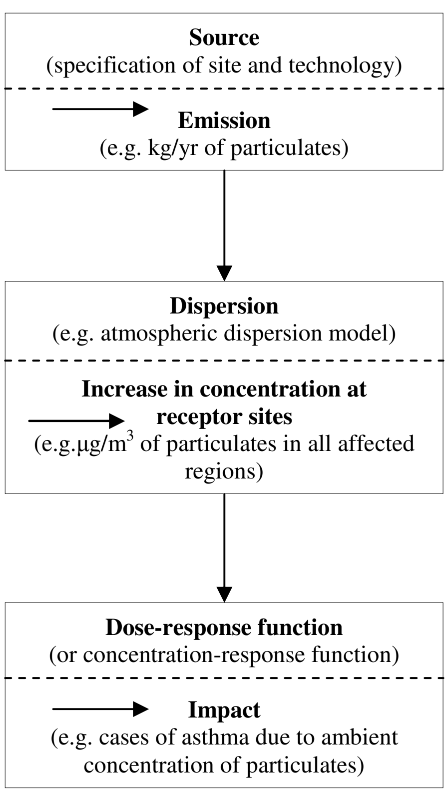
A little more sophisticated form of adding up is used in LCA: here, environmental interventions are added up to a limited number of impact categories. This is done by using a reference intervention and equivalency factors. For example, for the impact category of global warming the reference is CO_2, which therefore has an equivalency factor of 1. CH_4, a stronger greenhouse gas, has an equivalency of 23, which means that the emission of 1 kg CH_4 equals the emission of 23 kg of CO_2. In other words, 1 kg CH_4 can be expressed as 23 kg CO_2-equivalent. As all greenhouse gases have an equivalency factor, they can be added up to a total amount of kg CO_2-equivalents. The equivalency factors are calculated by using general environmental multimedia models that describe the fate and impacts of an emission. For each impact category, the modelling is different. While for global warming, acidification, eutrophication, ozone layer depletion and to a lesser extent photochemical smog formation the number of gases is limited and the agreement on how to derive equivalency factors is high, this is less so for other impact categories. In the area of toxicity, for example, the number of substances is huge, the impacts highly diverse and the underlying data on fate and toxicity incomplete. Depletion of resources is another impact category where consensus is yet far away. There are some approaches to derive equivalency factors for the depletion of abiotic resources. For biotic resource depletion, there are only some sketchy attempts, not yet applicable in practice. The same is true for land use, where there is no consensus on impact factors to add to the bare information of square meters used. Despite this fact, the adding-by-equivalency-factors is an easily applicable, generally accepted approach which is widely applied, within and outside the LCA community. From the point of view of defining all-encompassing indicators for decoupling, the advantage is that a huge number of different environmental interventions are reduced to a dozen or so impact categories. Further reduction in this approach is not possible: this can be done only by defining weighting factors for the different impact categories (see section 2.4.4).

2.4.4 Aggregation methods: modelling

A different approach to add up all the environmental interventions is to model them all the way through to the actual impacts they may cause. Not GHG- or toxicity equivalents, but mortality, morbidity (diseases), damage to building structures, agricultural crops and fishing stocks and reduced populations of certain species are the outcome of this approach. Units are, for example, Disability Adjusted Life Years (DALY) or Potentially Disappeared Fraction of certain organisms (PDF), (see e.g. NEEDS, 2008). Modelling defines the impacts on the so-called "end-point" level.

The modelling follows the impact-pathway approach.in which emissions are translated through dispersion models into physical impacts (see Figure 2.3).

Figure 2.3 Impact-pathway approach



Source: based on EC (2003)

The advantage is that the number of categories is even further reduced, to three or four categories. These can be further reduced by applying monetary valuation (see 2.4.6). Another advantage is that these endpoint-categories are expressing the real impacts, which after all is what it is all about. The major disadvantages are, in the first place the higher uncertainty compared to the midpoint approach, increasing with each modelling step, and in the second place the incomplete knowledge base, especially with respect to impacts on nature and biodiversity. .

While this way of aggregation comes a step closer to a real risk assessment, it must be kept in mind that the approach is still that of potential impacts and generalised or stylised environmental fate models.

2.4.5 Aggregation methods: panel / polictical weighting

One solution to the aggregation problem is to make a statement with regard to the relative severity of certain interventions, impact categories or areas of protection. This statement by definition is subjective. Some feel this is undesirable: the aggregation should be "scientifically sound" and therefore objective. Others see it as a recognition of the fact that there is always a subjective element in sustainability issues and sustainable development. Preferences and political priorities are important as well, and can be introduced in a prioritisation or weighting.

Weighting can be done in various ways:

- by a panel of scientists, drawing on their expert knowledge on the impacts of certain interventions or impact categories
- by a panel of stakeholders, as has been practiced before for specific case studies
- by politicians, based on the expressed policy priorities by governments
- by revealed preference, for example based on surveys

In the ISO-standard for LCA (ISO series 14040) weighting is explicitly restricted to certain situations. In other indicators, weighting is hidden in the procedure to add up. For example, the translation step in the Ecological Footprint from all kinds of environmental interventions to square meters involves non-objective choices. A seemingly objective indicator therefore can hide subjective elements. It is important to signal and recognise this.

2.4.6 Aggregation methods: monetary

Monetary aggregation is another way to come at a common denominator. In many tools from economics, like social cost-benefit analysis or green national accounting, environmental impacts are translated into their monetary value. Prices for environmental impacts are derived from implicit prices for environmental quality. As people cannot buy environmental quality on the market, the price for environmental goods must be derived implicitly from either questionnaires (stated preferences) or observed price changes of other goods (such as the price premium for a house in an unpolluted neighbourhood compared to the price of a house in a polluted neighbourhood – these are called revelead preferences).

There are two ways to arrive at a monetary estimation for environmental quality.

The **damage cost approach** originates from estimating a monetary value to the physical impacts at end-point level through modelling (see 2.4.4). Values for, for example, the risk of premature death due to environmental pollution are derived from higher salaries paid for more risky jobs, or through stated preferences. Research has indicated that the typical value of a life year lost would be somewhere between 40 to 200 thousand Euros. (Viscusy and Aldy, 2003; NEEDS, 2008). The literature on estimating values for health effects are abundant and country and source (e.g. agriculture, industry, transport) specific values for a number of pollutants have been published regularly from framework programs from the EC (see e.g. EC, 2003; NEEDS, 2008, Methodex, 2008). They are commonly used in cost-benefit analysis within the EC. However, monetary valuation of ecosystem and biodiversity effects is much less developed. One way put forward here is to arrive at an estimation based on the restoration costs to improve a land use with a higher number of species, i.e. assuming the restoration is performed in order to increase the biodiversity. The approach to estimate and evaluate the loss of biodiversity due to land use change is described in detail in Ott et al. (2006). This would imply costs like 0.45 euro/PDF/m2. Such values were also revealed using questionnaires by Kuik *et al.* (2008).

Damage costs have, so far and to our knowledge, not been used for weighting LCA-outcomes, although proposals and corresponding values have been proposed in the RECIPE project (see e.g. Heijungs, 2008).

The other approach uses **prevention costs** (abatement costs) to arrive at a monetary estimation of impacts on mid-point level. The idea is that instead of cumbersome monetary estimation of the preferences of citizens for environmental quality, an easier estimate can be established by determining the costs of meeting environmental policy targets. The costs established in this way boil down to specifying the additional costs for the national economy to avoid the interventions. If for example emissions of VOC would rise due to a policy plan, these costs need to be offsetted in order to safeguard the national emission limits for VOC.

Although this approach is more straightforward it critically hinges on the availability of national emission ceilings for pollutants. If such ceilings are not available, no estimate can be given using the prevention cost approach. Especially for all types of impacts on nature and biodiversity, the prevention cost approach gives no values as there does not exist a policy based “cap” on the expansion of the economic system in these areas.

The prevention cost approach has been used for weighting the outcomes from LCA (see e.g. CE Delft, 2007).

2.4.7 Comparison with carrying capacity

In order to judge the severity of the impacts, it can be useful to have a standard. This standard then could be the impact level that is still acceptable. What exactly is meant by acceptable is of course open to debate. The Dutch used to have a concept called "milieugebruiksruimte", sometimes translated as ecospace (Opschoor, 1995), meaning the amount of environmental interventions that can be caused without problems. A similar concept is that of "carrying capacity". Environmental indicators for specific problems often use a no-effect level or a critical load level. Most aggregate environmental indicators cannot be compared to such an acceptable level of interventions because they encompass lots of different interventions causing widely varying impacts. Such indicators can be used only in a comparative way: less is better. The Ecological Footprint, as an indicator expressing all interventions into one single unit, has the possibility to define a carrying capacity level. They have done so in the "biocapacity" of the world and individual countries. Mass or maney based indicators are expressed in a single unit but cannot be linked to an acceptable level, since the link with environmental impacts is too remote.

3 Indicators: description and data requirements

3.1 Indicator selection

Criteria to select potentially applicable indicators that at first sight conform to the demands of the Datacenters are the following:

- the indicator should be applicable at national level and at EU level
- it should be encompassing with regard to environmental impacts / pressure
- it should be based in statistical data and other generally accepted databases (potentially) available in EU data collecting institutions, more specifically Eurostat, EEA and JRC.

Based on these criteria we include the following indicators:

- Resource based indicators in resource input or throughput terms: DMC, TMR (section 3.2)
- Ecosystem/carrying capacity based indicators: HANPP (3.3), EF (3.4)
- Resource based indicators in terms of their life-cycle wide environmental impacts: EMC (3.5)

Aggregate environmental indicators can also be derived by adding up (for example, using the procedure out of the Life Cycle Impact Analysis) all environmental interventions being specified in a national Input Output table, or in a national satellite account of environmental interventions such as maintained by EEA. Such options are discussed in Section 3.6.

3.2 Domestic Material Consumption (DMC) and other MFA-derived indicators

3.2.1 Purpose, coverage and institutional aspects

MFA accounts are made for many countries in the world and certainly for all European countries, in time series from 1980 onwards. Eurostat has issued a methodology (Eurostat 2001), which is not yet used within its own doors: so far, the MFA time series have been drafted by a number of specialist institutes such as the Wuppertal Institut and IFF (Moll et al., 2003; Weisz et al., 2006). MFA accounts for the EU in the future are to be produced annually by Eurostat.

Indicators are derived from the MFA account. The most commonly used indicator is the DMC, the Domestic Material Consumption. This indicator is calculated as

total domestic extractions + total imports – total exports in terms of kg / year. Hidden flows (see section 2.2.1) are not included. Specific categories of materials, notably water, are excluded. For the remainder, everything appearing as trade flows in the statistics is included, be it raw materials, intermediates and products. The DMC is thus a measure for the total consumption in terms of mass in a national economy. As such, it is a measure for the metabolism or material basis of a society, or in other words a measure of the physical economy. MFA specialists maintain that DMC is also a measure, be it indirect, for the total environmental pressure of a national economy (Matthews et al., 2000): with each kilogram being taken out of the environment some impact is being created. This is disputed by others.

The DMC is not able to capture aspects of problem shifting to other countries. This aspect is covered in another MFA-related indicator: the TMR or Total Material Requirement, which is a sum of all imports and domestic extractions including both the domestic and the foreign hidden flows. The TMC (Total Materials Consumption) is derived from that: it is the TMR minus the exports and their hidden flows. TMC has the advantage, like the DMC but missing in the TMR, that it can be added up over different countries.

The DMC also does not specify the fate of the consumed materials. Waste and emissions are not visible, and neither is recycling. The Domestically Produced Output (DPO) is a measure of total waste and emissions from a national economy. It relies on less strong statistical data, with a wider variance over countries.

DMC is used to follow developments over time, but also to compare different economies with regard to their materials consumption. Figure 3.1 shows the DMC per capita for the year 2000 for 28 European countries; Figure 3.2 shows the DMC per capita development for these 28 countries together in a time series 1990 – 2000.

Figure 3.1 Domestic material consumption in 28 European countries in 2000, in 10^3 kg/cap.year (source: Moll et al., 2003)

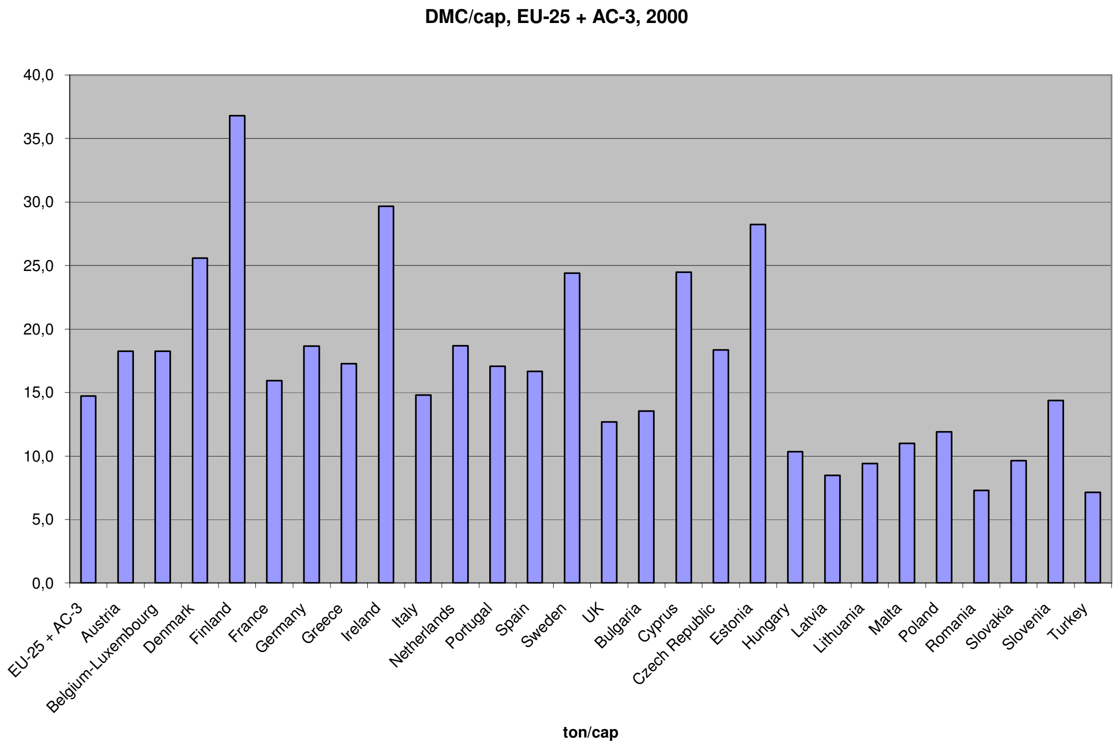
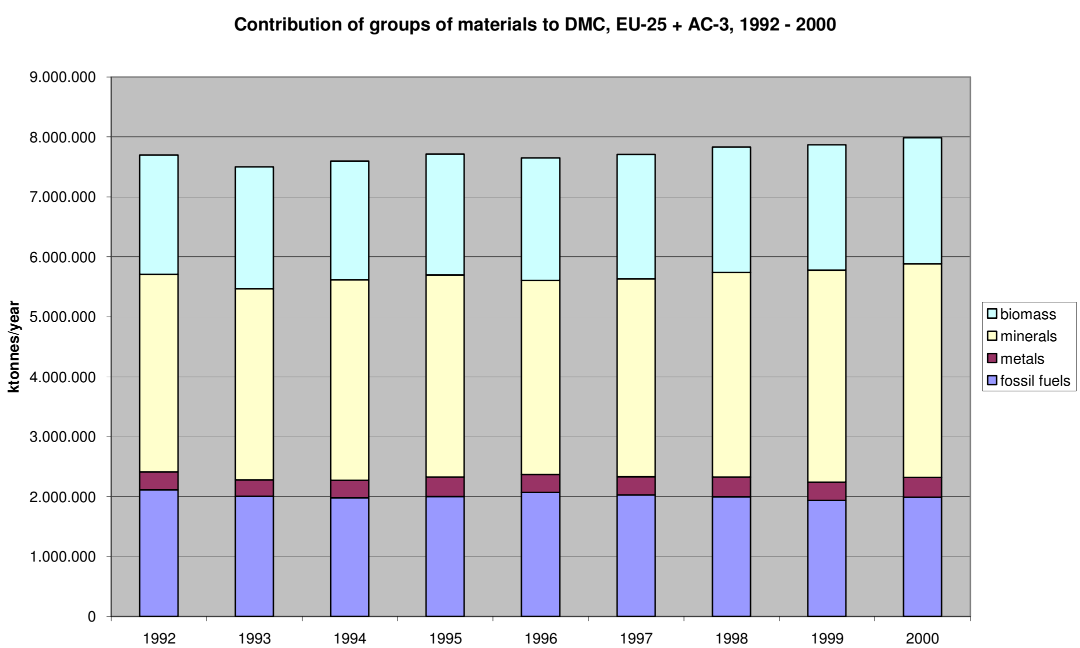


Figure 3.1 shows a quite large variation between countries.

Figure 3.2: Domestic material consumption for EU27+1, broken down into categories of materials, 1992 – 2000, in ktonnes/year. Source: van der Voet et al., 2005.



In Figure 3.2, rough categories of material flows are distinguished. The development over time is not striking. The comparison with Figure 3.1 leads to the conclusion that in Europe, there are significant differences between countries in the materials that they process, but that the changes over time in the metabolism of these economies are slow.

3.2.2 Description of economy

The description of the economy is consistent with the description provided in section 2.2.1: mass flows entering and leaving the national economy. A limited number of categories of flows can be distinguished (4 – 12).

3.2.3 Interface

The interventions in the MFA accounts are the domestic extractions plus hidden flows, and the waste and emissions of the DPO, again plus hidden flows. This last category of flows is excluded from the DMC and also from the TMC. The interventions therefore are limited to the extractions: only the domestic extractions in DMC, and all extractions (the total rucksack) in the TMC. It should be noted that harvesting of crops and grass is part of the extractions.

3.2.4 Environmental impacts: aggregation method and comparison with carrying capacity

No environmental impacts are provided or modelled in either the DMC or the TMC. The aggregation of consumed resp. extracted mass is presented as an indicator for environmental pressure. As stated above, this is one of the main criticisms heard with regard to these indicators, at least with regard to their use as indicators for environmental pressure.

3.2.5 Required data and (potentially) available data in EU Datacenters

Eurostat has drafted their MFA methodology guide based on generally available statistics. Trade and production statistics are to a large extent harmonised between countries, as are agriculture and forestry statistics. Some more problems are encountered for the estimate of the domestic extraction: statistics on mining and extraction of surface resources such as sand and gravel are less standardised and in some cases difficult to obtain. This can be a problem, since these flows are comparatively large and therefore have a large influence on the value of the DMC or TMC indicator.

3.2.6 Subjects for discussion

Environmental relevance and double decoupling.
As stated earlier, the relevance of the DMC and other aggregate indicators based on mass is disputed. The generally expressed criticism is that the input or throughput in kilograms, although obviously linked to environmental pressure, is only half of the story and because of that may point in a wrong direction. Large flows are connected to construction materials (sand and gravel) while their environmental impact is relatively small. Small scale toxic materials are relevant, but do not show up in a DMC. The other half of the story then is the impact potentials of specific resources or materials, which vary many orders of magnitude between resources. In the EU Resource Strategy, this point has been taken up elegantly by defining a double decoupling as a basic strategy: decoupling of economic growth from resource use, and decoupling of resource use from environmental impacts. That allows for the use of mass based indicators as indicators of the physical economy rather than environmental impacts: to measure decoupling of resource use from economic growth. But it means that a separate aggregate indicator has to be defined for environmental impacts, to measure decoupling of resource use from environmental impacts.

***System boundaries*:**
The MFA system boundaries, while consistently drawn and applied, are different from those used in LCA or IOTs. The most significant difference is that agricultural crop production is considered as part of the economic system in LCA and IOTs, while it is considered a part of the environment in MFA accounts. This means that crop harvesting is a resource extraction (intervention) in MFA, while it is not in LCA and IOTs. It also makes a difference in what is considered emission. The significance of this is not clear. However, in any attempt to combine the different methodologies to arrive at one comprehensive system or indicator, it has to be signalled and dealt with appropriately.

***Black box economy*:**
The main advantage of MFA accounts and indicators is that they provide a comprehensive picture of the physical economy. All inputs and outputs are included, as long as the statistics are there. This advantage is at the same time coupled to a disadvantage: the lack of transparency of the economic system itself. MFA accounts do not provide information on what happens to the inputs. No relation can be established between inputs and outputs. In what way the resources are used and enter the consumption phase is invisible. Recycling and reuse activities are only indirectly visible, f.e. as a reduction in flows of primary materials. This means that desaggregation is not really possible, and that the accounts are not suitable for any analysis at a more detailed level. As we have seen, they are mainly used to compare between countries and to follow developments over longer periods of time at the aggregate level.

3.3 *Human Appropriation of Net Primary Production*

3.3.1 Purpose, coverage and institutional aspects

Human Appropriation of Net Primary Production (HANPP) is a measure of human use of ecosystems. It measures which percentage of the net primary production of biomass (or energy or carbon embodied in it) in nature is used by humans, by land conversion and biomass harvest (e.g. Vitousek et al., 1986; Haberl et al., 2007; Imhoff et al., 2004). By this, it gives an indication of the scale of human activities compared to processes in nature (compare Daly, 2006).

The fundamental question how much of the earth's biomass production is used by humans was first raised in the 1970 (see e.g. Whittaker and Likens, 1973). Vitousek et al. (1986) came up with what now is widely regarded the first comprehensive analysis answering this question, estimating that 30 to 40% of primary biomass production was appropriated by humans. The concept was later elaborated particularly by the IFF group of Klagenfurt University in Vienna (e.g. Haberl et al., 2001a, 2001b, 2002, 2005 and 2007), and has also been used by NASA's scientists (Imhoff et al., 2004).

The concept finds a rather wide resonance in the academic world, but is not yet as widely used in policy making as for instance LCA- or MFA based indicators. Assessments using the HANPP are mainly produced by academics, and not or only incidentally by statistical offices or environmental agencies. Studies have been done at a regional level and a various assessments at global level are available, the latest with a base year of around 2000.(e.g. Imhoff et al., 2004; Haberl et al., 2007). Studies producing time series are available, but mainly at national and regional level (see f.i. Krausmann and Haberl, 2002, who studied amongst others the development of HANPP in Austria since the early 1800s). and if they are only at regional level. Since the number of groups performing HANPP studies is limited, the number of regions for which such studies with time series have been done are too. Where harmonized time series of emission and resource use/MFA data for most or a great number of countries in the world is available (cf Giljum et al., 2008) , the data mining in the field of HANPP seems not yet have reached this far.

Like with any indicator, differences in definitions can have a great influence in results. As will be discussed later, the IFF group has worked out a clear preferred method (Haberl et al., 2007), but in principle various approaches are possible, such as:

1. First, biomass flows can be expressed in various units. Examples are dry matter biomass (in kg/yr), energy (J/yr expressed as Upper heating value), or flows of carbon (kg/yr)
2. Second, various types of biomass can be covered (or excluded). Vitousek et al (1986) suggested three variations of the indicator: one based on direct use of biomass by humans (timber, food), one that added to this the primary production of human-dominated ecosystems (f.i. croplands), and one that took

additionally into account loss of Net Primary Production due to changes in ecosystem productivity (ecosystem degradation, land use change)[7];

3. Third, different reference situations for Net Primary Production can be chosen. One could for instance use the actual Net Primary Production in the ecosystem as is, but also the NPP in (hypothetical) undisturbed natural ecosystems (e.g. Wright, 1990)
4. Finally, particularly in regional studies one can make a difference between a production and consumption perspective: the NPP *produced* for human activity in that region, or the (direct and indirect) NPP *used* in that region by NPP embodied in products consumed. Virtually all HANPP studies use the production perspective, and assess which part of the NPP produced is input to the economy[8].

We will discuss the HANPP concept in more detail in sub section 3 of this chapter.

3.3.2 Description of economy

The HANPP concept as discussed above must be seen as a concept that only discusses processes in the environment. It calculates the primary production of biomass that is primary input to economic processes (most predominantly agriculture, forestry, etc.) – and stops there. Other economic processes are taken into account only indirectly, namely, if they lead to land use changes that impact NPP of the potential natural vegetation. In terms of the system of national accounts, HANPP can probably best be described as an 'extension' that characterises the impact of a sector on the environment in terms of primary biomass consumed.

The indicator hence

- does not describe material flows, economic activities nor financial flows in the economy.
- has no economic data as primary input for this indicator (neither from national accounts, input output tables, etc.)[9]

As discussed, the most prevalent applications of the indicator use a production perspective. The primary use of NPP in production processes in a region is what counts, not the NPP embedded in products and services consumed in that region. This already indicates that cross-country or cross-sectoral deliveries are unaccounted for. The forest industry and agriculture will most probably dominate the HANPP, where industries using products of these sectors (e.g. the furniture industry of food production industry) will

[7] On top of this, some authors seem to focus on the HANPP related to biomass consumed as food and fibre, which would exclude wood use and similar uses of biological material in the technosphere (Imhoff et al., 2004).

[8] A consumption perspective would show that densly populated areas would use far more NPP than produced in that area, simply since they import most primary materials from other areas, providing (immaterial) services or (less material-intensive) finished products in return.

[9] As will be discussed later, HANPP of course uses statistics on primary agricultural production, etc., but that concerns usually physical data from FAO.

have a HANPP of zero or close to zero. This simply relates to the fact that current applications and studies of HANPP are mainly done from an interest to assess how much NPP humans appropriate at global or country level and in general, rather than to single out specific sectors or consumption activities that drive HANPP[10].

As discussed, assessments of the development of HANPP in time are available, including analyses what drives changes in HANPP, but mainly at regional or national level. Global HANPP analyses tend to present the HANPP in specific grid cells and compares this pressure indicator between grid cells, rather than between countries (see e.g. fig. 2).

3.3.3 Interface

We will base our assessment on the HANPP concept as defined by IFF, which seems to have gained most acceptance at this moment. It has to be acknowledge though, that this consensus is by far not yet as solid as for instance is the case with MFA, LCIA and Ecological Footprint indicators. Despite some remaining discussions, the latter are all supported by seizable academic communities, standards, and/or handbooks endorsed by governments, statistical offices, or environmental agencies. In the case of HANPP, it mainly seems to be the considerable research and dissemination effort of IFF itself that makes their definition the most prominent available at the moment.

Figure 3.3 shows the IFF concept of HANPP (Haberl et al, 2007). As discussed, HANPP is calculated from a production perspective, and compares potential NPP produced in a region with harvested NPP used in a region as primary input into production. First, they assess the NPP_0, which is the NPP of the vegetation that would be assumed to prevail in the absence of human land use (potential vegetation; Tüxen, 1956). Second, they assess the NPP_{act}, i.e. the NPP of the currently prevailing vegetation. The difference between NPP_0 and NPP_{act} equals NPP changes due to processes like ecosystem change, soil degradation and soil sealing ($dNPP_{lc}$). Third, they analyse NPP_h, which is the NPP harvested for human use. The difference between NPP_{act} and NPP_h is the NPP remaining in the ecosystem after harvest (NPP_t). The HANPP can now be expressed in two ways:

$HANPP = NPP_o - NPP_t$ (NPP of potential vegetation minus NPP remaining after harvest)
$HANPP = NNP_h + dNPP_{lc}$ (NPP loss by harvest and land cover changes)

The indicator is hence essentially covering, as environmental intervention, a specific type of resource extraction (harvest) and land use change, and expresses this as use of biomass. The most elaborated studies use quite detailed location specific data-sets, and tend to present the percentage HANPP in a specific region on maps, which are also easily understandable by and communicable to non experts. An example is given in Figure 3.4

[10] Using HANPP in a context of environmentally extended input output analysis (EE IO) or physical input output tables could rather easily add such perspectives, but such approaches seem not (yet) broadly applied by the HANPP community nor EE IO community (cf. Haberl et al., 2004). For HANPP detailed calculations are needed, and the main issue is to allocate specific contributors to the overall HANPP in a region to specific industry sectors (as indicated, most notably agriculture and forestry)

Figure 3.3: HANPP definition as proposed by Haberl et al. (2004: 282; 2007)

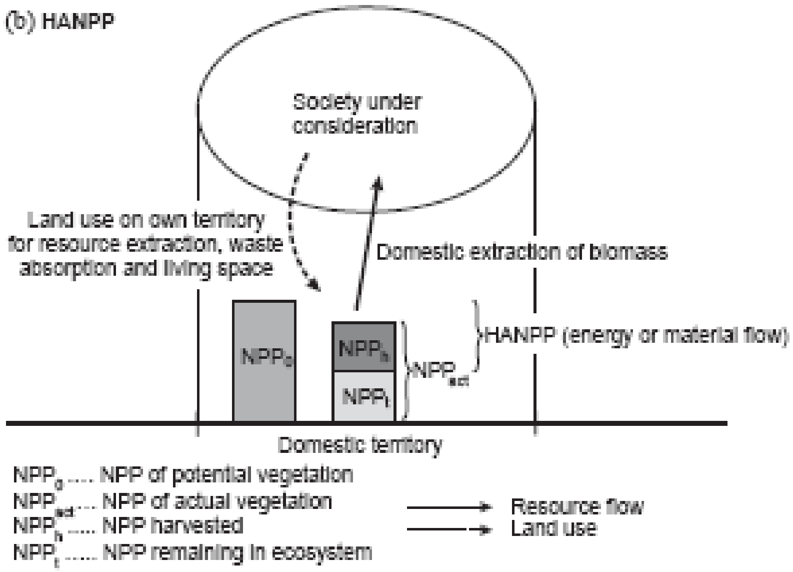
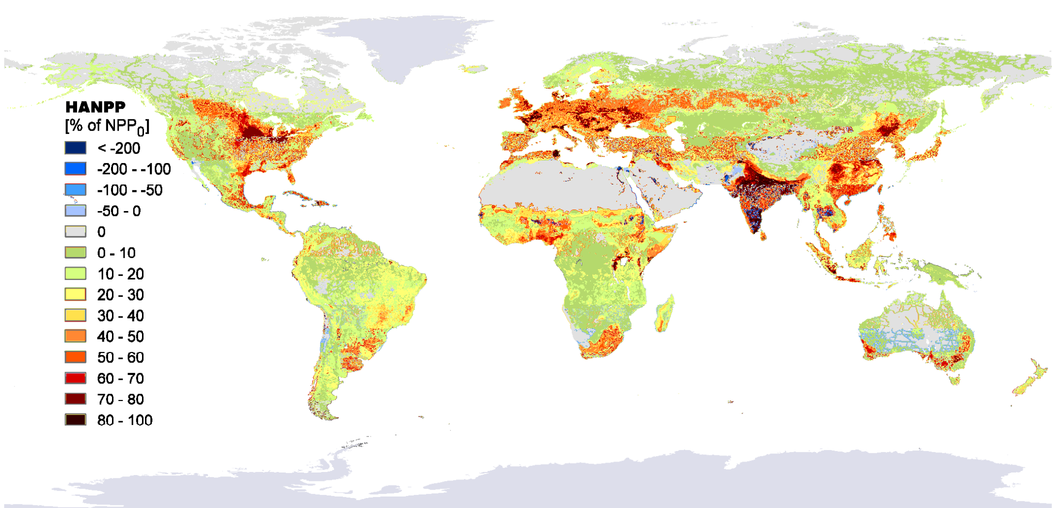


Figure 3.4: Map of the global human appropriation of net primary production (HANPP) in the year 2000 (taken from: Haberl et al., 2007).



3.3.4 Environmental impacts: aggregation method and comparison with carrying capacity

As follows from the former section, the HANPP essentially covers the following environmental interventions:

- Resource consumption as far as natural biomass is concerned;
- Land use change as far as this affects and changes NPP of biomass.

These are translated into the appropriation of NPP by humans. The impact therefore could be defined as: reduction of the biomass base of natural ecosystems and of all species besides Homo sapiens and its domesticated species. Indirectly, HANPP thus is an indicator on destruction or physical change of natural habitats.

A large number of other impacts for instance taken into account in environmental monitoring studies ore life cycle assessments remain uncovered. This is mainly due to the way how HANPP is defined, with its strict focus on NPP of biomass. HANPP hence does not take into account impact categories like (cf. Guinee, 2002; Best et al., 2008)[11]

- Extraction of non-renewable resources (fossil fuels, metals, etc.) [12]:;
- Emissions of substances contributing to
    - Human toxicity
    - Climage change
    - Acidification
    - Eutrophication
    - Stratospheric Ozone depletion
    - Photo-oxidant formation;
    - Ecotoxicity;
- Ionizing radiation.

In theory one could of course try to calculate the impact of emissions and ionizing radiation on NPP, but this would require extensive modelling excercises that to our knowledge not yet have been done for the purpose of fine tuning HANPP.

The HANPP does not formally aggregate different environmental impacts: it is an impact indicator in itself, that by calculating HANPP on gets insight into natural biomass

[11] Note that 'waste' is not an impact, though erroneously sometimes seen as such. The logic is that waste is treated or landfilled, and by this, generates impacts due to emissions or land use. It are such true impacts that should be taken into account to assess the 'impact' of waste.

[12] We neglect here the usually small contribution to HANPP by land cover changes by e.g. the mining industry. It is interesting to note that until now authors developing the HANPP refused to seek resource to an approach that the Ecological Footprint community applies to include impacts of energy use / global warming. In the Ecological Footprint, the use of fossil fuels or impacts of CO2 emissions are taken into account by a *virtual* land use that would be needed to grow biomass that would absorb the CO2 or lead to the same production of energy as embodied in the fossil fuels. The HANPP could rather easily include the use of fossil fuels via a similar approach. The likely result would be a very similar message as conveyed by the EF community: that humans are using far more NPP than produced currently in nature, and that humanity hence lives on its bank account rather than current income. With the main part of human energy use coming from fossil fuels from stocks build up millions of years ago, this should in fact be obvious without EF indicators or similar.

consumption, including implicit consumption related to land use change, which in turn gives some insight in impacts on ecosystems and biodiversity.

In principle, once could use the HANPP as a benchmark for carrying capacity. Very much in line with the Ecological Footprint, one could argue that a HANPP larger than 100% would be intolerable and hence would pose an absolute limit. Such a use of HANPP is however much less straightforward as in the case of the EF. In the words of Haberl et al (2004):

> *"There is no clear 'sustainability threshold'. While it is clear that 100% HANPP would be destructive because this would leave no resources for other species than those needed for human purposes, it is debatable how to set a meaningful lower threshold."*

Other problems include that economic growth does not in all cases imply a rise in HANPP. Modern intensive agricultural systems that come with industrialisation have a higher NPP_{act} (even to levels above NPP_o), so that even with a rise of NPP_h also a higher NNP_t occurs, and hence a lower HANPP is the result(Davidson, 2000, Haberl et al., 2001, Krausmann, 2001). They see a much more productive use of the HANPP as a relative indicator. A downward trend of NPP_{act} would be an early warning of environmental degradation. A HANPP rising over time is a clear warning that a society may put too much strain on its bioproductive land (Haberl et al., 2004; 2007).

3.3.5 Required data and (potentially) available data at EU-datacenters

The components of the indicator have been discussed in section 3.2.3. Calculating the indicator required a significant amount of data, particularly if one wants to do so on a high level of spatial resolution. For each spatial 'cell', somehow NPP_o, NPP_h and NPP_{act} have to be calculated. Usually, geographic information systems (GIS) are used as an auxiliary instrument. Haberl et al. (2007) indicate that data collection usually takes place as follows, and also list various conceptual and practical problems.

- NPP_o usually is calculated with the help of Dynamic Global Vegetation Models, DGVMs (for instance Cramer et al., 1999). Alternatively, typical values of NPP per unit area and year can be extrapolated from literature (e.g., Ajtay et al., 1979). Finally, there are very simple models that calculate an NPPo on the basis of simple parameters like mean annual temperature and precipitation, such as Lieth's "Miami model" (Lieth, 1975).
- NPP_{act} requires a reliable spatially explicit data set on land use and land cover in a a GIS database. Such data have to be combined with agricultural and forestry statistics as well as forest inventories, and a challenge here is the mutual consistency of such datasets. Per type of land, calculations work roughly as follows:
    - For cropland, total NPP is usually extrapolated via harvest indices from the amount of crop harvested according to agricultural statistics (e.g. FAO, 2005; Wirsenisus, 2003).

- For harvested forests, NPP is usually set equal to the NPP of unmanaged forest (e.g., Haberl et al., 2001).
    - For areas without much human use NPP_0 is often assumed to be equal to NPP_{act}.
    - Built up land is assumed to have an NPPact of zero, though parks, roadsides etc. often have a high NPPact and must not be neglected.
    - For grazing land, many problems exist. First, statistics usually do not discern different type of grazing land or, if they do, are unreliable. Second, the effect of mowing and grazing on productivity is not well understood.
- NPP_h requires data on the actual harvested amount of biomass. Sources for such data include:
    - For crops and timber harvest data are usually directly available from statistical sources (e.g. FAO 2005a). For forests, unreliabilities are introduced by woodfuel gathering and the non reporting of illegal logging in the tropics[13].
    - The estimation of NPPh from grazing land is much more problematic. Such flows are usually not recorded in statistics. The way out is to estimate what has been called the 'grazing gap', i.e the difference between a theoretical need for fodder of animals in the agricultural sector, minus fodder bought at the market. The differences is assumed to be biomass grazed by livestock or hay mowed (cf Wirsenius 2000).

