TECHNICAL REPORT SERIES

Environmental Impact of the Use of Natural Resources

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EUROPEAN COMMISSION
DIRECTORATE-GENERAL
Joint Research Centre

European Science and Technology Observatory

Institute for Prospective Technological Studies

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Institute for Prospective Technological Studies

European Science and Technology Observatory

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Preface

The Institute for Prospective Technological Studies (IPTS) is one of the seven scientific institutes of the European Commission's Joint Research Centre (JRC). Its mission is to provide European policy makers with techno-economic analysis to support the policy-making process. Such analysis studies the different links between technology, the economy, society and the environment.

In line with this mission, this report analyses the relationships between resource use and environmental impacts. The Environment Directorate General of the European Commission has asked the JRC-IPTS for such a report in support of the development of a 'thematic strategy on the sustainable use of natural resources', which has been called for by the EU's Sixth Environment Action Programme.

The report is the result of a research project sponsored and supervised by the JRC-IPTS with ESTO as the operating agent. The research has been carried out by a group of experts in environmental assessment of techno-economic systems, and the report reflects the common opinion of the research team. The team was made up of Per H. Nielsen of the Technical University of Denmark, Arnold Tukker of TNO-STB, Bo P. Weidema and Philippa Notten of 2.-0 LCA consultants, and Erik H. Lauridsen of the Technical University of Denmark. Per H. Nielsen acted as co-ordinator of the research team.

The views expressed in this publication are the sole responsibility of the authors and do not necessarily reflect the views of the European Commission.

Executive summary

Background

The European Commission is preparing a "Thematic Strategy for the Sustainable Use of Natural Resources", the so-called "resources strategy". A first Communication on this was adopted by the Commission in October 2003 (COM 527, 2003), and the strategy is planned to be completed in 2005. The general aim of the resources strategy is "to develop a framework and measures that allow resources to be used in a sustainable way without further harming the environment".

Objectives and scope

The present report aims to support the development of the resources strategy by extracting and assessing the science-based evidence from eight recent studies that have been identified as relevant for understanding the environmental implications of resource use:

- Labouze E, Monier V, Puyou J-B (2003). Study on external environmental effects related to the life cycle of products and services. BIO Intelligence Service and O2 France for the European Commission, Directorate General Environment.
- Moll S, Acosta J, Villanueva A (2004). Environmental implications of resource use – insights from input-output analyses. Copenhagen: European Topic Centre on Waste and Material Flows. Draft manuscript, January 2004.
- van der Voet E, van Oers L, Nikolic I (2004). Dematerialisation: not just a matter of weight - Development and application of a methodology to rank materials based on their environmental impacts. Leiden: Centre for Environmental Studies at Leiden University. CML report no. 160.
- Phylipsen D, Kerssemeeckers M, Blok K, Patel M, de Beer J (2002). Assessing the environmental potential of clean material technologies. Institute for Prospective Technological Studies, Joint Research Centre (DG JRC), European Commission. Report EUR 20515 EN.
- Nemry F, Thollier K, Jansen B, Theunis J (2002). Identifying key products for the federal product and environment policy. Final report. Institut Wallon de développement économique et social et d'aménagement du territoire ASBL and Vlaamse Instelling voor Technologisch Onderzoek (VITO) for the Belgian Federal Services of Environment, Department on Product Policy.
- Dall O, Toft J, Andersen TT (2002). Danske husholdningers miljøbelastning (Environmental impacts of Danish households). Danish Environmental Protection Agency. (Arbejdsrappport 13). In Danish.
- Nijdam DS, Wilting H (2003). Milieudruk consumptie in beeld (A view on environmental pressure on consumption) RIVM report 7714040004). In Dutch.
- Rixt K, Falkena H-J, Benders R, Moll HC, Noorman KJ (2003). Household metabolism in European countries and cities - Comparing and evaluating the results of the cities Fredrikstad (Norway), Groningen (The Netherlands), Guildford (UK), and Stockholm (Sweden). Toolsust Deliverable No. 9. Groningen: Center for Energy and Environmental Studies, University of Groningen.

The objectives of the present study were to analyse and evaluate this existing body of research with a view to identifying those materials and resources whose use has the greatest environmental impacts. This should result in:

- Conclusions on the present state of knowledge about the relationships between resource use, material flows and environmental impacts; and
- Proposals on how to approach future research in support of developing the environmental aspects of an EU resources strategy.

Nature of the studies

The common feature of the eight considered studies is that they aim at determining the driving forces behind environmental impacts and resource consumption in the European Union or parts of it.

The considered studies cover a range of methodological approaches, ranging from "top-down-approaches" where impacts are determined from National Accounts Matrix extended by Environmental Accounts (NAMEA) to "bottom-up-approaches" where environmental impacts are determined from Life Cycle Assessments (LCAs).

While all studies have been made with other purposes than supporting the EU's resources strategy, it has been analysed in the present study to what extent the results of the studies can be applied in the EU's resources strategy. It turns out that all of the considered studies do contribute to our understanding of what are the environmentally most relevant types of resource use, through identifying relationships between environmental impacts and specific material flows or product groups within the production and consumption realms. The immediate possibilities the studies offer to establish direct links between indicators of resource use and indicators of environmental impact are more limited and additional research would be required to explore such links.

Types of environmental impacts considered

Environmental impacts are typically classified in a number of impact categories of which the following are covered by most of the considered studies:

- Acidification
- Climate change (global warming)
- Ecotoxicity
- Human toxicity
- Nutrient enrichment (eutrophication)
- Photochemical ozone formation (smog)
- Stratospheric ozone depletion

This set of well-established impact categories is commonly used and spans the main part of the environmental concerns that are presently generally considered important.

Core activities at the origin of environmental impacts

From analysing the data and models applied in the considered studies, it has been found that the by far largest share of the major environmental pressures affecting those environmental impact categories originate from a limited number of human activities referred to as "core activities":

- Combustion processes
- Solvent use
- Agriculture

- Metal extraction and refining
- Dissipative uses of heavy metals
- Housing and infrastructure
- Marine activities
- Chemical industry

Second order driving forces of environmental impacts

The core activities can be seen as first order driving forces for the environmental impacts, themselves driven by second order driving forces largely in the form of market forces, ultimately reflecting human demands. The second order driving forces are the main focus of the considered studies, which look at products or product groups, sometimes aggregated in need groups, or material flows induced by these products.

Due to the great variation in applied methods and scopes, the results show a complex picture at the detailed level. However, at the more general level the studies reinforce each other in pointing to housing (construction and temperature regulation), transportation and food consumption as covering a large part of the most important consumption domains driving the environmental impacts and resource use in Europe.

Correlation and causal relationships between resource use and environmental impacts

With the exception of Moll et al. (2004), the considered studies do not analyse explicitly the correlation or causal relationships between indicators of resource use and indicators of environmental impact. However, from the underlying data and models it appears that, apart from environmental impacts directly related to resource *extraction*, there are only few instances where the relationship between resource use and environmental impacts are straightforward, and thus a more obvious target for policies aiming to reduce the environmental impacts from resource use:

- The use of fossil fuels and "global warming potential" and "potential acidifying effect".
- Use of specific metals, where there is a clear and linear relationship to environmental impacts from metal extraction and refining. A reduction in use of these metals will lead to a direct reduction in the associated impacts.
- Area occupation, where it is the resource use itself that is of environmental concern. A reduction in area occupation will reduce the pressure on biodiversity.
- Construction materials, where the resource use drives the waste stream, albeit mostly with a significant delay corresponding to the lifetime of the constructions.

This list is, however, only indicative at this stage, and further systematic analysis would be needed to consolidate it (see below). It should be noted, furthermore, that even in those cases where causal relationships may be established it is unlikely that these relationships will be linear, especially at the aggregated level.

Methodological alternatives

Two main approaches have been applied in the studies considered: “bottom-up” and “top-down”, each with specific advantages and disadvantages. The main advantage of the process-based “bottom-up” approach is its ability to treat each product or material separately in great detail. However, at the same time, it is notoriously incomplete when it comes to covering all activities involved in the production processes. In contrast, the main advantage of the input-output based “top-down” approach is its completeness. Since it takes its starting point in the national accounting matrices, it includes by definition all activities, materials and products in the economy. Its main disadvantage is the implicit assumption of homogeneity of the industries, i.e. that all products from an industry are assigned the same environmental impact per monetary unit. Methodological aspects are addressed in further detail in a following ESTO project: Evaluation of the Environmental Impact of Products (EIPRO).

Knowledge gaps

Based on the information and experience gathered from the eight studies and the critical assessment hereof, the following knowledge gaps with respect to development of the resources strategy have been identified:

- Lack of systematic insights into the causal relationships between resource use and environmental impacts, and therefore of possibilities to give consolidated advice on priority needs in policy development.
- Persisting weaknesses in environmental impact assessment models.

Proposals to develop further the scientific input concerning the environmental aspects of the resources strategy

Three different strategies for closing the knowledge gaps and developing further the scientific input to the resources strategy are proposed.

1. Exploit more thoroughly the models behind the existing studies with a focus on the relation between resources and environmental impacts.
2. Make a selection of the resources a priori seen as most relevant, and perform for each of them Substance Flow Analyses or other adequate resource-specific analyses.
3. Set up and use for the analysis a detailed European NAMEA (National Accounts Matrix extended by Environmental Accounts), specified from the outset in a way that takes into account the information needs of the EU's resources strategy (European top-down approach).

The first strategy can probably be realised for a limited investment of 100.000+ Euros. It gives, however, not a structural information basis that can be easily updated. The investment in the last two strategies is probably of a similar order of magnitude (some two million Euros each alternative). Strategy 3 actually covers similar research as Strategy 2, but it is more systematic with the advantage that a structure is built that lasts and allows for regular and relatively cost-effective upgrading and updating. If a major investment will be made, the authors express a clear preference for Strategy 3.

Improved and more comprehensive scientific input to the resources strategy following such lines is clearly recommended, but for effective policy development, it should be provided in close relation to parallel research and dialogue on:

- A precaution-based approach to a resources strategy building on existing knowledge.
- An approach based on the scarcity of resources in Europe and globally.
- An approach building on equality among the different parts of the world.
- The requirements of different methods of linking the state of the environment to resource consumption (through materials, product groups, consumption areas etc.).
- The abatement strategies used in cases of resources where policies are already in place.

1. Introduction

The European Commission is preparing a "Thematic Strategy for the Sustainable Use of Natural Resources", the so-called "resources strategy". The general aim of the resources strategy 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). More specifically the aim is "to develop a Community approach that will provide policy makers and other stakeholders in the relevant policy areas with the necessary framework and information for

- identifying and assessing the impacts of resource use on the various environment media (air, water, soil), on biodiversity and on human health;
- addressing scarcity where relevant;
- preparing and reviewing policies that influence resource use and its associated environmental impacts."

A first Communication on this was adopted by the Commission in October 2003 (COM 527, 2003). The strategy is planned to be ready by 2005, and the present report aims to support the strategy development by extracting and assessing the science-based evidence from existing research that promises to be useful for identifying those materials and resources whose use have the largest environmental impact.

The definitions of resources provided by the Commission of the European Communities (COM 527, 2003) are adopted in the study and a brief summary hereof is provided below.

- *Raw materials,* which include minerals such as fossil energy carriers, metal ores and biomass. Fossil energy carriers, metal ores and other minerals are non-renewable in the sense that they cannot be replenished within a human timeframe, whereas biomass is in principle renewable within the human timeframe. The latter includes quickly renewable resources such as agricultural crops and slowly renewable resources, such as timber.
- *Environmental media*, which include air, water and soil, which sustain life and produce biological resources.
- *Flow resources* which include wind, geothermal, tidal and solar energy.
- *Space*, which includes land used for human settlements, infrastructure, industry, mineral extraction, agriculture and forestry, and is required to produce and sustain other resources.

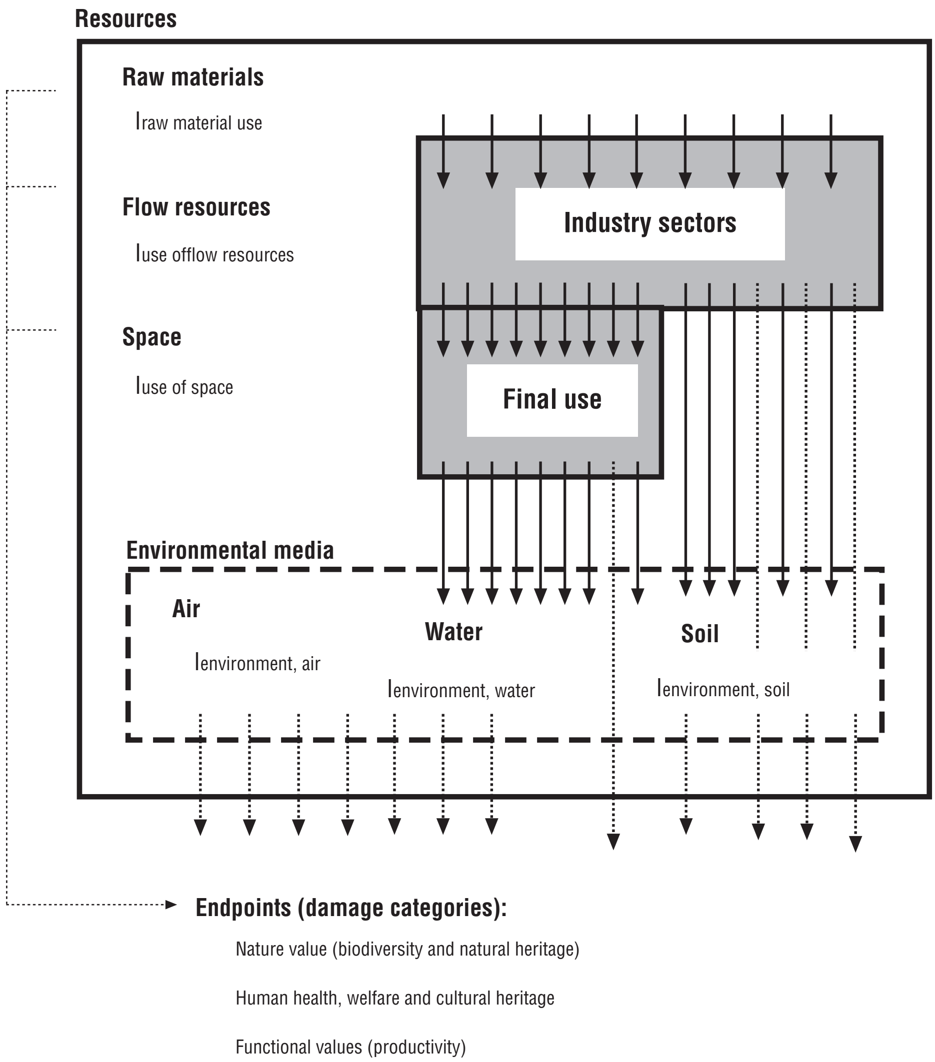
Among the resources covered by the definitions, "Environmental media" play a double role as illustrated in Figure 1. Firstly, they sustain human activities like other resources and secondly they act as recipients of the waste and emissions arising from human activities.

The area of concern for the resources strategy is thus both resource depletion and environmental impacts, although "At present the environmental impacts of using non-renewable resources like metals, minerals and fossil fuels are of greater concern than their possible scarcity" (COM 527, 2003).

In this context, it has been the aim of the present study to determine what information is currently available in the literature with respect to *identification of the environmentally most relevant types of resource use*, and what methods are most appropriate to provide further information on this issue by studying following eight reports.

1. Labouze E, Monier V, Puyou J-B (2003). Study on external environmental effects related to the life cycle of products and services. BIO Intelligence Service and O2 France for the European Commission, Directorate General Environment (Sustainable Development and Policy support).

Figure 1. Conceptual presentation of the flow of resources through the production and consumption realms (shaded boxes), the resulting impacts on environmental media, and the valuation of these impacts in terms of endpoints of value. Full-drawn arrows represent physical flows; dotted arrows represent the valuation of the impact indicators ($I_{subscript}$), which may relate both to the environmental media and to use of the other resources.



2. Moll S, Acosta J, Villanueva A (2004). Environmental implications of resource use – insights from input-output analyses. Copenhagen: European Topic Centre on Waste and Material Flows. Draft manuscript, January 2004.

3. van der Voet E, van Oers L, Nikolic I (2004). Dematerialisation: not just a matter of weight - Development and application of a methodology to rank materials based on their environmental impacts. Leiden: Centre for Environmental Studies at Leiden University. CML report no. 160.

4. Phylipsen D, Kerssemeeckers M, Blok K, Patel M, de Beer J (2002). Assessing the environmental potential of clean material technologies. Institute for Prospective Technological Studies, Joint Research Centre (DG JRC), European Commission. Report EUR 20515 EN.

5. Nemry F, Thollier K, Jansen B, Theunis J (2002). Identifying key products for the federal product and environment

policy. Final report. Institut Wallon de développement économique et social et d'aménagement du territoire ASBL and Vlaamse Instelling voor Technologisch Onderzoek (VITO) for the Belgian Federal Services of Environment, Department on Product Policy.

6. Dall O, Toft J, Andersen TT (2002). Danske husholdningers miljøbelastning (Environmental impacts of Danish households). Danish Environmental Protection Agency. (Arbejdsrappport 13). In Danish.

7. Nijdam DS, Wilting H. (2003). Milieudruk consumptie in beeld (A view on environmental pressure on consumption) RIVM report 7714040004). In Dutch.

8. Rixt K, Falkena H-J, Benders R, Moll HC, Noorman KJ (2003). Household metabolism in European countries and cities - Comparing and evaluating the results of the cities Fredrikstad (Norway), Groningen (The Netherlands), Guildford (UK), and Stockholm (Sweden). Toolsust Deliverable No. 9. Groningen: Center for Energy and Environmental Studies, University of Groningen.

All studies have been made with other purposes than supporting EU's resources strategy and it has been analysed to what extent the results of the studies can be applied in EU's resources strategy. This has been done by assessing 1) the relevance of each study in an EU resources strategy context, 2) the completeness of each study in relation to the broad European scope and 3) the reliability of the results of each study. Evaluation reports of the eight studies are provided in Annex 1, with a brief summary of relevant input to the resources strategy from each study. A common critical summary of all studies, with discussion of obtained results and comparison of applied methodologies, is provided in Chapter 2 and proposals concerning wider scientific advice for the development of an EU resources strategy, based on learnings from the studies and the critical summary, are provided in Chapter 3.

The present report is a result of a project of the European Science and Technology Observatory (ESTO) initiated by the European Commission's Joint Research Centre (Institute for Prospective Technological Studies) performed in co-operation between Technical University of Denmark, 2.-0 LCA consultants, TNO Strategie, Technologie en Beleid and Institute for Prospective Technological Studies.

Five of the studies (Labouze et al. 2003, Moll et al. 2004, van der Voet et al. 2004, Phylipsen et al. 2002, Nemry et al. 2002) were identified by IPTS before the project commenced and three (Dall et al. 2002, Nijdam and Wilting 2003 and Rixt et al. 2003) were identified during the project.

An expert workshop organised by the European Commission with delegates from European Commission services, authors of the five studies identified by IPTS and other experts was held at an early stage of the project. At this workshop, authors of the five studies presented results of their work, and the analytical framework of the study was discussed.

Michael Søgaard Jørgensen from Technical University of Denmark has provided inputs to the project as member of the working group.

2. Critical summary of information extracted from literature

The general goal of the eight considered studies has been to determine driving forces behind environmental impacts and resource consumption in European Union or parts hereof. Some of the reports analyse the subject from a material consumption perspective, others from a product consumption perspective and again others from a household consumption or national economy perspective. Various indicators are applied in the different studies, ranging from primary energy consumption in some studies, through a spectrum of mid-point indicators such as global warming potential, acidification potential etc., to a selection of endpoint indicators such as DALY (disability-adjusted life years) in other studies. Geographical scopes range from a single country in European Union in most cases, trough a selection of European countries, to the entire EU-15 in others. All studies are very recent and most studies apply quite recent consumption data (late 90ties or later). Production data are generally older and range from early 90'ties to the present and cover West European technology in most cases. The studies apply a range of different aggregation principles for products/materials ranging from a dozen of function classes to hundreds of materials or products. Some studies take a "top-down-approach" where impacts are determined from National Accounts Matrix extended by Environmental Accounts (NAMEA), others are based on "bottom-up-approach" where environmental impacts are determined from Life Cycle Assessments (LCAs) of products or materials, while one study is based on a hybrid approach where the "bottom-up" and "top-down" approaches are combined. An overview of the studies is provided in Annex 1.0 and details of each study are summarised in Annex 1.1 to 1.8.

The present chapter summarises and evaluates the results of the study of the eight reports in the view of the EU resources strategy as a whole. Section 2.1 and 2.2 describe what scientifically sound *conclusions* for the resources strategy can be drawn from the studies. Section 2.3 and 2.4 summarize the *methodological* aspects of the studies, and discuss the appropriateness of the different approaches for the EU's resources strategy. The conclusions of the summary (Section 2.5) evaluate gaps in knowledge and the limitations of the existing research for use in policy development, and the most promising approaches and methods for future research in the area are highlighted.

The information available from the eight studies is structured in the following way:

- *Section 2.1* assesses the information available with respect to the identification of *relationships* between use of resources and environmental impacts (i.e. between the indicators $I_{\text{use of raw materials etc.}}$ and $I_{\text{environment, air, water, soil}}$ in Figure 1): Whether the environmental impacts can be related to the quantities of specific resources used.
- *Section 2.2* assesses the information available with respect to the *driving forces* in the production and consumption realms for both environmental impacts and use of individual (types of) resources: Whether the environmental impacts can be related to specific characteristics of the resources, or to specific material flows, products or applications (i.e. what activities inside the shaded boxes in Figure 1 drives the quantity and nature of the resource input and the environmental impacts).
- *Section 2.3* deals with the methods available for *weighting* different categories of resource use and environmental impacts (i.e. relating the indicators of the Resources-box in Figure 1 to the endpoints), and assesses what methods are most appropriate to improve the available information.

- *Section 2.4* deals with the methods available to analyse and model the relationships dealt with in Section 2.1 and 2.2 (i.e. inside the Resources-box in Figure 1), and assesses what methods are most appropriate to improve the available information for the EU resources strategy.

2.1 The relationship between resource use and environmental impacts

All of the analysed studies establish relationships between material flows or product groups within the production and consumption realms and individual indicators of resource use and/or environmental impact. However, only one of the studies (Moll et al. 2004) explicitly investigates the direct relationships (correlation) between indicators of resource use and indicators of environmental impact.

Moll et al. (2003) explored the areas where such causal relationships are likely to be found, and list:

- Fossil fuel inputs and combustion-related air emissions.
- Construction materials inputs, the sealing of natural and productive land, and construction and demolition waste.
- Fertiliser inputs, land use for biomass production and emissions contributing to eutrophication.
- Metal inputs and heavy metal emissions.

One could equivalently list areas where causal relationships are not likely to be found, i.e. environmental impacts that are likely to be unrelated to resource use, including:

- Ozone layer degrading substances.
- Fossil fuel input and emission of toxic organic substances, such as pesticides and solvents.

In their follow-up study, Moll et al. (2004), seek to confirm their initial exploration through bi-variate correlation analysis. This analysis showed:

- Strong correlation between the use of fossil fuels and "global warming potential" and "potential acidifying effect".
- Correlation between the resource use indicator "Total Material Requirement (TMR)" for industrial and construction minerals and generation of "bulky-like construction and demolition waste".
- Correlation between land-use in terms of built-up area and "potential acidifying effects" and "global warming potential".
- Strong correlation between the TMR for metals and the air emission related impact potentials.

Since the correlation analysis by Moll et al. (2004) is performed at the level of aggregated category indicators (e.g. TMR and "potential acidifying effect"), the results will not reveal relevant correlations that may exist at lower levels of aggregation (e.g. at substance level). It may also be argued that what really matters is not correlations, but causal relationships, i.e. the extent to which a change in an indicator of resource use is causally linked to a change in an environmental indicator and *vice versa*.

Only the first of the above-mentioned correlations can be explained in direct causal terms:

- more fossil fuel use => more fuel combustion => more combustion related air emissions, while the remaining three can only be explained causally in an indirect way, through the level of activity in specific industries:
- more activity in the construction sector => more input of construction materials and more output of construction and demolition waste;
- more activity in agriculture => more land use and more of the agriculture-specific air emissions (N_2O, CH_4 and NH_3);
- more activity in relatively high energy consuming industries, such as the metal

processing, construction and transport industries => more air emissions and more input of the resources specifically in high demand by these industries (metals for the metal processing industry; land for construction and transport).