The data sources are summarized in Table 3.1, taken from Best et al. (2008: 119)

Table 3.1: Data sources needed to calculate HANPP (from Best et al., 2008:119)

Tool	Data category	Data source
HANPP	Harvest of biomass	Agriculture: • FAOSTAT (rated as generally good quality): http://faostat.fao.org/default.aspx Forestry: • FAOSTAT (rated as problematic for some countries; problems of underreporting of illegal logging and missing data on fuel wood consumption) : http://faostat.fao.org/default.aspx Grazing: • Most problematic category as not reported in official statistics. Most reliable approach to calculate the "grazing gap", i.e. the amount of biomass required for feeding the life-stock after considering other market feed products. Recommended: use of livestock feed balances.
	Net primary production of the potential vegetation	Different approaches to calculate potential net primary production • Use of Dynamic Global Vegetation Models • Extrapolation of typical net primary production reported in literature • Simple models, which calculate potential vegetation based on data on mean annual temperature and precipitation • If map shall be produced, these data must be spatially explicit (i.e. GIS data)
	Net primary production of the actual vegetation	Several components must be covered: • Agricultural production can be covered through extrapolating total NPP from the amount of harvested crop (taken from agricultural statistics) • Forestry production is mostly covered using the assumption that NPP of managed forests equals NPP of unmanaged forests • Grazing land is the most problematic category, as (a) data on grazing areas is relatively poor and (b) effects of grazing on actual primary production • Again, the availability o f a reliable data set on land cover and related land use is of high priority for the preparation of spatially explicit maps.

Overseeing this data mining approach, it is striking how much data from various sources have to be combined and how little readily available data from formal statistical sources

[13] A further practical problem is that trees take decades to grow, but are harvested in a specific year. In the year that a part of a forest is logged, hence inevitably a negative HANPP would occur at local scale. Such anomalies can be mitigated by using an average forest growth and wood harvest over larger regions.

like Eurostat, DG JRC and the European Environment Agency can be used. Estimates of NPP_o largely rely on model calculations. NPP_h does use to a large extent (physical) data on production from agriculture and forestry, but must be supplemented with other estimates. The same applies for NPP_{act}. Where in general such data are publicly available, they have to be gathered from many different sources and re-elaborated. It is hence not surprising that HANPP currently still is an indicator that is mainly produced by people in academic circles –a significant extension of formal statistical data gathering would be needed before e.g. EUROSTAT would be able to calculate HANPP on a regular basis. Furthermore, it is striking that many authors use in fact data from global statistical sources like FAO, most probably since they need consistent data sets across the countries they cover in their (often global) studies.

3.3.6 Subjects for discussion

Relation to economic activity
One of the issues related to the use of the HANPP indicator to measure decoupling, is the limited possibility to link it to economic activity in general, and economic activities in particular. Partly this is due to the fact that only a limited number of sectors (notably agriculture and forestry) are included at all. Partly, it comes from the fact that this relation is not established specifically as a model relationship. The starting point is different. This does not automatically imply the HANPP cannot be used as an aggregate impact indicator in a decoupling framework. It does, however, mean that changes in society do not translate automatically into changes in HANPP. This must be kept in mind when using this indicator.

Interpretation of the indicator
As discussed above, the interpretation of the HANPP indicator is not straightforward. The 100% of appropriation seems like an abolute limit, but even that is not quite clear since values above 100% are also possible. Even a general "less is better" does not seem to be valid in all cases. Nor is an optimum level to be distinguished. On the other hand, the HANPP allows for differences in intensity of land use by humans, which is not visible in an indicator of square meters. This is a really important aspect which is not covered in any other indicator.

Environmental impacts
The main problem with the use of HANPP as aggregate indicator of environmental impacts will be the fact that so little of the total of all environmental impacts is included. Unlike MFA-related indicators, HANPP is not presented as indicative for all environmental impacts. This would imply HANPP can, in such a policy context, only be used in a basket and not as a single indicator.

3.4 *Ecological Footprint*

3.4.1 Purpose, coverage and institutional aspects

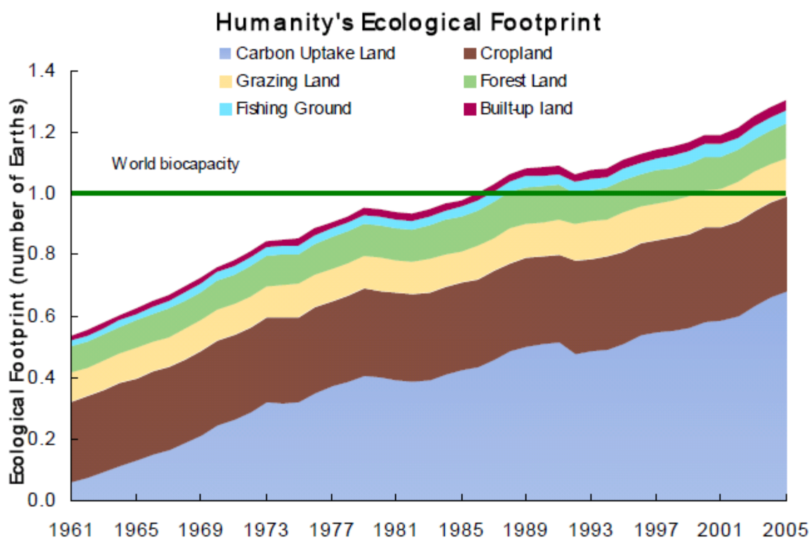
The concept of the Ecological Footprint was developed by William Rees and his student Mathis Wackernagel in the early '90s (McManus & Haugton 2006). It was developed as a tool to document to what extent human activities compromise the biosphere's ability to regenerate (Wackernagel et al. 2005).

The Ecological Footprint is a resource accounting tool that measures how much biologically productive land and water area a population uses to produce the resources it consumes and the waste it generates, taken the prevailing technology and resource management into account (Kitzes et al. 2007). Ecological Footprint *accounts* do not only consist of the Ecological Footprint, or the demand side, but also list the bioproductive areas, or the supply side. With these accounts, the amount of the regenerative capacity of the biosphere occupied by human activities can be measured. When a country has an ecological deficit, it means that the Ecological Footprint of the population exceeds the available biocapacity of the country. A global ecological deficit cannot be offset by trade and is equivalent to the annual global overshoot (Monfreda et al. 2004).

The Ecological Footprint is expressed in global hectares, which is a hectare with the world's average biological productivity. To translate actual into global hectares, equivalence factors and yield factors are applied. Equivalence factors represent the world's average potential productivity of a certain area to the world average potential productivity of all areas. Yield factors relate the productivity of an area in a particular country to the global average productivity of that type of area. (Wackernagel et al. 2005)

The Ecological Footprint is mostly used for communication and education purposes to show whether the current consumption is within the limits of what the earth can sustain (Schaefer et al. 2006). See for example figure 3.5. Ecological Footprints are very effective for raising awareness on environmental sustainability and can be used to evaluate personal lifestyles (Giljum et al. 2007). However, the Ecological Footprint is an accounting tool, which means that it may inform choices but cannot advocate any particular policy. Also, Ecological Footprint accounts have no predictive powers as they do not relate current nature use to future losses of biocapacity.

Figure 3.5. The global Ecological Footprint over time



Source: GFN (2008a)

The most widely used methodology for calculating national Footprints are the National Footprint Accounts by the Global Footprint Network. The Global Footprint Network (GFN) is the organization that promotes the application of Ecological Footprint accounts and is supported by more than 90 partner organizations. The National Footprint accounts are calculated annually for more than 150 countries. The Global Footprint standards (GFN 2006b) have been initiated by the Global Footprint Network to reach consensus on a common calculation method for the Ecological Footprints. Partners of the Global Footprint Network are required to comply with the most recent Ecological Footprint standards.

3.4.2 Description of economy

The Ecological Footprint follows the principle of consumer responsibility (Kitzes et al. 2007b). It is based on the land consumption of the residents of a country. Tourism and electricity generation are the only exceptions. Tourism activities are attributed to the country in which they occur, rather than the tourist's country of origin (Kitzes et al. 2007b). It is also not possible to allocate electricity to the final consumer, instead it is allocated to the country where it is generated (Kitzes et al. 2007).

There is no direct relationship between the Footprint and the GDP (Gross Domestic Product) of a country as the GDP relates to national production, while the Ecological Footprint relates to the national consumption. Furthermore, the Ecological Footprint does not include services.

The National Footprint Accounts include more than 700 renewable resources, among which crops, fuelwood, forage and fish and one waste product, carbon dioxide.
The Ecological Footprint does not account for the depletion of non-renewable resources like metals. Consequently, for the consumption of –for example- cars, only the energy needed to manufacture the cars is included in the Footprint.

The data necessary to calculate the National Footprint Accounts are mainly from international statistical and scientific agencies.
The primary resources are tracked based on FAOSTAT data. The FAO documents data on production, import and export data of many resources. The primary resources embodied in manufactured products are tracked using data from the UN Statistical Department COMTRADE global trade database.
Currently, research is undertaken to use input-output tables as input to calculate the Ecological Footprint accounts. Difficulties that have prevented applying the input-output method are related to data availability and compatibility (Turner et al, 2007). With input-output tables as input, sector analyses are possible.

3.4.3 Interface

The Ecological Footprint accounts consist of a supply side (Biocapacity) and a demand side (Ecological Footprint).

Six land categories are tracked: cropland, grazing land, fishing grounds, forest area, built-up land and carbon demand on land. These land categories are expressed in standardized units of biologically productive area: global hectares. One global hectare is equal to one hectare with a productivity equal to the average productivity of all the bioproductive areas on Earth. Two conversion factors are used to translate real hectares into global hectares:

1. yield factors, that compare national average yield per hectare to world average yield in the same land category;
2. equivalence factors, that capture the relative productivity among the various land and sea area types (see Table 3.2).

Table 3.2 Ecological Footprint Equivalence factors for types of land use, 2005

Area type	Equivalence Factor (gha/ha)
Primary cropland	2.64
Forest	1.33
Grazing land	0.50
Marine	0.40
Inland water	0.4
Built-up land	2.64

Source: GFN (2008b)

For the **demand side** of the accounts, the Footprints of renewable resources, built-up area and fossil fuels are calculated.

The Footprint of *renewable resources* include food items like milk, vegetables and fish, cotton, vegetable oils and wood. Primary products are the unprocessed outputs of an area, for example raw fruits and vegetables. They can be consumed directly or processed into secondary products. The Footprint intensity of primary products is the same anywhere in the world, since it is expressed in global hectares. However, the embodied Footprint of secondary products depends on transformation efficiencies ("extraction rates"), which vary between countries.
The consumption Footprint of a country measures the biocapacity demanded by the final consumption of all the residents of the nation. To arrive at the consumption Footprint, the Ecological Footprint of production is adjusted for the embodied Footprint of trade, which is calculated assuming the world average Footprint intensities for all products.

The Footprint of *built-up area* is equal to the foregone agricultural productivity of these areas. It is assumed that built-up areas occupy formerly cropland.

The Footprint of *fossil fuels* is equal to the bioproductive area needed to assimilate the waste (CO_2). It is estimated by the bioproductive area needed to sequester the CO_2 emission through afforestation. The national CO_2 emissions equal the CO_2 emissions from national fossil fuel production minus the CO_2 embodied in exported products plus the CO_2 embodied in imported products.

For the **supply side** of the accounts, the biocapacity of a country is calculated. The number of hectares are multiplied by their equivalence factors and the national yield factors. The global hectares of the six land categories are then summed to get the total national biocapacity.

3.4.4 Environmental impacts

The Ecological Footprint does not include activities that erode the nature's *future* regenerative capacity nor does it include the physical use of non-renewable resources. It therefore excludes the release of materials for which the biosphere has no assimilation capacity (pollution by heavy metals or radioactive materials) and processes that damage the future capacity of the biosphere (for example the loss of biodiversity or soil erosion from tilling). Moreover, the emissions of greenhouse gases other than carbon dioxide are not included in the calculations.

Since the Ecological Footprint was intended as a consumption indicator and not as an environmental impact indicator, it is, as Giljum et al. (2007) and Best et al. (2008) point out, an inadequate measure for environmental impacts of resource consumption (climate change, acidification, eutrophication) and biodiversity.

Table 3.3 gives an overview of the coverage of different environmental impacts by the Ecological Footprint from Best et al. (2008).

Table 3.3 Coverage of environmental impacts by the Ecological Footprint

Environmental impact	**Analysis**
Resource consumption	Includes only renewable and biotic resources.
Climate change	Includes the forestland to sequester CO_2 released by fossil fuel, but does not include other greenhouse gases.
Biological diversity	Is not explicitly addressed, but is indirectly assessed as it is connected with the pressure from the use of biological resources.
Land use	The Footprint expressed the amount of resources used in terms of the land area needed to produce these resources or to absorb wastes.
Stratospheric ozone depletion	Is not addressed.
Eco-toxicity	Is not directly addressed (although it can be reflected in future Footprint accounts[14]).
Acidification	Is not directly addressed (although it can be reflected in future Footprint accounts[13]).
Eutrophication	Is not directly addressed (although it can be reflected in future Footprint accounts[13]).
Ionising radiation	Is not addressed.
Human toxicity	Is not addressed.
Smog formation	Is not directly addressed (although it can be reflected in future Footprint accounts[2]).
Final waste	Includes only CO_2 as waste product.

Source: Best et al. (2008)

The population a particular area can support is known as the carrying capacity[15] of the environment. The Ecological Footprint measures how much regenerative capacity is occupied by human activities. The Ecological Footprint therefore inverts the carrying capacity ratio by trying to answer the question how large an area is needed to support a particular population. It does not measure the impact on the *future* carrying capacity (Rees, 2006).

3.4.5 Required data

The 2008 Edition of National Footprint accounts tracks the embodied Footprint of over 700 categories of traded agricultural, forest, livestock and fish products. The embodied energy in more than 600 categories of products is used with trade flows from the United Nation's COMTRADE database to generate estimates of the embodied carbon Footprint in traded goods.
A more detailed description of the data required to calculate the Footprint of the six components and the biocapacity is given below.

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[14] If eco-toxicity, acidification, eutrophication or smog formation lowers the biocapacity, it could alter future EF accounts.
[15] Carrying capacity refers to the number of individuals who can be supported in a given area within natural resource limits, and without degrading the environment for present and future generations (Carrying Capacity Network, http://www.carryingcapacity.org/)

1. Cropland Footprint

Table 3.4 Data sources for the cropland Footprint

Data	Data source
Production and area	FAO ProdSTAT Statistical Database
Imports and exports	FAO TradeSTAT Statistical Database
Conversion factors for secondary agricultural products	FAO Technical Conversion Factors for Agricultural Commodities (v beta 1.g)
Agricultural commodity prices	FAO TradeSTAT Statistical Database

Source: GFN (2008b)

2. Grazing Land Footprint

Table 3.5 Data sources for the grazing land Footprint

Data	Data source
Production and livestock populations	FAO ProdSTAT Statistical Database
Imports and exports	FAO TradeSTAT Statistical Database
Feed efficiency and feed intake	Haberl et al. (2007)
Dry matter percent	Haberl et al. (2007)
Market feed percent	FAO Supply Utilization Accounts Statistical Database, 2003
Animal weights	Vaclav Smil (2000)
Above ground NPP	Chad Monfreda (personal communication), 2008 SAGE, University of Wisconsin, Madison
Number of animals in stock	FAO ResourceSTAT Statistical Database
Extraction rates	FAO Technial Conversion Factors for Agricultural Commodities

Source: GFN (2008b)

3. Forest Footprint

Table 3.6 Data sources for the forest Footprint

Data	Data source
Production, imports, exports	FAO ForesSTAT Statistical Database
Secondary product extraction rates	UNECE & FAO (2005), European Forest Sector Outlook Study
Net annual increment	UNECE & FAO (2000), Temperate and Boreal Forest Resource Assessment. FAO (1998), Global Fiber Supply Model IPCC (2006)

Source: GFN (2008b)

4. Fishing Grounds Footprint

Table 3.7 Data sources for the fishing grounds Footprint

Data	Data source
Production, imports, exports	FAO FishSTAT Fisheries Statistical Database
Trophic levels	Fishbase Database, Froese & Pauly (2008)

Area of EEZ	Sea Around Us Project (2008)
Discard factor, transfer efficiency, carbon content of fish per tonne wet weight	Pauly & Christensen (1995)
Sustainable catch	Gulland (1971)

Source: GFN (2008b)

5. Carbon Footprint

Table 3.8 Data sources for the carbon Footprint

Data	**Data source**
Emissions from fossil fuels, by country and economic sector	IEA CO_2 Emissions from Fuel Combustion Database, 2007
Emissions from fossil fuels by country	Marland, Boden & Andres (2007)
International trade quantities by commodity	UN Commodity Trade Statistics Database
Embodied energy of traded commodities	GFN internal database, available upon request
Carbon sequestration factor	IPCC (2006)
Ocean sequestration	IPCC (2001)
World heat and electricity carbon intensity	IEA CO_2 Emissions from Fuel Combustion Database, 2007

Source: GFN (2008b)

6. Built-up Land Footprint

Table 3.9 Data sources for the built-up land Footprint

Data	**Data source**
Infrastructure area	World Resources Institute Global Land Cover Classification Database
Hydroelectricity production	British Petroleum, 2007, Statistical Review of World Energy
Yield for Hydroelectricity	Goodland (1997)

Source: GFN (2008b)

7. Biocapacity

Table 3.10 Data sources for Biocapacity

Data	**Data source**
First source for land areas	Corine Land Cover (2000)
Second source for data on cropland, grazing land, other wooded land, inland waters	FAO ResourceSTAT Statistical Database
Second source for built-up areas	Global Agro-Ecological Zones (2000)
Only source for area of marine continental shelf	WRI Global Land Cover Classification Database

Source: GFN (2008b)

3.4.6 Subjects for discussion

Definition of sustainability

The Ecological Footprint is an indicator based on 'strong sustainability'. Strong sustainability means that natural and economic resources are no substitutes. Sustainability within the EF concept can mean: is a country able to live within it's own biocapacity? A drawback is that densely populated countries are put at a disadvantage. This interpretation of sustainability could also be seen as anti-trade: "some form of self-sufficiency is the most desirable situation" as noted by Van den Bergh & Verbruggen (1999, p. 67). However, sustainability within the EF concept could also mean: is a person's Footprint below the global average biocapacity? This measure of sustainability is not anti-trade. Unfortunately, global yield factors are included in the Ecological Footprint and eventual efficiency gains translate themselves in national enlargement of the biocapacity. This implies that the measure of relating the EF to the global average biocapacity will miss eventual gains in national yield efficiency. Hence, this second measure misses some of the dynamics that are inherent in the first measure of sustainability.

Aggregation of land area categories

The aggregation of several land area categories to calculate the Footprint has been criticized by many authors.
The weighting factors used –the equivalence and yield factors- do not reflect relative scarcity over time, as Van den Bergh & Verbruggen (1999) point out. Stoeglehner & Narodoslawsky (2008) note that the aggregation of land areas does not distinguish sustainable and non-sustainable resource consumption. Finally, the assumption of a fixed substitution rate between different land use categories means that different categories are given the same weights, even though their environmental impacts can differ substantially. Land use for infrastructure for example has the same weight as land use for agriculture (Giljum et al. 2007).

Fossil fuel Footprint

As can be seen from figure 3.5, CO_2 from fossil fuels account for most of the global Ecological Footprint, although the method to calculate the Footprint of fossil fuels is subject to criticism. Critics like Van den Bergh & Verbruggen (1999) argue that the Ecological Footprint is biased upwards, because the calculation method neglects the selection of economically more rational options like CO_2 removal or shifts to other fuels. It is also not yet possible to allocate electricity to the final consumer, instead it is allocated to the country where it is generated (Kitzes et al. 2007a).

Biocapacity

The footprint of a country calculates the overshoot of an individual country: the EF is compared to the biocapacity. This is needed because technical progress reflects itself in an enlarged biocapacity – not into a reduced footprint. As a consequence densely populated countries have a much larger overshoot than sparsely populated countries. This gives little guidance to policy makers. Indeed reducing population growth through stringent immigration laws may have a more profound influence on the EF-overshoot than environmental policies.

3.5 Environmentally weighed Material Consumption (EMC)

3.5.1 Purpose, coverage and institutional aspects

The environmentally weighed material consumption indicator, EMC, is drafted as an overall decoupling indicator to support the EU Thematic Strategy on Natural Resources. Together with the GDP and the DMC (Domestic Material Consumption) based on Material Flow Accounts, the EMC can be used to measure "double decoupling": economic growth from resource use, and resource use from environmental impacts. The EMC is calculated by multiplying the material flows that are ‘consumed’ by an economy with a factor of their environmental impact per kg consumed material. A double aggregation step is made by adding over materials to approach the total metabolism of a national economy, and by adding over different impact categories to arrive at a total estimate of environmental impacts, where the contribution of the different materials as well as the contribution of the impact categories is still visible.

Two types of information are generated and used to determine the environmental impacts of materials that are consumed by an economy:
- the total cradle-to-grave impact per kg of each material
- the number of kilograms of each material being consumed.

To specify the environmental impacts of a material, a life-cycle approach is taken. This implies that impacts over the life-cycle, whether they occur within or outside the country, are included. For every considered material, an estimate is made of the emissions to and extractions from the environment throughout its life cycle. This includes not only the emissions and extractions of the material itself, but also those related to energy and auxiliary materials used for its extraction and production, emissions of impurities and pollutants included in the material during use or waste treatment, etcetera. These emissions and extractions are translated into a limited number of impact categories according to the LCA-methodology (Guinée et al., 2002), which in turn can be aggregated to one overall impact score.

The number of kilograms of a material being consumed in a national economy is determined by drafting material balances per material. For this, MFA accounts, industrial and agricultural production statistics and trade statistics are used, with some additional information.

In 2005 a first European version of the EMC, henceforward called EMC2005, has been elaborated for the EC for 28 European countries, in time series for the years 1990-2000 (van der Voet *et al.*, 2005). Options to improve this prototype-EMC are indicated in that report and are also discussed in Chapter 6 of this report.

3.5.2 Description of economy

The EMC2005 is designed to give an indication of the environmental pressure due to *total economy-wide activities* within an EU member state. As a proxy of the economic activity in an EU member state the *apparent consumption of finished materials* is used, expressed in physical terms, i.e. kg. A finished material is a material not yet applied in assembled, i.e. multi material, products. At the level of finished materials the resources from which the materials originate are still recognizable. At the same time, the list of materials is still rather limited, as opposed to a product-oriented approach.

EMC thus uses an MFA-like description of the economy, with materials and not economic sectors or activities as the point of entrance, although it does not conform to the Eurostat MFA guide. In the EMC2005 the apparent consumption of finished materials is calculated per material, using material balances:

consumption = import + production – export.

The economy is thus described in terms of flows of finished materials. Economy-wide MFA accounts are the major source of information for these material balances: extractions of raw materials, imports and exports of (raw, intermediate and finished) materials are derived from there. To estimate the production of finished materials from raw materials, additional information is required since MFA accounts only include transboundary flows. In the EMC2005, information is used on proxys about the application of raw materials into finished materials and the concentration of raw materials in those finished materials from USGS. An alternative route is indicated using production statistics, which would be more appropriate but sometimes problematic to use, in view of confidentiality (see Chapter 6).

In the EMC2005, double-countings and omissions are an issue. Double-countings have been excluded by excluding intermediary materials: for example, fertilizer is not accounted for as a finished material, since it is used completely in the production of agricultural materials, which do appear in the EMC. Omissions occur due to data gaps for especially small-scale materials, Moreover, imports and exports of end-products have not been included. The description of the economy is therefore incomplete.

3.5.3 Interface

To specify the environmental interventions of a material, a Material Life Cycle approach is taken. For the EMC2005 the ETH-database (Frischknecht, 2006) is used. The ETH database, presently updated to the Ecoinvent database, is one of the most widely used LCA databases. This database contains a large amount extraction and production processes, which can be used to construct the Life Cycle Inventory (LCI), i.e. the list of all environmental interventions in terms of extractions of resources, emissions and land use, of the cradle-to-grate chains for 1 kg of material. The LCI in the LCA methodology aims to be comprehensive, e.g. it contains emissions to air, water and soil that are relevant for a wide spectrum of environmental problems.

The interventions of the finished materials not only relate to the cradle to gate production of the materials. In the EMC2005 also the use of the material and waste disposal are taken into account. Therefore additional processes were added and/or connected in the ETH database. The material's losses during use, i.e. corrosion or dissipative uses, are taken into account. Furthermore assumptions have been made for the “end of life” waste management in terms of amounts of recycling, incineration and landfill. The choice has been made to exclude the use of electricity or fuels in the use phase of the materials, for example the use of gasoline in cars or electricity in household appliences. The connection of this type of energy use to the individual materials is rather loose. Instead, the use of electricity and fuels in households and passenger transport has been included in the chains of fossil fuels.

After having specified the LCI for 1 kg of materials, the total amount of environmental interventions of a material in a country are calculated by multiplying the LCI with the amount of kg apparent consumption of the material. By doing this for all materials, an approximation has been made of the total of environmental interventions related to a country's use of resources.

The ETH database contains process data on different levels of the cradle-to-grate process chain, e.g. the extraction of an ore, the transport of the ore from mine to refinery, the refinery of a metal etc. The impacts per kg material can be calculated on each of these levels, subsequently taking into account the environmental interventions of the process and its up chain suppliers. So when determining the environmental impact of a material, it is important to be specific about the position in the cradle-to-grate chain. In the EMC2005 the impacts are calculated on the level of finished materials (e.g. steel, zinc, glass, concrete, paper, PVC) rather than raw materials (e.g. iron ore, zinc ore, silica sand, construction sand, wood, oil). Finished materials are recognizable materials just one step away from being applied in products. In contrast to a definition on the level of raw materials, a definition on the level of finished materials allows for more detail in the analysis of and policy on materials. In appendix A an overview of the list of materials as applied in the EMC2005 is given.

3.5.4 Environmental impacts: coverage, aggregation method and relation with carrying capacity

The LCI of a material as specified above is a large list of extractions, emissions and uses of land. This list may contain several hundreds of interventions. To ease interpretation, these data are aggregated. This aggregation step is made in EMC2005 using the LCA Impact Assessment (LCIA), as described in Chapter 2. For EMC2005, the "midpoint" approach is used, translating the interventions into a limited number of impact categories by characterisation, and adding them up into one score for environmental impact by normalization and weighting. As is the case with this approach, no relation with an actual carrying capacity can be established: the inventory as well as the impact assessment is time and location independent. Therefore, the impacts specified in the EMC2005 are to be regarded as potential impacts. Weighting, as stated in Chapter 2, is a subjective step, wherein political priorities can play a role.

The characterization is the aggregation of emissions into one impact category, e.g. global warming, using characterization (or equivalent) factors. These factors are based on scientific models. The results of the LCI are translated with standard LCA software, the CMLCA program, (Heijungs, 2003) into contributions to 13 different impact categories, expressed in equivalency factors (see Chapter 2), and followed by a normalisation step.

For the EMC2005 the baseline characterisation and normalisation factors are used as described in the Dutch Handbook on LCA (Guinée et al., 2002).

LCA impact categories as applied in the EMC2005
global warming
stratospheric ozone depletion
acidification
eutrophication
photochemical ozone formation
abiotic resource depletion
human toxicity
aquatic ecotoxicity
terrestrial ecotoxicity
radiation
land use competition

The characterisation and normalisation step implies there is not just 1, but 11 indicators of environmental impact potential. This could be acceptable, but when the aim is to arrive at one single indicator for environmental impact, these 11 indicators must be aggregated. This issue of weighting is controversial in the LCA community. Several schemes exist to attach relative weights to environmental problems, based on different starting points, but none is generally accepted. For the EMC2005 it is decided to aggregate the 11 impact categories based on an equal weighting, as an example.

3.5.5 Required data

Basically two types of information are necessary to estimate the environmental impact related to the consumption materials by a country:

1. the environmental impacts related to the materials
2. the consumption of the materials by a country

Ad 1. On a material level estimates of environmental interventions are available based on process descriptions in LCA databases. For EMC2005 the ETH process database is used. (Frischknecht, 1996). An update is ongoing, based on the more comprehensive successor, the Ecoinvent v2.0 database. There are many other LCA databases. A European database is now being developed by JRC. The "European Reference Life Cycle Data System" (ELCD[16]) is the data set for LCA of the European commission that contains Life Cycle Inventory (LCI) data sets. The database is managed by JRC and still in development.

Ad 2. The apparent consumption of materials has been derived from the MFA accounts as composed according to the Eurostat methodology (Eurostat, 2002) by the Wuppertal Institute for EU-15 and AC-13 countries. This database is in itself insufficient: the impacts are described on a finished material level (e.g. glass), while the MFA accounts describe consumptions on all levels of the resource-material-product chain (e.g. respectively industrial sand, glass and bottles). Therefore the combination of the information needs some additional processing of the data. That is: all domestically extracted and imported raw materials and ores are translated into the domestic production of finished materials, which in turn is used in the equation to calculate apparent consumption. This has been done for the EMC2005 by using data from USGS (2006). There are other ways to establish material balances, which may be more convenient and appropriate: via the direct use of trade and production statistics. This is discussed in Chapter 6.

These two types of information must be combined. Below, the relevant equations and assumptions are presented.

The *EMC* of the consumption of a material by a country is described in the formula:

$$EMC_{p,c,m} = S_{p,m} * C_{c,m}$$

$EMC_{p,c,m}$ = EMC of environmental problem ‘p’ due to the consumption of material ‘m’ by a country ‘c’
$S_{p,m}$ = Stress factor (S) of environmental problem ‘p’ for material ‘m’
$C_{c,m}$ = consumption of material ‘m’ by a country ‘c’

The environmental stress factor ($S_{p,m}$) is the environmental impact score per kg material consumption as derived from the LCA database. Environmental impact scores are calculated for 13 different environmental problems (see impact categories in paragraph 3.4.4). The total stress factor for material ‘m’ can be calculated by adding the impact scores for different environmental problems using weighting factors. The weighting factors express the relative importance of the different environmental problems.

$$S_m = W_{p1} * S_{p1} + W_{p2} * S_{p2} + W_{p3} * S_{p3} + W_{p4} * S_{p4} ...... + W_{pn} * S_{pn}$$

The consumption of material “m” by a country ‘c’ can be derived from the MFA accounts using the equations given below.

$$C_{c,m} = I_{c,m} + P_{c,m} - E_{c,m}$$

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

$I_{c,m}$ = Import of material 'm' by country 'c'
$P_{c,m}$ = Production of material 'm' by country 'c'
$E_{c,m}$ = Export of material 'm' by country 'c'

The production of material 'm' is not given in the MFA accounts but can be estimated using the equation given below:

$$P_m = C_r * F_{r \to m} * \frac{1}{F_{r/m}}$$

P_m = estimated production of material 'm'
C_r = Consumption of resource 'r'
$F_{r \to m}$ = weight fraction of resource 'r' that is used for the production of material 'm'
$F_{r/m}$ = weight fraction of resource 'r' in material 'm'

Table 3.11 summarizes the different data necessary to calculate the EMC2005.

Table 3.11 Data requirements and data sources for calculating EMC

component	input	source	remark
Impacts per kg	LCI data, cradle-to-gate, waste treatment	LCA database ETH (Frischknecht, 1996)	Other LCA databases available
	Additional emissions during use	EMC2005 (van der Voet et al., 2005)	
	Additional information waste management	EMC2005 (van der Voet et al., 2005)	
	Characterization factors	Guinée et al., 2002	Alternatives available
	Normalisation factors	Guinée et al., 2002	Update of World interventions available (Sleeswijk et al., 2008)
	Weighting factors	EMC2005 (van der Voet et al., 2005)	
Consumption of materials	extractions	MFA accounts (Eurostat)	detailed (underlying) information
	imports	MFA accounts (Eurostat)	idem
	exports	MFA accounts (Eurostat)	idem
	$F_{r1 \to m1}$	EMC2005 (van der Voet et al., 2005	Original data USGS
	$F_{r1/m1}$	EMC2005 (van der Voet et al., 2005	Based on ETH database (Frischknecht, 1996)

The EMC_c of all consumed materials 'm' for a specific country 'c' can be calculated by summation of $EMC_{m,c}$ for all consumed materials 'm':

$$EMC_c = \sum_m EMC_{c,m}$$

The overall EMC_{EU25} of the European Union can be calculated by summation of the EMC_c of the different member states: $EMC_{EU25} = \sum_c EMC_c$

3.5.6 Subjects for discussion

Omissions
For several reasons, the description of the economic system is not comprehensive in the EMC2005. One reason is, that the MFA accounts provide insufficient information to arrive at material balances for finished materials. This could be solved by using trade and production statistics directly. The second reason is that finished products are excluded for practical reasons. Especially for small-scale materials such as the rare metals, this poses a real problem: most of the flows of these materials is in products rather than in raw or finished materials, therefore, it has not been possible to draft material balances for those. To include products in the materials balances is in theory possible. The composition of the products then should be known, and then they can be attributed to their various composing materials. In practice it is a job too huge to undertake if it must be done for all products and all materials on a yearly basis.

Double countings
As described above, while composing EMC2005 the avoidance of double countings has been a point of attention. Despite efforts, it is hard to avoid altogether. When applying EMC on a regular basis, this must remain a focus.

Weighting
During the process of composing EMC2005, the subjective weighting step to aggregate over the various environmental impact categories has been the main point of criticism to the approach. The fact that there is no generally accepted weighting procedure has been used as an argument against EMC. It must be noted (again), however, that whenever one is interested in constructing an aggregate indicator for environmental impacts, the aggregation step unavoidably contains subjective elements. In some cases, these are hidden in the aggregation procedure. In EMC, this step is explicit. It may, therefore, be regarded as an advantage of this indicator rather than a drawback.

3.6 Environmental Extended Input Output tables of individual countries

3.6.1 Purpose, coverage and institutional aspects

Environmental Extended Input Output Tables are a part of the system of national accounts. IO tables provide insight in all economic relations between sectors in an economy. Emissions and primary resource use per sector can be added in the same sector format, and are known as 'extensions'. EE IO hence is primary an accounting/inventory tool, which can be used to support a great variety of indicators, mainly depending on the extensiveness of the number of extensions included.

3.6.2 Description of economy

As discussed already in section 2.6, 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)[17].

[17] 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

3.6.3 Interface

Since EE IO provides a picture of the full economy, it allows calculating backwards which industry sectors have contributed which percentage added value to a final consumption category. With the impacts per Euro per sector also part of the table, this allows calculating easily and consistently how the total impacts generated by a country relate to final consumption activities. The nice thing about EE IO is that the picture is inherently complete, since the starting point of any EE IO table is a picture of all economic activities in a country, and all primary resource extraction and emissions.

EE IO tables also identify imports of products and services, and exports. EE IO tables for single countries have no ways to identify directly the impacts of production abroad. A shortcut applied by many analysts is hence to assume that imports are made with domestic technology. EE IO tables hence will detect burden shifting to other countries to some extent (e.g. if car manufacturing is displaced from Europe to India, this is identified as a lower production in Europe, and higher car imports). Yet, in such an analysis one cannot detect environmental quality differences between India and Europe. Ideally, one hence would like to have an EE IO table for Europe and of its most important trade partners, an exercise currently performed in the EU FP6 IP EXIOPOL.

3.6.4 Environmental impacts: aggregation method and comparison with carrying capacity

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):

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.

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[18].

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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.

[18] 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.

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[19].

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 Table 2.3 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.

One of the nice features of EE IO is that in principle it allows accommodation of various indicators. The practical trick though, is that the emission and resource use data that are part of the EE IO table are the determining factors if certain indicators can be calculated. Indicators potentially supported by EE IO include

- indicators based on life cycle impact assessment. LCIA simply multiplies emissions and resource uses with a characterisation factor to end up with a score on an environmental theme, such as Global Warming Potential, Acidification, resource depletion, etc. (e.g. Guinee et al., 2002).
- External costs. On the basis of the emissions or the LCIA indicators above, impacts on the environment can be expressed in monetary terms, either as avoidance costs, or as damage costs[20].
- the Ecological Footprint. EE IO tables include usually emissions of CO_2, land use and production of biomass / agricultural products, which all are part of the calculation of the EF
- Material flow indicators. EE IO tables usually include primary resource extraction per country per sector, the production of agricultural products, and may also include waste output in physical terms (NAMEA waste). This allows calculating per country indicators to calculate indicators such as domestic extraction. Imports need special attention though, since they are known in economic rather than physical terms.

3.6.5 Required data and (potentially) available data at EU-datacenters

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

[19] It is also thinkable to merge monetary and physical flows into one symmetric system arriving at so-called hybrid tables.
[20] A problem is though that external costs as calculated in the EXERNE series of projects take into account heavily the local situation in which emissions take place, which is rather difficult in a generic tool such as EE IO which covers always at minimum a country. This macro-micro dichotomy plays a role for all indicators discussed in the report, though.

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. Many countries have done this and time series of SUT hence are available for many EU countries. Some EU countries still have a derogation, but in the near future most data problems with regard to SUT and IOT should be mitigated, simply since ESA95 is a hard, legal obligation to all EU27 member states to provide this data.

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), covering the GWP, ODP and acidifying emissions. These NAMEAs in fact are environmental extensions in an identical sector format as the ESA95 SUT and IOT. Work on NAMEAS on primary resource extraction is well under way undera contract of EUROSTAT with IFF and Wuppertal Institute, providing time series of resource use per sector for the last 25 years. This material should be available in 2009. EUROSTAT further contracted a consultant early 2009 to complete any remaining gaps in the NAMEAs air, resources, but also for developing NAMEAs on water, energy,, and waste.

All this implies that by 2010/2011 EUROSTAT should have fairly complete EE SUT/IOT for the EU27 for the last decades, with probably only land use missing as a key environmental impact/extension. Another key issue is that EUROSTAT's department on SUT and IOT does not yet integrate the individual country SUT and IOT to an integrated EU27 SUT/IOT via a trade linking procedure, mainly due to a low capacity in human resources. DG JRC IPTS took up this task and developed such an EU27 table, albeit only for one base year (Rueda Cantuche et al., 2007).