Also, it is obvious that even though causal relationships may be established, it is unlikely that these relationships will be linear, especially at the aggregated level. For example, a change in the quantity of fossil fuel used is related to quite different changes in air emissions depending on how the change is distributed over the different fossil fuels (e.g. gas or coal), how the change in combustion is distributed over different types of combustion processes (e.g. stationary or mobile engines) with different emission factors, and whether there is a compensating change in biomass combustion. This is further complicated by the possible interactions within the production and consumption realms, where a change in one process may induce changes in other processes (through so-called re-bound effects). Thus, even though there is a linear relationship between the use of an additional MJ of oil in a specific type of engine and the resulting air emissions, such a relationship is not likely to be retrieved at the level of industry aggregates. For example, an additional MJ of oil into a particular furnace will yield a linear relationship, but at the sector level, say mining, an additional MJ of oil consumed in mining processes will not yield a linear relationship because its use will be spread across a number of different engines and equipment, each with different emission factors.

With the exception of Moll et al. (2004), the considered studies do not contribute directly to our knowledge of relationships (neither causal nor correlation) between indicators of resource use and indicators of environmental impact, simply because such relationships were not explicitly sought after in these studies. However, by identifying relationships of each type of indicator to specific material flows, activities or product groups within the production and consumption realms, these studies still contribute to our understanding of what are the environmentally most relevant types of resource use.

In the following sections, we assess the evidence from the eight studies with respect to the relationships between the activities in the production and consumption realm and the indicators of resource use and environmental impacts.

2.2 The driving forces for resource use and environmental impacts

Environmental impacts are typically classified in a number of impact categories. The following impact categories are covered by the considered studies (see Section 3.3 and Table 2):

- Acidification
- Climate change (global warming)
- Ecotoxicity
- Human toxicity
- Nutrient enrichment (eutrophication)
- Photochemical ozone formation (smog)
- Stratospheric ozone depletion

This commonly used set of well-established impact categories covers the presently generally accepted areas of environmental concern. The state of the art in impact assessment is discussed further in Section 3.3.

Although there may be many substances contributing to each impact category, there are typically very few substances dominating the contribution. For example, although many different substances have a global warming potential, more than 80% of the global potential is caused by three substances: CO_2, CH_4 and N_2O. Furthermore, analysing the data and models applied by the considered studies, it can be seen that the by far largest share of the major contributing substances to the mentioned environmental impact categories originate from a limited number of human activities, which we here name “core activities”:

- Combustion processes
- Solvent use
- Agriculture
- Metal extraction and refining
- Dissipative uses of heavy metals
- Housing and infrastructure
- Marine activities
- Chemical industry

These core activities can be seen as first order driving forces for the environmental impacts, themselves driven by second order driving forces in the form of market forces, ultimately reflecting human demands. The second order driving forces are the focus of the considered studies, which look at either:

- products or product groups (6 of the considered studies), sometimes aggregated in need groups, or
- material flows required by these products (2 of the considered studies: Phylipsen et al. 2002, van der Voet et al. 2004).

The different perspectives allow different questions to be answered:

- A focus on core activities allows a prioritisation of these core activities according to environmental relevance. From a policy perspective, core activities may either be a direct target for regulation, or may be targeted indirectly via regulation of the second order drivers.
- A focus on products, product groups or need groups allows a prioritisation of these according to environmental relevance, which ultimately depends on how much each product, product group or needs group draws upon the core activities. From a policy perspective, the added value in targeting the core activities through the product or needs levels, lies in the more holistic perspective offered, so that shifting problems from one core activity to another is avoided. The most environmentally relevant products are not only the ones that draw most upon important core activities, but also the ones where there are the largest possibilities for substitution to other products that draw less on the core activities, seen in a life cycle ("cradle-to-grave") perspective. Here the term substitution is used very widely to mean a change in the current product system to a system which provides the same service (although it may well have different side-effects) but with different environmental performance. It thus encompasses such changes as more material efficient processes, weight reduction, eco-design, and changes in functionality or user behaviour.
- A focus on material flows allows a prioritisation of specific materials according to environmental relevance, which ultimately depends on how much each material draws upon or is involved in the core activities. A material may be seen as a "cradle-to-gate product", i.e. where only a part of the life cycle is covered. From a policy perspective, this implies that materials are only well-suited for targeting the core activities when this can be done without problem-shifting to the parts of the life cycle not covered.

In line with this, it may be argued that prioritisation of resource use in terms of environmental relevance ultimately depends on how much each resource is involved in or affected by the core activities. A resource may be seen as a "cradle product", i.e. where only the very first part of the life cycle is covered. The condition for resource use to be a good policy handle for the core activities, and thus for environmental impacts, is that it can be applied without problem-shifting, i.e. that any policy that calls for a change from one resource to another fulfil the requirement that the substitution between resources results in a reduction in the core activities seen from a life cycle perspective, and consequently a reduction in system-wide environmental impacts.

We will now devote a sub-section to each of the eight core activities, to investigate the evidence on how and to what extent they act as drivers for the environmental impacts and/or resource uses. This has not been the aim of the considered studies, so the following sub-sections extend the conclusions of the studies by analysing the underlying data on which they are based. The following sub-sections thus highlight links and driving forces that can be identified from the same data sources as those used by the considered studies, but should not be seen as conclusions or recommendations from the considered studies themselves.

Following these eight sub-sections, we will draw some general conclusions regarding the areas in which policies directed towards activities, products, materials and/or resource use may be relevant.

2.2.1 Combustion processes

Combustion processes are identified by several studies as the main driver for the greenhouse effect, acidification and photochemical ozone formation (due to emissions of CO_2, NOx, SO_2, NMVOC and CO).

Labouze et al. (2003) go a step further saying that "Most of the environmental impacts linked to resources consumption and air emissions are generated by two main categories, for which the use stage is predominant:

- transport (goods transport and private transport of passengers by car),
- building occupancy (mainly due to the energy used to heat domestic and commercial buildings)."

This broad wording covers other important emissions from combustion; particulates are explicitly mentioned, but also noteworthy are PAH and heavy metals such as Cd and Hg, which are especially present in emissions from mobile combustion.

To refine this somewhat expected observation, it is necessary to consult the models applied by the different studies (see also Section 2.4). For this, the models based on NAMEA data (Moll et al. 2004, Nijdam and Wilting 2003) are especially useful, since the NAMEA data explicitly separate non-fuel-related emissions from fuel-related emissions and report the latter per fuel type.

Using these models it is thus possible to quantify the importance of different fuel inputs in terms of environmental impacts with a high degree of precision. For example, this would result in statements like "*approx. 40% of the CO_2 emissions are caused by liquid (oil-based) fuels"* and *"approx 1/3 of the CO_2 emissions are caused by electricity production"*. This may be further traced back to the use of these energy sources in individual industries and private households. Similar statements can be made for the emissions of NOx, NMVOC and CO (more transport-related than CO_2) and SO_2, since these are also reported in most NAMEAs. The exact values in such statements will vary somewhat depending on the geographical area covered. Unfortunately, NAMEA data are not available for all countries in Europe, but the available NAMEAs cover more than half of the European production volume, and should thus be adequate for a general identification of the environmentally most relevant types of fuel use.

Most NAMEAs do not report emissions of heavy metals, particulates and PAH, but these emissions may be related to fuel input via emission factors that relate emissions from different combustion engines to fuel input.

2.2.2 Solvent use

Besides the emissions from fuel combustion, the main source of NMVOC (contributing to photochemical ozone formation) is solvent use. This is the background for textiles being identified as among the largest sources of photochemical ozone formation in Labouze et al. (2003).

Many other industries use significant quantities of solvents, notably in motor vehicle maintenance, fat extraction, the plastics industry and in wood preservation and paints (used predominantly in construction) (Illerup et al. 2002).

Solvents include, among others, chlorinated organics, acetone, butanone, turpentine, and ethanol. When applied in closed environments, solvents can be stripped from the exhaust air and combusted, thus avoiding most of the emissions.

Currently, the best way to estimate solvent emissions for the EU is to combine supply and consumption statistics for these substances with emission factors for different applications.

There is no apparent, causal relationship between the production and use of these substances and resource inputs, and the considered studies are not able to point to the existence of any such relationship.

2.2.3 Agriculture

Many of the considered studies point to food as a major source of environmental impacts. The environmental impacts originate from agricultural emissions. Ammonia from animal manure is not only a major source of eutrophication, alongside nitrate and phosphorous emissions to water, but also of acidification. Agriculture also contributes significantly to global warming due to enteric fermentation (CH_4) and manure management (N_20). Furthermore, application of agricultural pesticides is main contributors to ecotoxicity and agricultural activity can be a major driving force of water consumption, issues that are not well covered by any of the considered studies.

Agriculture is also the most important activity with respect to use of area resources (land area) for biomass production. Besides area, the main resource input to agriculture is nitrogen and phosphorous.

The relationships between use of these resources and emissions cannot be expected to be linear, since their use is distributed over a large number of different processes with different emission factors.

For nitrogen and phosphorous, the most precise information is achieved by calculating substance balances. However, the environmental impacts of the resulting surplus still depends on the how the surplus is distributed over emission types, and the many different technology variables. In other words, the identified nitrogen surplus will be associated with considerably different environmental impacts depending on how it is emitted, e.g. as ammonia, nitrate to water, N_2O or denitrified N_2.

Whilst, model-based data on CH_4-emissions from agriculture is included in most NAMEAs, models for calculating specific emissions based on nitrogen and phosphorous balances are still in development. Nevertheless, currently available models allow the establishment of rough relationships between inputs and emissions of nitrogen and phosphorous under specified conditions. This allows the inclusion of these emissions in NAMEAs.

For pesticides, substance-specific consumption statistics are available for many countries. Statistics that link consumed quantities of specific substances to specific crops are available for a few countries, see e.g. van der Voet et al. (2004), and may be used for a first rough assessment of relative importance between crops. The link from consumed quantities of pesticides to emitted quantities is still in development. Besides the link to crops, there is no apparent, causal relationship between resource inputs and the production and use of pesticides.

2.2.4 Metal extraction and refining

The environmental impacts from metal mining and refining are not specifically reported in any of the considered studies, but are included in the overall impacts of those studies that rely on life cycle databases (Labouze et al. 2003, Nemry et al. 2002, Phylipsen et al. 2002, van der Voet et al. 2004). Phylipsen et al. (2002) and van der Voet et al. (2004) identify iron and steel, aluminium, copper and zinc as the most environmentally relevant metals.

When analysing the data from life cycle databases using the impact assessment methods referred to in Section 2.3, the main contributor to environmental impacts from metal extraction and refining appears to be the emission of heavy metals (besides the emissions from fuel combustion during these processes).

Life cycle databases (i.e. collections of life cycle inventory data for various materials and processes, constructed according to the methodology of life cycle assessment) provide a clear and linear relationship between resource use measured as a quantity of a specific metal and the emissions of heavy metals from its extraction and refining. However, it should be noted that life cycle data are most often calculated using simple linear models, so are unlikely to accurately represent complex mining and metals refining processes (many of which may well result in non-linear emissions, e.g. heavy metals in seepage from a tailings dam).

2.2.5 Dissipative uses of heavy metals

Van der Voet et al. (2004) give estimates of the emissions during use of selected metals. In the other studies that rely on life cycle databases (Labouze et al. 2003, Nemry et al. 2002 and Phylipsen et al. 2002) heavy metal emissions are included in the overall impacts, but dissipative emissions during use are not distinguishable from those arising during metal extraction/refining.

Data on heavy metal emissions can also be found in national Substance Flow Analyses (SFA), where the different sources are reported and quantified. It is thus possible to relate the heavy metal emissions quantitatively to specific industries and products, although the data sources do not cover all of Europe.

Within these limitations, national substance flow analyses identify the following sources as among the most important: Cu in piping, fireworks, paints and printing inks, printed circuit boards, fishing gear, building roofs and as a fodder additive; Zn in galvanised products and paints; Cd in anionic protection rods and galvanized products; Hg in dental fillings.

There is no linear relationship between the use of heavy metals and the emissions of heavy metals, since the part of the applied metals that are dissipated depend on a number of application specific physical variables. Furthermore, these emissions are distributed over air, water and soil (typically to agricultural soil and via sludge) where they have quite different environmental impact potentials.

2.2.6 Housing and infrastructure

Construction or construction materials are identified among the most important product groups or materials in almost all of the considered studies.

Housing and infrastructure draw upon significant amounts of energy and metals, which are already covered in Sections 2.2.1 and 2.2.4, and include dissipative uses of heavy metals (Section 2.2.5). Besides this, housing and infrastructure occupies land area, often in fertile areas also suited for agriculture, and draws upon significant quantities of construction minerals (stone, sand, clay, etc.). At the output side, housing and infrastructure delivers bulky waste, both directly from construction activities and later when constructions are demolished.

As construction minerals are relatively inert, they will eventually leave the production and consumption realm as construction waste, albeit with a significant delay. This relationship over time, between input of construction materials and output of construction waste, is typically not captured in the NAMEA data that look at the flows in one specific year, so the correlation that is sometimes found (e.g. in Moll et al. 2004) simply reflects that the activities in the construction sector simultaneously involve both demolition and new constructions.

2.2.7 Marine activities

The specific environmental impacts from marine activities are not separately reported in any of the considered studies, and also not well covered either in the NAMEAs or in the life cycle databases underlying the different studies.

It is especially the important toxic impacts from anti-fouling agents that appear to be missing or underreported in these data sources.

The main resource input to marine activities is fossil fuel for combustion, and for fishing, also the input of fish resources and seabed area (area swept by active bottom tending fishing gear, such as beam and bottom trawls).

The emissions of anti-fouling agents are mainly related to hull size, which may have some relation to fossil fuel use, but the relationship is clearly not linear.

2.2.8 Chemical industry

Toxicity is included as an impact category in three of the eight considered studies (Labouze et al. 2003, Phylipsen et al. 2002 and van der Voet et al. 2004), of which the latter gives the most detailed reporting. However, none of the studies give a suitable treatment of toxic emissions, other than heavy metals. Labouze et al. (2003) states: "most of available LCI[1] databases are of poor quality when considering toxic substances" and "The origin of human toxicity and ecotoxicity risks is likely to be different from what is obtained in this study. For instance, AOX[2] is likely not to be the major overall problem for aquatic and sediment toxicity contrary to what is obtained in this study from available data".

There is an abundance of different toxic substances, many of which are not included in the life cycle databases, and even those that are reported do not all have toxicity factors in the impact assessment methods applied.

There is clearly not a linear relationship between production and environmental impacts from toxic chemicals, as the different toxic compounds have completely different fates in the environment.

2.2.9 Relevant information for policy

From the analysis in the preceding sub-sections, it appears that there are only few instances where the relationship between resource use and environmental impacts are straightforward and thus a relevant target for policies aiming to reduce the environmental impacts from resource use:

- Use of specific metals, where there is a clear and linear relationship to environmental impacts from metal extraction and refining. A reduction in use of these metals will lead to a direct reduction in the associated impacts. The studies with a material focus (Phylipsen et al. 2002, van der Voet et al. 2004) identify iron and steel, aluminium, copper and zinc as the most important metals.
- Area occupation, where it is the resource use itself that is of environmental concern. A reduction in area occupation will reduce the pressure on biodiversity.
- Construction materials, where the resource use drives the waste stream, albeit mostly with a significant delay. Due to this delay, a reduction in use of construction materials will not necessarily reduce the current amount of construction waste, but will have an effect in the (very) long term.

Overall, it appears that resource use is only a good handle for environmental policies when the targeted environmental impacts are directly related to the resource *extraction*.

When expanding the perspective to materials, more options appear, provided that materials are understood as relatively specific substances or substance groups. Targeting materials or substances is especially relevant in the following cases, where the relationship between materials/ substance use and environmental impacts is relatively straightforward:

- Specific fuels with high environmental impacts per GJ, where there is the possibility to change to less problematic energy sources.
- Solvents in dissipative applications.
- Agricultural crops with high environmental impacts per service unit, where there is the

1 Life Cycle Inventory.
2 Adsorbable organic halogens.

possibility to change to less problematic crops.

- Heavy metals in specific applications.
- Specific toxic substances or substance groups.

Nevertheless, it is important to be aware that where there is the possibility to change from one material to another less polluting material, this may have effects outside the specific application, especially when the substituting material does not have exactly the same functional properties as the substituted material. To avoid problem-shifting, it is always relevant to investigate prospective material substitutions from a life cycle perspective.

The material perspective applied by Phylipsen et al. (2002) and van der Voet et al. (2004) is in fact more a ″material product″ perspective, addressing the aggregated environmental impacts of materials production, material recycling and waste handling, and in the case of van der Voet et al. (2004) also material emissions during use. Fuels are not included as materials in either of the two studies. Phylipsen et al. (2002) investigate polymers, paper and board, four metals (steel, aluminium, copper, zinc) and five mineral materials (cement, fired clay, glass, gypsum, lime). Van der Voet et al. (2004) investigate a very complete list of materials, which implies some double-counting since solvents and toxic substances are both regarded as materials in their own right, and included when used in the production or recycling of the other materials investigated: ″Hg emissions take place during chlorine production and therefore count for the material of chlorine, but through the same reasoning it is also an application of Hg and therefore counts for the material of mercury.″ (van der Voet et al. 2004). Still, neither solvents nor organic chemicals end up among the top-scoring materials in terms of environmental impact, while some of the more bulky heavy metals (nickel, copper and zinc) do.

Biomass is not included in the study by Phylipsen et al. (2002) but comes out as top-scoring in van der Voet et al. (2004). Both studies agree on the top-scoring materials, iron and steel, aluminium, copper, zinc, concrete and cement, PVC and PE, despite following different impact assessment methods applied on material flows from different geographical delimitations (Netherlands and Europe).

The remaining studies relate more explicitly to the product policy area, i.e. targeting the relationships between products and environmental impacts. As mentioned before, the advantage of the product perspective is that it is encompassing, and thus tailored to avoid problem-shifting. A weak point of the product perspective is the large number of products, which makes the approach more complex than direct intervention at the level of materials or core activities. It is particularly difficult to use product policies to target core activities such as shipping, that contribute to many different products, because the environmental impacts become ″diluted″, each product having only a minor share in the impact. Another example of this ″dilution″ effect is the packaging material PE, which is identified as important by the studies with a material focus, but which would not come up as such in a product study, because the packaging is a minor component in many different product life cycles. Also for toxic chemicals, a product approach may be hampered by lack of detailed knowledge on the relationship between specific products and specific toxic chemicals.

All the considered studies with a product perspective agree on food, transport and housing being the three need areas with the major environmental impact, with the exception that food was not included in the study by Nemry et al. (2002).

Within each of these need groups it is possible to identify specific products with above-average environmental impacts, for example meat products within the foods, private cars within transportation, and room heating within housing (Dall et al. 2002).

More detailed results, allowing a ranking of individual products or product groups, can be derived from the individual studies, but this will depend strongly on the aggregation level applied. For example, metal products (basic metals and machinery) appear as important in Moll et al. (2004), but in the other studies these intermediate products are not separately reported but instead included in the other final products. Also, the number of products separately studied varies from 31 to 800. Thus, although there is some divergence between the considered studies with respect to the materials or product groups identified as environmentally most relevant, this divergence appears to depend more on the specific perspectives of the studies, than on fundamental differences in their data basis.

Besides the resource, material and product approaches, it would be an option to target policies directly at the core activities. This is particularly relevant when the activities lend themselves to efficiency improvements (e.g. improving the fodder efficiency and thereby reducing methane emissions from cattle) and emission reductions (e.g. stripping of solvents from exhaust air), which are often possible without detrimental effects elsewhere. However, it should be noted that this is not always the case; for example, the emission reductions using vehicle catalysts involve a trade-off between air emissions from combustion and heavy metal emissions from the production of the catalyst.

Although this has not been the perspective of the considered studies, the underlying data and models applied by the studies (see preceding sub-sections and also Section 2.4), allow a quantification of the relative environmental importance of the different core activities. Such a quantitative analysis is, however, beyond the scope of the current study.

2.3 Valuing and weighting the use of resources and the related impacts

To identify the environmentally most relevant types of resource use it is necessary to have a concept of what it implies that something is "environmentally most relevant" and a method to make the concept operational.

All the considered studies aggregate emissions contributing to the same impacts into impact categories. For example, "acidification potential" with its indicator "kg SO_2 equivalents" is a commonly used impact category for acidification from NH_3, NO_x and SO_2 emissions. The results are provided in the form of "impact potentials," except for Rixt et al. (2003) and Dall et al. (2002), who use a single indicator of primary energy consumption. They thus calculate the potential "full effects" of all emissions, implying that the realised environmental impacts will be smaller, depending on site-specific conditions.

Impact indicators can be further modelled along the impact pathway from the impact categories to the final endpoints of value, also known as damage categories, see Table 1. Damage indicators are expressed in units relevant to the value of concern (e.g. damage to human health expressed in "Disability Adjusted Life Years"), which allows aggregation of various environmental issues that have the same ultimate effect (e.g. global warming and human toxicity both contribute to damage to human health).

The considered studies cover different impact categories (see Table 2) and most of the studies address environmental relevance *within* each of the

Table 1. Classification of damage categories (end-points) for environmental impact and resource use (slightly modified from Jolliet et al. 2003)

Objects considered: / Endpoint value:	Humans	Biotic environment (natural and man-made)	Abiotic environment (natural and man-made)
Intrinsic	Human health and well-being	Biodiversity	Natural and cultural heritage
Functional	Human productivity	Biotic productivity	Raw materials (Natural and man-made)

Table 2. Impact and damage categories covered by the considered studies.

Study	**Labouze et al. (2003)**	**Moll et al. (2004)**	**van der Voet et al. (2004)**	**Phylipsen et al. (2002)**	**Nemry et al. (2002)**	**Dall et al. (2002)**	**Nijdam and Wilting (2003)**	**Rixt et al. (2003)**
Impact categories:								
Acidification	X	X	X	X	X		X	
Climate change	X	X	X	X	X		X	CO_2
Photochemical oxidation	X	X	X	X	X			
Ecotoxicity:				X				
Aquatic	X		X					
Terrestrial	X		X					
Other	sediment		marine					
Human toxicity / carcinogenesis	X		X	X				
Nutrient enrichment	X		X	X			X	
Ozone depletion	X		X	X			X	
Pesticides							X	
Radiation			X	X				
Raw materials:								
Metals	X	X	X		X	X		
Minerals	X	X	X	X	X	X		
Fossil fuels	X	X	X	X	X	X	(X)	X
Biomass		X	X		X	X	Wood fish	energy
Land area		X	X	X			X	
Water					X		X	
Road traffic noise							X	
Solid waste		X	X		X	X		
Damage categories:								
Human health	X			X				
Ecosyst. qual.				X				
Resource depl.	X		X	X		X		

studied categories, without attempting to aggregate these into an overall concept of environmental relevance. Only three of the studies present more aggregated results, applying indicators at the level of damage categories. Dall et al. (2002) weights raw materials consumed according to their known reserves (non-renewable resources) or to their yearly productivity (renewable resources). Labouze et al. (2003) consider "Years of Life Lost" in addition to a set of impact indicators, whilst Phylipsen et al. (2002) consider damage to human health, ecosystem quality and resource depletion, in accordance with the EcoIndicator99 life cycle impact assessment method (Goedkoop and Spriensma 2000).

The number and types of impact categories considered is often limited by data availability. Only three of the considered studies include a consideration of toxicity impacts to humans and ecosystems, with lack of data and the high uncertainty of the models given as reasons for excluding these in some of the other studies (e.g. Nijdam and Wilting 2003). Dall et al. (2002) include a semi-quantitative toxicity assessment of the most important household chemicals, whilst Nemry et al. (2002) discuss the release of heavy metals and persistent organic pollutants, but do not provide results because of modelling difficulties and lack of data. Even where toxicity impacts are quantitatively considered, their interpretation is cautioned, e.g. in Labouze et al. (2003). It is expected that macro-level toxicity impact modelling will be improved in the future, e.g. by the OMNIITOX[3] project (funded under the EU's 5th Framework Programme for Research and Technological Development).

A set of unaggregated impact category indicators contain no explicit information as to the relative importance that should be assigned to the impacts. In practice, when impact assessment results are presented to a decision maker without aggregation into damage categories, this often results in wrong interpretations as to their relative importance. Typically, the impact categories will be judged as close to equally important, i.e. an implicit weighting of the impact categories 1:1, although the actual damage they inflict may be very different. Van der Voet et al. (2004) take this decision explicitly and present aggregated results based on an equal weighting of all studied impact categories, i.e. in their aggregated environmental indicator, all impact categories are taken as equally important.