The main limitation of the EUROSTAT work on SUT/IOT with NAMEAs is the rather limited sector detail and the lack of specific insight in impacts of products made by its trade partners. The EU FP6 IP EXIOPOL, with results available in 2011, mitigates these two drawbacks by expanding the SUT and IOT of the EU member states to 130 sectors, and by providing specific EE SUT/IOT for the 16 key trade partners of the EU. It will provide for the first time a true Multi-Regional, trade linked EE SUT/IOT in which the 43 most important economies are included, taking into account economic processes in the Rest of World. Trade is included comprehensively, i.e. not only between the EU27 and its trade partners, but between every individual country discerned.

3.6.6 Subjects for discussion

EE SUT/IOTs (or SUT/IOT with NAMEAs) have as main strength an inherent complete coverage of economic activities and related emissions and resource uses. The same data set is capable of providing analyses from very different perspectives (sector, consumption, resource extraction) in a consistent way. MR (Multiple Region) EE

SUT/IOTs developed in EXIOPOL even have make it possible to what extent final consumption in the EU27 causes impacts, in, say, China, Australia and Mexico.

Yet, the method also has some 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. Particularly for sectors with inhomogenous outputs, or that sells outputs at different prices to other sectors, important anomalies may take place when allocating impacts[21].
- Even when the data situation is improved, time lags may occur with regard to data reporting;
- 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.

3.7 Other aggregate indicators

By using the aggregation methods as described in Chapter 2, it is possible to compose aggregate indicators out of, for example, emission inventories or environmentally extended Input Output tables.

Aggegated emission inventories can be found, for example, in the original "environmental themes" of national environmental policies: emissions at the national level being aggregated by equivalency factors as described in Section 2.4.3, arriving at a national score for global warming, acidification and other environmental impact categories (Adriaanse, 1992). This approach has been used to support and monitor environmental policy for a long time, and still is. Only emissions within the territory of the country are included, which implies that a problem shifting to other areas is invisible. However, the cleaning up of the national industrial production can be monitored. Only a selection of impact categories are monitored in this way, although the list of included emissions can be very large (and differs from country to country). No attempt has been made to aggregate over the different impact categories. These environmental "themes" thus do not have a description of the economy. The emission inventory is basically a long

[21] Simply said, where the price-quantity relationship may differ between uses of the output of a product or sector, EE IO is blind for this. This problem is particularly relevant for highly aggregated sectors. For instance, Nijdam and Wilting (2003) included fisheries in their agricultural sector. Agriculture included also cattle, and hence there was deliver of agriculture to the textile sector (mainly fur, but that was not visible in the economic table). As a consequence, in the final analysis textile consumption seemingly had a major impact on fish depletion, simply since fish catch was proportionally to value allocated to the textile production sector…….

and detailed list of environmental interventions, and the translation of these emissions into themes conforms to LCIA at midpoint level as described before.

Integrated Assessment models have expanded the emission inventory with (1) a link to a list of economic sectors, and (2) a location, which enables to link the emission to an atmospheric dispersion model and trace the fate of the emissions. The models for climate change and large scale air pollution such as RAINS, GAINS or IMAGE (Amann, 2004; IMAGE team, 2001) conform to this principle. These models are quite sophisticated in the environmental fate and impact part, but lack depth and complexity in the economic part: for the Outlook reports where forecasts and projections are made for the future development of the environmental problems, rather straightforward economic growth factors are used to estimate the future emissions from the economic sectors involved.

Environmental impact categories have in later years been used in combination with environmentally extended Input Output tables. This approach has been harmonised to the NAMEA accounts, where emission factors based on emission inventories were added to the sectors of the input output tables. This makes it possible to link economic activities to potential environmental impacts. The emission inventory is thus used to construct a model which can also be used for analysis (f.e. decomposition analysis) and estimates of changes in the future. Unlike approaches using LCA data as a basis for impact assessment, the environmental interventions per sector in NAMEA accounts can be updated yearly. This is theory, however: in practice this does not happen.

A combination of environmentally extended IOTs and a product angle, including LCI data and LCIA, has been proposed in the EIPRO-study (Tukker et al., 2006). This was done to answer a request from the EU-IPP to prioritise between products or product groups.
A summary of the indicators and their basic characteristics can be found in the table below.

Table 3.11 Summary description of indicator characteristics

	description economy	interface	environ-mental impacts	aggregation to single indicator	reference	subjective element	foreign impacts included
HANPP	-	extraction biomass land use	reduction NPP for nature	adding kg	NPP for nature	reference	no
EE IO: NAMEA	IOTs	emissions (air)	LCIA impact categories	characteris ation (+ weighting)	- (targets)	weighting impact categories	yes
EE IO: EXIOPOL	IOTs	extractions emissions	LCIA impact categories	characteris ation (+ weighting)	- (targets)	weighting impact categories	yes
EF	material flows	extractions (biomass) emissions (CO_2) land use	global hectares	adding ha	biocapacity	translation into global hectares; reference	partly
DMC	material flows	extractions	-	adding kg	-	weighting by kg	no
TMC	material flows	extractions	-	adding kg	-	weighting by kg	yes
EMC	material flows + process trees	extractions emissions land use	LCIA impact categories	characteris ation (+ weighting)	- (targets)	weighting impact categories	yes
environ-mental policy themes	-	emissions (from emission inventory)	LCIA impact categories	characteris ation (+ weighting)	- (targets)	weighting impact categories	no

4 Indicator behaviour: selected “what-if” case studies

4.1 Introduction

In this chapter, in a qualitative manner eleven "what if" case studies are applied on the indicators discussed before. It typically concerns replacement of one technology by another technology domestically, or shift of a specific production process abroad. In some cases the technology used in the new situation is more eco-efficient (providing less environmental impact at the same output), where in other cases there is no difference.

The indicators discussed in the former sections will may ‘treat’ such changes in a different way. The indicators (and underlying data gathering procedures) have been developed for specific purposes, not necessarily for the purpose of comparing the change in environmental impacts of our cases. Indicators hence may turn a blind eye on important burden shifting processes in a case, or may suggest burden shifting that in fact is not occurring. They hence may suggest environmental improvements that are not occurring, but may also fail to indentify true environmental improvements. Such ‘blind spots’ typically may have to do with the following issues:

1. ‘Technical detail’: Burden shifting to other parts of the production-consumption chain. Example: a diet shift from meat to fish will reduce impacts of animal husbandry, but will increase impacts of fishery. A method hence:
    a. ideally needs to include a chain perspective
    b. have an appropriate technical detail to detect shifts to other processes.
2. ‘Displacement between impacts’: Burden shifting across impact categories. Example: a diet shift from meat to fish will reduce manure production and related acidifiation and eutrophication problems, but enhance fish depletion. A method hence
    a. Needs to be sensitive for burden shifting as such (by covering different impact types), and
    b. Have an adequate level of detail of impacts covered.
3. ‘Geographical displacement’:Burden shifting to other geographical areas. Example: a shift in textile production from Italy to China will reduce impacts in Italy, but increase impacts in China. A method hence:
    a. Ideally needs to have a truly global perspective, and be able to quantify shifts in environmental pressure from region a to region b.
    b. As a next best, needs to detect changes in imports/exports from/to region a, which at least provides a warning sign of burden shifting to other regions

Table 4.1 reflects the burden shifting mechanisms mentioned above. This table will be used to analyse how an indicator system performs in the case study at stake. Next to the column with the names of the indicators, there is a column stating if the impact in the case in reality is expected to go up, down, or does not change. The next column indicates what the indicator shows: impacts going up, down or no change. If the indicator does not give the right answer, this is shown underlined and with grey background in this column. Note that the list above consists of 'first order' burden shift mechanisms only. Dynamic, second order economic effects are left out of the scope of this study. We further neglected slight deficiencies in a current indicator if these are likely to be solved in the next 1-2 years, e.g. on the basis of recommendations of this report[22]. In some cases we also described the situation if a considerable additional effort would be made in elaborating the indicator.

In the next sections, we will discuss in brief how HANPP, EE IO, Ecological footprinting, DMC and EMC will deal with twelve changes in production and consumptoin processes We start each section with a general impression of what type of change in impacts one would expect, irrespective of the indicator. Building upon the descriptions in chapter 3, we here shortly summarize the strengths and weaknesses of each indicator in dealing with the four burden shifting/environmental improvement issues listed above, and list them already in Table 4.1. In brief, the first two columns in Table 4.1 indicate if the indicator gives a 'right' policy advice, the next 3 columns indicate why a 'wrong' policy advice may be given.

HANPP

- Technological detail: None. HANPP is in principle a geographically oriented indicator. Yet, the most elaborated approaches of HANPP cover the whole world, dividing it in gridcells. In principle hence HANPP could 'see' changes in impacts along the production-consumption chain, simply since a process at another location in that chain may influence the HANPP in the region of that process. This under the assumption that HANPP data are regularly updated over time;
- Displacement between impacts: HANPP covers only biomass production and its human appropriation, and does not take into account many other effects
- Geographical displacement: see under technical detail. Yet, it is not possible to link e.g. a rise in HANPP in Europe (due to displacement of activities abroad) to a lowering of HANPP abroad. The impacts abroad are not inherently included in a European HANPP indicator.

EE-IO

- Technical detail: EUROSTAT NAMEAs and SUT/IOT discern around 60 sectors, and lumps agricultural, mining and energy production sectors together, which would make it impossible to discern differences in impact intensity in different agricultural, mining and energy production activitivities.
- Displacement between impacts: EE IO usually covers a rather broad set of environmental interventions. By 2010, EUROSTAT will have a fairly extensive set of NAMEAs for Air (15 substances), Resources (most MFA resources),

[22] We otherwise would end up rejecting indicator systems, not because they have fatal flaws, but merely since there are a few minor issues in data transformation and the like not picked up due to a lack of priority setting, etc. This would particularly be unjust to promising indicator systems that can be fully operationalised with minor additional effort compared to the status quo.

Energy, Waste and other interventions covered. This implies that EE IO most probably can support a number of indicators such as TMR, LCIA themes, and to some extent the Ecological footpring

- Geographical displacement: the EUROSTAT SUT/IOT discern imports and hence will make visible that a lower European production will be compensated by higher imports. However, due to to a lack of EE SUT/IOT tables for the EU's trade partners, pollution embodied in imports can only be estimated by assuming they are made with domestic technology. Any impacts of the use of 'dirtier' technology abroad will hence be missed[23].

The issue of import environmental accounting is getting a lot of attention at various levels[24]. The SKEP IMEA, SKEP EIPOT and EXIOPOL projects, amongst others, have lead to a rather broad consensus that MR EE IO is probably the best way forward in this. The EXIOPOL project will have by 2011 datasets available for 2000 and 2005 that mitigates two problems with the EUROSTAT NAMEA/IOT data sets, and could be a basis for structural data gathering if the prroject results, as planned, are taken over by an official EU body. The key improvements improve a significant enhence sector detail (130 sectors versus 60); much more impacts (130 or more extensions), and coverage of 43 countries responsible for 95% of the global GNP. Development of such a system would require a significant effort of EUROSTAT in collaboration with a number of non European statistical offices, but it cannot be excluded that such developments will take place in the next 3-5 years. Such developments would mitigate most of the remaining drawbacks of EE IO.

Ecological Footprint

- Technological detail: EF calculates the bioproductive area needed for (renewable) resource consumption and waste assimilation (of CO_2 emissions). Excluded is the consumption of nonrenewable resources like metals. Even though EF is a consumption indicator, the CO_2 emissions from fossil fuels are taken into account based on the country where the energy is generated. This means that the energy used in for example the manufacturing industry is only included if the production facility is located in Europe.
  EF accounts take notice of the different yields/efficiencies in different countries. For example, at the supply side of EF accounts national yield factors are used. At the demand side, only the production of secondary resources takes national efficiencies into account by the conversion factors to translate them into primary resources. For all other calculations, global factors are used, without any technological detail.
- Displacement between impacts: The Ecological Footprint only calculates the effects on bioproductive area. Impacts like acidification, eutrophication and eco-toxicity are not explicitly addressed, even though it can be reflected in future EF accounts if it lowers the biocapacity.

[23] In this, it is assumed that by 2010 EUROSTAT will integrate on a regular basis its IOT and SUT to EU27 totals. Due to capacity problems this EU internal trade linking is not yet done, and was only executed by IPTS as a pilot study (Rueda Cantuche et al., 2007)

[24] Chinese minister in the Guardian

- Geographical displacement: EF is a consumption indicator, so -in principle- no geographical displacement should be apparent. However, energy production instead of energy consumption is used to calculate CO_2 emissions. This means that a move of a production facility abroad would result in a smaller Footprint.
- Chain perspective: EF can see changes in (land use) impacts across the chain, especially when consumption changes. Changes in production processes are only included if it concerns changes in the conversion of secondary into primary resources. A geographical change is included in the supply side of the accounts when it concerns a change in yield.

DMC (Direct Material Consumption)

- Technological detail: The DMC calculates the total material consumption defined as the raw material extraction of a country (or region) plus imports minus exports. All flows in DMC are expressed in kgs. The DMC is normally decomposed into 5-12 material categories. More detailed disaggregations may be difficult to achieve because of the emobied materials in products.
- Displacement between impacts: Environmental impacts are not directly covered by the DMC and displacement between impacts cannot be perceived directly by the indicator. However, through the mass balance equations (everything that goes into the economy sooner or later comes out as dissipative emissions and wastes), the DMC is perceived by some as an overall proxy for (future) environmental pressure hence covering all relevant environmental impacts.
- Geographical displacement: Geographical displacement is not covered fully by the DMC. The DMC takes imports and exports of all resources and products into account only for the physical weight of these imports and exports. The unused extraction behind the trade flows are not taken into account. A relocation of extractive and heavy industries to other countries should in general lower DMC quite significantly. The TMC, where the foreign unused extractions are included, does not have this disadvantage and should identify potential geographical displacement.
- Chain perspective: the DMC does not take a chain perspective explicitly.
- Early warning: DMC may have an early warning function for some environmental impacts. DMC relates to the input side of the economy. Part of these inputs will be dissipated as wastes and emissions but the largest part is stored in products, buildings, roads, etc.. Sooner or later these items must be demolished hence generating environmental problems for future generation, particularly with respect to waste management.

EMC (Environmentally weighted material consumption)

- Technological detail: The EMC calculates the environmental pressure stemming from consumption of finished materials. The EMC can be decomposed into many material categories and 10-15 environmental impact themes.
- Displacement between impacts. The EMC covers all environmental impacts that are present in the LCA database. Normally this consists of 10-15 environmental impacts organized around certain themes (e.g. acidification, climate change)

identifiying the environmental pressure at mid-point level.[25] Displacement between impacts can be identified explicitly in the EMC.

- Geographical displacment: The EMC takes imports and exports of all "finished materials" into account. Hence all displacement activities on this level are made explicitly visible in the indicator. Displacement activitiest at another stage in the material chain are not monitored explicitly in the EMC. A relocation of mining activities is, for example, not quantified explicitly in the indicator. If these mining activities have a different emission profile than in the EU, the EMC will not monitor such changes.
- Chain perspective: The EMC does take into account a chain perspective as the materials consumption is translated into environmental impacts from craddle to grave.
- Early warning: The EMC probably has no early warning potential. All impacts are direct impacts, although some impacts (like climate change emissions) only impact in the longer run.

Table 4.1: Assessment of indicators

	Actual impact change	Shown impact change	visibility / technological detail	displacement between impacts	geographical displacement	remarks
Indicator 1	Up	**Down**	-	-	-	impact shown only coincidentally in the right direction
Indicator 2	Up	Up	-	+	+	impact could be included with more detail in sectors
Indicator 3	Up	**Neutral**	-	-	-	only domestic impacts visible
Indicator 4	Up	**Down**	+	-	-	…
Indicator 5	Up	Up	-	+	+	…

4.2 Case study 1: Closure of a German coal mine and enhanced coal production in the Ukraine with higher impact

4.2.1 Introduction and general assessment

This case concerns the closure of a coal mine in Germany. We assume that as a result, the EU will import more coal from abroad, in this case the Ukraine. It is also assumed that mining in the Ukraine causes more environmental impacts than mining in Germany, particularly with regard to accidents and the production of mine tailings. The coal quality is assumed to be similar, so that there are assumed no emission differences for coal incineration.

[25] In principle, the EMC could also take into account the environmental impacts at the end-point level (e.g. effects on health, ecosystems, buildings and production from nature,) this would require, however, a different set of characterisation factors. Here we focus on the EMC at the mid-point level.

Under these assumptions, from a global perspective one would see an environmental detioriation. The positive effects in Germany are offset by higher negative effects in the Ukraine. There are furthermore additional transport impacts involved.

4.2.2 HANPP

HANPP deals as follows with this change in coal production:

- Technical detail. HANPP is geographically oriented. If applied for the EU, it shows a lower impact in Germany due to reduced land use, but the rise in impacts in the Ukraine would only be visible in a HANPP for the Ukraine.
- Displacement between impacts. Not relevant in this case. HANPP covers however by far not all relevant impacts of coal mining
- Geographical displacement. A global HANPP will detect improvement of HANPP in Germany, and a reduction in HANPP in the Ukraine. Yet, it will not identify that the two effects are related. A HANPP indicator for Europe will not inherently take into account burden shifting to non EU countries

In sum, HANPP probably will just note the improvement in Germany, and has no inherent way to take into account that the displacement of the mine to the Ukraine has a (higher) negative effect there.

4.2.3 EE I-O

EE IO deals as follows with the change in coal production:

- Technical detail: most EE IO tables discern around 60 sectors. With coal mining usually being a sector on its own, this is adequate for this case
- Displacement between impacts: EE IO usually covers a significant set of environmental interventions, but accidents are usually not and land use is often not covered.
- Geographical displacement. The EU27 EE IO table will show a diminishing domestic coal production in the EU27, and a corresponding rise of imports of coal. However, simple EE IO tables will miss the quality difference between domestic processes and those in the Ukraine, and hence assume that net no deteioriation of impacts takes place.

In sum, EE IO would probably judge this change as neutral, where at global level there is detioriation. An EXIOPOL type of MR EE IO table would not have these drawbacks since it calculates real impacts in the country or origin, and also covere a broader set of impacts.

4.2.4 Ecological Footprint

Ecological Footprint deals as follows with this change in coal production:

- Technological detail: EF misses the deterioration in the state of technology, because coal is a nonrenewable resource and therefore not included in the EF accounts.
- Displacement between impacts: EF does not cover all relevant impacts, only additional transport within Europe is detected.
- Geographical displacement: Since coal is a nonrenewable resource, EF does not take into account that more coal is imported. Geographical displacement is therefore not detected by EF.

In sum, the Ecological Footprint does not detect the location change of the coal mine, since it does not cover (the production and/or consumption of) nonrenewable resources like coal. The indicator shows no change –or perhaps a very slight increase due to higher transport

4.2.5 DMC

The DMC deals as follows with this change in coal production:

- Technological detail: The DMC does not detect the deteroriation in the state of technology in this example. Only technology changes with respect to dematerialisation are being measured in the DMC.
- Displacement between impacts: The DMC takes the weight of coal mining and coal consumption as the relevant impact here. The DMC detects the fuel used for additional transport within the EU-territory.
- Geographical displacement: A shift of domestic production towards foreign production results in a smaller DMC, since the DMC does not include the foreign unused extraction associated with coal mining in the Ukraine. The DMC is lowered by the reduced unused extraction from coal mining in Germany.

This case will result in a decline in the DMC (a reduction of impacts) in the EU. This is due to the fact that the unused extraction is no longer taken into account.

4.2.6 EMC

The EMC deals as follows with this change in coal production:

- Technological detail: The EMC does not detect the deteroriation in the state of technology in this example. For coal mining Western European averages are being used. In principle, the EMC could take into account specific information on the state of technology in other countries if LCA databases are to be improved in the future.
- Displacement between impacts: The EMC takes a chain perspective: all relevant impacts associated with coal consumption are included. The EMC detects additional transport within Europe as the result of the additional consumption of fuel for transportation in the EU and it's associated environmental effects.

- Geographical displacement: A shift of domestic production towards foreign production does not result in a change in the indicator (but the different state of technology is also not measured, see technological detail).

In sum, there will be no change in the EMC – or a very slight increase due to the higher transportation costs.

4.2.7 Review

The table below gives a review of the performance of all indicator systems. None of the indicators provide the expected outcome, i.e. that overall environmental quality deteriorates by a shift in coal production from Germany to the Ukraine. EE-IO could do the job, if the assumption of foreign technology being equal to domestic technology were dropped. Covering a comprehensive set of impact and sensitivity for imports and exports including transport needs is key in this case, and these methods are the only one having these characteristics. All other indicators are either insensitive or show only a part of the changes. Because of this last issue, both HANPP and DMC point in the wrong direction.

Table 4.2: Assessment of indicators Case 1

	Actual impact change	Shown impact change	visibility / technological detail	displacement between impacts	geographical displacement	remarks
HANPP	Up	**Down**	-	-	-	HANPP does inherently not cover transboundary issues
EE IO	Up	**Neutral**	+	-	+	Regular EE IO assumes that imports are made with domestic technology, but here it concerns dirtier technology.
EF	Up	**Neutral**	-	-	-	EF does not cover nonrenewable resources like coal.
DMC	Up	**Down**	+	-	-	DMC does not cover foreign unused extractions
EMC	Up	**Neutral**	-	+	+	EMC does not differentiate between state of technology

4.3 Case study 2: Closure of a Polish zinc mine, enhanced zinc ore production in Africa, equal impact

4.3.1 Introduction and general assessment

This case concerns the closure of a zinc mine in Poland. We assume that as a result, the EU will import more zinc ore from abroad, in this case Africa. It is assumed that all impacts related to mining are similar in both cases. This leaves as only difference that longer transport routes are at stake, mainly by sea vessels. It is known however, that in the zinc chain impacts of such transports are marginal compared to ore refining, etc.

Under these assumptions, from a global perspective one would see no or just a marginal environmental detioriation. There are just marginal effects due to higher transport distances involved.. Inclusion of spatial and temporal variability would reduce the relevance of shipping even further, since most emissions related to shipping take place at sea.

4.3.2 HANPP

HANPP deals as follows with this change in coal production:

- Technical detail. HANPP is geographically oriented. It shows however a rise in impacts in Africa and a lower impact in Poland
- Displacement between impacts. Not relevant in this case. HANPP covers however by far not all relevant impacts of zincl mining
- Geographical displacement. A global HANPP will detect improvement of HANPP in Poland, and a reduction in HANPP in Africa. Yet, it will not identify that the two effects are related. A HANPP indicator for Europe will not inherently take into account burden shifting to non EU countries

In sum, HANPP probably will just note the improvement in Poland, and has no inherent way to take into account that the displacement of the mine to Africa has a (higher) negative effect there.

4.3.3 EE I-O

EE IO deals as follows with the change in coal production:

- Technical detail: most EE IO tables discern around 60 sectors. Zinc mining is part of the non-ferro mining sector, but since impacts do not change here, this problem of detail is less relevant.
- Displacement between impacts: EE IO usually covers a significant set of environmental interventions. Yet, since no impact change is assumed, this is not relevant in this case.
- Geographical displacement. The EU27 EE IO table will show a diminishing domestic zinc mining in the EU27, and a corresponding rise of imports of zinc from Africa. Simple EE IO approaches will assume that imports are made with domestic technology, which is appropriate in this case..

In sum, EE IO would probably judge this change as neutral, which is right, simply because the non EU and EU process have the same quality. An EXIOPOL type of MR EE IO table, available by 2011, would avoid a number of problems of simple EE IO tables. Sector detail is greater (with zinc mining specified), and the real impact intensities of foreign processes are used.\

4.3.4 Ecological Footprint

EF deals as follows with this change in zinc production:

- Technological detail: Very small, since the consumption of nonrenewable resources like zinc is not included in the EF.
- Displacement between impacts: There is no displacement between impacts in this case study. EF does not notice the increase in CO_2 emissions due to more international transport, since this is included in the indicator by a fixed percentage of total CO_2 emissions.
- Geographical displacement: Geographical displacement would be missed by EF since it does not detect the move of the zinc mine. However, in this case study, there is no geographical displacement.

In sum, the Ecological Footprint does not detect the location change of the zinc mine, since it does not cover (the production and/or consumption of) nonrenewable resources like zinc. The indicator shows no change.

4.3.5 DMC

The DMC deals as follows with this change in coal production:

- Technological detail: Zinc consumption is taken into account in the category metals and both production and trade flows are included.
- Displacement between impacts: There is no displacement between impacts in this case study. The DMC does not include international marine shipping if the ships bunker their fuels in Europe as these are not included in the Eurostat/IEA statistics being used for the DMC..
- Geographical displacement: A shift of domestic production abroad results in a smaller DMC for the EU, since the DMC does not include the foreign unused extraction associated with zinc mining in Africa. The DMC is lowered by the reduced unused extraction from zinc mining in Poland..

In sum, this case translates itself in a decline in the DMC (a reduction of impacts) in the EU. This is due to the fact that the unused extraction is no longer taken into account.

4.3.6 EMC

The EMC deals as follows with this change in coal production:

- Technological detail: Zinc consumption is covered by the EMC directly but no differentiation between the state of technology is used in calculating the DMC.
- Displacement between impacts: The EMC takes the environmental impacts associated with zinc consumption as the relevant impact here. The EMC does not detect additional transport since no distinction is made in zinc production between countries.

- Geographical displacement: The EMC takes a chain perspective: all relevant impacts associated with zinc consumption are included, but these are not differentiated to used technology.

Hence, this case will have no impact on the EMC..

4.3.7 Review

The table below gives a review of the performance of all indicator systems. Most methods give the expected outcome: there is no change in impacts. MR EE IO has the slight advantage that it could include the potential additional impacts related to the longer transport distance, but since these impacts are marginal, this advantage is not deemed decisive. The EF and DMC give a false positive: a decrease is indicated, while in fact globally there is no change.

Table 4.3: Assessment of indicators Case 2

	Actual impact change	Shown impact change	visibility / technological detail	displacement between impacts	geographical displacement	remarks
HANPP	Neutral	**Down**	-	n.r.	-	HANPP does not inherently cover transboundary issues
EE IO	Neutral	Neutral	+	n.r.	+	Regular EE IO assumes that imports are made with domestic technology, which is right in this case. MR EE IO is superior due to specifying the zinc sector and the real impact intensity of non EU production
EF	Neutral	Neutral	-	n.r.	-	EF does not cover nonrenewable resources and therefore sees no impact.
DMC	Neutral	**Down**	-	n.r.	-	DMC does not include foreign unused extraction.
EMC	Neutral	Neutral	+	n.r.	+	Since this case assumes similar technology, EMC will cover this.

4.4 Case study 3: Replacement of rapeseed oil produced in the EU by import of palm oil from Malaysia, lower impact

4.4.1 Introduction and general assessment

The third case study implies a reduction of rapeseed oil production in the EU for use as biofuel, and replacement of this by palm oil produced in Malaysia. This is a rather complex case, since various issues play a role at the same time:

- Impacts of rapeseed oil production versus impacts of palm oil production. In this example it is assumed that palm oil production has lower overall impacts. It is then understood that palm oil is not produced on peaty soils converted from forests, but on soils already in use for agricultural production.

- Impacts due to longer transport distances. These impacts may not be marginal, since potentially large flows are involved.
- Impacts in the use phase. For the sake of argument, it is assumed that rapeseed oil and palm oil have the same impact when used as biofuel.

In sum, one would expect overall to see a reduction in environmental impact by this shift.

4.4.2 HANPP

HANPP deals as follows with this change in production of biofuel:

- Technical detail. HANPP is geographically oriented and shows on the location of the old (abandoned) process a rise and the new process a lowering of HANPP
- Displacement between impacts. Not relevant in this case. HANPP covers however by far not all relevant impacts of biofuel production
- Geographical displacement. : HANPP will show a reduction in Europe, since less rape seed will be harvested. It will show a rise of HANPP in Malaysia, since there more palm fruit will be harvested. Yet, HANPP for the EU27 is not an indicator that inherently makes a causal relation between the better HANPP in Europe, and the lower HANPP in Malaysia. It hence only will see the positive effect in Europe.

In sum, HANPP provides more by chance than wisdom the right policy information, i.e. that the new situation is an improvement. Yet, it will overestimate the benefits by just seeing the improvement in Europe, and not taking the (lower) detioriation in Mailaysia into account.

4.4.3 EE I-O

EE IO deals as follows with the change in biofuel production:

- Technical detail.EE IO tables discern around 60 sectors, and lump all agricultural sectors together. EE IO hence does not discern reap seed production and palm oil production.
- Displacement between impacts. EE IO covers a rather broad set of environmental interventions.
- Geographical displacement.A European EE IO table does see a change in imports and exports and hence can detect geographical burden shifting, although not specifying the region to which burden shifting takes place. But again, they miss the quality difference between domestic processes and processes in Malaysia.

In sum, an analysis with a European EE IO table will not see differences in impacts. It shows that burden shifting to outside Europe is at stake, is not capable to include the better performance of the foreign process. MR EE IO such as practiced in EXIOPOL mitigates all the drawbacks mentioned: it discerns a vegetable oil production sector, and discerns process specific impacts in non EU countries.

4.4.4 Ecological Footprint

EF deals as follows with this change in production of biofuel:

- Technological detail: EF will not use the fact that palm oil is produced in Malaysia and/or that rapeseed oil was harvested in Europe. If (globally) palm oil is harvested more efficiently than rapeseed oil, less bioproductive area is needed and the EF will decline. However, EF cannot see that Malaysian palm oil production is more or less efficient than the average global palm oil production
- Displacement between impacts: The increase of CO_2 emissions due to an increase in international marine shipping will not be detected. EF does show a lower need for bioproductive land due to lower rapeseed oil and higher palm oil (with higher yields) consumption.
- Geographical displacement: Geographical displacement is visible in the EF, because EF notices the reduction of rapeseed oil consumption and the increase in palm oil consumption.

In sum, the EF will decline because palm oil is harvested more efficiently than rapeseed oil. The indicator therefore shows a lowering of impacts.

4.4.5 DMC

The DMC deals as follows with this change in production of biofuel:

- Technological detail: The DMC takes the weight of flows associated with rapeseed production and the consumption of palm oil as the relevant impact here. These are probably not explicitly distinguished in the DMC as production data on these often fall in the category: oil crops. The DMC does not detect international marine shipping..
- Displacement between impacts: The diminishing use of land is not visible in the indicator directly. If the higher yield of palmoil is connected to a larger yield per kg biomass inputs, this effect will be covered by the DMC. If the higher yield of palmoil is connected to a larger yield per ha, the effect is not covered by the DMC.
- Geographical displacement: A shift of domestic production abroad results in a smaller DMC, since the DMC does not include the unused extraction associated with palm oil production in Malaysia. The DMC is lowered by the reduced unused extraction from rapeseed oil in Europe.

The overall assessment is given in the table below. The indicator shows a decline in the DMC (a reduction of impacts) in the EU. This is largely due to the fact that the unused extraction is no longer taken into account and not because of the environmental benefits from palm oil production. However, in this case the DMC coincides with the “true” environmental gain.

4.4.6 EMC

The EMC deals as follows with this change in coal production:

- Technological detail: This difference is only visible in EMC, however, if rapeseed oil and palm oil are both included as separate "materials". In EMC2005, this is not the case. In the list of materials in Chapter 6, rapeseed is included, while palm oil belongs to the "other oil crops" category. The additional environmental effects from international marine shipping is mostly included in the LCA databases .
- Displacement between impacts: The EMC takes the difference between lifecycle environmental impacts associated with “other oil crops” consumption and rapeseed oil consumption as the relevant impact here.
- Geographical displacement: The EMC takes a chain perspective: all relevant impacts associated with biomass production are included irrespective of where they occur.

The overall assessment is given in the table below. The indicator shows most likely a decrease in the EMC.

4.4.7 Review

The table below gives a review of the performance of all indicator systems. EE IO assumes that imports are made with domestic technology and hence is not capable of showing that impacts related to the imported product are lower than of the original domestic production.. Following our initial assumptions HANPP of rape seed production in Europe is deemed to be higher than palm oil production in Malaysia, and this is made visible by the indicator in a lower HANPP in Europe, and a relatively lower rise in HANPP in Malaysia. An improvement in non-biomass related effects is not detected by HANPP. The Ecological Footprint and EMC also point in the right direction, provided the technological detail is sufficient to enable detecting the difference between the two oil crops. DMC points in the right direction, but coincidentally: it will be lower because the material flows connected with agriculture are shifted outside the EU.

Table 4.4 Assessment of indicators Case 3

	Actual impact change	Shown impact change	visibility / technological detail	displacement between impacts	geographical displacement	Remarks
HANPP	Down	Down	n.r.	-	-	Overestimates lower impacts since HANPP does not see HANPP rise in Malaysia in an EU27 indicator
EE IO	Down	**Neutral**	-	+	+	EE IO assumes imports are made with domestic technology and hence misses improved quality of the process in Malaysia. MR EE IO does not have this drawback
EF	Down	Down	+/-	+	+	EF only shows the right impact if local yields are similar to global yields for rapeseed and palm oil.
DMC	Down	Down	+	-	-	Score in right direction coincidentally. Neglects foreign unused extraction associated with palm oil production.
EMC	Down	**Neutral**	-	+	+	Development of EMC crucially hinges on the level of detail arrived in the "oil crops" category

4.5 Case study 4: Replacement of fossil fuel diesel by rape seed diesel oil, produced in EU

4.5.1 Introduction and general assessment

This case concerns the reduction of diesel fuel use, production and refining, and replacement of it by rapeseed production, refining and use of rapeseed oil as diesel. The rapeseed oil is produced in the EU.

Overall one would expect a mixed effect when it comes down to environmental impacts. Using rapeseed oil reduces CO_2 emissions, avoids transport of oil from e.g. the Persian Gulf, and prevents impacts of oil extraction. On the minus side, it leads to a higher agricultural land use and impacts of agriculture in Europe. Without weighting of such different impacts, one cannot tell if there is an overall improvement. Different indicators handle this issue differently – weighting is an explicit step in some indicators, but in others it is included implicitly in the calculation procudure..

Such changes are also known to have important secondary effects. There can be competition with food production, and the agricultural sector as a whole may grow at the expense of other sectors. Here, too, there may be a difference in how indicators include such changes.

4.5.2 HANPP

HANPP deals as follows with this change:

- Technical detail. HANPP is in principle a geographically oriented indicator. Yet, due to its geographical orientation, it detects higher production of rape seed oil in Europe as a rise in HANPP in Europe.
- Displacement between impacts.HANPP covers only biomass production and its human appropriation, and does not take into account other effects. In this case, HANPP misses fully the benefit of CO_2 neutrality.
- Geographical displacement. It is unlikely that the reduction in oil production in the Persian Gulf will lead to a reduced HANPP there, if only since the NPP in desert regions is very low. In any case, a European HANPP indicator does not inherently take changes in HANPP outside the EU27 into account.

In sum, HANPP would provide an unbalanced insight for policy making in this case. It would suggest environmental detioriation in terms of more biomass appropriation in Europe, whilst neglecting the benefit of reduced overall CO_2 emissions.

4.5.3 EE I-O

EE IO deals as follows with this change:

- Technical detail. EE IO will not discern rape seed oil production specifically, but will see a rise in impacts of agriculture due to rape seed oil production if tables are updated regularly. Otherwise one will see just a rise in agricultural production, with an average rise of impacts of agriculture rather than the specific impacts of rape seed production. EE IO tables do discern oil extraction. It is likely though, that no specific biodiesel refining is discerned in the IO table. Then, refineries will have a mixed input of fossil fuel and biofuel, and in the use phase it is not possible to ‘see’ biofuel specifically. The CO_2 emissions in the use stage are part of NAMEAs which are updated annually, and it is likely that such NAMEAs will be corrected for the fraction of non fossil CO_2 emissions.
- Displacement between impacts. EE IO usually covers a rather broad set of environmental interventions. A problem may be that land use, relevant for biofuel production, is not always included in simple EE IO tables.
- Geographical displacement. After introduction of biofuel, the European EE IO table should have a lower import of crude oil for diesel production. The related reduced impacts of production of crude oil are estimated with domestic technology, which probably is an acceptable approximation in this case

Overall, one in principle will see a reduction in the fossil fuel based CO_2 emissions since less fossil fuel is used. On the negative side, we will not see the real impacts of rape seed oil production, but a rise of average agricultural impacts proportional to the value of the rape seed oil produced. An MR EE IO table would perform better in this case, since it discerns sectors producing vegetable oil.

4.5.4 Ecological Footprint

EF deals as follows with this case:

- Technological detail: EF finds that biocapacity in Europe increases (forest land is converted into cropland and cropland is the most bioproductive of all the land types). EF also notices that Europe uses less fossil fuels due to the substitution by rapeseed oil. This results in less CO_2 emissions. However, rapeseed oil consumption increases. This means that there are three effects: the supply side of EF increases, EF declines because less forest area is needed to sequester the CO_2 emissions of fossil fuel use and EF increases because more cropland is needed to produce the rapeseed oil. Biocapacity increases. Since more global hectares are needed to sequester the CO_2 emissions associated with one liter diesel oil than the hectares needed to produce one liter rapeseed oil, the EF declines
- Displacement between impacts: The impacts of oil extraction and fertilizer use in Europe are missed, but the fact that less CO_2 is emmitted and more agriculture land is used is visible in the EF.
- Geographical displacement: Geographical displacement is visible in the EF, because EF notices the reduction of diesel oil consumption and the increase in rapeseed oil consumption.

In sum, the supply side of the EF accounts increases and the demand side of the EF accounts declines. The indicator therefore shows a lowering of impacts.

4.5.5 DMC

The DMC deals as follows with this change in the composition of material inputs into the economy:

- Technological detail: The DMC will discern both the flows of fossil fuels and biomass in this case.
- Displacement between impacts: The DMC takes the weight of flows associated with the rape seed production and the import of fossil fuels as the relevant impact here. The DMC captures the technological change here as a reduction of the fossil fuels and an increase in the use of biomass. The DMC does not include the unused extraction associated with fossil fuel production outside the EU nor the impacts on land use directly.
- Geographical displacement: As the imports of fossil fuels diminishes and is replaced by production within the EU, the indicator will show a substantial increase due to the "rucksack" associated with biomass production (including the transportation of the biomass). The "ruscksack" of biomass will be larger than those of fossil fuels.

In sum, this case most likely shows an increase in the DMC for the EU.

4.5.6 EMC

The EMC deals as follows with this change in the composition of material inputs into the economy:

- Technological detail: The EMC captures the change here rightly as a reduction of the fossil fuels and an increase in the use of rapeseed oil and their associated environmental effects
- Displacement between impacts: The EMC takes the difference between lifecycle environmental impacts associated with rapeseed oil production and fossil fuel production as the relevant impact here. Hence the indicator will show a decrease in global warming and an increase in land use and agriculture related emissions. The diminished environmental effects from the reduced demand for international marine shipping is as an average included in the LCA data.
- Geographical displacement: The EMC takes a chain perspective and all relevant impacts associated with biomass production and fossil fuel production are included irrespective of the country of origin.

In sum, this case shows a decrease in the EMC due to the fact that CO_2 emissions are weighted as being more important than land use changes. However, this assumption crucially hinges on the weighting factors that are being used in the EMC.

4.5.7 Review

The table below gives a review of the performance of all indicator systems. Most methods give the expected outcome: a replacement of diesel by biodiesel reduces environemntal impacts, under that assumption that a higher land use and use of pesticides is valued as less important as a reduction in fossil CO_2 emissions.

The HANPP indicator would provide a fully contrary advice, mainly because it focuses on biomass use as impact, and does not take CO_2 emissions (reduction) into account, which is the main benefit in this case. EE IO can have as drawback that if agriculture is not detailed, the rise in rape seed oil production will be reflected by an average rise of impacts by agriculture, rather than a rise of the specific impacts of rape seed oil production, that biorefinery is not included as a sector and that in the use phase emissions are not distinguished as to their fossil or biogenic origins. The EF shows an increase due to the increased land use for agriculture, and a decrease as a result of reduced CO_2 emissions – we cannot decide now what the net result will be. DMC will show an increase, while EMC will show a shift from global warming to land use and other agriculture related impact categories. Since the case has mixed results – a decrease in one problem, offset by increases in others – the indicators where this is explicitly visible provide the most relevant information.

Table 4.5 Assessment on indicators Case 4

	Actual impact change	Shown impact change	visibility / technological detail	displacement between impacts	geographical displacement	remarks
HANPP	Down	**Up**	-	-	-	HANPP misses fully the lower GWP due to biofuel use
EE IO	Down	Down	+/-	+	+	MR EE IO would be better, since it shows vegetable oil production specifically in the EU27, rather than a general rise in agricultural production
EF	Down	Down	+	+/-	+	EF covers positive (reduced CO_2 emissions) as well as negative (more rapeseed oil consumption) impacts, but not all.
DMC	Down	**Up**	+	-	-	DMC misses the impacts on land use here and includes unused extraction from biomass which are larger than unused extraction from fossil fuels.
EMC	Down	Down	-	+	+	EMC captures this case in all impacts.

4.6 Case study 5: Replacement of steel by aluminium in cars, with more efficient fuel use by cars as a consequence

4.6.1 Introduction and general assessment

This fifth case concerns the replacement of steel in cars by aluminium. This is a complicated issue, since it leads to many impacts that may be opposing:

1. More bauxite has to be mined, and melted to aluminium, whereas less iron ore has to be mined and melted to steel.
2. Aluminium production is more energy intensive than steel production.
3. It is not clear if there is a significant difference in land use change between iron ore extraction and bauxite extraction.
4. Aluminium makes cars lighter, and hence will save fuel use and production.

Unlike most of the other cases, without quantitative calculations like done in Life cycle assessment, it is not possible a priori to judge if the overall impact is positive and which negative. The only thing one can say is that an indicator and assessment system ideally should cover all the changes referred to above. We assume in this case that aluminium as well as steel are imported and that car manufacturing takes place in the EU.

4.6.2 HANPP

HANPP deals as follows with this change:

- Technical detail. None. HANPP is geographically oriented, but in principle can detect the shift of production of bauxite and iron ore production in different regions. It is unlikely that HANPP will note a shift from iron to aluminium refining.
- Displacement between impacts: HANPP covers only biomass production and its human appropriation, and does not take into account any other effects. The HANPP indicator will only detect the impacts on HANPP due to land use changes in iron ore and bauxite production. The reduction of fossil fuel based CO_2 emissions due to lighter cars is not 'seen' in this indicator. It is unlikely that HANPP will note a shift from iron to aluminium production, and certainly will mis impacts due to changes in emissions, energy use, etc.
- Geographical displacement. A EU27 HANPP will not see any shift from iron ore to bauxite ore extraction outside the EU.

An EU27 HANPP most probably will not show any change, since issues like bauxite and iron ore mining take place outside Europe. Any change in industrial process activity within Europe probably has just a minor influence on HANPP. Yet, it is certain it will miss a very important positive consequence of the change, i.e. the reduction of fuel use by cars.

4.6.3 EE I-O

EE IO deals as follows with this change:

- Technical detail. most EE IO tables discern around 40-60 sectors. In such less detailed IO tables bauxite production and –melting will not be separated from the mining and refining of other metals. Particularly if iron ore and iron production is not seen as a separate sector, an EE IO table will not be able to see differences in car production. Annual updates of EE IO tables will see however a reduction in fossil fuel use for car driving as a result of the gradual move to leighter cars
- Displacement between impacts. Impacts covered: EE IO usually covers a rather broad set of environmental interventions.
- Geographical displacement we here assume an EE IO table for a single country, where it is assumed that imports are made with domestic technology. A true global perspective is absent. This is less relevant here, since the main change is a rise in production in one sector and a decline in production in another (i.e bauxite / alumium versus iron). Some distortion may be at stake if the impacts in countries where bauxite and iron ore are mined deviate heavily from the impacts in Europe, which will be used as default in the calculations.

Overall, an aggregated EE IO table will be capable of discerning the benefits of reduced fuel consumption by cars, but will not be capable of relating impacts of production of iron and alumium according to the precise mix of alumium and iron used in the car industry; average impacts of the average mix of all metals extraced and refined will have to be used. MR EE IO tables like developed in EXIOPOL mitigate such drabacks, since they discern iron or and bauxite extraction as specific sectors, and do so with specific impacts for a large number of countries.

4.6.4 Ecological Footprint

EF deals as follows with this case:

- Technological detail: Since aluminium production is more energy intensive than steel production, CO_2 emissions will increase which would increase the Ecological Footprint, but only when aluminium production takes place in Europe. The EF will decline as a result of the lower fuel use for the lighter aluminium cars. EF does not note the shift from iron to aluminium refining.
- Displacement between impacts: The differences in land use change of bauxite and iron ore extraction are not included in this indicator. Also, the fact that more bauxite and less iron ore has to be mined is not taken into account, since EF only looks at the consumption of renewable resources.
- Geographical displacement: The shift of production of iron and aluminium in different regions is missed by the EF.

In sum, EF is capable of discerning the benefits of reduced fuel consumption by cars as well as the increased CO_2 emission of aluminium refinery, but the latter only when in Europe. It will miss the land use change between iron ore and bauxite extraction as well as other impacts associated with the refining and production of steel and aluminium (other than CO_2-emissions).

4.6.5 DMC

The DMC deals as follows with this case:

- Technological detail: The DMC takes the weight of flows associated with the steel production, aluminium production and fuel use as the relevant impact here. All these impacts are explicitly covered in the indicator.
- Displacement between impacts: The DMC investigates the weight of flows in this respect. DMC does not take into account potential impacts on land use directly.
- Geographical displacement: This highly depends on the location of the mining activities in this case. If alumina and iron ores are imported, the DMC might regard this as an improvement as aluminium is lighter than steel and fuel consumption goes down. However, if the mining and first steps of reduction take place inside EU territory, the DMC will increase due to the higher wastes associated with alumina production.

The overall assessment is given in the table below. The indicator shows most likely a decrease in the DMC for the EU as the EU almost has no bauxite mining.

4.6.6 EMC

The EMC deals as follows with this case:

- Technological detail: The EMC takes the difference between lifecycle environmental impacts associated with aluminium consumption and the lifecycle environmental impacts associated with steel consumption. Reduced fuel consumption is included through the energy consumption that is part of the EMC. The EMC captures the change here as a material substitution of steel for aluminium but does not link this explicitly with the reduced fuel consumption.
- Displacement between impacts: A decomposition of the EMC into environmental impacts may show global warming impacts, both the reduction in the use phase and the increase in the production phase, and land use increases.
- Geographical displacement: The EMC takes a chain perspective: all relevant impacts associated with aluminium and steel consumption and the consumption of fossil fuels are included irrespective of the place of production.

In conclusion, it is unclear beforehand which direction the indicator will go in this example, much will depend on the weight of the loss of land use versus the gain in energy efficiency.

4.6.7 Review

The table below gives a review of the performance of all indicator systems. It is not clear what is the expected effect, but it is likely that a detailed MR EE IO table will come closest to the real impact. It covers the benefits (reduced CO_2 emission) and does specify specifically the effects of reduction in iron and rise in alumium production. Other methods have drawbacks:

- HANPP does not ‘see’ the increased nor the reduced CO_2 emissions, or any other impacts.
- Aggregated EE IO tables cannot discern between metals, and hence will not allocated impacts according to the actual iron/aluminium mix to the automotive production. A more detailed MR EE-IO where the aluminium and iron sectors are separated can do this.
- The EF sees both increased and reduced emissions, but not other impacts
- The DMC does show a reduction due to the reduced fossil fuel use and the fact that aluminium is lighter than steel.
- EMC shows both the reduction of CO_2 emissions of driving (in the oil chain) and the changes due to the shift from steel to aluminium, in terms of CO_2 and otherwise.

Table 4.6 Assessment on indicators Case 5

	Actual impact change	Shown impact change	visibility / technological detail	displacement between impacts	geographical displacement	remarks
HANPP	?	**Neutral**	-	-	-	HANPP misses the positive effect of CO_2 emission reduction.
EE IO	?	?	+/-	+	-	EE IO is less precise than detailed MR EE IO, since it cannot discern metal ore extraction and refining
EF	?	**?**	+/-	-	-	EF covers the positive effect of CO_2 emission reduction of fuel, but it does not detect the change from steel to aluminium production if produced abroad.
DMC	?	**Down**	+	-	-	DMC covers positive effect of less fuel consumption and also the fact that aluminium is lighter than steel
EMC	?	?	+	+	+	EMC covers all relevant impacts here but the final outcome depends on the weighting schemes employed.

4.7 Case study 6: Recycling of glass enhanced from 50% to 80%

4.7.1 Introduction and general assessment

This sixth case concerns the rise in glass recycling from 50 to 80%. There probably will be a slight rise in transport for waste management, due to the specific collection system. Costs for waste management will probably rise by this. All this may lead to a slight rise in transport emissions.

On the beneficial side, there are much higher reductions in impacts. First, the glass volume will not end anymore in landfills which transforms in lower land use(in Europe still a considerable part of municipal waste is being landfilled). But more importantly, the production of new glass from secondary glass is significantly less energy intensive as the production of new glass from primary resources. This implies directly a significant reduction in CO_2 emissions, Furtherore, the production of auxiliary and primary materials (mostly industrial sand) used in glass production can be reduced, leading to even less impacts in the economic system.

In sum, it is likely that overall the environmental impacts are reduced.

4.7.2 HANPP

HANPP will deal as follows with this change (a rise in glass recycling)

- Technical detail. HANPP is unable to detect the marginal changes in production volume upstream of the glassproduction, when more recycled glass is used. Such marginal reductions will not lead to decomissioning of industrial plants and hence not show up as reduced land use.
- Displacement between impacts. HANPP covers only biomass production and its human appropriation. It is hardly conceivable that higher glass recycling has any impact on this. The exception may be a very small reduction of land use for landfill, reducing the HANPP due to land use change, and may be the reduction of land use for mining primary materials for glass production[26]. HANPP will however miss completely the positive effect on energy consumption and related global warming problems.
- Geographical displacement. Irrelevant in this case, since the change is in Europe

In sum, HANPP will probably not or hardly detect any environmental improvement, where one would expect a very clear improvement.

4.7.3 EE I-O

EE I-O will deal as follows with this change:

- Technical detail, Most EE IO tables discern around 60 sectors. Glass production as such is part of a broader group of production processes that includes glass and ceramics. Furthermore, all recycling processes are lumped in one sector. Yet, time series of NAMEAs/ EE IO tables would show a diminishing input of energy and resources and related emissions into the glass and ceramics sector with enhanced recycling.
- Displacement between impacts/ EE IO usually covers a rather broad set of environmental interventions, and hence in principle can detect issues like reduced primary resource consumption, reduced energy consumption and global warming, etc..
- Geographical displacement. Not relevant in this case.

In sum, in principle time series of EE IO tables should show overall lower impacts due to savings in energy and resource use in glass production. NAMEAs usually base CO_2 emissions on actual energy use in a sector, and just like is the case with the EF the diminishing CO_2 emissions due to higher input of recycled glass are hence accounted for. It would have been nicest if this change could be seen in the glass production sector as

[26] Even this negative effect may not be detected if e.g. the landfill or quarry is covered nicely with new fertile ground, and new biomass is allowed to grow there. See the conversion of landfills into golf yards, parks, etc.

such, but as said in most EE IO tables glass production is part of a broader sector. The main problem is that the change happens at a very high level of detail, and time series of EE IO tables only will show the improvement of an aggregated sector where glass production is part of. MR EE IO tables as developed in EXIOPOL perform better in this case, since glass production is a dedicated sector.

4.7.4 Ecological Footprint

EF deals as follows with this change:

- Technological detail: EF can see the lower CO_2 emissions associated with the decline in energy use for glass production. The lower consumption of primary resources is also detected. Furthermore, EF can distinguish different efficiencies in glass production when this production takes place within Europe.
- Displacement between impacts: The indicator detects that the CO_2 emissions and the consumption of primary resources decline. However, land use for landfill is not included in this indicator.
- Geographical displacement: Not relevant for this case study.

In sum, EF will show an environmental improvement due to lower resources and fossil energy use.

4.7.5 DMC

The DMC deals as follows with this case:

- Technological detail: the DMC will notice the reduced consumption of virgin glass and the associated net reduced consumption of energy.
- Displacement between impacts: DMC does not take into account potential impacts on land use.
- Geographical displacement: Not relevant here.

In sum, DMC will be lower.

4.7.6 EMC

The EMC deals as follows with this case:

- Technological detail: the EMC until now has not distinguished virgin from secondary glass consumption but estimates this using a fixed coefficient for the consumption of sand. As this coefficient is not determined each year individually, the EMC will miss this case entirely although the LCA database distinguishes between primary and secondary glass consumption.
- Displacement between impacts: All relevant impacts are included here but since the EMC will not change, it will also miss these changes.

- Geographical displacement: not relevant here.

In sum, EMC will not notice this improvement directly. Only a change in the coefficients used for calculating the EMC may make this visible.

4.7.7 Review

The table below gives a review of the performance of all indicator systems. Some indicators end up with 'right' information for policy. Some indicator systems are however less appropriate.

- HANPP misses the benefit of reduced energy use and CO_2 emissions
- EE IO detects the reduction in CO_2 emissions in relation to lower energy use, but it would even be better if this would have been identified for the glass production sector in specific rather than for the overall sector of which glass production is a part .
- The EF detects the reduction in CO_2 emissions due to reduced primary glass production.
- DMC is reduced because of the lower sand and fossil fuel requirements
- EMC remains the same and does not notice the shift from virgin to secondary glass at present.

Table 4.7 Assessment on indicators Case 6

	Actual impact change	Shown impact change	visibility / technological detail	displacement between impacts	geographical displacement	Remarks
HANPP	Down	**Neutral**	-	-	n.r.	HANPP does not see a main benefit, the reduction of energy use.
EE IO	Down	**Neutral**	-	+	n.r.	EE IO gives the right judgment, but has insufficient detail to 'show' that glass recycling is the cause. MR EE IO tables show glass production specifically
EF	Down	Down	+	+/-	n.r.	EF shows that less energy and renewable resources are consumed but not the reduction in metal use
DMC	Down	Down	+	-	n.r	DMC notices that less virgin materials and energy are being used.
EMC	Down	**Neutral**	-	+	n.r	EMC does not detect the increased recycling rates directly.

4.8 Case study 7: Replacement of plastic waste incineration with energy recovery within the EU by similar treatment abroad

4.8.1 Introduction and general assessment

This case concerns the 'export' of plastic treatment by inceneration with energy recovery from Europe to abroad. This leads to a higher need for primary energy production in Europe, and a reduction in primary energy production abroad. We assume that the net global effect of this is zero. Both technologies have the same quality and impacts. The only global change hence is the fact, that the plastic now has to be transported over a larger distance to reach the treatment plant. Assuming this is done by sea-vessel, it is well known that transport emissions are marginal compared to the impact of plastic incineration. Overall an indicator hence should show a negligible detioration.

4.8.2 HANPP

HANPP deals as follows with this case:

- Technical detail. Not relevant for HANPP in this case. Since we assume no change in capital stock due to marginal change in incineration volumes, HANPP does not detect land cover change in the EU27. It does not detect the any additional transport of products and resources used, but that has been assumed less releavnt in this case.
- Displacement between impacts. HANPP does not notice changes in relevant impact such as noise and toxic effects, but these are assumed equal in this case[27].
- Geographical displacement . HANPP focuses on changes in biomass production. Assuming we talk about marginal changes in incinerated material, it is unlikely that there will be a change in the amount of capital good presents in the form of incinerators in Europe nor abroad. An EU27 HANPP indicator hence will not show any change.

In sum, HANPP gives the expected outcome, i.e. that no overall change in impacts takes place. This is however due to the specifics of this case, i.e. that we assume that lower plastic incineration in Europe will not lead to a lower number of incineration plants. HANPP does not show the shift of impacts from Europe to the other country where plastic is incinerated, and in effect ignores any causal rise in HANPP outside Europe.

[27] Taking secondary effects into account, it may even be that there is no land use cover change in Europe nor abroad at all. The energy in Europe now must be produced by a regular power plant, claiming its own share of HANPP due to land use cover change.

4.8.3 EE I-O

EE IO deals as follows with this case:

- Technical detail. The plant in the Europe and abroad will be part of the sector waste management. Annual updates of NAMEAs will show a lower CO_2 emission from these plants due to lower incineration. A higher import of fossil fuels is visible, and would lead to higher CO_2 emissions due to an increased demand for electricity from power plants (see below)..
- Displacement between impacts: EE IO covers the most relevant emissions in this case, except for those related to toxicity. Yet, with equal quality of treatment this is not relevant.
- Geographical displacement. EE IO does show that import of waste mangement services takes place, and allocates the environmental benefits of this from a EU27 consumption perspective. It is assumed that these services are provided with domestic technology, which in turn implies that the EE IO table provides the right answer (i.e. no change in impacts). EE IO also shows the increased import of fossil fuels. In principle however the calculated energy benefit of exported waste management services should offset the higher imports of fossil fuels.

In sum, EE IO would provide the right information for policy, i.e. that there no net change of CO_2 emissions related to final European consumption: the exported waste is assumed to be treated with EU technology and benefits are allocated to EU consumption. It is however right for the wrong reasons: it does not show the shift of location of impacts of plastics incineration (only that exports of waste rises). Its assumption, and flatly assumes that impacts abroad are similar to those in Europe due to the use of domestic technology is coincidentally correct. MR EE IO as developed in EXIOPOL mitigates a few problems in this case, i.e. a more specific waste management sector and the ability to use specific technology assumptions for the country where waste incineration takes place. Just by this the drawback is mitigated that EE IO is not detailed enough to show incineration of plastics with energy recover specifically, but sees it as waste management in general.

4.8.4 Ecological Footprint

EF deals as follows with this case:

- Technological detail: Not relevant for this case study (both technologies have the same impacts).
- Displacement between impacts: The higher energy production in Europe is reflected in the EF, but it cannot see that the energy production abroad has decreased by a similar amount. The CO_2 emissions of international marine shipping is estimated as a percentage of the total European CO_2 emissions, so the increase of international marine shipping is not detected by EF.
- Geographical displacement: Geographical displacement is not detected by EF, since it does not notice the lowering of energy production abroad.

In sum, EF does not give the expected outcome, it will probably show an increasing impact, while in reality no change in impacts takes place. This is because EF can only see the changes within Europe i.e. the fact that more energy needs to be produced within Europe, but it cannot see the gains and losses abroad.

4.8.5 DMC

DMC deals with this case as follows:

- Technological detail: DMC will cover the higher energy need in Europe. Export of waste is included as a material flow and this will lower the DMC. As the weight of the latter flow is larger than the former, the DMC will decrease. The increase of CO_2 emissions due to an increase in international marine shipping is not included.
- Displacement between impacts: Not relevant in this case.
- Geographical displacement: The higher energy production in Europe is reflected in the DMC, but it cannot see that the energy production abroad has decreased by a similar amount. Export of waste makes the DMC of the EU lower without noticing that in the receiving country the DMC will go up.

In sum, the DMC will decrease in this case.

4.8.6 EMC

EMC will react to these changes as follows:

- Technological detail: The EMC will not cover the higher primary energy production in Europe, since it is a consumption based indicator. The increase of CO_2 emissions due to an increase in international marine shipping could be included through fixed coefficients in the LCA, as a specific case of end-of-life treatment of plastics. This however is an unlikely extension of EMC. The assumption on end-of-life treatment of plastics will not change either, which in this case coindices with the caser: the EOL of plastics does not change, it is just relocated.
- Displacement between impacts: Not relevant in this case.
- Geographical displacement: EMC cannot see that the energy production abroad has decreased by a similar amount directly, again due to the consumption-based nature of the indicator.

In sum, the EMC will show no change in this case.

4.8.7 Review

The table below gives a review of the performance of all indicator systems. Various indicator systems like HANPP and EE IO give the expeced outcome, i.e. no change in impacts. Yes, they do so for the wrong reasons and in fact the right score is more luck than due to the appropriateness of the indicator in this case.

MR EE IO may go slightly astray too, mainly since the lack of detail is not sufficient to single out plastic waste incineration with energy recovery specifically. It sees a rise in activity in the waste incineration sector abroad, and a reduction of acivity of this sector in Europe. It is not a given that technical co-efficients and emission factor per Euro for the waste incineration sector as a whole are identical in both regions. MR EE IO hence may show non existing differences.

Table 4.8 Assessment on indicators Case 7

	Actual impact change	Shown impact change	visibility / technological detail	displacement between impacts	geographical displacement	Remarks
HANPP	Neutral	Neutral	-	-	-	HANPP sees no HANPP change in Europe since capital stock changes are abset. HANPP misses any change outside Europe
EE IO	Neutral	Neutral	-	+	+	EE IO shows no change in impacts due to the standard assumption that production abroad is similar to domestic, coincides with the assumption in this case.
EF	Neutral	**Up**	+/-	-	-	EF can see the losses (more energy production) within Europe, but it does not see the gains and losses abroad.
DMC	Neutral	**Down**	+	-	-	DMC shows the reduction in material flows within EU, but not the changes outside. Export of waste makes the DMC lower.
EMC	Neutral	Neutral	-	-	+	EMC does not show any change, due to the consumption oriented nature of the indicator

4.9 Case study 8: Replacement of plastic waste incineration with energy recovery within the EU by open air incineration abroad

4.9.1 Introduction and general assessment

This case has similar characteristics as the former one, but here the treatment abroad is of much lower quality. The 'technology' used abroad is open air incineration. This has a great number of drawbacks:

- Energy is not recovered anymore
- Open pit incineration is uncontrolled, usually lead to incomplete combustion, hence high emissions, which boviously are not treated at all (where in Europe incinerators have extensive flue gas cleaning to comply with the most stringent emission standards in the world). It is more than likely that significant amounts of toxic substances such as dioxins will be formed. Plastics like PVC and polyurethane will form toxic gases, such as HCl.

The conclusion is obvious: overall this shifts leads to a sharp drop in environmental performance. Within Europe, the demand for primary energy will rise slightly, but the impacts related to plastics incineration will be reduced. This implies that the environmental degradation will mainly take place outside the EU.

4.9.2 HANPP

HANPP will deal as follows with this case:

- Technical detail. HANPP is geographically oriented. Since we assume no change in capital stock due to marginal change in incineration volumes, HANPP does not detect land cover change in the EU27.
- Displacement between impacts. HANPP does not notice changes in relevant impact such as noise and toxic effects, which are significant in this case. It also misses in full the fact that more fossil fuel emissions take place due to lower energy recovery.
- Geographical displacement . HANPP focuses on changes in biomass production and is not apt to relate changes outside Europe in a causal way to a decision made by Europe. HANPP misses in full the very negative effects abroad of open pit incineration..

Overall, HANPP most probably will suggest that this change is neutral. This is contrary to what really happens. The main reason for this is that HANPP does not include the impacts of the toxic emissions from open pit incineration, and does not take into account the loss of energy recovery and hence higher CO_2 emissions globally[28].

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[28] Over time, toxic emissions may lead to less production on agricultural land near the open pit incineration activity. Yet, this most probably will not influence HANPP. HANPP assumes a potential net primary production and looks at 'what is left' after harvest to calculate the fraction appropriated by humans. Here,

4.9.3 EE I-O

EE IO deals as follows with this case:

- Technical detail. The plant in Europe will be part of the sector waste management; it is unlikely that incineration with energy recovery is specifically visible in this case. The main problem is however that EE IO assumes that waste management service abroad take place with similar technology, so no change will be detected. The increase in CO_2 emissions due to a higher demand for electricity from power plants is visible, but this effect is offset due to the fact that the energy recovery that is assumed to take place abroad with the 'similar technology' is allocated as a benefit to European consumption..
- Displacement between impacts. EE IO misses toxic emissions, very relevant in this case.
- Geographical displacement. EE IO does show however that import of waste mangement services takes place. It is assume that these services are provided with domestic technology, which in turn implies that the EE IO table is blind for the fact that the process abroad has such lower quality.

In sum, EE IO would provide incomplete information for policy. It does detect the increase in emissions from power plants in Europe, but not the shift from waste incinerator to open pit burning, i.e. that overall there is no change in impacts. The reason is the assumption that processes abroad take place with similar technologies as in Europe, which is clearly not the case here. MR EE IO as e.g. developed in EXIOPOL would not make this mistake, since it gives country specific waste management processes.Treatment abroad leads to toxic emissions, and lower energy recovery.

4.9.4 Ecological Footprint

EF will deal as follows with this case:

- Technological detail: EF misses the fact that waste incineration with energy recovery is replaced by open air incineration.
- Displacement between impacts: EF will detect the fact that more energy needs to be produced in Europe, since the plastic waste incineration with energy recovery has fallen away. However, EF does not detect the open pit incineration abroad along with the associated emissions and release of toxic substances.
- Geographical displacement: Geographical displacement is missed by EF, because it misses all the impacts associated with the open air incineration abroad.

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the potential harvest will be diminished, but the theoretical NPP in that area stays the same. The (lower) harvest will be fully taken, and the result is that a similar residual amount of biomass is left in nature. Overall there hence will not be a change in HANPP.

In sum, EF will suggest deterioration in Europe (more energy needs to be produced in Europe), but it will not see the deterioration abroad. EF does not include waste treatment for substances other than CO_2 and therefore does not include the impacts of the toxic emissions from open pit incineration. Furthermore, the loss of energy recovery abroad is not noticed, since EF only focuses on energy production within Europe.

4.9.5 DMC

DMC will react as follows:

- Technical detail. Export of waste is included in the DMC as well as primary energy use. As the former flow outweighs the latter, the DMC is assumed to be lower. International maritime shipping is not included.
- Displacement between impacts: The DMC will not notice the difference between environmental impacts in this case.
- Geographical displacement. The higher energy production in Europe is reflected in the DMC. Export of waste reduces the DMC.

In sum, the DMC will show the exact same changes as in Case Study 7, and will be lower.

4.9.6 EMC

The EMC will react as follows:

- Technical detail. Waste treatment is only included in the fixed coefficients from the LCA. Eventuel changes here are not directly noticed, only if LCA databases are being updated. Higher energy use in Europe is not included, since EMC is a consumption oriented indicator.
- Displacement between impacts: The EMC does in principle discriminate between the relevant impacts but these will not be visible in this case due to the fixed coefficients from the LCA.
- Geographical displacement. Neither the higher energy production in Europe, nor the environmental effects of waste treatment abroad is reflected in the EMC due to the fixed EOL assumptions on waste treatment.

In sum, the EMC will not show any change.

4.9.7 Review

Most indicators are insensitive for changes like these. HANPP, EE IO and EMC miss in full the change in emission patterns, and the loss of energy recovery. EF shows part of the changes and at least goes in the right direction. DMC shows an opposite outcome due to the net result on material flows within EU, missing changes outside. For all of the indicators, the level of detail is not sufficient to single out plastic waste incineration with energy recovery specifically.

Table 4.9 Assessment on indicators Case 8

	Actual impact change	Shown impact change	visibility / technological detail	displacement between impacts	geographical displacement	remarks
HANPP	Up	**Neutral**	-	-	-	HANPP misses in full the toxic emissions caused in the new situation and lack of energy recovery
EE IO	Up	**Neutral**	-	-	-	EE IO assumes that waste management abroad uses domestic technology, which is totally wrong in this case. MR EE IO would not make this mistake due to country specific process modelling
EF	Up	Up	+/-	-	-	EF will show energy related impacts within Europe, but will not show the waste related impacts abroad.
DMC	Up	**Down**	+/-	-	-	DMC will decrease due to the material flows being exported.
EMC	Up	**Neutral**	-	-	-	EMC will show neither the impacts within EU (consumption oriented) nor abroad (fixed EOL assumptions) automatically.

4.10 Case study 9: End of pipe emission reduction by a desulfurization plant in the EU

4.10.1 Introduction and general assessment

This case concerns an end of pipe emission technology: a desulphurisation plant related to the electricity sector. The benefit of the installation are much lower SO_2 emissions, but building the plant needs a lot of auxiliary materials etc. These would be mainly non-renewable construction materials for pipes etc.

4.10.2 HANPP

HANPP deals as follows with this case:

- Technical detail. HANPP focuses on changes in biomass availability in nature due to human appropriation and land use cover change. A desulphurization plant is an

activity using limited space in an area that had already an industrial use, so it is not likely that important land use cover changs will be at stake.
- Displacement between impacts. HANPP is blind for the positive benefits of reduced SO_2 emissions, nor sees the use of capital goods for building the SO_2 capture plant.
- Geographical displacement . Not relevant.

Overall HANPP will not show any change, despite the vast environmental benefits SO_2 emissoin reduction will have.

4.10.3 EE I-O

EE IO deals as follows with this case:
- Technical detail. EE IO tables have a specific electricity production sector. They also show the higher demand for capital goods in the year that the desulphurisation plant is built, but in absence of full capital accounts the use of capital goods probably will not be allocated in a fully right way to the sectors that demand them.
- Displacement between impacts. Impacts covered: EE IO usually covers a rather broad set of environmental interventions. NAMEAs will show a drastic limitation in SO_2 emissions in the year that the plant becomes operational.
- Geographical displacement. Irrelevant in this case

In sum, EE IO would show the SO_2 reduction and the impacts related to higher production of capital goods a the level of the EU27, but would be less succesful in allocating the use of capital goods to the electricity sector. Overall, EE IO would suggest an environmental improvement which is likely to be the right answer.

4.10.4 Ecological Footprint

EF deals as follows with this case:
- Technological detail: EF misses all changes in the technological system.
- Displacement between impacts: EF does not detect the increased consumption of auxiliary materials, since non-renewable materials are not included in EF. Furthermore, the only waste product considered is CO_2, so the reduced emissions of SO_2 are not noticed. EF shows no impact at all.
- Geographical displacement: Not relevant for this case study.

In sum, EF would not show any changes in environmental impacts since it does not cover SO_2 emissions nor the consumption of nonrenewable materials.

4.10.5 DMC

The DMC will react as follows.

- Technical detail: DMC does not notice the lower sulphur emissions.
- Displacement between impacts: DMC will notice the higher material needs for building the desulferisation plant.
- Geographical displacement. Irrelevant in this case.

In sum, the DMC will (slightly) increase and hence points in the wrong direction.

4.10.6 EMC

EMC will show the following changes:

- Technical detail: The EMC covers a rather broad set of environmental interventions but will miss the reduced SO_2 emissions as these are fixed in the LCA that the EMC uses. Only if LCA databases are being updated, this will become visible.
- Displacement between impacts: The EMC will notice higher material goods as these are reflected in an increase in finished materials.
- Geographical displacement. Irrelevant in this case

In sum, the EMC will increase and hence points in the wrong direction. In the long run, the EMC might however capture this if the LCA databases are being updated.

4.10.7 Review

The table below gives a review of the performance of all indicator systems. HANPP misses fully the benefit of reduced emissions. EE IO will probably be insensitive to more material use in the year of construction or at least will not allocate them correctly, but it will show lower SO_2 emissions from the year the plant is commissioned. The DMC and EMC will notice the higher demand for materials but miss the direct environmental gains of lower SO_2 emissions. For the EMC these might be captured in the long-run if the LCA databases are regularly being updated.

Table 4.10 Assessment on indicators Case 9

	Actual impact change	Shown impact change	visibility / technological detail	displacement between impacts	geographical displacement	remarks
HANPP	Down	**Neutral**	-	-	n.r.	HANPP misses in full the positive impacts of reduced SO_2 emission as well as the negative impacts of extra material use.
EE IO	Down	Down	+	+	n.r.	EE IO sees both reduction of SO_2 emissions and higher impacts due to material use, but will not be able to allocate the latter to electricity production
EF	Down	**Neutral**	-	-	n.r.	EF misses all the impacts, since it does notice neither the reduction of SO_2 emissions nor the higher material use.
DMC	Down	**Up**	-	+	n.r.	DMC notices the higher material demand but neglects impacts on SO_2 emissions
EMC	Down	**Up**	-	+	n.r.	EMC notices the higher material demand but neglects impacts on SO_2 emissions as long as LCA databases are not being updated.

4.11 Case study 10: Productivity enhancement in agriculture, with equal emissions per ha, and equal emissions per kg product

4.11.1 Introduction and general assessment

The tenth case is a productivity enhancement in agriculture in Europe. We assume further that demand for agricultural products stays the same, so that the productivity enhancement will essentially result in transformation of agricultural land to other land types, assumably nature. As a result, imports and exports will not change either. The case has two variations:

1. equal emissions and use of pesticides and fertilizers per ha. In this sub-case, there is not only productivity enhancement, but this is even realised with less use of pesticides, fertilisers per kg of product. Total emissions hence will diminish, not only in agriculture, but also in the supply chains.
2. equal emissions and use of pesticides and fertilizers per unit of product. In this scenario, the only benefit is the reduction of land use for agriculture, all the rest stays the same.

4.11.2 HANPP

HANPP deals as follows with this case:

- Technical detail: HANPP focuses on changes in biomass availability in nature due to human appropriation and land use cover change. In both sub-cases, land use for agriculture is diminished, and this land is turned into nature. The result is a significant improvement of HANPP: the net primary production in the land 'freed' of agriculture is not appropriated anymore.
- Displacement between impacts: HANPP will not notice the impacts of a more intensive agriculture on environmental quality, and neither will it see the benefits of improved agricultural efficiency. HANPP therefore cannot distinguish between the two variants.
- Geographical displacement: not relevant in this case, since it implies a change in Europe without knock-on effects in the supply chain beyond Europe.

Overall HANPP will hence improve (=diminish) equally in both cases. Where an improvement of the environmental situation is expected, in the first sub-case there is a neglect of the additional benefits of reduced pesticide and fertiliser consumption, and related lower emissions.

4.11.3 EE I-O

EE IO deals as follows with this case:

- Technical detail. Most EE IO tables discern around 60 sectors. The agricultural sector often discerns no further sub-sectors. Since here in both sub-cases the main issue is a general productivity improvement in agriculture, this issue is not relevant. EE IO has inherently a chain perspective. It hence will show a lower economic input of pesticides and fertilisers in the first sub scenario. Technical detail can be a problem, though. – the EE IO table will not specify pesticide or fertiliser production reduction, but reduction in a general sector such as chemistry. This implies that a lower production in the chemistry sector, and related lower emissions, will be visible, but they will not be specific.
- Displacement between impacts. EE IO usually covers a rather broad set of environmental interventions, but miss a relevant one in this case: Not all EE IO tables include land use.
- Geographical displacement. Not relevant in this case, since it implies a change in Europe without knock on effects in the supply chain beyound Europe

In sum, EE IO would miss the lower land use, but would show in the first sub case (higher productivity with equal input of pesticides and fertilisers) a lower impact related to the chemical industry. In the second sub-case, EE IO would miss the benefit of lower land use and suggest no change. MR EE IO as developed in EXIOPOL does cover land use, and hence may not make this mistake. Also the development of a NAMEA Land by Eurostat could mitigate this problem.

4.11.4 Ecological Footprint

EF deals as follows with this case:

- Technological detail: Not relevant in this case study.
- Displacement between impacts: In both sub cases, agricultural land is turned into nature. For the biocapacity of a region, national/regional yield factors are used, but when calculating the area needed for consumed resources, global yield factors are applied. This means that the demand side of the EF accounts will not change, but the supply side –the Biocapacity- will actually improve. The diminished use of fertilizers and pesticides and the associated decrease in emissions in the first sub case go undetected.
- Geographical displacement: Not relevant in this case study.

In sum, the supply side of the EF accounts will improve equally in both cases. The additional benefit of reduced use of pesticides and fertilizers in this first sub-case is not noticed.

4.11.5 DMC

The DMC will treat this case as follows.