The disadvantage of an equal weighting of impact categories, whether implicit or explicit, is that the results become dependent on how the impact categories are defined, e.g.:

- If terrestrial eutrophication and aquatic eutrophication are each given their own impact category, eutrophication will become twice as important as when eutrophication is seen as one single impact category.
- Impacts that affects a large part of the ecosystems, such as global warming, is given the same weight as ecotoxicity that affect a much smaller fraction of the ecosystems.
- Human toxicity and acidification will be weighted equally although the affected endpoints are very different (humans and nature, respectively).

It is common practice to normalise the indicator results to aid in their interpretation. For example, a product's acidification potential expressed as its percentage contribution to the total acidification potential for the region is more meaningful to a decision-maker than "kg SO_2 equivalents". However, this is done by only three of the considered studies. Dall et al. (2002) normalise their impact categories to an average person's yearly contribution to the indicator. Van der Voet et al. (2004) normalise impact categories by the material with the highest score to allow the calculation of an aggregated score of equally-weighted impact categories. Phylipsen et al. (2002) follow the EcoIndicator99 method, which involves the normalisation and weighting of the impact category indicators to arrive at three damage categories, human health, ecosystem quality and resource depletion. These can be further aggregated to a single "ecopoints" indicator (Goedkoop and Spriensma 2000).

The EcoIndicator99 applied by Phylipsen et al. (2002) is a good example of the current state-of-the-art modelling from environmental impact categories to damage endpoints. Impacts on human health are aggregated in "Disability Adjusted Life Years" and impacts on the biotic environment are aggregated in "Potentially Affected Fractions" of ecosystems in area and time. Whilst this pioneering attempt at comprehensive damage modelling is inherently uncertain and can be - and has been – criticized for its inherent assumptions, it is a good example of the direction of the current developments n impact assessment.

The method applied by Phylipsen et al. (2002) thus represents well the dilemma encountered when basing impact assessment on damage categories rather than impact indicators. As the relevance of the results increases (e.g. evaluation of ecosystem quality rather than separate indicators for eco-toxicity, acidification, eutrophication etc.), so does their uncertainty (since damage models are mostly highly uncertain and require many data inputs and assumptions). A balance therefore needs to be found between model uncertainty and valuation uncertainty.

3 www.omniitox.net.

In spite of this situation, there are options for a more science-based approach that avoid the need for decision makers to (implicitly or explicitly) weigh up the importance of the various environmental impacts (often incorrectly resulting in an implicit 1:1 weighting). One such option is to base the weighting on epidemiological data. For example, studies on how much of the "burden of disease" is attributable to environmental factors (de Hollander et al. 1999, Smith et al. 1999) provide a basis for a quantitative ranking of causes of human health impairment, even when the detailed cause-effect mechanism is not known. In parallel, it is possible to rank the different impacts on nature in relation to how large a fraction of the species and how large an area is affected. Such "epidemiological" data should preferably be related to changes, i.e. how large a change in the damage category will be the consequence of a change in the impact category. Obviously, the currently available data are still coarse, and will need to be refined in the time to come.

The eventual aim of environmental impact assessment is to draw reliable quantitative impact pathways connecting each resource use and emission to impact indicators and ultimately, to all relevant damage categories or areas of human concern. However, at the current state of scientific knowledge, these connections cannot be made for all types of impacts (Jolliet et al. 2003). Whilst the EcoIndicator99 method (Goedkoop and Spriensma 2000) is arguably the most comprehensive environmental impact assessment method in use, it is not able to address all relevant damages (as identified in Table 1). Damages to the man-made environment (both biotic and abiotic) are particularly neglected as they have traditionally not been a focus of environmental impact assessment. An assessment of the overexploitation of renewable raw materials (e.g. water, biomass etc.) is also a notable omission from the method.

The EU resources strategy is concerned with both resource depletion and environmental impacts, although the environmental impacts of resource use are viewed as of greater concern than their possible scarcity (COM 527, 2003). As shown in Figure 1, both these issues contribute to the damage categories of Table 1.

Labouze et al. (2003), Phylipsen et al. (2002) and Dall et al. (2002) provide examples of the modelling of damage indicators for the depletion of non-renewable abiotic raw materials. The methods all consider the reduced availability of the resource for future generations (since the consequence of the resource extraction is the destruction or dissipation of the resource body), but do so in different terms. Phylipsen et al. (2002) consider the additional energy that will be required for future raw material extraction of lower quality ores, whilst Labouze et al. (2003) characterise the resource types according to their abiotic depletion potential (in «kg antimony equivalents»), based on the depletion of the ultimate reserves in relation to their annual extraction rate. Similarly, Dall et al. (2002) weight the non-renewable resources consumed according to their known reserves.

The relevance of weighting resource consumption based on known reserves has been questioned (Jolliet et al. 2003). In particular, several specialist studies have shown that the total quantity of most of the abiotic resource stocks accessible for human use are difficult to evaluate, and are generally underestimated to the extent that short term shortages do not warrant concern. Assessment methods based on recoverable reserve estimates are thus generally considered unsatisfactory.

The approach of the EcoIndicator99 method (Goedkoop and Spriensma 2000) is arguably a more robust approach, but may be criticised because of its limited considerations on resource substitutability. This is especially notable with respect to the substitutability of fossil fuels. Whilst increasing energy requirements are relevant with respect to extracting materials from resource bodies of decreasing quality, it is also necessary to take into account possible advances in extraction technologies over time, as well as the alternative technology that will be applied when extraction of the particular resource is no longer economically or technically viable (together referred to as the «backup technology»). Identifying backup technologies for various resources and the points in time that they are likely to occur have been identified as a particular research need in the modelling of resource damages (Jolliet et al., 2003).

The considered studies are particularly weak in their assessment of renewable resources. Only two studies consider water use (Nemry et al., 2002, Nijdam and Wilting, 2003), whilst only Dall et al. (2002) include a consideration of the overexploitation of biotic renewable resources. They do so by weighting the consumption of renewable resources by their yearly productivity. However, also on this point their assessment is not able to consider the value or substitutability of the different resources, nor is it able to consider threatened renewable resources (e.g. wild fish).

The need for damage methods to consider renewable resource depletion is thus clearly identified. However, the fact that there are a number of concepts that are common to the impact assessment of all groups of functional resources, be they biotic (wild or domesticated plants and animals) or abiotic (metallic or non-metallic minerals, energy minerals, water or soil), points to the possibility of valuing these resource types in the same manner as that discussed above for non-renewable resource depletion (i.e. in terms of "backup technology" and "ultimate quality limit", the point in the future when the alternative technology will be implemented). A uniform framework would be a considerable advance in ensuring that the depletion of all relevant resource materials are considered in an impact assessment, but further research on defining quality limits and backup technologies is required.

In conclusion, the considered studies do not explicitly identify and prioritise the most environmentally relevant resources and environmental impacts. Compared to an epidemiologically based damage modelling, the general approach of implicitly weighting all impact categories equally, tend to emphasise:

- ecotoxicity, acidification and eutrophication impacts on nature at the expense of land occupation, and
- photochemical oxidation and ozone depletion at the expense of human toxicity (including respiratory effects from particle emissions).

From our knowledge of how environmental impacts are aggregated in epidemiological damage models, it is possible to predict that when applying such models to the available data sources, the most environmentally relevant resources would be identified as land area, fuels, and metals.

2.4 Methods for investigating the use of resources and the related impacts

2.4.1 System delimitation

Only one of the considered studies (Moll et al. 2004) deals with the entire production and consumption in national accounting terms. Out of the remaining seven studies, four deal with private household consumption only, and three with a selected group of products or materials: Nemry et al. (2002) include consumption of products by both private consumers and industry. Although double-counting is allegedly sought to be avoided by limiting the investigation to final products (defined as "products that require no additional transformation prior to their use by end consumers, either industrial or household"), it is not clear how double-counting can be avoided when final products are used by industries producing final products for private consumption. Phylipsen et al. (2002) and van der Voet et al. (2004) each have their own definition of what materials mean, and use somewhat different system delimitations. However, both conclude that material production make up ¼ to ½ of the total environmental impacts of the national economies. While the definition of national production and consumption and the division between industry, private household consumption and public consumption all have specific definitions in the national accounting schemes, there is more uncertainty in establishing materials consumption data as this does not have a standard statistical definition. Phylipsen et al. (2002) provide a detailed comparison of different data sources for material consumption, but as the sources, data quality and collection procedures differ across the different materials, this may result in inconsistencies when comparing materials.

None of the product-oriented studies give arguments for not looking at the entire production and consumption (i.e. including products for export and public consumption), except that this has not always been the perspective of the commissioner. As the dividing line between public and private consumption differs between nations, it appears that the most consistent results are achieved when looking at the entire national consumption.

2.4.2 Bottom-up or top-down

Most of the considered studies use a process-based approach to build their product or material life cycles bottom-up, process by process. Only Moll et al. (2004) and Nijdam and Wilting (2003) use a top-down, input-output based approach based on the national accounting matrices. Rixt et al. (2003) use a hybrid approach, which is basically a process-based approach supplemented with input-output data to minimize data gaps.

The main advantage of the process-based approach is its ability to treat each product or material separately in great detail. However, at the same time, it is notoriously incomplete: "In breaking the life cycle down into processes, it is not always clear how far one should go in including processes belonging to the product concerned. In the production of polyethylene, for example, oil has to be extracted; this oil is transported in a tanker; steel is needed to construct the tanker, and the raw materials needed to produce this steel also have to be extracted. For practical reasons a line must be drawn. For example, the production of capital goods is usually excluded." (Labouze et al. 2003).

As a measure of completeness, it is interesting to note that the studies report very different percentages of the total energy consumed directly by households, which is a value that should be established with a high degree of precision at around 15-30% of the total energy use, depending on country. Rixt et al. (2003) report 40-50%, which would seem to point to a completeness of the whole study of less than 60%. Judging from this, it appears that the hybrid approach applied by Rixt et al. (2003) has some of the same problems with completeness as the purely process-based studies. It also confirms the notion by Lenzen (2001) that bottom-up studies can have data gaps that add up to 50% of the total environmental exchanges.

In contrast, the main advantage of the input-output based approach is its completeness. Since it takes its starting point in the national accounting matrices, it includes by definition all activities, materials and products in the economy. Its main disadvantage is the implicit assumption of homogeneity of the industries, i.e. that all products from an industry are assigned the same environmental impact per monetary unit. The higher the level of aggregation of industries, and the more diverse the industry in question, the more erroneous this assumption. Since the aggregation level of national accountancy matrices is typically between 50 to 500 industries, this is a significant source of uncertainty, which can only be overcome by further disaggregating the inhomogeneous industries. Such disaggregation can be done on the basis of different data sources, notably national accountancy work files and the process-based life cycle assessment data (LCA data).

The input-output based studies also differ from the process-based studies in terms of the emission data. While the process-based studies rely on LCA process-databases, where the data are typically derived from industry- and process-specific sources, the input-output studies rely on national emission data registrations. For emissions of CO_2, SO_2 and NO_x these are typically calculated from the detailed statistics of trade in energy carriers and industry-specific emission factors, resulting in highly reliable, and geographically representative totals. For heavy metals and several other chemicals, it is also the total trade figures from material flow analyses that allow a verification of the reliability of the total emissions. In a few cases, total emissions may also be verified by matching actual levels of pollution, e.g. for nitrogen and particulate emissions.

When adding up - from process-databases - all known processes within one industrial sector, they should, in principle, come close to the result arrived at by national emissions statistics for the same sector. However, in practice the bottom-up processes often have to be adjusted for omitted or forgotten emissions before the two totals match. The top-down data thus becomes an important tool for completing the bottom-up data, which have the advantage of larger resolution. For example, the national statistics may not sub-divide household energy use on specific purposes, which can lead to errors like the underestimation of the energy required for clothes washing in the study by Nijdam and Wilting (2003). The national emissions data are typically also less complete when it comes to emissions of toxic substances from private households. Thus, rather than seeing the two sources of data as incompatible, they should be seen as complementary (Weidema 2003).

Besides the problem of aggregation level, there are a number of other limitations of using input-output matrices and national emissions statistics as a basis for environmental analysis. Some of these are inherent to the methodology, and some have to do with data availability.

The key methodological issues encountered in using input-output data for environmental analysis are discussed in the following sub-sections, including how these limitations may be overcome by adjusting and expanding the data. These methodological limitations do not apply to bottom-up approaches, which are rather limited by issues of data availability.