- Technical detail: DMC focusses on material flows, biomass production is one of them. Decreased use of pesticides in the one case is included, but will probably be undetectable since the actual flows of pesticides are many orders of magnitude smaller than the flows dominating DMC. Land and nature not used for production is not included in the DMC.
- Displacement between impacts: As the total production of agriculture does not change, the DMC will remain equal.
- Geographical displacement: Not relevant in this case

In sum, the DMC will show an infinitesimal decrease due to the decreased use of pesticides in the second variant of this case.

4.11.6 EMC

The EMC will react as follows:

- Technical detail: EMC focusses on material flows; biomass production is one of them. Pesticides are not included directly as material flow but appear in the impact factors of agricultural products. Land use is included in EMC similarly, as impact factors of agricultural chains.
- Displacement between impacts: As the total production of agriculture does not change and the impact factors will not change automatically, the EMC will remain

equal. The decrease in pesticides and land use will, like all changes in environmental impacts, only become visible if impact factors from LCA are being updated.
- Geographical displacement: Not relevant in this case

In sum, the EMC will neglect the improvement in agricultural productivity in the short-run. Only if impact factors are being revised, this will become visible.

4.11.7 Review

The table below gives a review of the performance of all indicator systems. Most methods do not detect these changes. Only the HANPP and the EF, due to their focus on land use, make the reduced land use visible, although they cannot deal with the changes in agricultural practice. EE IO and EMC have the potential to show benefits of reduced land use as well as of lower agrochemical related emissions. EE IO would have to modify emission factors, include land use factors, and provide sufficient detail in the chemical industry sector. EMC would have to include new impact factors related to agricultural crops.

Table 4.11 Assessment on indicators Case 10

	Actual impact change	Shown impact change	visibility / technological detail	displacement between impacts	geographical displacement	Remarks
HANPP	Down	Down	+/-	-	n.r.	Sees only land use change, not the relatively lower use of pesticides etc. in the first sub case
EE IO	Down	**Neutral**	-	-	n.r.	It is assumed land use is not covered in EE IO, and this is a relevant effect. MR EE IO in EXIOPOL would cover this, though
EF	Down	Down	+/-	-	n.r.	EF sees the land use change, but not the reduced use of pesticides in the first sub case.
DMC	Down	**Neutral**	-/+	-	n.r.	The DMC in theory notices the lower use of pesticides.
EMC	Down	**Neutral**	-	-	n.r.	The EMC will not notice these changes in the short run. Only if impact factors are revised this will become visible.

4.12 Case study 11: Less car use in the EU, with hence less imports of cars

4.12.1 Introduction and general assessment

The final example is a diminishing use and sales of cars in Europe, produced abroad. This has a number of effects that overall should lead to lower impacts, both in Europe as abroad:

- For the sake of argument, we assume that less imports leads truly to less use of cars. This implies less kilometers driven, lower CO_2 and other emissions, lower fuel use, related refining, and oil extraction, and the like. We assume that road infrastructure available will not change.
- Car production abroad will diminish. This has all kinds of knock on effects in the supply chain: less iron ore mining, less blast furnace operations, less car production, less transport for moving new cars across the globe, and the like, with diminishing emissions and impacts in all these sectors.

4.12.2 HANPP

HANPP deals as follows with this case:

- Technical detail: HANPP simply detects a change in land cover changes at places where production takes place, but these are of limited relevance here.
- Displacement between impacts: HANPP misses the reduction of many impacts related to car driving, including lower GWP, lower toxic emissions, and the like.
- Geographical displacement: HANPP focuses on changes in biomass appropriation, including appropration by land use change. In Europe, no HANPP changes can be expected, since the reduction of emissions is not 'part' of the HANPP indicator. With road infrastructure not changing, there is no land use cover change. There may be some minor positive effects in countries where iron ore mining takes place. Less iron ore is needed, and land cover may change for the better. This effect is however not included in an EU HANPP indicator.

In sum, HANPP does not show any changes for Europe. It misses important issues like reduction of CO_2 emissions, etc.

4.12.3 EE I-O

EE IO deals as follows with this case:

- Technical detail: most EE IO tables discern around 60 sectors, including the most relevant ones for this case: fuel production, vehicle production, etc. Iron ore extraction and blast furnace operations are however part of metal mining and metal refining in general. This implies that the EE IO table will see a reduction of iron use as a reduction in metal use, with average emission reductions in that sector. Since the direct emissions of cars dominate and are also included in EE IO, this lack of detail has not too much of a distorting effect.

- Displacement between impacts: no displacement is expected, but EE IO will see wider environmental benefits due to the reduction in production and use of cars.
- Geographical displacement: EE IO has inherently a chain perspective. Less car use and sales will immediately be translated in diminishing import or production of cars, diminishing production of fuel, diminishing production of metals etc..EE IO assumes that this production will take place with domestic technology, which may provide some minor errors, irrelevant compared to the greatest benefit (reduced CO_2 emissions due to less car driving)

In sum, EE IO would provide the right information for policy, i.e. that overall there is a drop in impacts, both in the use phase and in the car production and its supply chains. Yet, EE IO does not show the geographical distribution of (lower) impacts. MR EE IO would be more powerful in this sense, and also is capable of taking country specific impacts into count per process.

4.12.4 Ecological Footprint

EF deals as follows with this case:

- Technological detail: EF only detects the lower fuel use within Europe, but completely misses the lower car production abroad.
- Displacement between impacts: EF misses the reduction of many relevant impacts. It detects the lower fuel use within Europe and the associated decline in CO_2 emissions. Other emissions related to the use of cars and other impacts related to refining and oil extraction are missed. Car production is also not taken into account, since the consumption of metals, a nonrenewable resource, is not included in EF. Since the direct emissions of cars dominate, this lack of detail has not too much of a distorting effect
- Geographical displacement: the lower car production abroad along with the knock on effects in the supply chain are completely missed.

In sum, EF shows a drop in environmental impacts due to lower CO_2 emissions associated with lower fuel use. The decline in impacts due to lower car sales is missed.

4.12.5 DMC

The DMC will act as follows:

- Technical detail: The DMC includes the flows of primary materials, both produced, imported and exported, and the import and export of products. Most of the effects within the EU territory will be visible in terms of reduced weight of material flows: mainly through imports of raw materials and cars and reduced

consumption of automotive fuels. Since the direct emissions of cars dominate, this lack of detail has not too much of a distorting effect.
- Displacement between impacts. The DMC will see the reduced consumption of materials here as the relevant impact (see also under technical detail).
- Geographical displacement: The DMC will notice some of the improvements in non-EU countries but neglects the flows of foreign unused extraction associated with car production. Hence it may underestimate the true environmental gains.

In sum, the DMC will notice an improvement although it may underestimate the true environmental gain due to the fact that foreign unused extraction are not included.

4.12.6 EMC

EMC deals as follows with this case:
- Technical detail: The EMC includes the flows of finished materials associated with car production, however, it does not include imports and exports of finished products such as cars. A reduction in car production abroad therefore would not be visible. EMC does notice the reduced demand for transport fuel.
- Displacement between impacts. EMC covers a rather broad set of environmental interventions. Since a great variety of impacts is reduced in this case, this advantage is highly relevant.
- Geographical displacement: EMC has inherently a chain perspective albeit at the level of finished materials. Hence, it does not include the reduced import of cars and the materials that are being used for car production abroad. However, these are probably small compared to the greatest benefit (reduced CO_2 and other emissions due to less car driving)

4.12.7 Review

The table below gives a review of the performance of all indicator systems. Almost all indicator systems give the right advice to policy, i.e. that a reduction in car use leads to environmental gains. EE IO provides the most comprehensive insight in emissions reduced and resources less extracted. HANPP on the other hand will not detect any of the benefits. Even the potentially lower problems with land use change due to iron ore production will not be visible since this benefit occurs outside the EU, leading to the suggestion that no improvement is at stake at all. DMC also points in the right direction: it is lowered both as a result of reduced fuel use and of lower car imports. EF and EMC also show a reduction, but only as a result of the reduced fuel use. For different reasons, the reduction of car imports is visible in neither of the two indicators.

Table 4.12 Assessment on indicators Case 11

	Actual impact change	Shown impact change	visibility / technological detail	displacement between impact	geographical displacement	remarks
HANPP	Down	**Neutral**	-	n.r.	-	HANPP misses all benefits of this case.
EE IO	Down	Down	+	n.r.	+	EE IO shows all changes in impacts along the production consumption chain, but may make a mistake by assuming that car and fuel production abroad takes place with European technology.
EF	Down	Down	+/-	n.r.	-	EF can see the benefits of lower CO_2 emissions. However, the benefits of lower car sales are completely missed.
DMC	Down	Down	+	n.r.	-	DMC shows both lower fuel use and lower car imports as reduced material flows.
EMC	Down	Down	+/-	n.r.	-	EMC detects the benefits of reduced car driving, but cannot see the reduction in car import and hence misses the benefits of reduced car production.

5 Indicator assessment

5.1 Introduction

The literature on sustainable development indicators has proposed various selection criteria that enable to distinguish good indicators from bad indicators. The following four main selection criteria can be mentioned (Liverman *et al.*, 1988; Braat, 1991):

- Scientific values;
- Communicative values;
- Relevancy: the indicator behaviour and adequacy for the intended purposes
- Data availability and reliability;

The **first** criterion is that the chosen indicator must make sense scientifically. The indicator must say something about the underlying processes it attempts to describe, and must have a significant correlation with these processes. The indicator must have predictive value, in the sense that a changing condition in phenomena relevant for sustainable materials management and use must be indicated.

Discussions of sustainability often focus on rates of change over time. An indicator must, therefore, be collected at a frequent enough time intervals to detect significant trends and variations, and ideally should be part of a historic time series that can illustrate long-term trends. The very long-term changes and cycles, spanning centuries or longer in the case of physical and chemical phenomena, are more difficult to measure, but can sometimes be reconstructed, as in the case of biological proxies for climatic change. Of course, change alone does not necessarily imply movement to or from sustainability, but can be part of the healthy functioning of a system (for example, seasonal cycles). A good indicator should be able to separate such normal cycles from trends away from a supposed stainable state.

From a management perspective, it is critical to identify indicators which reveal whether changes are reversible and controllable. Perhaps the most critical changes to life support systems are those which involve a permanent and irreversible shift in conditions. Such changes might include the total removal of topsoil, destruction of tropical forests, desertification, and the release of non-degradable toxic materials.

As a **second** criterion, the indicator must have communicative values. The data should also be presented in an attractive format for the target group (scientists, policy makers, public). Issues of aggregation and integration between the various subdimensions of the indicator are important here in order to compress information and to communicate the indicators to the public and politicians. Some may emphasize the existence of reference values. Reference values are required in order to interpret whether the change in the indicator has contributed to sustainable development or not. The problem is that in most cases, clear reference values are not available. Sustainable use of natural resources remains a rather vague concept, from which often no direct criteria can be derived – although some indicators, like the Ecological Footprint, implictly assume reference values. The question is whether such reference values are supported by the users of this indicator. For example, we cannot know for certain what level of material consumption is sustainable for modern societies. But if one accepts the idea that lowering the metabolism of societies is contributing towards sustainable development, the rate of change in reducing materials consumption can be taken as a guideline towards sustainable use of natural resources.

The **third** criterion is the question what the indicator exactly measures and whether the indicator is appropriate for the purpose of measuring progress according to the Natural Resources Strategy. This assessment will be done on the basis of the 'what if case studies' in chapter 4.

Finally, the **fourth** criterion data availability and reliability is obviously a key selection criterion too. In fact, data availability often determines the final indicator set to be used. We take here as a first criterion that the data ideally should be readily available at Eurostat, or be made available easily in the near future[29]. However, in the future, Eurostat may expand it's scope of data gathering to fit the needs by the indicator. Reliability of the data used by the indicator uses is then another important aspect.

As the European Commission specified in its publication "Impact Assessment Guidelines" (European Commission, 2005) indicators should fulfil the so-called RACER criteria. RACER is an evaluation framework applied to assess the value of scientific tools for use in policy making. RACER stands for relevant, accepted, credible, easy and robust:

- Relevant – i.e. closely linked to the objectives to be reached
- Accepted – e.g. by staff and stakeholders
- Credible for non experts, unambiguous and easy to interpret
- Easy to monitor (e.g. data collection should be possible at low cost)
- Robust – e.g. against manipulation

In this research we did not formally conduct a RACER test. For the indicators metnioned above, such an exercise already has been performed by Best et al. (2008). The present study rather adds extra information to the RACER criteria, especially with regard to indicator behaviour in practice.

5.2 Criteria related to scientific quality

The scientific quality criteria have to do, mostly, with the aggregation of data into the encompassing indicator:

- aggregation steps must be transparent

[29] For instance, it can be that this report suggests a good indicator, but that some additional effort at EUROSTAT is needed to deliver this indicator in future.

- aggregation steps must be reproducible
- aggregation steps must be understandable and/or rely on generally accepted methods.

The methods have been described extensively in Chapter 2 and 3. All methods have an acceptable scientific quality in terms of the criteria above, which is not to say that there is no debate on the indicators. Some remarks on each of them:

<u>HANPP</u>
As discussed there are various ways to calculate HANPP, but the methods available are transparent, reproducable and generally accepted. One can of course always debate if the approach chosen to calculate the NPP0 (the 'natural' or 'standard' NPP) is not estimated with a too rough method. Yet, the methods are generally accepted and transparent, and that is what matters.

<u>EE IO</u>
As discussed, EE IO is different as the other indicators discussed, in the sense that EE IO is more a way of gathering economic and environmental data in a consistent way than it is a framework to deliver a specific indicator. EE IO can support a variety of indicators based on the interventions specified: an LCIA step can be added to the emissions, it is possible to make MFA type of indicators, land use indicators, and external costs, as long as the information is added into the EE IO framework. In a sense, it would be possible to use the EE IO framework to calculate some of the other indicators. A handicap of EE IO is then that it by nature allocates impacts to final consumption by economic allocation, and this is not how the original indicator EE IO is supporting always is calculated.

<u>Ecological Footprint</u>
Discussions on the Ecological Footprint mainly focuses around the calculation of the fossil fuel footprint. Critics argue that EF is biased upwards, because the method neglects the selection of economically more sensible options like CO_2 removal. Another drawback of the EF is the fact that to determine the overshoot of a region, the footprint is compared to the biocapacity, which puts densely populated countries at a disadvantage, while in fact there are environmental advantages connected to a high population density. This comparison is however necessary, since technical progress is reflected in a bigger biocapacity and not in a reduced footprint. Only at the global level, this disadvantage disappears. A third issue relates to system boundaries. It seems that for renewable resources, the EF takes a consumption-oriented system. For CO_2-emissions, however, it takes a more production oriented system as a starting point. Only at the global level the two coincide. It seems, therefore, that the use of the EF has least problems when using the global situation as a reference.

<u>DMC</u>
The DMC is one of the indicators that can be derived from a system of material flow accounts. The methods to establish MFAs and derived indicators have been outlined in various documents (Eurostat, 2001; OECD, 2007). Aggregation steps are clear and straightforward in the DMC framework.

EMC
The EMC is the outcome of a set of LCA calculations performed on a dataset of apparent consumption of finished materials. It itself the method is transparant, however, allocation issues have to be resolved in calculating the EMC as –in some cases- estimates must be made for the amount of materials ending up in products. Such allocation issues tend to cloud the transparency of the method. Another issue is that of double-counting. Although with a sensible choice of materials double counting does not have to be an issue, the EMC is vulnerable for that, and it should be a point of attention always. Another criticism sometimes expressed with regard to EMC is the need for weighting. If the aim is to arrive at a single number, the environmental impacts must be aggregated. There is no aggregation method that is scientifically preferrable so that any choices here may be perceived as arbitrary. This same criticism applies for other indicators, such as EE IO-based ones, that use the LCIA.

5.3 Criteria related to the relevancy of the chosen indicator (adequacy for intended purpose)

The indicator can fulfil all RACER criteria but still not be adequate. Criteria for adequacy have to do with the purpose that the indicator is actually designed for. This purpose can be detected in the policy documents regarding the Resource Strategy. An aggregate indicator of environmental pressure or impacts, to be used to measure decoupling, within the framework of the Resource Strategy must be able to detect:

- burden shifting to other impacts: be encompassing with regard to resource use and environmental impacts and be able to detect burden shifting between impacts
- burden shifting to other areas: have a life cycle approach including the ability to detect burden shifting to other areas
- burden shifting to other sectors: have a life cycle approach including sufficient technical detail to spot burden shifting within the economic system
- be analysable, i.e. the contribution of the various building blocks must be visible or detectable.

This assessment can mainly be derived from the "what if" cases from Chapter 4. Table 5.1 shows a review of these cases, and how the indicators dealt with them.

HANPP: We see that in many cases, HANPP provides the wrong answer for policy making. HANPP is by definition unable to provide a causal relation between a shift of activities geographically, due to its lack of economic chain perspective. HANPP further focuses on land use intensity aspects only, and hence is blind for other type of impacts. As a general decoupling indicator, it therefore seems unsuitable. It could provide relevant information in a basket of indicators in combination with others.

DMC: A clear discussion around DMC is the question whether or not counting kilos of mass is a sensible indicator for environmental pressure. The relationship with environmental impacts such as global warming, toxic effects, etc. is at the least indirect.

Although at the aggregate level there appears to be some correlation, the relationship between weight and environmental impact is absent at the level of the individual materials (van der Voet *et al*., 2004). In similar vein, DMC has limited capabilities to detect burden shifting to foreign countries due to the absence of unused foreign extraction in the calculation of the DMC. The burden shifting to other countries however is present in other MFA-related indicators, such as TMC. The disadvantage of just looking at mass flows remains.

Ecological Footprint: EF is partly capable of detecting burden shifting between countries. EF combines a consumption based orientation with regard to renewable resources (enabling to see burden shifting abroad) and a production based inclusion of CO_2 emissions (excluding burden shifting abroad). The EF is incomplete in its inclusion of environmental problem categories (only global warming, via CO_2 emissions, and land use). For that reason, problem shifting to other impact categories is not included in all cases. Burden shifting within the economic system is also partly visible: renewable resources (and their sectors) are included, non-renewables are not.

EE-IO: EE IO covers impacts more comprehensively. The type of EE IO assumed here, purely based on European 60 by 60 sector tables, often lacks sufficient detail and assumes foreign production to have the same emission factors as domestic production. For these reasons, EE-IO is sometimes insensitive to changes. EE-IO can perform significantly better by using the MR EE IO approach as delivered by EXIOPOL in 2011. Such MR EE IO tables have a much higher sector detail (130) and are capable of specifying the impact intensity of the country in which imported products are produced, rather than assuming imports are made with domestic technology.

EMC: EMC covers a wide range of impacts, enabling in principle to spot burden shifting to other environmental impacts. As a consumption-oriented indicator it does show burden shifting to other countries. However, EMC is often insensitive due to the fixed nature of the LCA coefficients, not allowing technical improvements to show up in the indicator. A frequent update and regional specification of LCI data may improve the indicator.

With regard to the question if the indicator is analysable, most of them are. They can be split in components showing the contribution of various building blocks. DMC, EMC and EF use part of the economy as information in their indicator. DMC can be decomposed in 5-12 material groups: EF and EMC allow for greater variety in decomposition. EE IO covers the full economy in a rather detailed way. For instance, and EE IO data set can be used to analyse environmental pressures from a consumption, sector and resource input perspective. In the context of this project, HANPP has as drawback that it is not related at all to economic activities, and that it hence cannot provide clear causal relations between e.g. a rise in HANPP in country A if a factor is shifted to there from country B (leading to a lower HANPP in country B).

Table 5.1: Performance of indicators in the cases in chapter 4

	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7	Case 8	Case 9	Case 10	Case 11
Expected result	**Up**	**Neutral**	**Down**	**Down**	**?**	**Down**	**Neutral**	**Up**	**Down**	**Down**	**Down**
HANPP	Down	Down	Down	Up	Neutral	Neutral	Neutral	Neutral	Neutral	Down	Neutral
EE IO	Neutral	Neutral	Neutral	Down	?	Down	Down	Neutral	Down	Neutral	Down
EF	Neutral	Neutral	Down	Down	Down	Down	Up	Up	Neutral	Down	Down
DMC	Down	Down	Down	Up	Down	Down	Down	Down	Up	Neutral	Down
EMC	Neutral	Neutral	Neutral	Down	?	Neutral	Neutral	Neutral	Up	Neutral	Down

5.4 *Criteria related to communicative power*

The communicative power of the indicator is an important, though slippery criterion. It can have different aspects:

- expressive power and sensitivity to changes with regard to the included impacts
- transparency in the detection of the underlying information
- appealing power of the image to the larger public

The question is first who is the prime user of the information: an indicator-set developed for further scientific investigations or extraction of policy relevant information may be totally different from an indicator required for communication to the public audiences. We will focus here on the latter aspect. However, this study is not intended to conduct practical experiments or inquiries with the larger public (such as via focus groups, etc.). Such could be done in further study to reveal the perception of the public.

With respect to communicative powers, EF seems to be the most all-including indicator. The concept of occupied hectares is intuitively appealing as well as the “overshoot”. It is a clear perception by the public that the planet’s size is limited to serve all our wants and the EF is an indicator that makes this clear. To a lesser extent, the DMC also communicates a similar message. However, the “knowledge” that an average person of a nation has consumed 16 tons of materials is less appealing as the sustainability threshold is missing. The general public may question this figure and ask what a "normal" figure would be.

The HANPP also communicates a simple message: how much biomass is appropriated by humanity. Although the upper limit is clear to some extent, the question is where the sustainability threshold may lie. Moreover, the general public may not understand the concept of human appropriation fully.

The EMC and EE IO (depending on which indicator is used with EE IO) always will to some extent have the drawback of trying to be complete: they encompass many individual pressures, hence need a weighting method to come to simple indicators, and that always seems to result in a loss of appealing power.

5.5 *Criteria related to data requirements and availability*

In general, the data needed to support an indicator must be clearly identifiable and available. For an aggregate indicator to measure decoupling, to be used by EU and member states, additional requirements are:

- data must be available for all member states
- data must be available in time series
- data must pass any quality requirements demanded by the EU.

Table 5.2 shows the data situation in the EU today, any additional effort required from Eurostat at this stage to make the indicator operational as assessed, and some realistic improvements feasible if Eurostat embarks on some additional efforts in the next 3 years. The situation per indicator is roughly as follows.

<u>HANPP:</u> the HANPP discussed here is developed by IFF in Vienna, Austria, and to our knowledge there is no direct data available at Eurostat to calculated HANPP globally. Eurostat hence should contract an institute to gather this for them.

<u>EE IO</u>: Eurostat has for most EU member states time series of SUT and IOT, as well as NAMEAs. There are gaps, but these are rapidly being filled, either as a result of the legal obligation of ESA95 to provide SUT and IOT to Eurostat, or by a series of major projects on NAMEAs contraced by EUROSTAT. The real existing gap is that EUROSTAT does not yet integrate SUT and IOT of individual member states to an EU27 table. EUROSTAT could further consider to followt the EXIOPOL example and strategy, i.e. expanding sector detail and getting access to EE IOT data of other countries outside the EU. This is a realistic proposal, since many non EU countries appear to be interested in assessing pollution embodied in their imports as well.

<u>Ecological Footprint</u>: the methodology for calculating the EF is developed by the Global Footprint Network. Data mainly comes from the UN's COMTRADE database (on trade flows) and the FAO ProdSTAT (on the production of renewable resources). However, for some calculations –like the embodied energy of traded commodities- an internal database is used (which is available upon request).

<u>DMC</u>: the methodology to calculate DMC is described in the Eurostat MFA guide. Imports and exports are derived from trade statistics. Domestic extractions are a bit more difficult to establish. A variety of statistical sources is used for that, as well as some non-statistical sources when statistical information is lacking.

<u>EMC</u>: the EMC indicators relies on two types of data: data to calculate the apparent consumption of materials on the one hand, and data for the impact factors per kg material on the other. Apparent consumption is calculated based on statistical trade and production data: agricultural balances or FAOSTAT for the biobased materials, and a variety of statistics for the non-renewable resources. In Chapter 6, this will be discussed more extensively. Impact factors are derived from Life Cycle Inventory data. Different databases exist; in this study Ecoinvent 2.0 has been used.

Table 5.2: Data demands and availability per indicator

	Data needed	Available at Eurostat	What needs Eurostat to do to use the indicator now	What can Eurostat improve in the next 3-5 years
HANPP	NNPo (Net Primary Production of potential vegetation) Present NPP Remaining NPP after harvest at gridcell level	No, developed by research institutes	Contract research institutes	If HANPP is considered as a priority indicator, Eurostat and other members of the Group of Four, particularly EEA, could consider to set up HANPP accounts themselves.
EE IO	SUT/IOT NAMEAS as time series	Yes, but incomplete. For most EU27 MS, gaps are being filled in projects on NAMEAs on air, resources, water, energy, waste	Create capacity to aggregate SUT/IOT of the 27 MS to an integrated EU27 SUT/IOT	EUROSTAT could consider building a partner network with key non EU trade partners to produce harmonized NAMEAs. This is realistic since many countries work on NAMEAs and have projects on pollution embodied in trade. Additionally, EUROSTAT could consider approaches to enhance sector detail[30]
EF	Agricultural balances, ProdSTAT, COMTRADE database and other	Agricultural, forestry and fishery data available in statistics. CO_2 data are available in NAMEAs. Yield and equivalency factors only at GFN.	EUROSTAT has no insight in some propriatry data to calculate EF, nor energy/CO_2 embodied in traded products. EUROSTAT would need to engage GFN to solve these deficiencies	EUROSTAT could set up a statistical base allowing to calculate EF independent of the GFN. Ideally, this would imply getting insights in energy/CO_2 embodied in imports to the EU27 (see also under EE IO)
DMC	PRODCOM/Comtrade/production statistics mining/agriculture	Yes, MFA accounting is (or will be) a standard Eurostat activity	Make MFA accounts obligatory for MS.	Extend MFA in the direction of PIOTs to enable breaking down into resources. Use TMC instead of DMC.
EMC	Europroms/Agricultural balances for finished materials, LCI data for impact factors	Yes for agricultural data, partly for other materials. ILCD not available yet,	Use other reliable data sources for apparent consumption: FAOSTAT, MFA accounts. Use available LCI database	Improve supply balance sheets agricultural products, develop supply-balance sheets for non-agricultural products. Establish EU-accepted LCI database or certification scheme for LCI databases.

[30] This goes beyound pure accounting, but the activities of EUROSTAT with regard to the Data Centres on Products and Resources allow EUROSTAT to provide to some extent modelled but useful data there.

5.6 Overall assessment of selected indicators

From the assessment above, we see that HANPP is probably the least appropriate indicator to assess the impacts of resource use. This simply is due to the fact, that HANPP never was developed as a comprehensive economic indicator. The DMC has a a clear focus on resources but is an inadequate impact indicator. Its disadvantage in system boundaries, being blind for burden shifting elsewhere, can be circumvented by using TMC instead of DMC. Data requirements for TMC are of course much larger.

EF, EMC and EE IO all perform better. It has to be noted that EE IO in fact is not an indicator, but an inventory tool, that can be used together with an impact assessment pathway to derive impact indicators. In its description of the economic system, it is probably the most complete system. Yet, also these accounting systems have their limitations. Existing EE IO tables include only a very limited number of emissions and no resource extraction at all. This makes their use for deriving impact indicator quite limited. This list could be expanded, obviously, increasing the usefulness. This would however require a commitment and effort by many countries.

EMC is designed to overcome some of the limitations of DMC. It is based on consumption of finished materials and hence has a consumption perspective, which enables to detect burden shifting abroad. It adds environmental impact factors to the kilograms of material via an LCA approach, which is the most comprehensive in terms of emissions and impacts. Due to its focus on finished materials it misses however the inherent comprehensiveness of the DMC. Therefore the danger of double counting is present and a careful assessment must be made on how to correct for finished materials that are being used as inputs for other finished materials. The EMC measures from a statistical perspective the intermediate use for the manufacturing industries as "apparent consumption". Hence the indicator does not measure final consumption itself directly. A country with a large automobile industry will therefore report higher use of steel than a country with no automobile industries even if car possession per capita were the same for these two countries.

The Ecological Footprint is a very appealing indicator, and the only one that has a sustainability threshold. Yet, it covers only a limited number of impacts: renewable (biomass) resources and CO_2-emissions. It is therefore is blind to many changes in the environmental performance of societies. With the inclusion of CO_2 as an emission, it has gained in overall relevance but at the same time it has lost the connection with the reference: the world's land area. Where there are plans to add other impact categories to the EF, this is methodologically and datawise a major challenge that is unlikely to be solved on short notice. A methodological inconsistency is that it aims to measure impacts of consumption, but measures CO_2 emissions on the basis of energy use *in* a country (rather than embedded in products and services consumed). For the EF, two routes can be imagined. The first is the route towards expansion, transforming it into an indicator that can be used as a general decoupling indicator. This implies becoming more abstract, and it is accompanied with the loss of one of the EF's most valued feature: the connection with the real land area. The second is the retreat upon core business: including all activities that actually occupy land, and not attempting to broaden the scope with emissions. Such an EF cannot be used as a general decoupling indicator because it includes only land use as an impact category, but it can be a more powerful addition to a basket of indicators.

EE-IO, finally, theoretically seems to be the best candidate to deliver a general decoupling indicator because of its consistent and complete description of the economy, while at the same time enabling a link with environmental pressure and impacts. The framework allows a sufficiently detailing of sectors and environmental interventions, enabling to detect most changes, technologically or throughput-wise. Imports are identified, and in the case of multi-regional EE IO one can even take the actual environmental pressure in production on foreign countries into account. However, at present, the potential of EE-IO is by far not used. An urgent issue is that EUROSTAT should create capacity to **do** something with the SUT the 27 member must supply: integrating them to an EU total, and transforming the EU SUT to an EU IOT. Another issue is expanding the limited number of environmental interventions included in the accounts. Without these rather straightforward steps, all SUT and IOT at EUROSTAT are close to useless for work on an EU wide environmental or resource indicator.

Other issues are that work on NAMEAs is still under way and by 2010/2011 we will see in the EU at best extensions encompassing 10-15 emissions to air, a comprehensive set of resource uses, water usage, waste output, and and energy use per sector. EE IO works with economic allocation and assumes homegenity in prices and outputs of a sector. A higher sector detail as the current sixty sectors/products would enhance the analytical power of EE IO as well and avoid allocation errors. Finally, with EU tables alone one must estimate the impacts embodied in imports assuming EU technology is used abroad. In ongoing projects like EXIOPOL a more sophisticated and comprehensive EE-IO approach is being developed, however, this is not available yet and it remains to be seen whether this approach can in fact be maintained by countries and updated frequently.

From the above, it has become clear that some of these limitations are inherent to the indicators. Especially HANPP and DMC seem to be constrained and therefore suitable for different purposes than the use as general decoupling indicators. The other three seem to be more suitable for that purpose. Their system boundaries are relevant and they could be more open to improvement options to widen their scope or make them more flexible.

6 Calculating and reporting EMC

6.1 Introduction

EMC is developed for the EU Resource Strategy, as a decoupling indicator in a form that is relevant for a strategy aiming at natural resources. It is now one of the indicators specified in the so-called "basket of indicators", that together must provide a picture of ongoing decoupling in the EU and member states. In this chapter, options to establish EMC as an indicator based on generally accessible, publicly available and EU-approved data are explored.

The EMC indicator represents the environmental impact potential related to the consumption of materials of a national (or regional, or supra-national) economy. "Materials" are chosen as the starting point, because of their still close relation with the "resources" of the Resource Strategy, while on the other hand the relation with environmental pressure or impacts can be made aleady. The concept of the indicator is described in Chapter 3: multiply the consumption of a material (in kg) with its cradle-to-grave impact (per kg consumed material), then aggregate over the materials to arrive at one indicator. This concept needs two types of information:

1) the apparent consumption of resources of an economy in a region,
2) the impact per kg consumed resource.

The indicator should be able to present differences in environmental pressure over time and between member states of the European Union. The above mentioned information therefore should be specified for:

3) member states
4) series of subsequent years.

Finally the indicator should give encompassing information on the environmental pressure of an economy, taking into account possible problem shifting between environmental problems and between regions. For this the indicator should represent:

5) different environmental impact categories based on different environmental interventions, i.e. extractions and emissions to air, water and soil.

In the sections below, we will elaborate on these requirements, sketch a picture of the data that would be needed, and go into the practical constraints, given the notion that the elaboration of the indicator should practically be possible by the data centers formed by Eurostat, JRC and EEA.

6.1.1 Material consumption

"Materials" can be defined on different levels of the process chain. It is a rather loose concept that may include ores and minerals at the point of extraction, refined raw materials such as crude iron, and elaborate fininshed materials which could be considered products. Van der Voet et al. (2005) argue that a definition of materials at the level of finished materials is most useful. A finished material is a material not yet applied in assembled, i.e. multi material, products. At the level of finished materials the resources are still recognizable, as opposed to final products which are composed out of many different materials, while on the other hand the processes related to extraction, refining and material production can be assessed with regard to their environmental impacts. This definition results in a limited list of materials (see below).

In principle the list of materials should be comprehensive. However, one should take into account that many consumed materials are inputs for others. To avoid double counting, these "intermediate" materials should be left out (Van der Voet et al., 2005).

The consumption of a finished material by an economy is defined as:
Consumption = Production + Import – Export

In this material balance, the import and export of materials embodied in assembled products ideally should be included. Additional information on the composition of products is then necessary.

Because of possible differences in environmental pressure, ideally material balances should be made separately for primary and secondary materials, or a fraction of secondary materials should be identified in the total material consumption.

6.1.2 Impacts of materials

For every considered finished material, its contribution to environmental problems throughout its life cycle needs to be specified. This includes not only the impacts related to the material itself, but also the impacts of auxiliary materials, energy used for its production, emissions of impurities and pollutants included in the material during use or waste treatment, etcetera. This is a two-step procedure. First, an inventory must be made of the life-cycle environmental interventions, i.e. extraction of resources from the environment and emissions of pollutants to the environment. In the LCA methodology, this is the LCI (Life Cycle Inventory) step. A second step is the LCIA (Life Cycle Impact Assessment), a procedure to translate the emissions and extractions of the LCI into their (potential) contribution to environmental impacts.

The LCI results for the production of the finished materials can be based on existing LCA databases. These LCA databases often also contain processes for waste treatment of specific materials. Additionally one needs to define "use" processes in which the up-chain (production) processes and down-chain (waste treatment) processes are linked to cradle-to-grave chains. In these "use" processes one also can include emissions during the use of the material, like corrosion etc.

Besides an extensive LCA database with process data on production and waste treatment of materials, one needs information on the waste management of materials, i.e. % recycling, % incineration and % landfill. Furthermore additional information on emissions during use of the materials is necessary. This excludes energy consumption of products. Energy consumption by the use of products (containing finished materials) will be monitored separately.

Because of possible differences in environmental pressure, ideally the LCA database should be able to distinguish between primary and secondary materials.

For the LCIA, several more or less standardised options are available. Characterisation is a first step, translating emissions and extractions into impact potentials. This is done by so-called equivalency factors. For example, for the global warming problem, emissions of greenhouse gases are translated into CO_2-equivalents, and emissions of toxic compounds are translated into 1,2-dichloroethane equivalents. This enables adding up and agrgegating lists of hundreds of different emissions to a limited number of impact categories. If one has to arrive at 1 indicator, aggregation must take place over the different impact categories as well. This is a subjective step, usually referred to as "weighting". Lists of equivalency factors are available in LCA handbooks. Weighting is a controversial issue in LCA (see Chapter 2).

6.1.3 Country and time specific data

Country and time specific LCI data

Extractions and emissions during production, use and waste treatment of a material might be different between countries because of differences in technology, i.e. efficiency of processes, differences in waste management etcetera. Therefore, ideally, country specific processes should be available in the LCA database. Because of the world market, country specific data should be available world wide. Technology will change over time. Therefore also the impact per kg material will change. To monitor these technology changes one needs a regular update of the LCI data, i.e. process data and waste management.

Country and time specific material balances

The consumption of materials should be estimated for separate EU member states. For this one needs the following statistics:

1) Production of finished materials
2) Import of finished materials; because impacts per kg material might be country specific, also the location of origin of the imported material is relevant
3) Export of finished materials

To monitor changes of consumption over time one needs a regular update of the material balances.

In the next sections, an investigation is presented with regard to these data: is it possible to calculate EMC from existing databases, and to be more precise, from databases being collected and managed by EU-entities?

6.2 Calculation of material consumption

6.2.1 Data sources available at Eurostat

There are two data sources maintained by Eurostat that contain relevant information for the calculation of the apparent consumption of materials:

1. The supply balance sheets of agricultural products
2. The Europroms statistics of non-agricultural products.

The supply balance sheets of agricultural products
The supply balance sheets of agricultural materials are available for the economic activities of section A: Agriculture, Forestry and Fishing (section A of Nace Rev. 2). These sheets provide information in physical units (kg) on the import, production, export, stock changes, domestic use, losses, degree of self sufficiency etc. Each balance refers to all uses and all transactions which have occurred on the market between harvesting or production (finished product) and the wholesale stage (just before reaching the retail and consumer market). So for example for milk there are balance sheets for whole milk (raw material) and fresh milk products, like drinking milk, butter and cheese.

Balance sheets are available for the following materials,
Agriculture

1. crops
2. meat,
3. milk
4. eggs

Forestry

5. sawn wood and wood based panels
6. woodpulp, paper and board

Fisheries

7. fishery products

A more detailed breakdown of materials is available in the Eurostat database (see also spreadsheet “balance_sheets_agricultural_products_EU15.xls” and “balance_sheets_agricultural_products_NL.xls”).

The data are presented as annual time series for each country and for the EU as a whole. The period covered depends on each country's date of accession to the Union.

The Europroms statistics

The Europroms statistics are available for economic activities of sections B and C: Mining and Quarrying, Manufacturing (sections B and C of Nace Rev. 2). Europroms refers to the combination of production and external trade data. Europroms contains statistics on physical volume (e.g. kg) and value (€) of production of manufactured goods (Prodcom) together with related external trade data (ComExt)[31]. This enables to calculate the apparent consumption, defined as production + import – export.

The Europroms statistics include non-agricultural materials, like minerals and ores, plastics, metals, glass, construction minerals and assembled products based on these materials. The Prodcom list of "materials" contains about 4500 resources, materials and products. Since 1995 the data are presented as annual time series for each country and for the EU as a whole. The period covered depends on each country's date of accession to the Union. Most of the data for physical volume are expressed in kg. However also other units are used like m2, m, pieces, liters.

In principle, the Europroms data format is useful and appropriate to calculate material balances. However, the production statistics are far from complete for each country and time period, because data are not available (:), confidential (C) or not applicable (-). For many of the 4500 materials listed in the Prodcom list the production data are missing. The trade statistics seem to be more complete.

The breakdown of materials in the database is very detailed. For the purpose of EMC, aggregation of the data into a more limited set of materials is desirable. However, the aggregation of production data is not directly possible because this would lead to double counting. The reason is that the categories of materials that are listed in the Prodcom list refer to different states of the same material. The production of one state of the material may be the input for the production of the successive state of the material.

As the trade and production statistics are collected independently, there is considerable danger of discrepancies between them (for instance because different people in different organisations have to decide how to classify a product). Quite often the calculation of P+I-E produces a negative result, which is clearly wrong[32].

website:
http://epp.eurostat.ec.europa.eu/portal/page?_pageid=0,1136195,0_45572097&_dad=portal&_schema=PORTAL

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[31] The Prodcom survey is based on the Prodcom List, consisting of about 4500 products. The 8-digit codes used in the List are based on the 6-digit CPA headings and hence the 4-digit NACE rev 1.1. The Prodcom codes normally relate to one or more Combined Nomenclature headings, thus enabling external trade data to be related to production data.

[32] This problem might also be less if more aggregated data are used.

Conclusions on databases at present available at Eurostat.
Considering the usefulness of the databases for the calculation of the apparent consumption the following can be concluded.

1. Supply balance sheets of agricultural products contain all the relevant information (Production, Import and Export) necessary to calculate the apparent consumption. The data can be used with minor data processing.
2. Supply balance sheets of agricultural products are available for a large number of agricultural product groups, in sufficient detail. However, data series of supply balance sheets of agricultural products are not always complete for all countries and all years.
3. The Europroms statistics in its present state can not be used for the calculation of the apparent consumption for the EMC. For the calculation of the apparent consumption the data appear to be incomplete and collected at a level that is too detailed to be useful for EMC.
4. Europroms statistics do contain relevant basic information on Production, Import and Export of materials. The data needs a lot of processing, combining and additional assumptions, in order to calculate apparent consumption for non agricultural materials, like metals, plastics and construction materials.

To enable using EU-statistics directly for the calculation of EMC time series, the following problems must be solved:

- Data gaps in the supply balance sheets of agricultural products should be filled. The FAOSTAT agricultural database is more complete and can be used to supplement the EU-data. Another option is to use the FAOSTAT database altogether, to guarantee consistency of the database.
- A more complete, less detailed, more aggregated, set of statistics is necessary for non-agricultural materials, in order to arrive at the material consumption part of EMC. The preferable option would be for Eurostat to report supply balance sheets for several non-agricultural materials similar to the supply balance sheets as available for agricultural products, based on *reported* production, import and export by national statistical bureaus. Other sources of information might be branch organizations, like for example PWMI for plastics, and ILZSG, for lead and zinc. For the moment, it is not possible to derive apparent consumption statistics from Europroms for the materials relevant for EMC. Therefore, in the next section an approach is outlined to use present information from Europroms to derive more complete and more aggregated information on *estimated* production, import and export. This option is elaborated further in Section 6.2.

6.2.2 Procedure to calculate the apparent consumption of materials for the EMC from Europroms and agricultural statistics

Outline of the procedure for the calculation of the apparent consumption

For the calculation of the apparent consumption based on the Supply balance sheets and Europroms the following procedure is followed:

1. Calculation of apparent consumption, selecting the relevant items
   - production (physical amount)
   - import (physical amount)
   - export (physical amount)
   - unit
   - production flag
   - production base
2. Selection of materials
   - omit auxiliary materials
   - one state of material in the cradle to grave chain
   - check for co-products, omit all co-products but one
3. Conversion of data
   - unit conversion: m, m2, liters, pieces to kg
   - conversion to state of the material for which impacts per kg are available using the $factor_{material1\ to\ material2}$ (e.g. $f_{raw\ milk\ to\ drinking\ milk}$ or $f_{steel\ in\ car}$)
4. Estimation of missing data
5. Aggregation of data
   - aggregation within a 4 or 6-digit Prodcom code, if possible, i.e. independent

Calculation of apparent consumption

Since the impacts of a material as estimated with LCA-data is given per kg material, the consumption of the material should be expressed in kg. A translation may be needed in case the statistical physical unit is different. For the Europroms data, the production flag gives information on missing or confidential data. On a national level many data are not given because they are not applicable, confidential or missing. On a European level, some of these missing data are estimated and EU totals are rounded to protect national confidential data. So calculation of the apparent consumption based on the Europroms statistics as reported on the website only make sense on the European level. Summing of available data on a national level will give an underestimation. In Europroms the "production base" is given as well: an indication of the uncertainty margins of the production data at EU-level that are estimated because of missing underlying data.

Selection of materials

When composing the apparent consumption of selected materials for the EMC, two problems related to double-counting present themselves. The first problem relates to the choice of materials, and is relatively easy to solve. Because the impact factors (see Section 6.3) per kg of material already take into account the accompanying impacts related to energy and auxiliary materials for the production of that material, we have to take care to omit those as separate materials. For example, for the material "wheat" the emissions from the chains of auxiliary materials "pesticides", "fertilizer" etc. are already included in the cradle-to-grave impacts. Therefore, when adding up materials to an EMC, pesticides and fertilizers must not be included in the list of materials separately, because impacts would then be double-counted with the impacts of the wheat chain.

The second problem is more complicated and is related to the nature of the Europroms production statistics. The materials listed in ProdCom refer to different stages of the material in the cradle to grave chain, i.e. resource, material, processed material and material assembled in products (e.g. raw cotton, cotton yarn, cotton woven textiles, cotton shorts). The production output of some of the up-chain materials represent inputs for the production of down-chain materials. Aggregation of the Europroms data by adding up the productions within one category (cotton) will therefore lead to double counting of the production of materials and therefore a (serious) overestimation of the apparent consumption of the material.

The apparent consumption of a material thus can be calculated for different stages of the material in the cradle to grave chain. Roughly one can distinguish:

1. the raw materials and ores,
2. the materials, which are consumed by industry and
3. the (assembled) products, which are consumed by households.

To avoid double-counting, we have to define our "material" at one specific stage of the life-cycle. Note that the choice of the state may influence the amount of apparent consumption of that material. A region that does not contain a mining and metal refinery industry, for example, will have no apparent consumption of metal ores and concentrates. Based on this level, the region would have no apparent consumption, because all metals are imported as refined material and via products. However, on a material level and certainly on a product level there will be an apparent consumption.

To avoid this problem of double counting, a choice has been made in the past to use "finished materials" as the most appropriate level: the material as it appears just before it is applied in an assembled product. The relation with the concept of "resources" is still clear and we do not get lost in the world of finished, composite products. This is as close to the consumption stage as we can get under that condition. This choice still seems the most appropriate one. But even if we choose the level of "finished materials" and thus omit the up-chain raw materials and down-chain products there still is a problem of double counting using the Europroms statistics that must be solved (see ***aggregation*** further down in this section).

Conversion of data

Two types of conversions might be necessary when processing consumption data of materials as input for the calculation of the EMC2009:

- unit conversion, all data should be expressed in kg
- conversion to "finished material".

Most data in Europroms are expressed in kilograms. However, sometimes data are expressed in m, m2, litres or pieces. Additional information is then needed to make the translation into kg material (weight per m2, per litre or per piece). This information is generally not difficult to come by. Another conversion is to translate the consumption to the state of "finished material". A few examples:

- Assume "raw milk" as a finished material. If apparent consumption data are gathered on the level of milk products, like drinking milk, butter and cheese, one needs to know how much milk is necessary for the production of these products. For example for the production of 1 kg of cheese one needs 10 kg of milk.
- Assume "copper" as a finished material. If apparent consumption data are collected at the level of ores, like copper ore, one needs to know the copper content of the copper ore.
- Assume "steel" as a finished material. If apparent consumption data are gathered on the level of products, like cars, one needs to know the steel content of the car. Besides steel the car naturally consists of many other materials, like plastics and textiles. To attribute these to the right impacts per kilogram also these other material contents should be available.

Estimation of missing production figures

As stated above, the Europroms statistics are incomplete. For most of the goods listed in the Europroms statistics it is not possible to calculate the apparent consumption, mainly because production data are missing.

For many materials the balances are not complete, although basic data seem to be available to make them. For example, for most metals on the material level production data are missing (categorized often as “not applicable”). However, on the ore level apparent consumption data can be calculated, which implies that production at the material level must be available, too. A similar problem occurs for plastics.

In the absence of direct information on material production, Europroms may still contain relevant information upon which an estimation of the production can be based.

A solution may be found in combining data. For example, metal production data at the material level can be estimated using available ore consumption data. Consumption data of a specific metal ore, together with the metal content of the ore, can be used to approximate the production of primary metal. Consumption data of a scrap, together with the metal content of the scrap, can be used as an approximate for the production of secondary metal. Together with the import and export of data of the metal on the material level this leads to an estimate of the consumption of metal on the material level.

$C_{material} = P_{material} + I_{material} - E_{material}$

$P_{material} = f_{resource\ to\ material} * C_{resource}$

$C_{resource} = P_{resource} + I_{resource} - E_{resource}$

In this way, the consumption of raw materials, like minerals and ores, can be translated into the production of a limited number of end uses of materials.

Aggregation of data
The Europroms statistics contains a detailed list of goods, up to 4500. Even if one omits the auxiliary materials, raw materials and assembled products the list still contains many materials, up to 1000. Many of these defined goods refer to slightly different states of a specific material. For example Europroms reports approximately 14 different states of copper as a finished material produced by the sector “copper production” (Nace code 2744). The list of materials for the sector “Manufacture of basic iron and steel and of ferro-alloys” (Nace code 2710) list approximately 270 different types of iron and steel.

Aggregation of data to a higher, less detailed, level would be a solution, but is only possible if the data are independent. For example if the production of goods defined in the same 4 digit level are independent they can be aggregated to an overall production on an aggregated level of a specific good, e.g. steel and goods made of steel (like tubes, pipes, plates etc). However, it seems that within one 4 digit level the production of one good may be input for the production of another good and so aggregation of apparent consumption (=Production+Import-Export) will lead to double counting of the consumption (comment Brian Williams Eurostat).

For the calculation of the EMC this is a serious problem. The data in Europroms are not organized in such a way that there is a simple method to derive these aggregated results from the present Europroms statistics. A possible method might be to have a look at the descriptions of the goods reported in the statistics and judge the likelihood of a good being used as an input to another manufacturing process. However, based on the descriptions given in the statistics this is a time consuming job and not always possible. And moreover, even if one may assume that a specific good may be an input for the production of another good than one still doesn't know to what extent the production of good A is input for the production of good B.

It seems that for the aggregation of the production figures in the Europroms statistics more information is needed on the structure of the economy. Note that in contrast to the production statistics, the trade statistics are independent and so for the aggregation of import and export figures there is no problem of double counting.

6.2.3 Results

In this section, some results are presented of the survey of using EU statistics for the calculation of the apparent consumption. As stated in the previous section the present Europroms statistics are incomplete. For most of the “finished materials” listed in the Europroms statistics it is not possible to calculate the apparent consumption, mainly because production data are missing. Therefore an estimation procedure is used as described in section 6.2.2. The stepwise procedure as described above, applied to Europroms and agricultural balance data, can be found in the spreadsheets “balance_sheets_agricultural_products_NL.xls”, “balance_sheets_agricultural_products_EU15.xls”, “Europroms data NL.xls” and “Europroms data EU15.xls”.

List of selected materials

The long list of goods in Europroms and the agricultural balances is translated, according to the abovedescribed procedure, into a much shorter list of finished materials that are included in the EMC calculations. This list is considerably longer than the list of materials included in the EMC2005.

Fossil fuels

natural gas for heating in households
natural gas for electricity in households
oil for heating in households
oil for electricity in households
hard coal for heating in households
hard coal for electricity in households
brown coal for heating in households
brown coal for electricity in households

plastics

PE
PS
SAN
ABS
PVC
PC
PET
PP
PUR
other plastics

Metals

aluminium
copper
iron and steel
lead
nickel
zinc
silver
gold
platinum group
tin
magnesium
cobalt
cadmium

Industrial materials

glass
salt

Construction materials

concrete
ceramics

clay (as such)
natural stone (as such)
basalt
dolomite
sand

Biomass (crops and animal products)

food, crops
wheat
rye and maslin
barley
cereals other
potatoes
pulses
nuts
rapeseed
soya
oil crops, other
rice
sugar beet
vegetables
fruit

food, animal products
beef
pork
mutton
poultry
meat, other
fish
milk
eggs

fibres, crops
cotton
flax
vegetable fibres, other

fibres, animal products
leather
wool

Biomass from forestry

sawnwood, coniferous
sawnwood, non-coniferous
wood based panels

Paper and board

paper and board

Additional data used for estimation of missing production data

Primary production
Missing production data for (primary) materials can be estimated using data on raw materials, if these are available, according to the formula given below:

$$P_{m1} = C_{r1} * F_{r1 \rightarrow m1} * \frac{1}{F_{r1/m1}}$$

P_{m1} = estimated production of material 'm1'
C_{r1} = Consumption of resource 'r1'
$F_{r1 \rightarrow m1}$ = weight fraction of resource 'r1' that is used for the production of material 'm1'
$F_{r1/m1}$ = weight fraction of resource 'r1' in material 'm1'

For example, glass production data are missing in Europroms. The main resource for the production of glass is industrial sand. Europroms has data on import, production and export of industrial sand, which means that the apparent consumption of industrial sand can be calculated. According to USGS (United States Geological Survey) (2004), about 37% of the consumption of industrial sand is used for the production of glass, so $F_{r1 \rightarrow m1}$ is 0.37. The weight of industrial sand going into glass production can then be calculated. According to the LCA-database (Frischknecht, 1996) for the production of 1 kg of glass about 0.75 kg of industrial sand is necessary, so $F_{r1/m1}$ is 0.75. This factor is used to calculate the weight of the glass actually produced.
For a number of materials, these factors are reported in the accompanying spreadsheets.

Secondary production
The Europroms statistics contain trade statistics on waste for recycling. The production statistics reported in Europroms should contain both primary and secondary production. In case of missing data, primary production can be estimated using the above procedure. Secondary production is then still missing. Internal waste collection and recycling is not reported in Europroms. However, for a number of materials an extrapolation is possible based on ratios of primary and secondary production in Europe (Ecoinvent, 2009). The total apparent consumption can be calculated by using this ratio on top of the primary production data. Percentages used are reported in the accompanying spreadsheets.

Apparent consumption of finished materials
Below, the apparent consumption of a number of materials calculated in this way is presented in Figure 6.1. Apparent consumption has been calculated for the EU-15 (time series for EU-28 are not yet available) and for the Netherlands, as an example country. It should be noted that for none of the non-agricultural materials the apparent consumption has been calculated directly from Europroms. For all materials, approaches like the one sketched above were necessary. Detailed data and calculation of apparent consumption can be found in the accompanying spreadsheets.

Figure 6.1 Apparent consumption of finished materials in the EU-15, 1995 – 2005, based on Europroms and the Eurostat Agricultural Balances (in kg/y)

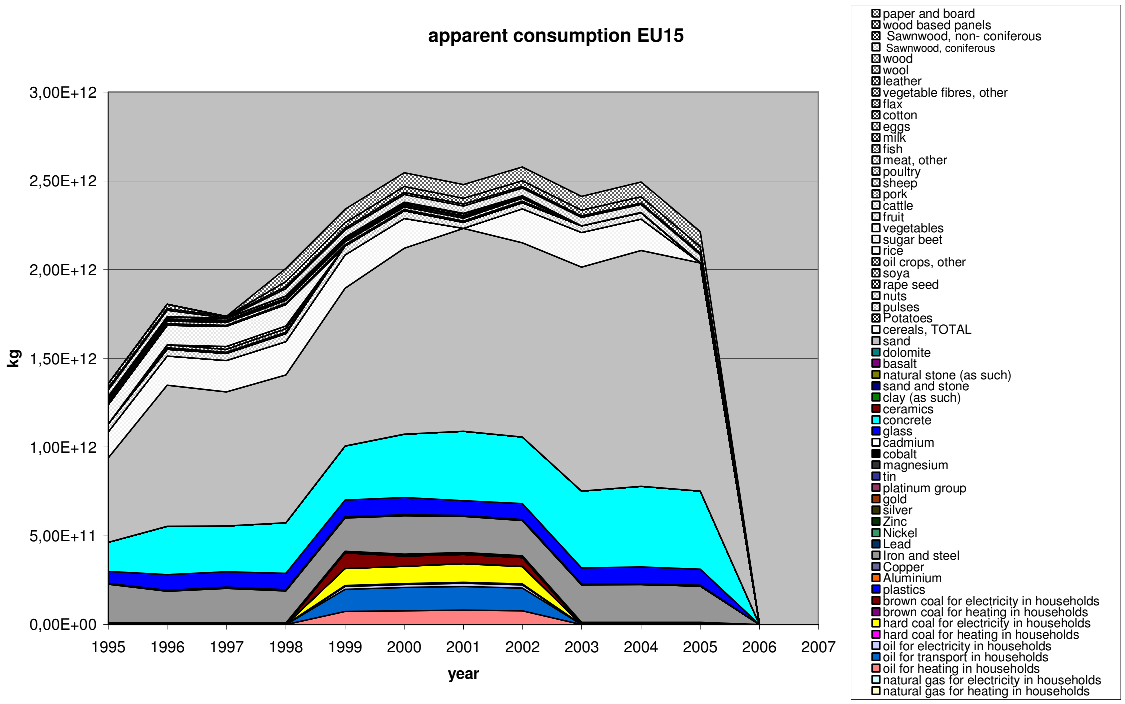
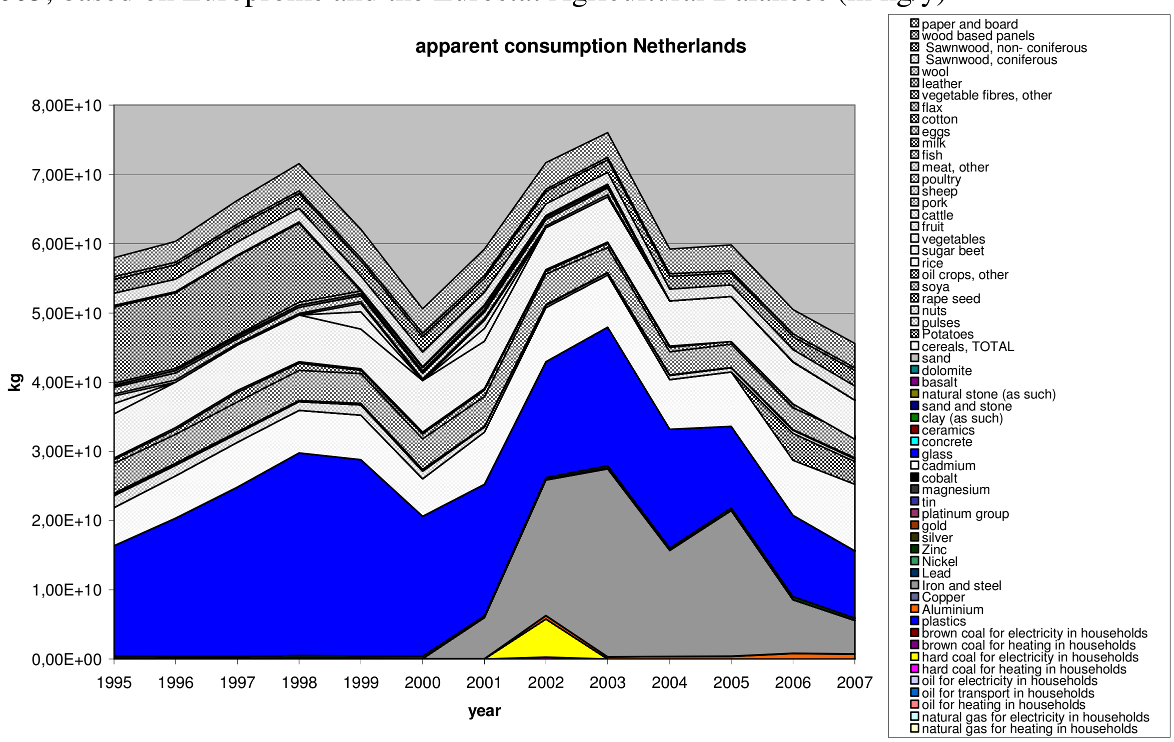


Figure 6.2 Apparent consumption of finished materials in the Netherlands, 1995 – 2005, based on Europroms and the Eurostat Agricultural Balances (in kg/y)



It is clear from these figures that, even with estimation procedures for missing data, the apparent consumption data are far from complete. For the EU-15 this is less of a problem than for the Netherlands. Apparently, the estimation procedure described before is effective to some extent. However, also for the EU-15 the incompleteness in time series shows. Fossil fuels, for example, only are reported from 1999 – 2002. It is also clear that fossil fuel production data must be known also for the other years. Other databases, such as the IEA, do report these data. The same is true for data on metals, and also for missing agricultural data: FAOSTAT does have complete time series.

For the Netherlands, the picture is even worse. Only agricultural data and a few others show. Construction materials and fossil fuels are lacking completely. Almost always, this is because of missing production data. In some cases, this is related to confidentiality. In other cases, the reason is unclear to us.

In all, we can conclude that Europroms in principle is a very suitable database. The data structure is adequate. The problem lies mainly in the profound incompleteness of the production data. The reason for this is not completely clear, since for a number of materials other well-established databases do report complete datasets and time series. At present, therefore, Europroms cannot be used as a basis for EMC. We recommend Eurostat to give priority to completing this database, even if it is only at the EU level. For EMC, at present other databases can be used.

6.3 Impacts per kilogram of material

6.3.1 Impacts of consumed resources, i.e. finished materials

For every considered finished material, an estimate should be made of its contribution to environmental problems throughout its life cycle. This includes not only the impacts related to the material itself, but also the impacts of auxiliary materials, energy used for its production, emissions of impurities and pollutants included in the material during use or waste treatment, etcetera.

The LCI results for the production of the finished materials can be based on existing LCA databases. These LCA databases also contain processes for waste treatment of specific materials, at least for some materials. Additionally one needs to define “use” processes in which the up-chain (production) processes and down-chain (waste treatment) processes are linked to cradle-to-grave chains. In these “use” processes one also can define emissions during the use of the material, like corrosion etc.

Besides process data on production and waste treatment of materials, one needs information on the waste management of materials, i.e. % recycling, % incineration and % landfill. Furthermore additional information on emissions during use of the materials is necessary. This excludes energy consumption of products. Energy consumption by the use of products (containing finished materials) will be monitored separately.

Because of possible differences in environmental pressure, the LCA database should be able to distinguish between primary and secondary materials.

6.3.2 Availability of LCI data

The "European Reference Life Cycle Data System" (ELCD) is the data set for LCA of the European commission that contains Life Cycle Inventory (LCI) data sets. The database is managed by JRC and still in development. At this moment the database only contains a limited number of production and waste treatment processes at the finished material level. Until the ELCD becomes more encompassing, the best solution is to use other, more extended LCA databases, such as Ecoinvent 2.0 (Ecoinvent, 2008).

Most LCI databases do not, or only very limitedly, contain time specific and country specific data. There is a certain development in the LCA wordl to start collecting country specific data. Also, updates of databases are published with a certain regularity. In the meantime, data for average ‘European’ or ‘world’ processe can be used. Another solution may be to connect to Environmentally Extended Input Output Tables. An important advantage of EEIOT is the regular update of data, for example every 3-5 years for each of the EU member state. In this way possible technical developments within sectors are monitored over time and country specific within the EEIOT. However, the number of materials for which Inventories can be calculated is very limited. Also the number of interventions are very limited. The present IOT contain about 60 sectors (which should be translated into materials) and about 30 interventions (emissions and extractions). In the future possibly more detailed IOT will be developed for example the in the EXIOPOL project. For now, the use of LCA data, even if they are not country-specific, is far more preferable.

6.3.3 Encompassing environmental assessment

The environmental impact assessment should be as complete as possible. Table 1 shows a number of environmental impact categories typically taken into account in an LCA.

Table 6.1 LCA Impact categories

global warming
stratospheric ozone depletion
acidification
eutrophication
photochemical ozone formation
abiotic resource depletion
human toxicity
aquatic ecotoxicity
terrestrial ecotoxicity
radiation
land use competition

A standardised procedure for LCIA is presently developed at the JRC. At this moment, it is not yet available.

In Life Cycle Impact Assessment some possible relevant problems are still missing. Loss of ecosystems, depletion of biotic resources (e.g. fish), depletion of water resources are impact categories still missing. Land use is included in the inventory of most LCA databases, but the impact assessment is not developed. The same is true for water consumption. This means that for these problems, characterization factors still have to be developed, based on characterization models. Furthermore, in order to calculate normalization factors, also interventions for these problems on a world scale should be gathered. The development of these impact categories is on the agenda of the LCA-community.

6.3.4 Results: impacts per kilogram for selected materials

While the ELCD database is still incomplete, the impacts per kg materials are based on the process descriptions from the Ecoinvent database (Ecoinvent, 2008) using static average European data. Process data for animal products, like meat from cattle, pigs and poultry, milk and eggs are based on the LCAfood database (LCAfood, 2008). The characterization factors to aggregate interventions into environmental impact scores are based on the CML2002 method as described in the Dutch LCA Handbook (Guinée et al., 2002). The result, the impacts per kg material, are given in the appendix.

6.4 Calculation of the EMC

The time series of apparent consumption, presenting several consumed materials (in kg), are multiplied with their impact factor as described in 6.3.1 and specified in the appendix. To arrive at one encompassing EMC indicator, aggregation takes place over the different impact catgories. The first step to do this is normalisation: translating the impact categories in kg equivalent into comparable terms, so they can be added. This is done by dividing the emitted impact category equivalents related to the materials by the world total, so they are expressed in a fraction of the world total emissions. Normalisation totals are based on the world emissions and extractions in 2000. (Wegener Sleeswijk et al., 2008). Normalisation factors are given in the appendix. The next step is weighting: attaching a factor to the impact categories based on a sense of their relative importance. Since no consensus has been reached with regard to these weighting factors, we use equal weights across the environmental impacts. We compare equal weighting with some other weighting sets: the NOGEPA weighting factors, the shadow price-based weighting factors, and the EcoIndicator LCIA + weighting procedure.

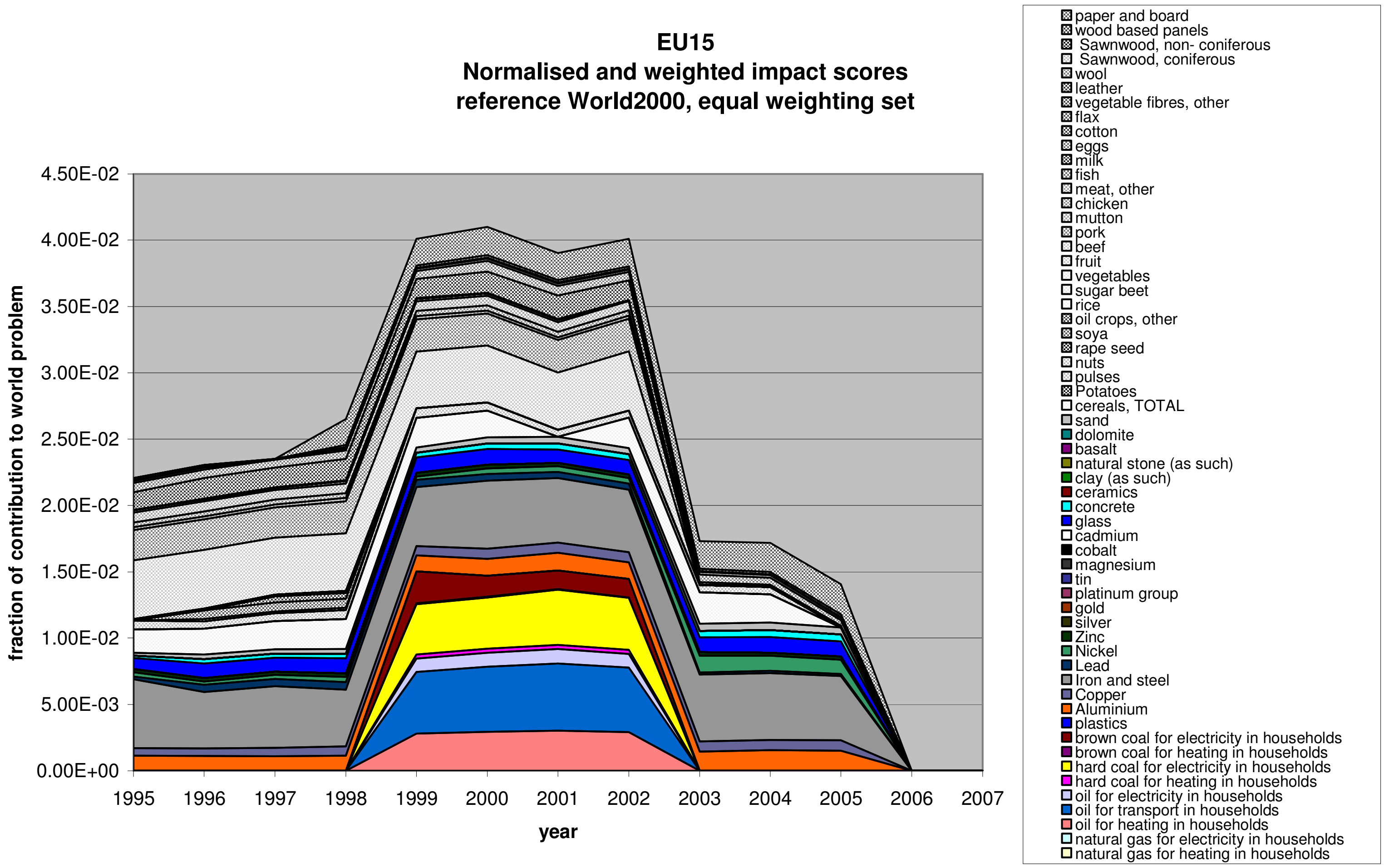
Since the dataset for apparent consumption based on Europroms is so incomplete, we add also an EMC based on the time series as reported in the report "Policy Review on Decoupling" (van der Voet et al., 2005). A comparison is made between EMC2005, with impact factors from the ETH database, and the EMC based on the new impact factors from the Ecoinvent database. In this way the influence of the new impact factors can be detected.

6.4.1 EMC based on apparent consumption derived from EUROPROMS & agricultural products balance sheets and Ecoinvent 2.0 impacts

Figure 6.3 gives the EMC2009 based on new impacts per kg material and apparent consumption based on the Eurostat statistics. So the EMC2009 is based on the following basic information:

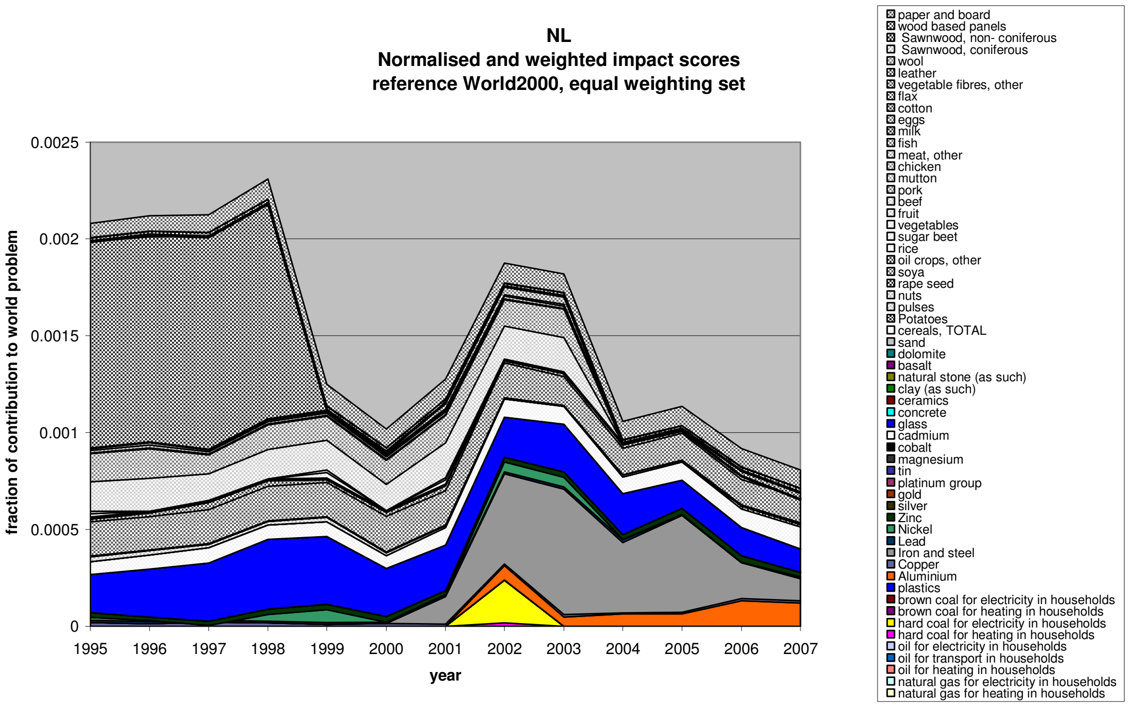
1. apparent consumption: EUROPROMS & agricultural products balance sheets,
2. impacts per kilogram material are based on
    a. process data of the Ecoinvent2.0 database (Ecoinvent, 2008) and LCA food database for agricultural animal products (LCAfood, 2008)
    b. Characterization factors (Guinée et al., 2002)
3. Normalisation data: world 2000 emissions and extractions (Wegener Sleeswijk et al., 2008).

Figure 6.3 EMC of EU15 for the years 1990-2000, apparent consumption from Europroms and agricultural balances, impact factors from Ecoinvent 2.0



For the years 1999 – 2002, the picture is least incomplete. However, even in those years we still miss important flows. Ups and downs in the figure mostly arise from data gaps. Whether or not decoupling occurs, cannot be concluded. Important materials for environmental impacts can be identified, however.

Figure 6.4 EMC of the Netherlands for the years 1990-2000, apparent consumption from Europroms and agricultural balances, impact factors from Ecoinvent 2.0



The EMC for the Netherlands calculated from Europroms and the agricultural balance sheets is rather useless. It is very incomplete, due to missing apparent consumptions. It can be used neither for spotting trends, nor for the identification of important materials.

6.4.2 New impact factors applied to the EMC 2005 apparent consumption data

To assess the influence of the new impact factors based on the Ecoinvent database, the apparent consumption time series from Van der Voet et al. (2005) have been used. The number of materials is less and time series are available only until 2000, but at least they are complete. Figures 6.5 and 6.6 show the EMC for the EU-15, with the old and new impact factors respectively.