Methodological aspects are addressed in further detail in a following ESTO project: Evaluation of the Environmental Impact of Products (EIPRO), see Tukker et al. (2004).

Imported products

An important assumption of traditional input-output analysis, which is also used by Moll et al. (2004), is that imported products are produced in the same way as the similar domestic products, even though, it is well-known that emission factors (e.g. CO_2/Euro) can vary significantly from country to country. These potentially significant variations are due to differences in geographic and administrative conditions, industry compositions, applied technology, management systems and sizes of production units. For example, in a traditional input-output analysis, the European textile industry's purchase of cotton will be treated as if the cotton was produced by European agriculture, thus missing out important specific pesticide emissions that would more likely have been included by a process-based approach. The import assumption is especially problematic in very open economies with large imports and exports, such as the smaller European economies.

However, it is possible to eliminate the import assumption by linking the national input-output matrices, thus obtaining a more realistic picture. A step in this direction is taken by Nijdam and Wilting (2003) by linking the Dutch input-output matrix with three foreign matrices, representing Europe, Rest-OECD and the Rest-of-the-World. Unfortunately, the foreign matrices used are at a very high level of aggregation (30 industries), which make the results highly uncertain. However, more detailed input-output matrices exist for many countries, and procedures are available to estimate detailed tables by country-to-country extrapolations, eventually allowing a more realistic linking of national matrices. The data for imported products will remain more uncertain than for domestically produced products, but in this way the uncertainty can be limited.

Investments

As mentioned by Labouze at al. (2003) an industry's purchase of capital goods or investment goods (i.e. goods that are expected to be consumed over more than one year) is typically not included in process-based studies.

In parallel, the accounting convention applied in the national accounts implies that an industry's purchase of investment goods are counted as a final use, rather than as a commodity input to the industry. This implies that the investment goods are included, but not linked to the final consumer products produced by that industry.

This is less appropriate for environmental input-output studies, and should therefore ideally be corrected by linking the investments to the industries delivering the investment goods. This correction was apparently not done by any of the considered input-output based studies. The main error implied is an underestimation of the importance of construction.

Proportionality

Using monetary input-output matrices to represent physical flows of commodities between industries implies an assumption of proportionality of monetary and physical flows. For example, 100 Euro electricity bought by the fertiliser industry is assumed to lead to equal amounts of electricity supplied as 100 Euro spent on electricity by travel agencies. However, electricity prices vary considerably among sectors, thus violating the proportionality assumption. The associated uncertainty can in principle be overcome by replacing monetary entries in all basic input-output matrices with entries in physical units. However, such physical input-output matrices are not produced on a regular basis in any country. The national statistics are typically only related to physical flows of specific fuels, based on energy matrices, which are provided in both economic and physical units. However, this is only relevant for energy related air emissions.

In connection to the disaggregation of input-output data suggested above, it would be possible to isolate physical product flows related to other specific emissions, such as ozone depleting substances from refrigeration.

2.4.3 Retrospective/prospective

Both input-output matrices and LCA databases typically reflect past performance because input data are usually retrospective, while decision-making should ideally be based on current or future performance. To compensate for this limitation, the input-output matrices and LCA databases should ideally be applied with forecasting procedures, e.g. scenarios and models reflecting possible future changes. Out of the considered studies, only Phylipsen et al. (2002) address this limitation, in that they use scenario analysis of material requirements and the related environmental impacts. Although they are able to conclude “that ‘traditional’ material technologies, such as more efficient material production, material-efficient product design and material recycling are important options to reduce the environmental impact in each of the impact categories of most of the materials”, they go on to say that for material substitutions “only in a product life-cycle approach can the net effect on environmental impacts be determined” which was beyond the scope of the study.

2.4.4 Elasticity and Recycling

Input-output analyses use a standard economic logic that implies that all supplies are fully elastic (i.e. that the demand for a unit of product leads to an increase in production of one unit of that product). The same logic is applied in many LCAs and certainly in the LCA databases used for the considered process-based studies. This may lead to wrong conclusions if the data are used to rank and compare different products, since some of the processes may not be able to change in response to a change in demand for a product. For example, the standard procedure will predict that a change in output of leather will lead to a change in production of animal products in agriculture, while a more market-based procedure would assert that the production volume of animal husbandry is determined by the meat or milk output, and that the change in leather output would only change the amount of animal hides going to waste management. However, at the very highly aggregated level applied by the considered studies the limitation of the standard procedure is not likely to influence the results. If desired, the problem can be corrected for by adjusting the input-output relations to reflect the actual prospective market reactions.

A special case of this is the way recycling is treated in the product-oriented studies. In the input-output based approach, and when applying economic allocation in the LCA databases, the industries (product groups) that use recycled material will have a smaller resource input and less emissions than if they had not been using recycled material. This is opposite to LCA databases that use system expansion as an alternative to allocation (as recommended in the ISO standards). In these market-based LCA procedures it is the industry (or product) supplying material to recycling that is to be ascribed the benefits of smaller resource input and less emissions. The latter was apparently not applied in any of the considered product-oriented studies.

2.4.5 Aggregation problem in ranking

The level of aggregation in a presentation is very important for the ranking of materials and product groups. Highly aggregated groups can come up high in the ranking simply because of their size, while the same group would disappear from the top of the ranking when disaggregated, because the environmental impacts are then spread over many products. This problem can be avoided by ranking the materials or product groups per monetary unit, since disaggregation does not change the environmental impact per monetary unit. Still, a basic homogeneity within the groups is required, so that high-impact materials or products do not "hide" within general classes of low-impact materials or products.

2.4.6 Options for keeping data updated

An advantage of the top-down approach is that national accounting matrices and emissions statistics are most often updated annually, or at least on a regular basis. Data in LCA databases, on the other hand, most often come from particular commissioned studies, that may or may not, make provision for updating in the future. For a continuous monitoring of the environmental relevance of different resources, materials and products, input-output data is therefore preferable as a back-bone of a database for environmental analysis. LCA data are ideally suited to supplying detail to such a database (e.g. disaggregation of the industry sectors), as this does not require frequent updating of the data source.

2.5 Conclusions

A key question to be answered by this study is whether environmental impacts can be related to a specific quantity of resource use. Only Moll et al. (2004) explicitly set out to investigate this, but all of the considered studies do contribute to our understanding of what are the environmentally most relevant types of resource use, through identifying relationships between environmental impacts and specific material flows or product groups within the production and consumption realms.

Moll et al. (2004) find strong correlations between fossil fuel use and "global warming potential" and "potential acidifying effect", as well as other weaker correlations, such as that between Total Material Requirement and "bulky-like construction and demolition waste". Nonetheless, it is causal relationships that are ultimately required to determine relevant target areas for policy aiming to reduce the environmental impacts from resource use. The possibility to isolate causal relationships between particular resource flows and environmental impacts is thus explored for each of those areas of human activity identified as contributing most to environmental impacts (combustion processes, solvent use, agriculture, metal extraction and refining, dissipative uses of heavy metals, housing and infrastructure, marine activities and chemical industry).

A straightforward relationship between resource use and environmental impacts is found in only a very few cases, namely, the use of specific metals (where there is a clear and linear relationship to environmental impacts from metal extraction and refining), area occupation (where it is the resource use itself that is of environmental concern), and construction materials (where the resource use drives the waste stream, albeit with a significant delay). In general, it appears that resource use only provides relevant target areas for environmental policy when the targeted environmental impacts are directly related to the resource extraction.

If the perspective is expanded from resources to materials or substances, more instances of relatively straightforward causal relationships between environmental impacts and the use of specific materials/substances emerge. An option for environmental policy is thus to target specific materials or substance groups where such a relationship has been found, notably fuels with high environmental impacts per GJ, solvents in dissipative applications, agricultural crops with high environmental impacts per service unit, heavy metals in specific applications and specific toxic substances or substance groups. However, it is important to be aware that policies targeting materials can lead to problem shifting, i.e. substituting materials without exactly the same functional properties may result in effects outside the specific application.

A product focus is thus arguably more relevant than materials/substances, since this more holistic life cycle perspective is able to take product substitution into account without the danger of problem shifting. Taking a product perspective does, however, also have some weak points, notably the complexity of dealing with a large number of products, and the problem of "diluting" impacts across a large number of products.

The considered studies do not explicitly identify and prioritise the most environmentally relevant resources, and are found to differ considerably in the number and complexity of environmental indicators considered. A significant limitation encountered in the valuation and prioritisation of resource use is that, with the exception of Phylipsen et al. (2002) and Labouze et al. (2003), the studies base their valuation/prioritisation on a group of impact categories and/or material flows, and not the damage categories/endpoints identified as the ultimate areas of concern for the resource strategy (namely, biodiversity and natural heritage, human health, welfare and cultural heritage, and the functional values of nature). A valuation of the effects of resource use is thus considerably more difficult, since their effects have to be simultaneously compared over a number of "indicators". This usually results in a subjective interpretation of the relative importance of the environmental indicators, or, at worst, an equal weighting being applied to each of the impact categories (in both cases, either implicitly or explicitly carried out). An epidemiologically based modelling of damage categories/endpoints, such as that carried out by Phylipsen et al. (2002), is thus the preferred approach to impact assessment (notwithstanding the early developmental stage of these models). A more scientifically based approach to the valuation of impact categories is of particular importance since different approaches arrive at different outcomes (e.g. an equal weighting of impact categories tends to under-emphasise land use and human toxicity compared to epidemiologically based damage models).

Two clearly different modelling approaches are taken by the studies, the so-called bottom-up approach (life cycle process modelling based) or a top-down input-output approach (based on national accounting matrices). A bottom-up approach is applied in the majority of studies with only Moll et al. (2004) and Nijdam and Wilting (2003) using the top-down approach, whilst Rixt et al. (2003) use a combination of the two. Each of the approaches have some clear advantages and disadvantages relative to each other. Most notably, the life cycle approach is able to treat each product/material group separately and in great detail, but is notoriously incomplete. The input-output approach, on the other hand, is very complete with respect to the materials, products and activities it considers, but has some methodological considerations which make it less suited to an analysis of products/materials. Most significant of these is the assumption of homogeneity, i.e. that all products within an industry are assigned the same impact per economic unit. Nonetheless there is considerable potential to address these limitations by augmenting/adjusting economic input-output data with life cycle assessment data (process-based data).

In addition to the different modelling approaches, the different system delimitations chosen by the studies make it difficult to draw comparisons across them. The number of industries/products assessed, and especially the degree of aggregation into product "families" or function groups also makes comparisons difficult, as does the fact that van der Voet et al. (2004) and Phylipsen et al. (2002) take a material focus, whilst the rest of the studies take a product focus.

Nonetheless, the six studies taking a product perspective are relatively consistent in their conclusions, and identify food, housing (building construction and occupation) and transport as the need areas with the major environmental impacts (other than Nemry et al. (2002), who do not include food in their study and Labouze et al. (2003), who do not include biomass or land as an environmental indicator).

It is apparent that there are sophisticated and applicable methods available for modelling the economic and environmental processes required for prioritising products/materials with respect to their environmental impacts and resource use (notably input-output models adjusted with LCA data, and state-of-the-art impact assessment damage models). However, in each of the studies considered there is room for improvement, and each shows strengths in different areas. Thus, it can be argued that none of the considered studies structure the available knowledge in the best way possible. Nonetheless, all advance the methods and establish strong relationships between products/materials and environmental impacts.

3. Proposals for developing further the scientific input to the resources strategy

The present chapter focuses on providing proposals for developing further the scientific contributions to the resources strategy. The chapter builds on Chapter 2 and is structured in three main sections.

Section 3.1 reviews a number of principles to take into account when using scientific knowledge in (environmental) policy relevant for the resources strategy. Section 3.2 analyses and aggregates the most important gaps in knowledge identified in Chapter 2, in view of the goals of the resource policy. Section 3.3 proposes on this basis how science based support could be organised.

3.1 Generic challenges of scientific input to a resources strategy

This section addresses some generic challenges related to the use of the eight considered studies as science-based support to the resources strategy. With outset in the EU policy on governance and the collection and use of expert advice, a key issue is how this kind of science-based support can acknowledge the principles adopted by the Commission in December 2002 (EC 2002a). The principles include 17 general guidelines addressing diverse issues as the role of in-house expertise, making documents available to the public, explaining how advice has been used in policy outcomes, dealing with conflicts of interest, accommodating diverse viewpoints and making uncertainty and divergent views explicit (Cross 2003). Key issues of relevance to the scientific input to the resources strategy are identified and thematically outlined. This includes a brief thematic presentation of considerations with regard to the accountability, contestation and plurality of the considered models and methodologies and the need for recognition of the role of value-based choices in any development of scientific models.

The analysis acknowledges that all conceptualisations of the environment must be understood as products of historical processes. How specific environmental issues become part of and are represented in scientific investigation, as objects of regulation, or elements in the general environmental discourse is dependant on specific contexts (Braun and Castree 1998, Macnaghten and Urry 1998). This implies that the complexity, legitimacy and accountability of scientific models involved in science-based support for policy will continually be changing, as these aspects of scientific models are transformed by the changing framing of the environmental issues. Some problems will appear stable (e.g. ozone depletion), some may become new centres of focus (e.g. hormone-like substances), while others get less attention (e.g. acidification and forest death). These changes may be a result of targeted environmental regulation, an outcome of new scientific insights or a combination of the two. As environmental issues become integrated in the institutionalised practices of regulation they acquire a taken-for-granted status, where the origins and complexities of the original issues is no longer present (Latour 1999).

3.1.1 Accountability of results is important

The resources strategy will be an element in a highly exposed policy area, where different stakeholders can be expected to scrutinize the scientific basis of the policy initiatives. Very often environmental policy regards sensitive cases, where stakes are high in terms of political, social or economic consequences of a policy decision.

The EC White Paper on governance stresses that: ".. a better-informed public increasingly questions the content and independence of the expert advice that is given. These issues become more acute whenever the Union is required to apply the precautionary principle and play its role in risk assessment and risk management." (EC 2001 quoted in Cross 2003). When the policy area is highly exposed, uncertainty in the environmental sciences might also increase as a result of the unpredictability of human actions as well as of the sheer complexity of interaction between the natural environment and the effects of humans on it. This makes the question of accountability a key issue to be considered.

The present study analyses the ability of specific studies to contribute to the focus of the EU resources strategy. The individual studies are based on complex NAMEA-like input-output models and/or models of product life cycles using LCA methodologies. The use of the results from those models has the potential of increasing the accountability of the environmental policy, as the scientific basis of the policy decision can be expressed quite detailed and explicitly through the quantifications in the models.

In the concrete use, however, the accountability of the results will depend on the ability to present the background for attributing significance to certain issues, while not downplaying the ambiguities and uncertainties from the studies. The inherent uncertainties in the considered models and methodologies are clearly stated, when they are used outside policy advice in e.g. product development, where they are considered ″subjective″ by nature[4]. However, when using these models for policy advice purposes, there will often be a bias towards using aggregated results in order for the results to be sufficiently significant to be ″visible″ for policy use, while the detailed assumptions and uncertainties of the scientific investigation are not brought to attention (Barry 2001). It appears, however, to be very difficult to incorporate the complexity of issues in the considered models, which cannot be represented as causal relations as they depend on factors as human behaviour or choice of technology. Thus, the dilemma of the trade-off will be a persistent issue if the models and methodologies are not to develop into what has been called "technologies of predictive policy analysis, grounded in overconfidence in their own accuracy and certainty" (Jasanoff 1990).

3.1.2 Scientific models as part of policy development

It is evident, that the discussion on how to model resource flows and environmental impacts includes several schools that have difficulties in identifying each other's relevance and usefulness (EC 2002b).

The models and their results are typically termed "exercises" by the involved scientists. This shows how the models tend to exist as separate domains, and also reflects how the studies are considered to provide input as an enlightenment of politics, where they contribute by illustrating and bringing attention to certain issues. On the other hand, there is not much evidence that the models have functioned as justification of specific policy measures or initiatives concerning the prioritisation of specific materials or resources. It is also important to be aware that scientific methods are not equally adequate to support different kinds of policy measures (Cross 2003). There is a need for a more elaborated assessment of the types of policy measures the models are able to support than it has been possible to carry out in the present context.

Existing resource-related environmental policy has mostly started by the relatively coincidental identification of new issues. A variety of different scientific approaches - Risk Assessments, SFA, ecological footprints, environmental space, natural resource economics etc. (EC 2002b) have contributed to the framing

4 This is reflected in the wording of some of the ISO standards on LCA , e.g. in the ISO 14042 standard.

of the specific problems as policy issues. Thus, several other scientific methodologies than the models evaluated in this study have provided input for the political agenda. It is not likely that scientific controversies will cease due to the introduction of more detailed studies of impacts from resource consumption. As a result, robust results for the prioritization of environmental impacts across different types of resources cannot be expected to be realized on the basis of scientific input alone.

Even though the different schools of environmental modelling presently are not actively contested, this must be expected to happen, when and if results are used in a more direct way in policy processes as highlighted by Barry: "Measurements of 'pollution' simply recorded by a government or a private laboratory are not likely to become political matters. But they can easily become political once they are found in the press release of an environmental organisation or circulated in public documents." (Barry 2001). Reliable knowledge as validated in its disciplinary context is no longer self-sufficient once it is contested. Contestation will be a challenge that cannot be avoided. "Even the protection provided by speaking in a collective voice, to give advice as a committee and to generate authority in a self-authorising way, does not confer immunity against contestation." (Nowotny 2003). On the other hand contestation will also be a necessity in order for scientific knowledge to gain robustness.

Science-based support will have to be not only robust on a secluded institutional level, but also "socially robust" in order to function through processes of contestation. At the same time "social robustness" will only come about, when the methodologies remain open to continuous social monitoring, testing and adaptation. This implies that socially robust knowledge must be tested not only in the laboratory, but also outside where social, economic, cultural and political factors shape the implications drawn from the scientific investigation.

3.1.3 The need for plurality of concepts and the recognition of the role of value-based choices in policy development

Moving from scientifically reliable knowledge towards socially robust knowledge requires a regime of pluralities. One step towards this goal can be through continuously drawing on independently developed and competing concepts as contributions to major policy decisions. Thus, in the laboratory social robustness is most likely to be achieved through involving an extended group of experts, users and lay-persons (Nowotny 2003). If the assumptions of the scientific input is forgotten in the policy process this will weaken the resulting regulation (Jasanoff 1990). Scientists should therefore go into dialogue with other stakeholders in order to point to assumptions and uncertainties. This would stress how the construction of models also involves value-based choices, which have to be undertaken as part of the later political process, and thereby contribute to developing new concepts of policy (Jørgensen 2001). In relation to a resources strategy some of the value-based choices, which need to be undertaken, are: (EC 2002b)

- What constitutes a sustainable level of resource use
- How should the issue of equality between different parts of societies and between different parts of the world be addressed

Different opinions on these choices have lead to a plurality of concepts for addressing resource management like Environmental Space, Ecological Footprints, Factor 4/10 reductions etc. (see EC 2002b).

Another important value-based choice is the role of precaution in the development of the resources strategy. Moll et al. (2003) points to the need for precaution and political/normative assessment as basis for the further development of the resources strategy, since it is not scientifically possible in the mid to long-term range to close the information gap concerning the causal linkages between single raw materials, their subsequent life cycles and the related environmental impacts.

In relation to the resources strategy a possible way to further qualifying the policy development could be to enter into a continuous dialogue oriented process. This dialogue should involve scientists, policy makers, industry and NGO's in discussions of alternative concepts, the assumptions they build upon and their approach to a resources strategy. Two alternative approaches to a resources strategy are 1) an approach focusing on reduction of the resource flow volume without very detailed knowledge about the contribution of the single application (like the precaution approach proposed in (Moll et al. 2003)), and 2) an approach focusing on more detailed knowledge about linkages between single raw materials, their subsequent life cycles and the related environmental impacts (like the approach proposed later in this chapter). Even though the work with alternative concepts and approaches will require increased expenses, the cost of developing alternative scientific concepts and approaches has been recommended from a democratic perspective in general discussions about power of scientific models (Teknologirådet 1995). The concern for plurality and democratic control also implies that limitations on access to data and basic assumptions caused by e.g. intellectual property rights should be avoided (Teknologirådet 1995).

3.2 Gaps in knowledge concerning what determines the environmental impacts of resource use

The gaps in knowledge on what determines the environmental impacts of resource use, or in other words in knowledge necessary to identify the "hot spots" a resource policy needs to tackle, will be analysed and specified in this section. This gap analysis builds the outcome of Chapter 2 and follows the same structure.

3.2.1 Relationship between resource use and environmental impacts

The Commission Communication on the resources strategy (COM 527, 2003) states that scarcity of resources in general is not the greatest problem. The problem is rather the impacts related to the use of the resources. Policy priorities hence have to be derived from the *impacts* resources cause, rather than their use in itself. This implies an interesting complication for scientific advice. The use in itself is in general easily measurable whereas to what extent impacts (in terms of emissions to water, soil, and air) can directly be attributed to the use of certain resources is much less clear, as discussed in detail in Chapter 2.

Only one of the considered studies (Moll et al 2004) did an attempt to do this, but this was at a high level of aggregation (Total Material Requirement versus impact). There is hence a need for studies that are able to identify correlations or causal relations between impacts and resource inputs to the production-consumption system, at a relatively low level of aggregation (individual resources versus impact categories). The alternative is to organise a thorough re-evaluation or re-analysis of the existing studies with this goal.

3.2.2 Driving forces for resource use and environmental impacts

Eight core activities in the production-consumption structure that appear to contribute most to environmental impacts were identified in Chapter 2. They can be seen as first order driving forces that pull resource use and generate environmental impacts.

The mere conclusion that these sectors are of key importance for impacts is only a starting point for developing a resource policy. However, by analysing these key sectors in more detail, a better idea of the relation between resource use and environmental impacts and on appropriate research approaches can be obtained.

Combustion processes

Combustion processes contribute mainly to greenhouse effect, acidification and photochemical ozone formation. Causal relations are best reflected by NAMEA models, that explicitly separate non-fuel related emissions from fuel-related emissions. Gaps in knowledge here are:

- NAMEA-type databases are only available for countries that cover 50% of the European production volume, and often on a rather aggregated level.
- NAMEA-type databases typically do not cover emissions of heavy metals, particulates and PAH.

These two points could be a need for improvement.

Solvent use

Solvent use is among the main contributors to photochemical ozone formation. Emissions are not inherently related to resource use, due to potential mitigating measures like stripping, combustion, etc. From a point of view of resource policy there seems no need for more information in this field as there is no clear relationship between use and emissions of these substances and resources input into the economy. Measures typically are process-oriented abatement technologies, or in case that risk assessments show unacceptable emission levels, a phase out.

Agriculture

As discussed in Chapter 2, agriculture contributes to global warming, land use, emissions of nitrogen and phosphor and pesticides. If the products of agriculture (i.e. biomass) are regarded as a resource, the related contribution to global warming and pesticide emissions are relevant from a point of view of resource policy[5].

Dedicated studies into the relations between environmental impacts and agriculture are capable of dealing with all these points. Input/output studies in principle as well, though in practice the current NAMEAs are relatively weak in including nitrogen, phosphorus and pesticide emissions.

Metal extracting and refining

Metal extracting and refining can form a major source of (dissipative) emissions of metals. There are major complexities in estimating emissions/leaching from landfills and mining residues. Dedicated studies into related emission factors can to some extent handle this; it is, however, likely that this problem cannot be totally solved since uncertainties are high and emission factors depend also on normative choices[6]. Due to a lack of good emission factors, existing NAMEAs tend to be notoriously weak in including such emissions.

Dissipative use of heavy metals

Substance flow analyses are the best way to analyse the emissions from dissipative use from heavy metal applications (e.g. zinc plating). There are major complexities in estimating emissions/leaching metal applications and their impacts (e.g. some applications such as lead in roofing result in a slow leaching of lead by weathering; data about the speed of leaching are quite uncertain and contested). Dedicated studies into leaching behaviour to some extent can handle this. Due to a lack of good emission factors, existing NAMEAs are likely to be weak on this point. A point of attention is e.g. that emissions tend to be related to the *stock in use* in society, and not a fraction of an annual throughput.

Housing and infrastructure

Housing and infrastructure demand the input of mineral resources and wood, and generate a major part of the "inert" waste in society. Again, the problems related to estimating emissions/leaching

5 Note that agriculture actually is one of few sectors that have double relevance in resource policy. First, it *produces* (renewable) resources. And second, in doing so, it uses (like any other sector) resources.