Figure 6.5 EMC of EU15 for the years 1990-2000, ETH-impact factors

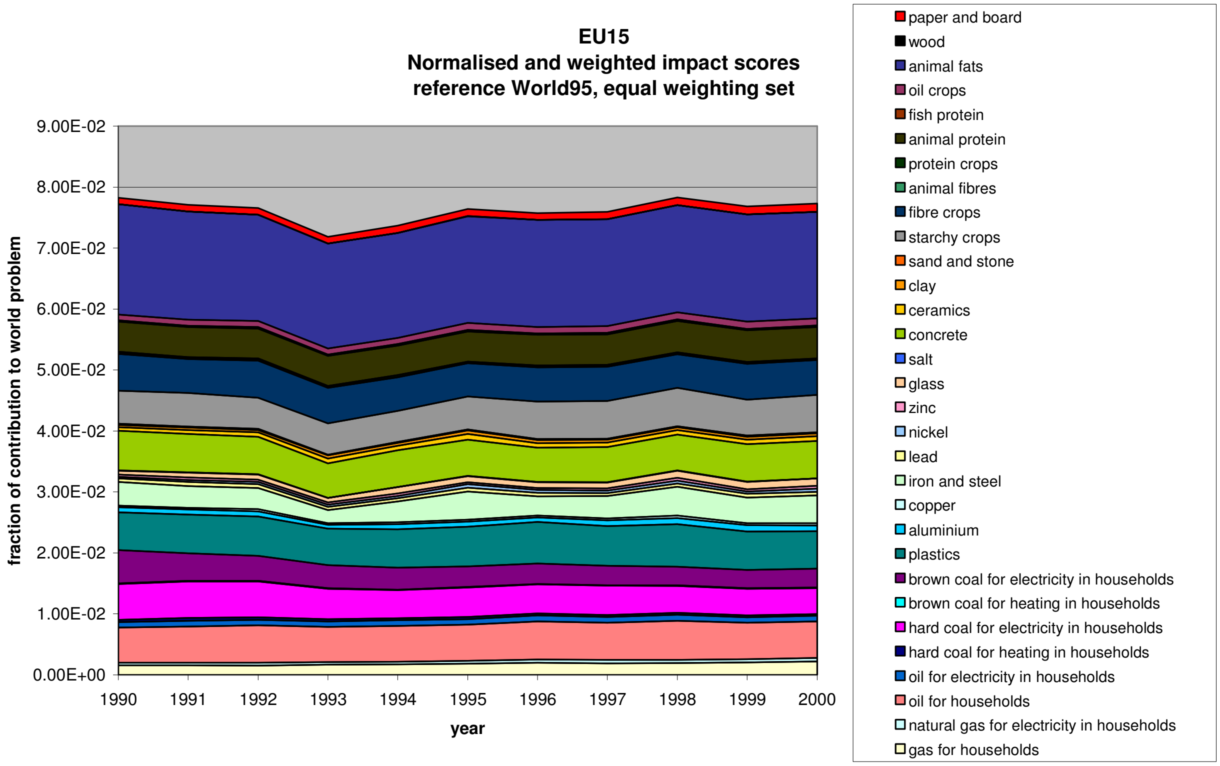
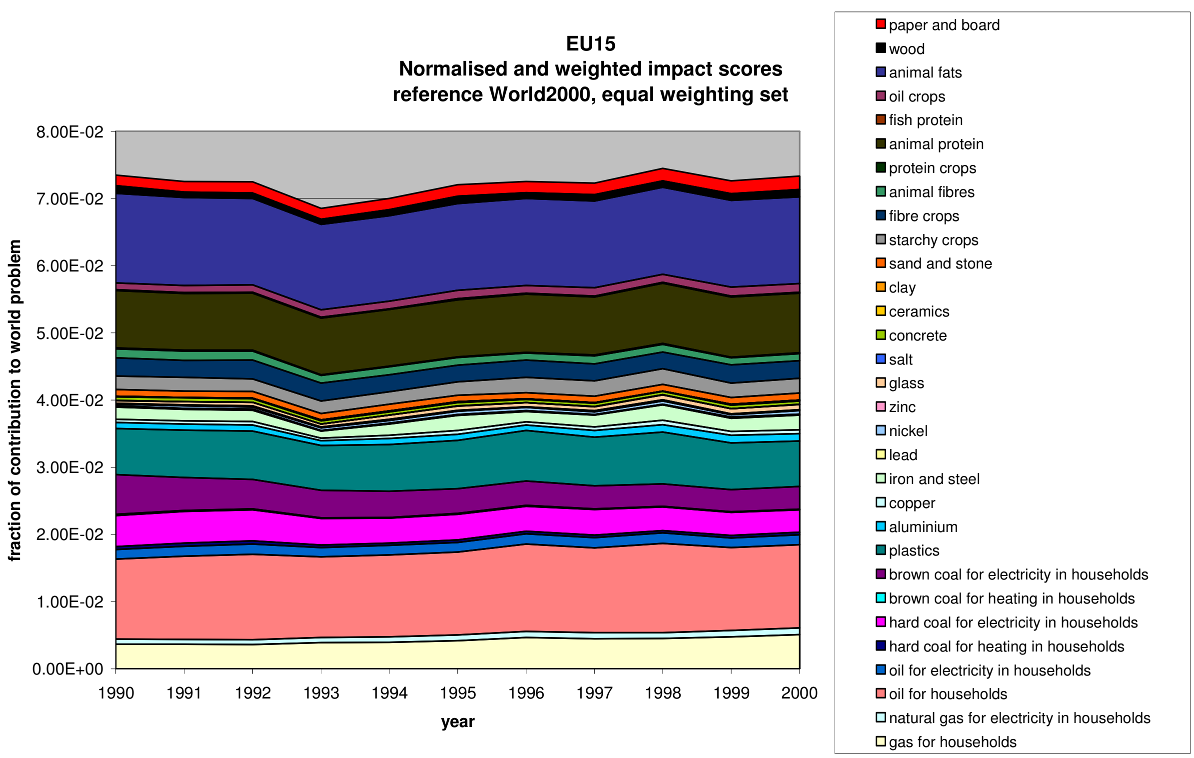


Figure 6.6 EMC of EU-15 for the years 1990 – 2000, Ecoinvent impact factors



A comparison shows that there are no large changes in the overall environmental impact scores. The weighted total environmental impact score is slightly larger with the new impact factors. A more detailed look at the contribution of materials to the EMC shows that the relative importance of the materials has changed in some cases. In Table 6.2 the relative changes are visible in the rightmost column: EMC new / EMC old. Most striking differences occur for wood (ratio: 253) and animal fibres (ratio: 13). Note however that the relative contribution of both wood and animal fibres to the total EMC is very small. Therefore the large differences in EMC for these materials do not result into large differences in the total EMC.

The new impact factors for fossil fuels are somewhat higher than the old ones. A breakdown of the environmental impact score per kilogram fossil fuel into the different environmental problems shows an ambiguous picture (see appendix D). For some environmental impacts the scores are larger whilst for others they are smaller. Most striking is the difference in contribution of abiotic resource depletion. In the old EMC the extraction of fossil fuels seems to be underestimated most likely because of a mistake made in the impact assessment (characterisation) of the inventory results of the ETH database.

For metals, impact factors are generally somewhat lower, although per impact category there are considerable differences up and down. Most probably, this is the result of new process descriptions in Ecoinvent: new technologies, and/or a larger share of secondary materials. Sand and gravel have a higher impact factor – the line is just visible in the new EMC, while it is not in the old. Even with an increase of a factor 5 in the impact factor, therefore, sand & gravel remains unimportant in its contribution to EMC. Concrete shows clearly in the old EMC, while it is invisible in the new: the old impact factor is a factor 10 higher. This is due to the fact that final solid waste generation, dominating the score for concrete in the old EMC, is not included in the impact categories for the new EMC.

The large increase in the environmental impact score of wood mainly can be explained by a large increase for the problem of land occupation (LUC). (see appendix D) In the ETH database the land necessary for the production of wood was severely underestimated, which was corrected in the Ecoinvent 2.0 database. The difference for animal fibres is caused by the use of different sources to calculate the impact per kilogram of animal fibre (e.g. wool). Since in the ETH database agricultural processes data were missing, the impacts of agricultural products were based on proxies (very rough own estimates). The Ecoinvent 2.0 database does contain data for several agricultural products, like wool and different kind of crops, and is supplemented by data from the LCA-food database. For agricultural products, therefore, the new impact factors can be considered more reliable than the old ones.

Table 6.2 EMC for EU-15, year 1990, comparison of impact factors from the ETH-database (EMC2005) with impact factors from Ecoinvent 2.0 (EMC2009).

	EMC2009	EMC2005	EMC2009	EMC2005	EMC2009/ EMC2005
			% of total EMC		
Fossil fuels and plastics	**3,58E-02**	**2,67E-02**	**48,68**	**34,08**	**1,34**
gas for heating and cooking	3,67E-03	1,58E-03	4,99	2,02	2,32
natural gas for electricity in households	7,32E-04	4,21E-04	1,00	0,54	1,74
oil for transport and heating	1,19E-02	5,75E-03	16,24	7,35	2,07
oil for electricity in households	1,40E-03	8,89E-04	1,90	1,13	1,57
hard coal for heating in households	4,69E-04	4,08E-04	0,64	0,52	1,15
hard coal for electricity in households	4,61E-03	5,85E-03	6,27	7,46	0,79
brown coal for heating in households	1,76E-04	1,19E-04	0,24	0,15	1,47
brown coal for electricity in households	5,93E-03	5,47E-03	8,07	6,98	1,09
plastics	6,85E-03	6,21E-03	9,32	7,93	1,10
Ores & metals	**3,77E-03**	**6,21E-03**	**5,13**	**7,93**	**0,61**
aluminium	8,70E-04	8,00E-04	1,18	1,02	1,09
copper	4,93E-04	3,08E-04	0,67	0,39	1,60
iron and steel	1,85E-03	3,84E-03	2,52	4,91	0,48
lead	1,54E-04	6,15E-04	0,21	0,78	0,25
nickel	2,44E-04	2,61E-04	0,33	0,33	0,94
zinc	1,57E-04	3,85E-04	0,21	0,49	0,41
Minerals	**4,20E-04**	**6,79E-04**	**0,57**	**0,87**	**0,62**
glass	3,96E-04	6,44E-04	0,54	0,82	0,62
salt	2,36E-05	3,53E-05	0,03	0,05	0,67
Construction materials	**1,61E-03**	**7,63E-03**	**2,19**	**9,74**	**0,21**
concrete	5,28E-04	6,49E-03	0,72	8,28	0,08
ceramics	9,41E-05	6,06E-04	0,13	0,77	0,16
clay	1,08E-06	3,73E-04	0,00	0,48	0,00
sand and stone	9,88E-04	1,64E-04	1,34	0,21	6,03
Biomass	**3,19E-02**	**3,71E-02**	**43,43**	**47,37**	**0,86**
starchy crops	1,98E-03	5,43E-03	2,70	6,94	0,36
fibre crops	2,76E-03	6,02E-03	3,75	7,68	0,46
animal fibres	1,31E-03	8,85E-05	1,79	0,11	14,84
protein crops	1,32E-04	2,83E-04	0,18	0,36	0,47
animal protein	8,55E-03	4,94E-03	11,63	6,31	1,73
fish protein	1,36E-04	2,37E-04	0,19	0,30	0,57
oil crops	1,00E-03	9,17E-04	1,36	1,17	1,09
animal fats	1,33E-02	1,81E-02	18,17	23,12	0,74
Biomass from forestry					
wood	1,12E-03	4,52E-06	1,53	0,01	247,81
paper and board					
paper and board	1,57E-03	1,08E-03	2,14	1,38	1,46
TOTAL environmental impact score	**7,35E-02**	**7,83E-02**			

6.4.3 Different weighting factors applied

It is of course possible to define indicators for environmental pressure at the level of the individual impact categories. We then end up with a set of indicators instead of just one. This could be acceptable, since comparisons between countries are still possible and developments over time are still visible. It is also policy relevant information, since it allows monitoring differences in progress between the different impact categories. If the aim is to have just one indicator however, the scores for the different environmental impact categories have to be added up. In order to do so, a weighting step is required: an indication of the relative importance of the environmental impact categories.

There is no generally accepted set of weights to be added. In practice, different weighting procedures are used in LCA studies which could be applied here as well. Annex 5 discusses a number of them. A first requirement for using a method is that it is more or less encompassing. A number of methods do not live up to this requirement because they focus on energy or global warming only. Three weighting procedures are applied and compared with equal weighting:

- NOGEPA weight factors (Sas et al., 1996; updated by Huppes et al., in prep.): this could be seen as a political set of weights, negotiated between representatives of industry, government and science for the NOGEPA covenant between the Dutch government and oil companies, but more widely used in LCA studies.
- Eco-indicator99 (Goedkoop & Spriensma, 2000): this is a method that could be regarded as expert opinion. It tries to remain “objective” as long as possible and uses model calculations to translate impact categories into impacts on human health, ecosystem damage and resource depletion.
- Shadow prices (Wit et al., 1997; updated by Davidson et al., 2002): this is an economic weighting method based on damage control costs.

Figures 6.7 to 6.9 show the results of application of these weighting procedures, applied to the former EU-15 countries.

Figure 6.7 EMC for EU-15, Ecoinvent impact factors, NOGEPA weighting set

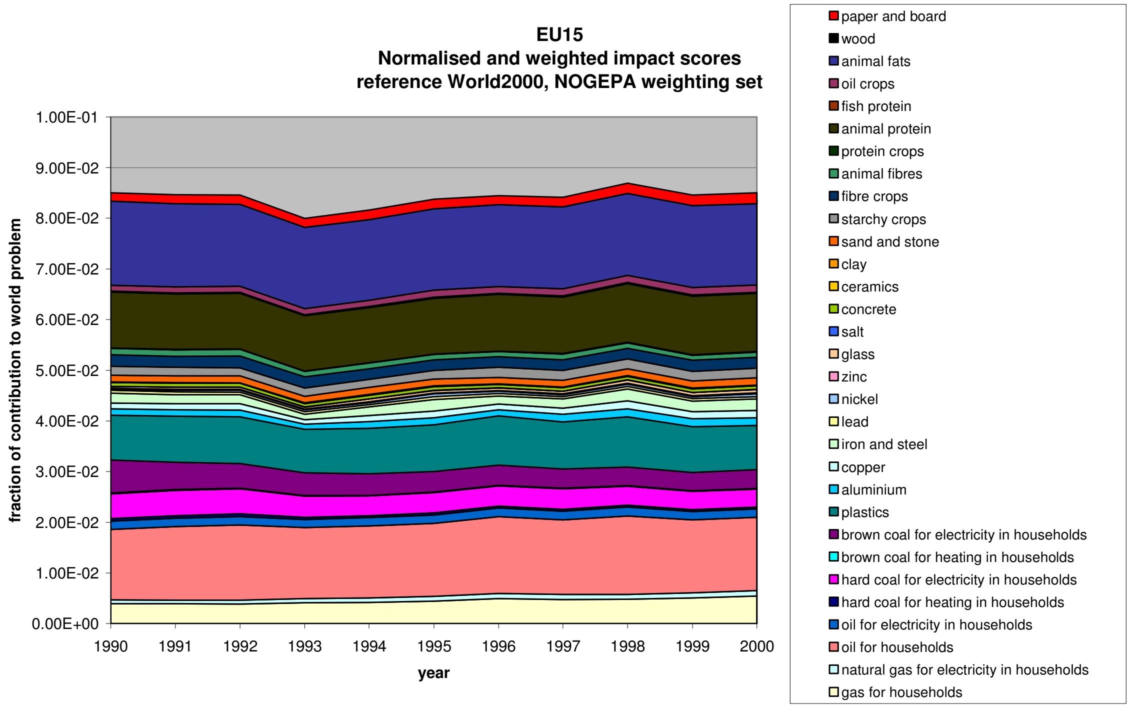


Figure 6.8 EMC for EU-15, Ecoinvent impact factors, shadow prices weighting set

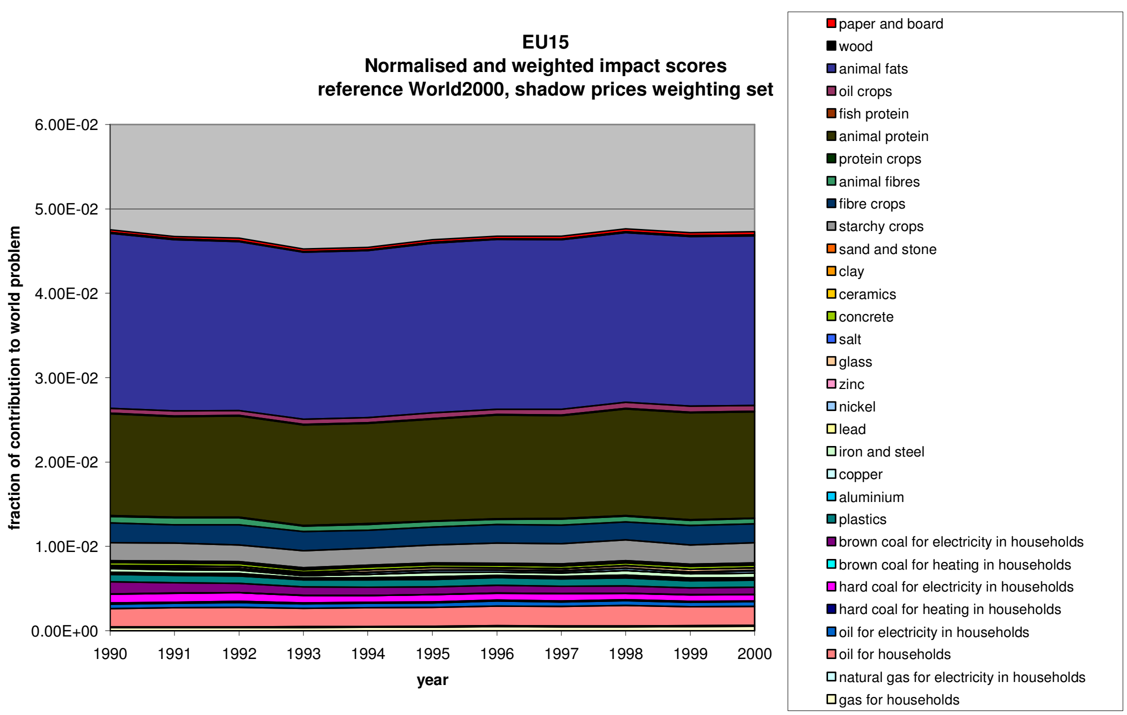
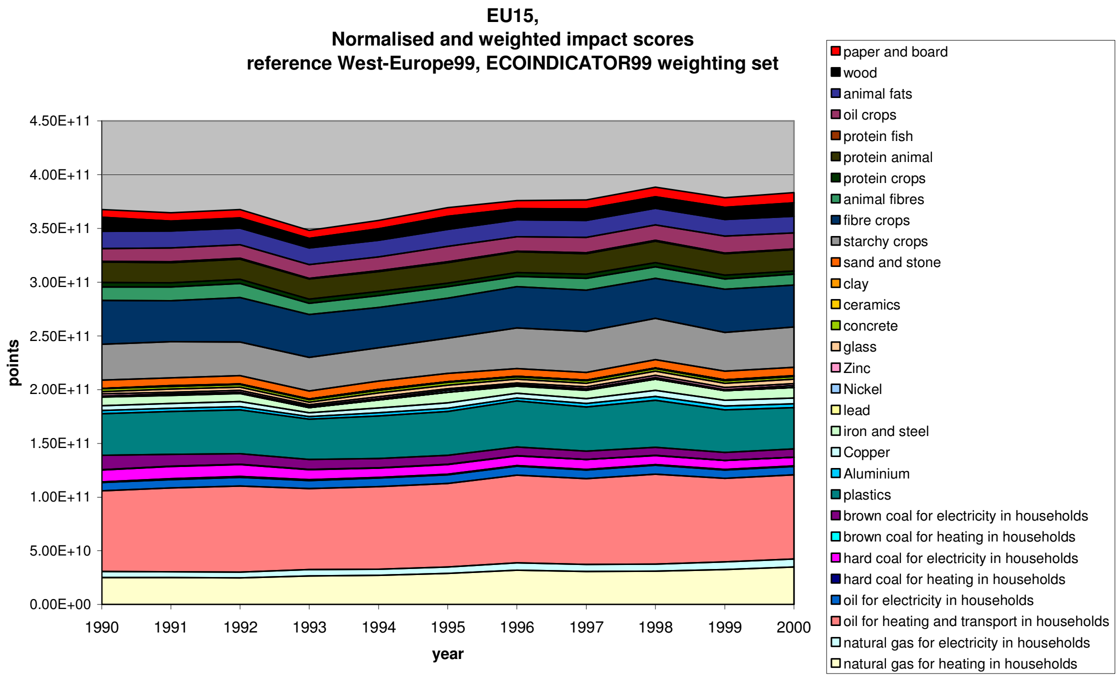


Figure 6.9	EMC for EU-15, Ecoinvent impact factors, Ecoindicator99 weighting set



It can be seen clearly that the outcomes of the different weighting procedures are quite different. Some key reasons for these differences are hidden in the details of the weighting schemes:

- NOGEPA attaches a heavy weight to global warming, with eutrophication and acidification next in line. Waste is not included, nor is land use and abiotic depletion.
- Implicitly, Ecoindicator99 attaches a lot of weight to the respiratory damage and damage to health due to global warming. Ecoindicator99 uses different impact categories due to the philosophy of modelling the environmental impact chain throughout the final impact on human health, ecosystems and depletion of resources. Waste is not included.
- In shadow prices, ozone layer depletion and eutrophication have the heaviest weight and together account for 85% of the score. Land use and depletion of resources are not included.

The above comparison on weighting methods shows that weighting is an important issue. Therefore it should get attention, especially from politics since weighting is normative rather than objective. Since at present there is no generally accepted method for weighting, to use any weighting scheme is by definition controversial and the results from this study could be considered to be valid only at the disaggregate level of the different impact categories. For the EMC 2005, we used equal weighting as an illustration. As is shown above, it is easy to replace this with any other weighting scheme. When an approved impact assessment and weighting procedure is issued by JRC, this can be used without any problems.

6.5 Conclusions and recommendations with regard to composing EMC

In the above, we have tried to calculate the EMC indicator based on standard, EU-managed databases: Europroms and the Agricultural balances for the apparent consumption, and the ELCD for the impact factors. This was not succesful. With regard to the apparent consumption, the general structure of the EU-managed databases is explicitly suitable, but the incompleteness of data and time series is too much of a problem. This is especially the case for Europroms, where trade data are generally available but production data are lacking to a great extent. At country level the incompleteness is such that meaningful results are impossible to make. At EU-15 level it is better but still important materials are lacking and comprehensive time series cannot be made. With regard to the ELCD database, at present only a limited amount of materials is included in the LCI.

A first recommendation, therefore, is to increase the usefulness of Europroms by completing production statistics. Especially at country level confidentiality may be a remaining issue, but we suspect that it is indeed possible to arrive at more complete data sets. This recommendation can also be made for the Agricultural Balances, although they are much more complete than Europroms. For agricultural products, for fossil fuels and for metals we think it should be possible to report productions in Europroms, especially at the aggregate EU-15 or EU-25 level, but in many cases also for individual countries. Established databases such as FAOSTAT and IEA data do report productions. In the Material Flow Accounts for EU-countries, production is not included but extractions are, which can be used to derive production data. With regard to the ELCD database, we understand the completion is an ongoing process.

In the meantime, we recommend calculating EMC from other databases. FAOSTAT, IEA statistics, reports from branch organisations and MFA accounts are good sources and will most certainly be sufficient to calculate apparent consumptions, even for the larger list of materials. For the impact factors, several established LCA databases can be used, that include a great many materials. We used Ecoinvent 2.0, and applied it to the apparent consumption data of the "old" EMC based on MFA data. With the use of such a database, it seems that the impact factors pose far less of a problem than the apparent consumption data. However, the infrequent update of LCA databases remains an issue to solve.

7 Conclusions and recommendations

In this report, the development and use of general decoupling indicators are discussed. The report can be split up into two separate parts: the discussion and assessment of a number of candidates for general decoupling indicators, and the further development of one of those indicators, the EMC. For each part, conclusions are drawn and recommendations are made separately.

7.1 On EMC development

The first version of the EMC indicator was developed specifically for the EU Resource Strategy: an indicator to measure decoupling, based on Material Flow Accounts on the one hand, and linked to environmental impacts on the other. In Chapter 6 of this report, we have explored possibilities to formalise this indicator by using only EU-approved data and by developing standardised procedures to arrive at the EMC indicator. We explored databases for the two parts of EMC: apparent consumption and impact factors.

Apparent consumption in the prototype EMC was based on MFA accounts. Contrary to expectation, not the LCA data but the MFA data proved to be the bottleneck: impact factors could be derived for more than 100 materials, but material balances could be made only for 30 – 35 materials. For the calculation of apparent consumption, the ideal solution seemed to be to use Europroms and Agricultural balances. These contain data on a large number of goods. Both databases are EU-managed and in theory they offer more adequate information to calculate material balances than the MFA accounts do. By directly using trade and production statistics, it would no longer be necessary to take the "detour" via the MFA accounts, where production is not included, and an expansion would be possible of the list of materials from roughly 35 to at least double that amount. The agricultural balances appeared to be usable and fairly complete. The Europroms database however shows large gaps. Especially the production statistics are very incomplete for many categories and it was not possible to directly use them to make material balances for apparent consumption. For metals, an approach is outlined to arrive at apparent consumption data via statistics on ores, which are more complete. For other materials, even this was not possible.

At the moment, therefore, it is not possible to make time series for the apparent consumption of a relevant set of materials based on Europroms and Agricultural balances. A first recommendation to Eurostat, therefore, is to start filling in the gaps. We think it should be possible, even in case of confidential data, to come up with for more complete time series at least at the aggregate EU-level. Countries could do their own calculations based on their own statistics and could then include the confidential data without disclosing them. In the meantime, the best way to go forward seems to be the use of non-EU data. Some fairly well established databases that could be used:

- FAOSTAT for the agricultural materials
- IEA for fossil fuel-related data

- Metals and mining statistics for the metals
- MFA accounts for the construction minerals

Together, those databases deliver sufficient information to calculate material balances for a lot of materials. They then have to be "approved", at least for the time being, by EU and could be supported by the Eurostat Datacenter on Resources.

For the impact factors, a similar story can be told. At JRC, a Life Cycle Inventory database is presently being established. At the moment, this database is quite incomplete. It is not likely that a sufficiently complete database will be ready in the near future at JRC. In the meantime, we recommend to use one of the various other databases available in the LCA-field. To illustrate our calculations for this report, we have used Ecoinvent 2.0, and thus updated the impact factors of the prototype EMC which were based on the ETH-database. To allow for the EMC to include technological progress, it is important that the impact factors be updated frequently. Of course, LCI-databases are updated every now and then, but it may take a long period and does not follow a systematic approach. Rather, present LCI databases are focused on enlarging their database yet. Ecoinvent 2.0 for example includes many processes from agriculture and biotechnology that were not yet included in the previous ETH database. The standardisation of LCI-databases and their updates is still work in progress for the LCA community. Another issue is the differentiation between processes in one country or another. It may make a large difference if for example copper originates from Chile or from South Africa, due to the difference in ore grades and mining practices. This is presently not reflected in the EMC due to lack of data. The regionalisation of LCI databases is also still in an early stage. In the future, this situation may improve.

We have used the Life Cycle Impact Assessment according to Guinée et al. to translate the LCI data into a limited number of impact categories. To further aggregate into one overall indicator, weighting between the impact categories is necessary, which we did using different weighting sets. At JRC, a standardised procedure for the LCIA is also being developed. At this date (April 1, 2009) this procedure has not yet been published. When it becomes available, it can be adopted to the EMC without difficulty.

7.2 On decoupling indicators

We have described and assessed a number of general indicators that have been presented as decoupling indicators. Next to the abovementioned EMC, these were: HANPP, the Ecological Footprint, DMC and an EE IO based aggregate indicator. The assessment is related to a number of criteria that we consider relevant for decoupling indicators:

- Scientific value: the scientific and methodological basis of the indicators
- Communicative value: the appealing quality of the indicators for the general public
- Indicator behavior and Adequacy for the intended purposes: the extent to which the indicators repond adequately to assumed changes in society
- Data availability and reliability: the extent to which the indicators can be built from acceptable databases.

Some issues come back for all indicators. One major challenge is the translation of the – by necessity – large dataset into one single value for environmental pressure or impacts. Different indicators have taken this up differently as well, either by using elaborate procedures (such as the LCIA which is used for EMC and EE IO-based indicators), by expression in a single unit (such as the DMC and EF) or by taking a limited scope (EF and especially HANPP).

All of the indicators appear to rely on fairly consistent methodologies. Question marks in this respect can be placed at the Ecological Footprint, where a consumption-based system for biomass resources is combined with a production/region based system for CO_2-emissions, and at EMC where one should be aware of the risk for double counting. With regard to the communicative power, this really depends on the user. For a user who wants information to support policy, the more encompassing and detailed indicators have the most added value: EMC and EE IO. These can be decomposed in various ways, thereby showing insight in the causes for its behaviour. For the general public, the EF and to some extent DMC are probably most appealing: simple, easily understandable indicators with a clear message.

Indicator behaviour was tested in a number of case studies and led to some interesting conclusions. We have defined (1) the capacity to show the intended change, (2) the capacity to side-effects to other environmental impacts, and (3) the capacity to show a burden shift to other countries as the relevant criteria for this area.
A first conclusion is, that none of the assessed indicators is the perfect one, showing the correct behaviour in all cases. In general, all of the indicators fall short in case of end-of-the-pipe emission reductions and in waste management. Even the indicators that do include emissions are not always sensitive enough to show changes like this.

A second conclusion is, that all indicators have limitations, which have consequences for their use as decoupling indicators

- HANPP has a limited scope which makes it insensitive for impacts other than those related to land use change, and cannot show burden shifting to other areas
- DMC does not include impacts but uses material flows as a proxy, which implies that sometimes impacts are overstated, but mostly they are understated, and it does not show burden shifting to other regions. Using TMC instead of DMC may solve the second problem.
- EF does not include any emissions besides CO_2, therefore is blind to burden shifting to other impact categories, and excludes large parts of the economic system by not including non-renewable resources. Due to its dual nature, burden shifting abroad is also not always visible.
- EMC in principle shows impacts, side-effects and displacement abroad, but in its present shape is insensitive for technological improvements, sometimes in non-obvious ways, due to the inflexibility of the impact factors
- EE IO also in principle shows impacts, side-effects and discplacement abroad, but presently includes a rather limited list of emissions, sometimes suffers from lack

of detail in the sector classification, and assumes foreign technology to be identical to domestic technology.

From the above, it has become clear that some of these limitations are inherent to the indicators. Especially HANPP and DMC seem to be constrained and therefore not very useful as general decoupling indicators. For the other three, improvement options could be defined, making them more flexible and sensitive:

- For EE IO, a larger scope of environmental interventions would be helpful, as well as a more detailed sector classification, and a differentiation between technologies in various countries. Developments are presently ongoing, especially in the EXIOPOL project, to realise this.
- EMC would benefit by more detail in the materials included, a regular update of LCA-based impact factors and a region-specific definition of impact factors.
- For the EF, the inclusion of other emissions besides CO_2 would be a major challenge, not just in the data but also in the translation to global hectares.

Regarding data availability and quality, we can conclude that all appraoches are quite data intensive. To arrive at one indicator ultimately, a load of data must be processed, translated, added, subtracted, multiplied etcetera. This is probably inevitable for general decoupling indicators that need to include all of society somehow. DMC in this respect is probably the simplest and most straightforward indicator. Nevertheless, most of the indicators are based on generally available data. HANPP is the only indicator relying mainly on non-statistical data. All others are based mainly in standard statistics. This seems to be a prerequisite for decoupling indicators that are meant to be composed and reported frequently, and are to be used to support government policy.

A final summing up of the indicators leads to the following conclusions:

HANPP is a very specific indicator, that is not designed, nor can be used as a general indicator for environmental pressure in a decoupling context. Its scope is limited, it is not based in statistics, the link to the economic system is absent, and it does not show burden shifting. It does, however, offer specific information that none of the other indicators does. Therefore, it can be used in addition to those, to highlight NPP appropriation as an indicator of pressure on land.

The Ecological Footprint has been designed as a general indicator for environmental pressure. It, too, focuses on land, but it uses hectares as a measure for pressure rather than commenting on land use itself. It is a very appealing indicator, and the only one that has a sustainability threshold. Nevertheless, it is also limited: it encompasses renewable (biomass) resources and CO_2-emissions, and therefore is blind to many changes in the environmental performance of societies. It's original set-up is consumption oriented, which allows to detect burden shifting. However, with the addition of CO_2, this clearcut focus has been abandoned to some extent, as has the relevance of the globally available hectares. Extending the EF with other emissions would be possible in theory, however, there is a serious risk for loss of meaning of global hectares as a relevant measure if this were to be done. Although as an indicator for the general public EF may point in the right direction in many cases and raise awareness of the impacts of consumption patterns, as a general decoupling indicator to support policy, the EF presently has a too limited and not easily expandable scope.

The DMC is a clearcut indicator that in its own way, i.e. counting the material flows, is encompassing. It has two drawbacks in light of its use as a general indicator for decoupling. The first is the regional scope, which does not allow for detecting burden shifting to other countries. This can be circumvented by using TMC instead of DMC: TMC includes "embodied kilograms". The second drawback is the fact that kilograms of materials use is not really a relevant indicator for environmental pressure. Although at a general level there is a certain correlation between material consumption and environmental pressure, DMC dometimes points in the wrong direction if it comes to detecting certain changes in society's pressure on the environment. DMC (or TMC) however can be used to measure decoupling of economic growth from resource use, which none of the other indicators is able to do. It therefore can play a specific role to support a resource policy.

EMC is designed to overcome the limitations of DMC: it has a consumption chain oriented approach, thereby enabling to detect burden shifting abroad, and it adds environmental impact factors to the kilograms of material, thereby adding environmental relevance. In its coverage of emissions and impacts, EMC presently is the most comprehensive indicator. It misses the inherent comprehensiveness of DMC, however: being as complete as possible is a constant point of attention. Another point of attention is the risk for double-counting of impacts. Because of its focus on materials, it seems a very useful indicator to support resource policies. It is less adequate in detecting changes related to technological improvements or waste management, due to the fixed impact factors. EMC can be improved further by expanding the scope of materials included, and by frequently updating the impact factors.

EE-IO, finally, theoretically seems to be the best candidate to deliver a general decoupling indicator. It is encompassing and allows to include a great many environmental interventions. It also allows for a sufficiently detailed distinction of sectors to enable detecting most changes, technologically or throughput-wise. It includes the embodied environmental pressure of imports and corrects for those of the exports, which makes it suitable to detect problem shifting to foreign countries. However, at present, EE-IO falls short of its potential: NAMEAs composed by some EU countries include only a limited amount of pollutants, mainly emissions to air, its sectors are defined at a high aggregation level, and foreign production is assumed to be similar to domestic production. In ongoing projects a more sophisticated and comprehensive EE-IO approach is being developed, however, this is not available yet and it remains to be seen whether this approach can in fact be maintained by countries and updated frequently.

It seems, therefore, that the different indicators may serve different purposes. As concluded above, EE-IO may provide the best framework for a general decoupling indicator. For more specific policy areas, such as policies aimed at resources, products or waste, it would be less suitable. Since EE-IO inherently works via monetary exchanges of sectors, the link to resources, materials, products and waste cannot be made directly. To some extent even this could be included in the IO-framework. Relevant to be mentioned are the NAMEA-waste accounts that are being reported in a number of EU countries. In the EIPRO project, a link of EE-IO to product groups has been established, allowing a prioritisation among product groups. EIPRO however is a huge effort to repeat frequently, and relies on many shortcuts that will not be discussed here. In the EXIOPOL project, links are also made to resource extractions. The EE-IO framework therefore seems to be the most versatile and generally applicable one. On the other hand, it will not be able to supply resource, waste or product policies with sufficient information or sufficiently targeted indicators.

To start with a policy on resources: for this, it is imperative to have the resources and resource flows visible in the indicator, rather than have them added as multiplyers to sectors based on their monetary throughput. Resource flows themselves are captured in the DMC or TMC indicator, based on MFA accounts. The EMC seems most suitable to add the environmental dimension. EMC captures many environmental impact categories. Land use is included in EMC, however, the land use data for renewables in the EF are of a better quality. A recommendation could be to try and combine the two indicators. They both have resources rather than sectors as a starting point, and their system boundaries are rather similar. The EF then could supply the land use data for renewables and the EMC the emissions, including CO_2. Land use data for non-renewables should be added, however, these would be minor in comparison to the renewables land requirement. EE-IO would add little to this set. If PIOTs were produced for a wide number of materials, the added value would be considerable: this would allow for a more sophisticated assessment of the pathways of resources through the economic system. In the absence of PIOTs, specific Substance Flow Analysis studies could be done with regard to certain priority materials with the same results.

For a waste policy, the NAMEA waste accounts could be a valuable starting point. Most likely, more information is required here as well. Impacts of waste trade, of different waste treatment options and of various forms of recycling are very important and may not be sufficiently included in an EE-IO framework. Additional information is also required on specific hazardous waste streams and their treatment. For waste prevention, it is important to have insight in the origins of waste streams. Links must be established with resources and products, for which it is uncertain that the road via monetary exchanges of sectors is the best one to follow.

A product policy could benefit greatly from an EIPRO-like approach. This may be the only way to get a perspective on all combined products in a national economy. A product policy obviously should be supplemented by product studies for priority product groups based on detailed LCAs. Without these, it would not be possible to do eco-labelling or provide guidelines for product design – be it ecodesign, design for recycling or otherwise. However, the individual products are too numerous to keep track of all of them: instead of roughly a hundred materials, there are tens of thousands of different products to keep track of. A certain amount of aggregation therefore is inevitable, and to do this via EE-IO seems a sensible road to take.

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Appendices

Appendix A Impacts per kg material (characterized results), used in EMC2009

method of impact assessment:	**Problem Oriented Approach**			**Impacts are based on baseline characterisation factors (Guinée et al., 2002) and process descriptions of the Ecoinvent database 2.0 (Ecoinvent, 2008)**									
(baseline) impact category:	ADP (Guinee et al. 2001)	LUC (Guinee et al, 2001)	climate change_ GWP 100a	stratospheric ozone depletion _ODP steady state	human toxicity_ HTP infinite	freshwater aquatic ecotoxicity_FAETP infinite	marine aquatic ecotoxicity_MAETP infinite	terrestrial ecotoxicity_TAETP infinite	photochemical oxidation (summer smog)_high NOx POCP	AP (Huijbregts, 1999; average Europe total, A&B)	EP (Heijungs et al. 1992))	(Frischknecht et al., 1999)	final solid waste
Fossil fuels													
Natural gas													
natural gas for heating in households	0.02242	0.00475	2.7094	3.7E-07	0.28006	0.02117	202.16	0.002	0.00041	2.29E-03	2.03E-04	1.25E-09	0.0655
natural gas for electricity in households	0.02559	0.00179	3.002	3.8E-07	0.19844	0.00984	154.956	0.00072	0.00034	0.00287	0.00043	1.90E-10	0.0776
Crude oil													
oil for heating in households	0.026	0.01097	4.03515	6.3E-07	0.7686	0.09309	339.038	0.00611	0.00077	0.00892	0.00079	4.31E-09	0.0729
oil for electricity in households	0.02727	0.00873	4.4145	5.6E-07	1.9665	0.22635	1237.5	0.04379	0.00202	0.04635	0.00236	1.76E-09	0.0374
hard coal													
hard coal for heating in	0.02509	0.10904	4.379	2E-08	0.8526	0.12209	1667.5	0.0058	0.01024	0.02065	0.00054	1.11E-09	0.619

households													
hard coal for electricity in households	0.02887	0.1036	3.70222	2.5E-08	0.49156	0.08773	3453.33	0.00513	0.00071	0.01745	0.00108	1.27E-09	0.733
brown coal													
brown coal for heating in households	0.02397	0.01423	3.4	2E-08	1.1271	0.11509	836.4	0.01357	0.00401	0.00542	0.00055	8.06E-10	0.0637
brown coal for electricity in households	0.01605	0.00443	2.13492	3.7E-09	0.40049	0.26803	2041.42	0.00248	0.00062	0.01574	0.0004	4.44E-10	0.00809
plastics	0.03808	0.01825	4.61167	1.2E-07	1.23275	1.85	2129.17	0.00587	0.00135	0.01199	0.00154	2.34E-09	0.07207
Ores													
Aluminium	0.0495	0.14	8.01	5.5E-07	16.9	3.87	23500	0.0983	0.00192	0.0396	0.00319	4.62E-08	2.35689
Copper	0.0155	0.828	2.01	2.3E-07	88.2	2.54	5090	0.369	0.00582	0.14	0.00409	1.21E-08	3.34381
Iron and steel	0.0144	0.0596	1.65	4.2E-08	0.36	0.263	747	0.00384	0.00113	0.00574	0.00123	2.90E-09	1.52548
Lead	0.0106	0.0527	1.06	7.6E-08	132	0.488	681	1.31	0.00121	0.026	0.00074	6.12E-09	1.61453
Nickel	0.0654	1.15	11.2	1.1E-06	43.6	29.8	35300	0.257	0.0692	1.71	0.0121	5.61E-08	2.42632
Zinc	0.0245	0.132	3.36	2E-07	6.07	0.242	2050	0.196	0.00203	0.0458	0.00278	1.73E-08	1.69378
Industrial materials													
glass	0.00593	0.041	0.563	9E-08	0.252	0.0586	1050	0.0016	0.00034	0.00861	0.00067	1.81E-09	1.08644
Construction materials													
concrete	0.00035	0.00479	0.123	6.7E-09	0.0243	0.0201	21.2	0.00023	1.7E-05	0.00028	4.39E-05	2.89E-10	1.01007
ceramics	0.00127	0.00842	0.23	2.1E-08	0.0739	0.023	475	0.00029	6.6E-05	0.00064	8.06E-05	4.47E-10	1.00867
clay	1.93E-05	0.00018	0.00292	4.8E-10	0.00116	9.2E-05	0.333	4E-06	1.3E-06	2.25E-05	4.80E-06	1.80E-12	1.00008
sand and stone	8.61E-05	0.00428	0.0132	2.8E-09	0.015	0.0186	16.9	4.7E-05	6.7E-06	0.0001	1.79E-05	7.92E-11	0.0003
Biomass (crops and animal products)													

starchy crops	1.14E-03	1.1245	-0.215	2.4E-08	0.21893	0.0446	84	0.01718	6.3E-05	0.00329	0.00639	5.67E-10	0.34538
fibre crops	1.68E-03	1.35	-0.341	3.8E-08	0.149	0.186	78.2	0.0226	7.3E-05	0.00453	0.00598	8.03E-10	0.34538
animal fibres	0.299	305	84.8	5.8E-06	34.5	8.69	14900	-0.615	0.0361	1.16	0.541	2.76E-07	0.42397
protein crops	1.21E-03	3.03667	0.269	2.7E-08	0.1711	0.04877	92.0667	0.04978	7E-05	0.00216	0.00442	8.80E-10	0.34538
protein animal	0.00713	4.8475	4.90175	1.3E-07	0.762	0.764	417	0.04493	0.00073	0.039	0.245	6.16E-09	0.42397
protein fish	0.00122	0.0985	1.61	3.2E-08	0.0966	0.026	108	0.00184	0.00028	0.0119	0.00422	2E-09	0.369
oil crops	1.76E-03	2.58867	-0.3103	3.8E-08	0.228	0.81297	94.7	0.10907	0.00038	0.00797	0.00867	1.59E-09	0.34538
animal fats	0.00164	0.677	1.28	3E-08	0.148	0.245	101	0.021	0.0002	0.0112	0.117	1.28E-09	0.42397
Biomass from forestry													
wood	0.00075	5.9	-0.597	2.6E-08	0.05675	0.0186	42.05	0.00059	0.00016	0.00065	1.43E-04	6.44E-10	0.00979
paper and board													
paper and board	0.00885	3.27033	1.71267	1.2E-07	0.836	0.34533	1125.33	0.0104	0.0005	0.0053	0.0016	6.82E-09	0.1175

Normalisation factors for the impact categories (Guinée et al., 2002) for the world in 2000, based on Wegener sleeswijk et al., 2008

ADP (Guinee et al. 2001)	LUC (Guinee et al, 2001)	GWP100 (Houghton et al., 2001)	ODP steady state (WMO, 1992 & 1995 & 1999)	HTP inf. (Huijbregts, 1999 & 2000)	FAETP inf. (Huijbregts, 1999 & 2000)	MAETP inf. (Huijbregts, 1999 & 2000)	TETP inf.(Huijbregts, 1999 & 2000)	POCP (Jenkin & Hayman, 1999; Derwent et al. 1998; high Nox)	AP (Huijbregts, 1999; average Europe total, A&B)	EP (Heijungs et al. 1992))	(Frischknecht et al., 1999)	final solid waste
1.8E+11	1.2E+14	4.2E+13	2.3E+08	3.8E+13	3.5E+12	1.9E+14	1.1E+12	6.54E+10	2.4E+11	1.6E+11	167736	7.3E+12

Appendix B Impacts per kg material (characterized, normalized and weighted results), used in EMC2009

	ADP (Guinee et al. 2001)	LUC (Guinee et al, 2001)	GWP100 (Houghton et al., 2001)	ODP steady state (WMO, 1992 & 1995 & 1999)	HTP inf. (Huijbregts, 1999 & 2000)	FAETP inf. (Huijbregts, 1999 & 2000)	TETP inf.(Huijbregts, 1999 & 2000)	POCP (Jenkin & Hayman, 1999; Derwent et al. 1998; high Nox)	AP (Huijbregts, 1999; average Europe total, A&B)	EP (Heijungs et al. 1992))	(Frischknecht et al., 1999)	final solid waste
Fossil fuels												
Natural gas												
households	1.23E-14	3.83E-18	6.47E-15	1.62E-16	2.42E-16	2.01E-16	6.03E-17	6.22E-16	9.59E-16	1.28E-16	7.48E-16	8.93E-16
natural gas for electricity in households	1.40E-14	1.44E-18	7.17E-15	1.67E-16	1.72E-16	9.34E-17	2.17E-17	5.16E-16	1.20E-15	2.75E-16	1.13E-16	1.06E-15
Crude oil												
households	1.42E-14	8.85E-18	9.64E-15	2.74E-16	6.65E-16	8.84E-16	1.84E-16	1.18E-15	3.74E-15	4.96E-16	2.57E-15	9.94E-16
oil for electricity in households	1.49E-14	7.04E-18	1.05E-14	2.42E-16	1.70E-15	2.15E-15	1.32E-15	3.09E-15	1.94E-14	1.49E-15	1.05E-15	5.10E-16
hard coal												
hard coal for heating in households	1.37E-14	8.79E-17	1.05E-14	8.83E-18	7.37E-16	1.16E-15	1.75E-16	1.57E-14	8.65E-15	3.41E-16	6.64E-16	8.44E-15
hard coal for electricity in households	1.58E-14	8.35E-17	8.85E-15	1.09E-17	4.25E-16	8.33E-16	1.55E-16	1.09E-15	7.31E-15	6.82E-16	7.57E-16	1.00E-14
brown coal												
brown coal for heating in households	1.31E-14	1.15E-17	8.12E-15	8.56E-18	9.75E-16	1.09E-15	4.09E-16	6.13E-15	2.27E-15	3.45E-16	4.80E-16	8.69E-16
brown coal for electricity in households	8.78E-15	3.57E-18	5.10E-15	1.61E-18	3.46E-16	2.54E-15	7.48E-17	9.46E-16	6.59E-15	2.54E-16	2.65E-16	1.10E-16
plastics	2.08E-14	1.47E-17	1.10E-14	5.23E-17	1.07E-15	1.76E-14	1.77E-16	2.06E-15	5.02E-15	9.73E-16	1.40E-15	9.83E-16
Ores												
Aluminium	2.71E-14	1.13E-16	1.91E-14	2.39E-16	1.46E-14	3.67E-14	2.97E-15	2.94E-15	1.66E-14	2.01E-15	2.75E-14	3.21E-14
Copper	8.47E-15	6.68E-16	4.80E-15	9.89E-17	7.63E-14	2.41E-14	1.11E-14	8.90E-15	5.86E-14	2.58E-15	7.21E-15	4.56E-14
iron and steel	7.87E-15	4.81E-17	3.94E-15	1.83E-17	3.11E-16	2.50E-15	1.16E-16	1.73E-15	2.40E-15	7.77E-16	1.73E-15	2.08E-14

lead	5.80E-15	4.25E-17	2.53E-15	3.29E-17	1.14E-13	4.63E-15	3.95E-14	1.85E-15	1.09E-14	4.64E-16	3.65E-15	2.20E-14
Nickel	3.58E-14	9.27E-16	2.68E-14	4.77E-16	3.77E-14	2.83E-13	7.76E-15	1.06E-13	7.16E-13	7.64E-15	3.34E-14	3.31E-14
Zinc	1.34E-14	1.06E-16	8.03E-15	8.72E-17	5.25E-15	2.30E-15	5.92E-15	3.10E-15	1.92E-14	1.76E-15	1.03E-14	2.31E-14
Industrial materials												
glass	3.24E-15	3.31E-17	1.35E-15	3.91E-17	2.18E-16	5.56E-16	4.83E-17	5.17E-16	3.61E-15	4.21E-16	1.08E-15	1.48E-14
salt	1.39E-16	2.43E-18	2.38E-16	2.66E-17	3.02E-17	4.40E-17	2.22E-17	7.08E-17	3.51E-16	2.37E-17	3.82E-17	6.53E-16
Construction materials												
concrete	1.90E-16	3.86E-18	2.94E-16	2.93E-18	2.10E-17	1.91E-16	6.94E-18	2.65E-17	1.18E-16	2.77E-17	1.72E-16	1.38E-14
ceramics	6.94E-16	6.79E-18	5.50E-16	9.16E-18	6.39E-17	2.18E-16	8.63E-18	1.01E-16	2.66E-16	5.09E-17	2.66E-16	1.38E-14
clay	1.06E-17	1.43E-19	6.98E-18	2.07E-19	1.00E-18	8.77E-19	1.20E-19	2.03E-18	9.42E-18	3.03E-18	1.07E-18	1.36E-14
sand and stone	4.71E-17	3.45E-18	3.15E-17	1.22E-18	1.30E-17	1.77E-16	1.40E-18	1.02E-17	4.27E-17	1.13E-17	4.72E-17	4.10E-18
Biomass (crops and animal products)												
starchy crops	6.25E-16	9.07E-16	#######	1.04E-17	1.89E-16	4.23E-16	5.18E-16	9.56E-17	1.38E-15	4.04E-15	3.38E-16	4.71E-15
fibre crops	9.18E-16	1.09E-15	#######	1.64E-17	1.29E-16	1.77E-15	6.82E-16	1.12E-16	1.90E-15	3.78E-15	4.79E-16	4.71E-15
animal fibres	1.63E-13	2.46E-13	2.03E-13	2.50E-15	2.98E-14	8.25E-14	#######	5.52E-14	4.86E-13	3.42E-13	1.65E-13	5.78E-15
protein crops	6.60E-16	2.45E-15	6.43E-16	1.18E-17	1.48E-16	4.63E-16	1.50E-15	1.08E-16	9.05E-16	2.79E-15	5.25E-16	4.71E-15
protein animal	3.90E-15	3.91E-15	1.17E-14	5.71E-17	6.59E-16	7.25E-15	1.36E-15	1.12E-15	1.63E-14	1.55E-13	3.67E-15	5.78E-15
protein fish	6.67E-16	7.94E-17	3.85E-15	1.37E-17	8.35E-17	2.47E-16	5.55E-17	4.28E-16	4.98E-15	2.67E-15	1.22E-15	5.03E-15
oil crops	9.63E-16	2.09E-15	#######	1.67E-17	1.97E-16	7.72E-15	3.29E-15	5.75E-16	3.34E-15	5.48E-15	9.46E-16	4.71E-15
animal fats	8.97E-16	5.46E-16	3.06E-15	1.28E-17	1.28E-16	2.33E-15	6.34E-16	3.01E-16	4.69E-15	7.39E-14	7.63E-16	5.78E-15
Biomass from forestry												
wood	4.12E-16	4.76E-15	#######	1.12E-17	4.91E-17	1.77E-16	1.78E-17	2.38E-16	2.71E-16	9.03E-17	3.84E-16	1.33E-16
paper and board												
paper and board	4.84E-15	2.64E-15	4.09E-15	5.14E-17	7.23E-16	3.28E-15	3.14E-16	7.58E-16	2.22E-15	1.01E-15	4.06E-15	1.60E-15

Appendix C Impacts per kg material (characterized, normalized and weighted results), used in EMC2005

	ADP (Guinee et al. 2001)	LUC (Guinee et al, 2001)	GWP100 (Houghton et al., 2001)	ODP steady state (WMO, 1992 & 1995 & 1999)	HTP inf. (Huijbregts, 1999 & 2000)	FAETP inf. (Huijbregts, 1999 & 2000)	TETP inf.(Huijbregts, 1999 & 2000)	POCP (Jenkin & Hayman, 1999; Derwent et al. 1998; high Nox)	AP (Huijbregts, 1999; average Europe total, A&B)	EP (Heijungs et al. 1992))	(Frischknecht et al., 1999)	final solid waste
Fossil fuels												
Natural gas												
households	2.30E-16	1.95E-17	6.75E-15	4.70E-17	4.41E-17	9.86E-17	2.11E-16	4.83E-16	7.46E-16	4.15E-16	5.19E-16	8.93E-16
natural gas for electricity in households	1.55E-15	6.65E-18	9.33E-15	1.77E-17	8.84E-17	5.43E-16	1.32E-16	3.94E-16	1.30E-15	7.04E-16	3.45E-17	1.06E-15
Crude oil												
households	3.83E-16	2.19E-17	9.59E-15	1.06E-15	1.74E-16	3.69E-16	8.96E-16	6.77E-16	2.88E-15	4.44E-16	6.47E-16	9.94E-16
oil for electricity in households	2.90E-16	8.23E-18	9.28E-15	1.07E-15	8.55E-16	2.18E-15	6.36E-15	2.37E-15	1.55E-14	8.32E-16	1.67E-16	5.10E-16
hard coal												
hard coal for heating in households	1.31E-14	1.30E-17	7.38E-15	8.35E-17	1.32E-15	4.80E-15	2.34E-15	6.31E-15	5.60E-15	3.58E-16	1.67E-16	8.44E-15
hard coal for electricity in households	1.71E-14	1.78E-17	8.07E-15	2.83E-17	9.94E-16	5.92E-15	1.64E-15	8.47E-16	5.23E-15	6.54E-16	1.85E-16	1.00E-14
brown coal												
brown coal for heating in households	1.07E-14	1.31E-17	5.59E-15	1.54E-17	3.13E-16	2.28E-16	9.48E-16	3.09E-15	2.73E-15	2.91E-16	8.52E-17	8.69E-16
brown coal for electricity in households	1.00E-14	9.60E-18	5.04E-15	3.24E-18	1.83E-16	5.63E-17	4.99E-16	1.13E-15	8.09E-15	3.12E-16	6.60E-17	1.10E-16
plastics	1.36E-15	2.95E-17	1.30E-14	1.49E-15	1.86E-15	4.59E-15	1.04E-14	1.84E-14	7.00E-15	6.69E-16	9.95E-16	9.83E-16
Ores												
Aluminium	2.48E-14	3.19E-16	3.16E-14	1.31E-15	3.16E-15	1.04E-14	9.34E-15	3.91E-15	2.45E-14	2.24E-15	9.77E-15	3.21E-14
Copper	1.01E-14	1.83E-16	1.30E-14	6.48E-16	1.31E-15	2.71E-15	1.91E-15	7.30E-15	5.18E-14	8.50E-16	6.22E-15	4.56E-14
iron and steel	1.29E-14	2.38E-17	4.97E-15	8.51E-17	8.80E-16	4.66E-15	9.64E-16	1.13E-15	2.29E-15	4.17E-16	3.96E-16	2.08E-14

lead	5.26E-13	5.48E-17	3.88E-15	1.85E-16	7.74E-14	5.20E-15	1.64E-13	2.04E-15	1.45E-14	2.77E-16	1.85E-15	2.20E-14
Nickel	3.45E-14	4.10E-16	3.65E-14	1.76E-15	1.04E-14	2.64E-13	2.02E-14	1.28E-13	9.42E-13	3.38E-15	1.48E-14	3.31E-14
Zinc	1.77E-14	1.59E-16	1.19E-14	3.22E-16	2.68E-14	1.69E-14	6.86E-14	2.29E-15	1.36E-14	1.53E-15	5.81E-15	2.31E-14
Industrial materials												
glass	1.34E-15	1.38E-17	1.88E-15	2.54E-17	1.13E-16	4.56E-16	1.18E-16	1.98E-16	7.05E-16	1.98E-16	2.00E-16	1.48E-14
salt	1.62E-16	2.43E-18	2.40E-16	1.19E-17	2.02E-17	7.49E-17	9.04E-17	4.83E-17	2.61E-16	2.84E-17	4.79E-17	6.53E-16
Construction materials												
concrete	1.82E-16	5.47E-18	1.56E-16	6.19E-18	1.04E-17	6.05E-17	3.00E-17	2.31E-17	9.84E-17	3.58E-17	3.04E-17	1.38E-14
ceramics	2.16E-16	7.10E-18	8.93E-16	9.52E-18	1.98E-16	6.49E-17	5.49E-17	8.85E-17	4.54E-16	1.21E-16	1.59E-16	1.38E-14
clay	2.02E-18	1.16E-18	4.33E-18	3.71E-19	1.60E-19	5.81E-19	5.16E-19	8.22E-19	3.45E-18	1.55E-18	1.45E-18	1.36E-14
sand and stone	5.49E-18	3.76E-18	2.41E-17	2.39E-18	7.28E-19	2.04E-18	2.38E-18	3.19E-18	1.42E-17	4.52E-18	4.55E-18	4.10E-18
Biomass (crops and animal products)												
starchy crops	4.35E-17	6.44E-17	1.91E-15	2.82E-18	6.68E-18	1.10E-15	3.38E-16	8.35E-18	4.48E-17	1.62E-14	2.85E-17	4.71E-15
fibre crops	4.35E-17	6.44E-17	1.91E-15	2.82E-18	6.68E-18	1.10E-15	3.38E-16	8.35E-18	4.48E-17	1.62E-14	2.85E-17	4.71E-15
animal fibres	3.93E-16	1.00E-15	5.26E-15	2.68E-17	5.83E-17	8.26E-15	2.64E-15	3.01E-16	3.47E-15	1.04E-13	2.67E-16	5.78E-15
protein crops	4.35E-17	6.44E-17	1.91E-15	2.82E-18	6.68E-18	1.10E-15	3.38E-16	8.35E-18	4.48E-17	1.62E-14	2.85E-17	4.71E-15
protein animal	3.93E-16	1.00E-15	5.26E-15	2.68E-17	5.83E-17	8.26E-15	2.64E-15	3.01E-16	3.47E-15	1.04E-13	2.67E-16	5.78E-15
protein fish	4.91E-16	1.78E-17	5.59E-15	3.47E-16	8.43E-17	2.73E-16	3.15E-16	8.69E-16	4.17E-15	1.01E-14	3.58E-16	5.03E-15
oil crops	4.35E-17	6.44E-17	1.91E-15	2.82E-18	6.68E-18	1.10E-15	3.38E-16	8.35E-18	4.48E-17	1.62E-14	2.85E-17	4.71E-15
animal fats	3.93E-16	1.00E-15	5.26E-15	2.68E-17	5.83E-17	8.26E-15	2.64E-15	3.01E-16	3.47E-15	1.04E-13	2.67E-16	5.78E-15
Biomass from forestry												
wood	2.07E-16	2.28E-17	#######	1.22E-17	1.93E-17	1.12E-16	8.69E-17	5.99E-17	2.49E-16	6.79E-17	1.62E-16	1.33E-16
paper and board												
paper and board	1.74E-15	3.87E-17	4.86E-15	1.80E-16	2.88E-16	1.29E-15	1.77E-15	7.27E-16	4.49E-15	3.98E-16	9.28E-16	1.60E-15

Appendix D Comparison EMC2009/EMC 2005: Ratio of impacts per kg material (characterized, normalized and weighted)

method of impact assessment:	**Problem Oriented Approach**			**Impacts are based on baseline characterisation factors (Guinée et al., 2002)**								
(baseline) impact category:	ADP (Guinee et al. 2001)	LUC (Guinee et al, 2001)	climate change_ GWP 100a(CO 2 biogene and resource GWP=1, NMVOC average)[GLO]	stratospheric ozone depletion _ODP steady state(NM VOC average)[GLO]	human toxicity_ HTP infinite(P AH average, Xylene average, NMVOC average)[GLO]	freshwater aquatic ecotoxicity _FAETP infinite(PA H average, Xylene average, NMVOC average)[G LO]	terrestrial ecotoxicity_ TAETP infinite(PAH average, Xylene average, NMVOC average)[G LO]	photochemical oxidation (summer smog)_hi gh NOx POCP(**N OT** NOx average, NMVOC average)[RER]	AP (Huijbregts, 1999; average Europe total, A&B)	EP (Heijungs et al. 1992))	(Frischknecht et al., 1999)	final solid waste
Fossil fuels												
Natural gas												
natural gas for heating in households	53.30	0.20	0.96	3.45	5.49	2.04	0.29	1.29	1.29	0.31	1.44	1.00
natural gas for electricity in households	9.01	0.22	0.77	9.41	1.94	0.17	0.16	1.31	0.93	0.39	3.28	1.00
Crude oil												
oil for heating in households	37.15	0.40	1.01	0.26	3.81	2.40	0.21	1.75	1.30	1.12	3.98	1.00
oil for electricity in households	51.41	0.86	1.14	0.23	1.99	0.98	0.21	1.30	1.25	1.79	6.28	1.00
hard coal												
hard coal for heating in households	1.05	6.77	1.42	0.11	0.56	0.24	0.07	2.48	1.54	0.95	3.96	1.00
hard coal for electricity in households	0.93	4.69	1.10	0.38	0.43	0.14	0.09	1.29	1.40	1.04	4.08	1.00
brown coal												
brown coal for heating in households	1.22	0.87	1.45	0.56	3.12	4.79	0.43	1.99	0.83	1.18	5.64	1.00
brown coal for electricity in households	0.87	0.37	1.01	0.50	1.90	45.23	0.15	0.84	0.81	0.81	4.01	1.00

plastics	15.27	0.50	0.85	0.04	0.57	3.83	0.02	0.11	0.72	1.46	1.40	1.00
Ores												
Aluminium	1.09	0.35	0.61	0.18	4.62	3.52	0.32	0.75	0.68	0.90	2.82	1.00
Copper	0.84	3.65	0.37	0.15	58.41	8.88	5.84	1.22	1.13	3.04	1.16	1.00
Iron and steel	0.61	2.02	0.79	0.21	0.35	0.54	0.12	1.52	1.05	1.86	4.37	1.00
Lead	0.01	0.78	0.65	0.18	1.47	0.89	0.24	0.91	0.75	1.67	1.97	1.00
Nickel	1.04	2.26	0.73	0.27	3.63	1.07	0.38	0.83	0.76	2.26	2.26	1.00
Zinc	0.76	0.67	0.67	0.27	0.20	0.14	0.09	1.36	1.41	1.15	1.78	1.00
Industrial materials												
glass	2.42	2.39	0.72	1.54	1.94	1.22	0.41	2.61	5.11	2.12	5.41	1.00
salt	0.86	1.00	0.99	2.24	1.50	0.59	0.25	1.47	1.35	0.83	0.80	1.00
Construction materials												
concrete	1.04	0.71	1.88	0.47	2.02	3.15	0.23	1.14	1.20	0.78	5.67	1.00
ceramics	3.21	0.96	0.62	0.96	0.32	3.36	0.16	1.14	0.59	0.42	1.67	1.00
clay	5.23	0.12	1.61	0.56	6.29	1.51	0.23	2.47	2.73	1.95	0.74	1.00
sand and stone	8.57	0.92	1.31	0.51	17.82	86.70	0.59	3.20	3.01	2.50	10.37	1.00
Biomass (crops and animal products)												
starchy crops	14.37	14.08	-0.27	3.70	28.34	0.39	1.53	11.46	30.76	0.25	11.88	1.00
fibre crops	21.13	16.90	-0.43	5.81	19.29	1.61	2.02	13.39	42.33	0.23	16.83	1.00
animal fibres	415.55	244.91	38.53	93.07	511.41	9.99	-7.02	183.63	139.93	3.29	616.85	1.00
protein crops	15.18	38.01	0.34	4.17	22.15	0.42	4.45	12.89	20.19	0.17	18.44	1.00
protein animal	9.91	3.89	2.23	2.13	11.30	0.88	0.51	3.73	4.70	1.49	13.76	1.00
protein fish	1.36	4.46	0.69	0.04	0.99	0.90	0.18	0.49	1.20	0.26	3.40	1.00
oil crops	22.17	32.41	-0.39	5.92	29.51	7.05	9.74	68.94	74.44	0.34	33.25	1.00
animal fats	2.28	0.54	0.58	0.48	2.19	0.28	0.24	1.00	1.35	0.71	2.86	1.00
Biomass from forestry												
wood	1.99	208.99	1.28	0.91	2.54	1.58	0.21	3.97	1.09	1.33	2.37	1.00
paper and board												
paper and board	2.78	68.11	0.84	0.29	2.51	2.55	0.18	1.04	0.49	2.54	4.38	1.00

Appendix E Normalised impacts for year 2000 (fraction of total world problem)

	impact categories										
	ADP	LUC	GWP100	ODP ss	HTP inf.	FAETPinf	TETP inf.	POCP	AP	EP	radiation
Fossil fuels											
natural gas for heating in households	2.56E-02	8.01E-06	1.35E-02	3.39E-04	1.53E-03	1.27E-03	3.82E-04	1.30E-03	2.01E-03	2.68E-04	1.56E-03
natural gas for electricity in households	5.38E-03	5.54E-07	2.76E-03	6.40E-05	2.00E-04	1.09E-04	2.52E-05	1.98E-04	4.61E-04	1.06E-04	4.34E-05
oil for transport and heating in households	4.69E-02	2.92E-05	3.18E-02	9.04E-04	6.64E-03	8.83E-03	1.84E-03	3.89E-03	1.23E-02	1.64E-03	8.47E-03
oil for electricity in households	3.49E-03	1.65E-06	2.47E-03	5.66E-05	1.20E-03	1.52E-03	9.36E-04	7.22E-04	4.54E-03	3.49E-04	2.46E-04
hard coal for heating in households	8.19E-04	5.25E-06	6.25E-04	5.28E-07	1.33E-04	2.10E-04	3.17E-05	9.35E-04	5.17E-04	2.04E-05	3.97E-05
hard coal for electricity in households	1.33E-02	7.04E-05	7.46E-03	9.18E-06	1.09E-03	2.13E-03	3.96E-04	9.18E-04	6.16E-03	5.75E-04	6.38E-04
brown coal for heating in households	3.56E-04	3.12E-07	2.21E-04	2.33E-07	8.03E-05	9.00E-05	3.37E-05	1.67E-04	6.17E-05	9.37E-06	1.31E-05
brown coal for electricity in households	1.07E-02	4.34E-06	6.20E-03	1.96E-06	1.28E-03	9.37E-03	2.75E-04	1.15E-03	8.01E-03	3.09E-04	3.22E-04
plastics	2.11E-02	1.49E-05	1.12E-02	5.29E-05	3.27E-03	5.39E-02	5.43E-04	2.08E-03	5.08E-03	9.85E-04	1.41E-03
Ores											
Aluminium	1.73E-03	7.20E-06	1.22E-03	1.53E-05	2.83E-03	7.11E-03	5.74E-04	1.87E-04	1.06E-03	1.29E-04	1.76E-03
Copper	2.17E-04	1.71E-05	1.23E-04	2.54E-06	5.93E-03	1.87E-03	8.66E-04	2.28E-04	1.50E-03	6.63E-05	1.85E-04
iron and steel	7.25E-03	4.42E-05	3.63E-03	1.68E-05	8.69E-04	6.97E-03	3.23E-04	1.59E-03	2.21E-03	7.15E-04	1.59E-03
lead	4.00E-05	2.93E-07	1.75E-05	2.27E-07	2.39E-03	9.69E-05	8.27E-04	1.28E-05	7.52E-05	3.20E-06	2.52E-05
Nickel	1.30E-04	3.38E-06	9.76E-05	1.74E-06	4.17E-04	3.13E-03	8.57E-05	3.86E-04	2.61E-03	2.79E-05	1.22E-04
Zinc	3.04E-04	2.42E-06	1.82E-04	1.98E-06	3.61E-04	1.58E-04	4.07E-04	7.05E-05	4.35E-04	3.99E-05	2.34E-04
Industrial materials											
glass	1.96E-03	2.00E-05	8.12E-04	2.36E-05	3.99E-04	1.02E-03	8.83E-05	3.12E-04	2.18E-03	2.54E-04	6.51E-04
salt	2.93E-05	5.12E-07	5.01E-05	5.60E-06	1.93E-05	2.81E-05	1.42E-05	1.49E-05	7.40E-05	5.01E-06	8.06E-06
Construction materials											
concrete	8.08E-04	1.64E-05	1.25E-03	1.25E-05	2.71E-04	2.46E-03	8.96E-05	1.13E-04	5.05E-04	1.18E-04	7.34E-04
ceramics	3.26E-04	3.18E-06	2.58E-04	4.29E-06	9.08E-05	3.10E-04	1.23E-05	4.73E-05	1.25E-04	2.39E-05	1.25E-04
clay	3.92E-06	5.31E-08	2.60E-06	7.70E-08	1.13E-06	9.89E-07	1.35E-07	7.56E-07	3.50E-06	1.13E-06	3.99E-07
sand and stone	1.14E-03	8.35E-05	7.63E-04	2.95E-05	9.51E-04	1.29E-02	1.03E-04	2.47E-04	1.03E-03	2.74E-04	1.14E-03
Biomass (crops and animal products)											
starchy crops	1.57E-03	2.27E-03	-1.29E-03	2.62E-05	1.44E-03	3.22E-03	3.94E-03	2.40E-04	3.46E-03	1.01E-02	8.48E-04
fibre crops	2.14E-03	2.54E-03	-1.90E-03	3.82E-05	9.11E-04	1.25E-02	4.82E-03	2.61E-04	4.43E-03	8.81E-03	1.12E-03
animal fibres	8.95E-04	1.35E-03	1.11E-03	1.37E-05	4.95E-04	1.37E-03	-3.08E-04	3.02E-04	2.66E-03	1.87E-03	9.01E-04
protein crops	5.71E-05	2.12E-04	5.56E-05	1.02E-06	3.88E-05	1.21E-04	3.94E-04	9.31E-06	7.83E-05	2.42E-04	4.54E-05
protein animal	1.52E-03	1.53E-03	4.58E-03	2.23E-05	7.81E-04	8.59E-03	1.61E-03	4.38E-04	6.38E-03	6.05E-02	1.43E-03
protein fish	5.69E-05	6.78E-06	3.28E-04	1.17E-06	2.16E-05	6.38E-05	1.44E-05	3.65E-05	4.25E-04	2.27E-04	1.04E-04
oil crops	4.59E-04	9.95E-04	-3.53E-04	7.95E-06	2.85E-04	1.11E-02	4.75E-03	2.74E-04	1.59E-03	2.61E-03	4.51E-04
animal fats	1.19E-03	7.27E-04	4.07E-03	1.71E-05	5.17E-04	9.39E-03	2.56E-03	4.01E-04	6.25E-03	9.84E-02	1.02E-03
Biomass from forestry											
wood	8.04E-04	9.29E-03	-2.78E-03	2.18E-05	2.90E-04	1.04E-03	1.05E-04	4.64E-04	5.29E-04	1.76E-04	7.49E-04
paper and board											
paper and board	3.61E-03	1.97E-03	3.05E-03	3.83E-05	1.63E-03	7.41E-03	7.09E-04	5.65E-04	1.65E-03	7.53E-04	3.03E-03

Appendix F Normalised and weighted impacts for year 2000 (fraction of total world problem)

	weighting set			
	equal weighting	NOGEPA	shadow prices	Ecoindicator99
Fossil fuels				
natural gas for heating in households	5.08E-03	5.44E-03	5.40E-04	3.50E+10
natural gas for electricity in households	1.01E-03	1.08E-03	1.18E-04	7.53E+09
oil for transport and heating in households	1.24E-02	1.45E-02	2.25E-03	7.81E+10
oil for electricity in households	1.45E-03	1.65E-03	5.46E-04	7.89E+09
hard coal for heating in households	3.43E-04	3.78E-04	9.68E-05	5.64E+08
hard coal for electricity in households	3.37E-03	3.54E-03	7.50E-04	8.01E+09
brown coal for heating in households	9.96E-05	1.20E-04	1.59E-05	1.82E+08
brown coal for electricity in households	3.37E-03	3.71E-03	8.36E-04	7.52E+09
plastics	6.79E-03	8.74E-03	8.32E-04	3.86E+10
Ores				
Aluminium	1.07E-03	1.53E-03	1.58E-04	3.54E+09
Copper	5.82E-04	1.39E-03	1.77E-04	5.28E+09
iron and steel	2.20E-03	2.29E-03	5.10E-04	9.74E+09
lead	1.42E-04	4.84E-04	1.45E-05	1.18E+08
Nickel	5.10E-04	5.28E-04	2.58E-04	1.58E+09
Zinc	1.75E-04	2.01E-04	5.44E-05	2.02E+09
Industrial materials				
glass	7.45E-04	6.36E-04	3.10E-04	4.08E+09
salt	2.31E-05	3.09E-05	1.26E-05	
Construction materials				
concrete	5.00E-04	7.16E-04	3.23E-04	2.49E+09
ceramics	1.17E-04	1.44E-04	4.76E-05	6.59E+08
clay	1.47E-06	1.65E-06	2.12E-05	1.36E+07
sand and stone	1.04E-03	1.43E-03	1.88E-04	8.01E+09
Biomass (crops and animal products)				
starchy crops	2.23E-03	1.93E-03	2.39E-03	3.75E+10
fibre crops	2.61E-03	2.16E-03	2.23E-03	3.88E+10
animal fibres	1.07E-03	1.02E-03	6.29E-04	1.00E+10
protein crops	9.84E-05	9.66E-05	5.82E-05	3.21E+09
protein animal	8.90E-03	1.15E-02	1.26E-02	1.98E+10
protein fish	1.35E-04	1.88E-04	8.70E-05	6.93E+08
oil crops	1.27E-03	1.42E-03	6.96E-04	1.48E+10
animal fats	1.29E-02	1.68E-02	2.01E-02	1.56E+10
Biomass from forestry				
wood	1.08E-03	-7.51E-04	1.17E-04	1.26E+10
paper and board				
paper and board	1.99E-03	2.16E-03	3.63E-04	9.37E+09

Appendix G Contribution of materials to normalised and weighted impact score for year 2000 (%)

	Normalised impact categories											***Weighted score***			
	ADP	LUC	GWP	ODP	HTP	FAETP	TETP	POCP	AP	EP	Rad	Eq.	Nogepa	SP	Eco99
Fossil fuels															
natural gas for heating in households	17	0	15	20	4	1	1	7	3	0	5	7	6	1	9
natural gas for electricity in households	3	0	3	4	1	0	0	1	1	0	0	1	1	0	2
oil for transport and heating in households	30	0	35	52	18	5	7	22	16	1	29	17	17	5	20
oil for electricity in households	2	0	3	3	3	1	4	4	6	0	1	2	2	1	2
hard coal for heating in households	1	0	1	0	0	0	0	5	1	0	0	0	0	0	0
hard coal for electricity in households	9	0	8	1	3	1	1	5	8	0	2	5	4	2	2
brown coal for heating in households	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
brown coal for electricity in households	7	0	7	0	4	6	1	7	10	0	1	5	4	2	2
plastics	14	0	12	3	9	32	2	12	6	1	5	9	10	2	10
Ores															
Aluminium	1	0	1	1	8	4	2	1	1	0	6	1	2	0	1
Copper	0	0	0	0	16	1	3	1	2	0	1	1	2	0	1
iron and steel	5	0	4	1	2	4	1	9	3	0	5	3	3	1	3
lead	0	0	0	0	7	0	3	0	0	0	0	0	1	0	0
Nickel	0	0	0	0	1	2	0	2	3	0	0	1	1	1	0
Zinc	0	0	0	0	1	0	2	0	1	0	1	0	0	0	1
Industrial materials															
glass	1	0	1	1	1	1	0	2	3	0	2	1	1	1	1
salt	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Construction materials															
concrete	1	0	1	1	1	1	0	1	1	0	3	1	1	1	1
ceramics	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
clay	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
sand and stone	1	0	1	2	3	8	0	1	1	0	4	1	2	0	2
Biomass (crops and animal products)															
starchy crops	1	11	-1	2	4	2	15	1	4	5	3	3	2	5	10
fibre crops	1	12	-2	2	3	7	18	1	6	5	4	4	3	5	10
animal fibres	1	6	1	1	1	1	-1	2	3	1	3	1	1	1	3
protein crops	0	1	0	0	0	0	1	0	0	0	0	0	0	0	1
protein animal	1	7	5	1	2	5	6	2	8	32	5	12	14	27	5
protein fish	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
oil crops	0	5	0	0	1	7	18	2	2	1	2	2	2	1	4
animal fats	1	3	4	1	1	6	10	2	8	52	4	18	20	42	4
Biomass from forestry															
wood	1	44	-3	1	1	1	0	3	1	0	3	1	-1	0	3
paper and board															
paper and board	2	9	3	2	4	4	3	3	2	0	10	3	3	1	2