6 This concerns most notably the time horizon one takes into account. On an infinite time scale, all metals in e.g. a landfill must be regarded as potential emission; if one works with shorter time frames, one can start to make (the difficult!) estimations which fraction will leach out to soil and water within this time frame.

of this waste arises (see the former paragraphs). A point of attention is e.g. that waste generation tends to be related to the *stock in use* in society, and not a fraction of an annual throughput.

Marine activities

Under marine activities the problem of anti-fouling agents is mentioned. As indicated already in Chapter 2, this is not a problem directly related to resource input in our society.

Chemical industry

The chemical industry is identified as one of the main sources of toxicity. There is, however, no direct relation between toxic impacts and resource input and hence the resource policy is probably not the most appropriate entry point for dealing with such toxicity impacts[7].

3.2.3 Weighting methods

The weighting methods used in the studies concern two aspects: a) weighting methods with regard to emissions to air, water and soil, and b) assessment and weighting methods with regard to the use (input), or better formulated: over-exploitation of resources in the economic system. Though there are gaps in knowledge with regard to b), this issue is not seen as a priority in the Communication on the resource strategy (COM 527, 2003). Hence, only gaps in knowledge with regard to a) seem to be relevant. This implies basically gaps in knowledge in life cycle impact assessment and valuation methods.

To identify the environmentally most relevant types of resource use it is necessary to have a concept of what it implies that something is "environmentally most relevant" and a method to make the concept operational. It is recommended to apply epidemiology based damage models for the identification of the environmentally most relevant resources.

3.2.4 Available methodologies

Strengths and weaknesses and the approaches of different methodologies used in the eight considered studies with regard to providing information for the resource strategy have been discussed in Chapter 2. This has been done on a number of main aspects. For each of the aspects, the main implications for knowledge development in the context of the resource policy are addressed below.

System delimitation

Only two of the studies (Nijdam and Wilting 2003 and Moll et al. 2003) deal with the full societal production-consumption system. Four others deal with final household consumption only (Dall et al. 2002, Labouze et al. 2003, Nemry et al. 2002 and Rixt et al. 2003), whereas two deal with specific materials (van der Voet et al. 2003 and Phylipsen et al. 2002).

In principle, for identifying environmental "hot spots" in the context of the resource policy, the full production-consumption system or at least the most important consumption domains need to be covered. A focus on specific materials is useful if it is clear beforehand that these are environmentally important.

Bottom-up versus top-down

A disadvantage of bottom-up methods is their incompleteness. They are based on LCAs, which cut off process trees so that they are not totally covered. It appears that this in some cases can lead to an under-estimation of the environmental interventions of a few dozen percent. Furthermore, specific elements in the

7 The exception might be the use and conversion of heavy metals, but this point has been discussed explicitly above.

consumption patterns might not sufficiently be covered: a full consumption domain is often represented by just a few LCAs covering some main products, leading to large structural omissions. The underlying LCAs often do not include impacts related to production of investment goods, and are often weak in (diffuse) emissions of toxic substances. They are based on a multitude of studies by different author teams and hence often based on an incoherent starting point. Bottom-up studies are time consuming, but do not lead to a structural comprehensive database that can be improved, expanded, and regularly updated.

Input/output approaches perform better in this respect, but suffer from other problems:

- A relatively low resolution; i.e. assuming that per monetary unit the same goods/mass flows are delivered to different sectors
- Data gaps or resolution differences with regard to data that have to be used for imported products;
- Assuming a proportional allocation of environmental impact per monetary unit of services and goods delivered to different sectors;
- Treating investments as final use rather than elements contributing to final consumer goods.

Elasticity and recycling

Elasticity and recycling were mentioned as attention points in methodological development in Chapter 2. However, it was concluded that these points do not need major research or method development but rather a conscious choice in applying existing methods and approaches

Aggregation

Chapter 2 states under aggregation that "The level of aggregation in a presentation is very important for the ranking of materials and product groups. Highly aggregated groups can come up high in the ranking simply because of their size, while the same group would disappear from the top of the ranking when disaggregated, because the environmental impacts are then spread over many products".

This problem is not so much a matter of knowledge development, but defining good practice.

Updating data

It was concluded in Chapter 2 that top-down methods based on input/output models probably have clearly better possibilities to keep data updated than studies based on bottom-up approaches.

3.2.5 Summary of knowledge gaps

From the above, one can summarise that the following information gaps exist:

1. The Communication on resource policy sees the *impacts* related to resource use, rather than resource use as such, as the main problem. Insight in correlations and causal relations between resource use and environmental impacts is hence essential[8]. It is recommended to apply epidemiologicly based damage models for this purpose.
2. The studies available can hardly be used directly to set priorities for the resource policy (i.e. an overall ranking of resources that enter the economic system, in relation to the main environmental impacts they cause)[9].

8 Only one NAMEA study gave such insight to a limited extent. There is hence a need for studies (or re-analyses of existing studies) that are able to document correlations or causal relations between impacts and resource inputs to the production-consumption system, at a relatively low level of aggregation (individual resources versus impact categories).

9 This is not a criticism on the reviewed studies; they generally were not meant to give such a prioritisation and were done for other purposes.

3. General problems in assessing impacts from resource use include:

   i. Models for estimating emissions of heavy metals from mining activities and dissipative use are still relatively weak.

   ii. Methods for impact assessment of toxic releases are improving, but will stay weak in the foreseeable future.

   iii. The local character of many impacts (e.g. water use, diffuse emissions of heavy metals, direct versus indirect intake routes of e.g. lead emissions from pipes) is difficult to reconcile with the generic nature of assessment methods.

   iv. The over-exploitation of renewable resources tends to be a weak point in assessment methodologies.

4. Bottom-up studies currently have the following weaknesses:

   i. They are notoriously incomplete.

   ii. Investment goods are in general fully excluded in the underlying LCAs.

   iii. They make systematic errors since often a few products are taken as representative for whole consumption domains.

   iv. They are based on a large number of existing LCAs that are generally not mutually coherent.

   v. They are time consuming to perform, but do not lead to a database that can be structurally improved, expanded, and easily updated and hence form no structural investment.

5. Top-down studies based on NAMEA type databases currently have the following weaknesses:

   i. They are only available for countries that cover 50% of the European production volume, and often on a rather aggregated level[10]. The databases available in the different EU member states are not harmonized.

   ii. They typically do not contain data of the *stock in use* in society of a specific long life resource, whereas for metals and building materials emissions or waste flows are related to the stock in use.

   iii. There are data gaps or resolution differences with regard to data that have to be used for imported products[11].

   iv. They assume a proportional allocation of environmental impact per monetary unit of services and goods delivered to different sectors[12].

   v. They include investments as final use rather than elements contributing to final consumer goods.

   vi. They currently only partially cover emissions from the use phase and waste management of final consumer goods.

6. Common weaknesses in both NAMEA-type of databases and bottom-up studies are related to diffuse emissions such as:

   i. Heavy metal emissions from mining activities and dissipative use of heavy metals, and emissions from landfills.

   ii. Detailed emissions of toxic substances, such as individual heavy metals, particulates and individual PAHs from combustion processes.

   iii. Emissions of nitrogen, phosphorus and pesticides in relation to agricultural activities.

10 A relatively low resolution has drawbacks, since NAMEAs assume that per monetary unit the same goods/mass flows are delivered to different sectors.

11 This point is mainly relevant for NAMEAs of individual EU member states with rather open economies; the EU as a whole is relatively more closed, so that imports are less important.

12 At the same time, the resolution of the best NAMEAs (500-1000 final product groupings) is still better than of bottom-up studies, which often try to estimate the impacts of final consumption on the basis of some 70 product LCAs.

3.3 Proposal for improving the knowledge base

Section 3.2 shows that currently there are important gaps and weaknesses concerning knowledge for a satisfactory assessment of the environmental issues for a resource strategy. Such a environmental assessment would, across different types of resources used and across their different applications, indicate which application/ resource combinations are most relevant from an environmental point of view. When in the past policy was formulated with regard to resources, this did not follow a systematic approach. Usually a *specific* resource was for a certain reason singled out for further attention, and via risk assessments or substance flow analyses priority applications with regard to this specific resource would be identified[13].

In order to come to a more comprehensive and integrated knowledge base that can underpin the resource policy, a number of strategic questions can be posed. Answering these questions leads to different solution strategies. The following section discusses these strategic questions and subsequent sections discuss the related strategic options.

3.3.1 Strategic questions

From Section 3.2, one can single out two main strategic issues that have to be taken into account when defining knowledge development for the environmental aspects of resource policy.

1: Resources contributing mainly to local problems and/or toxicity: to include or not?

Firstly, one can make a distinction between resources in terms of the volume that is related to the problem field. Some resources form a problem due to the fact that they are used in relatively large quantities, and hence lead to large emissions into the environment in high volume, which in turn is the main reason for environmental impact (such as fossil fuels, phosphates, and other fertilisers). Other resources lead to relatively small emissions, but due to the high impact per emitted volume (and the potential of causing important effects due to high concentrations close to the point of emission or specific exposure routes) they still have high policy relevance. This is particularly true for resources that mainly are seen as problematic for their toxicity impacts (e.g. various heavy metals)[14].

At the same time, Section 3.2.5 makes clear that weighting of resource use on the basis of toxicity impacts is very complicated. Emission factors for diffuse emissions can be thoroughly debated, generic impact assessment methodologies do not honour the local nature of many real toxicity problems[15], and despite all improvements in the last decade life cycle impact assessment of toxic releases keeps on being one of the weakest points in environmental weighting/ assessment. One would make the problems with regard to knowledge generation incomparably less complicated to forego any ambition in the resource policy with regard to weighting of resource for their toxicity impacts[16].

2: How to fill knowledge gaps: via studies for individual resources, bottom-up studies, or top-down approaches?

As indicated in Chapter 2, basically two strategies exist to fill out the knowledge gaps with regard to the environmental impacts of resources.

13 See for instance the string of Substance Flow Analyses done by e.g. CML or commissioned by the European Commission (DG Environment, DG Enterprise) in the field of phosphorus, nitrogen, and heavy metals such as lead and mercury.

14 Some examples: one of the major problems with the use of lead was their use in water pipes and solder for food cans, leading to semi-direct exposure of humans via water and food. A problem with many mining residues is the local pollution of ground water. Such problems are generally not well covered in generic environmental impact assessment approaches covering material flows or product flows in the total economy.

15 Such as the problem of lead in water due to the former use of lead pipes.

16 In fact, other types of policies, such as chemicals policy, may be better suited to deal with toxicity.

It concerns the bottom-up and a top-down approach. Both approaches can be used to give a comprehensive overview of impacts (including resource use) related to final consumption activities, the first via extrapolating information from existing LCAs to product groups, and the second by using input/output tables or NAMEAs.

A third strategy is, however, possible as well, that not has been covered by any of the considered studies, but was suggested already in the early 1990s by Udo de Haes and others[17]. The principle is to select the resources (a priori) seen as most relevant ones, and to perform Resource Flow Analyses (RFAs)[18] for these materials, if needs be allocating all kinds of other supply chains to processes that these materials are going through. The related environmental interventions to the systems build can be analysed by making use of Life cycle Impact Assessment (LCIA). Overall this results in a combined RFA/LCIA approach. Probably a few dozen of such studies would cover most relevant resources and if executed in more or less similar fashion, in the end should allow for a weighting of impacts across the different studies.

The following three sections will discuss the three strategies individually.

3.3.2 Strategy 1: Bottom-up functional studies

Main approach

Bottom-up functional studies are roughly organised as e.g. in Nemry et al. (2002) and Labouze et al. (2003). They focus on getting insight in the environmental impacts related to final consumption in society by selecting a number (usually various dozens) of final consumption activities (in households and/or by government expenditure), and extrapolating the final impacts on the basis of some LCAs representative for that consumption activity.

Usefulness for resource policy

In principle, bottom-up functional studies could be used in a way useful for resource policy if one would use the underlying database to trace back to resource use, and to analyse relations between resource use and emissions and consumption. However, as has been shown in Chapter 2, this approach often does not directly lead to the most relevant results for resource policy. The focus of all these studies is on final consumption. In terms of impacts, the main focus is on emissions from the production-consumption chain. This, of course gives insight in the use of the "resources" environmental media (which the resource policy includes in the definition of resources, see Figure 1 in Chapter 1). However, this information is not really added value; a variety of databases exists that give estimates for the total emissions of substances to air, water and soil in Europe.

Only as a "spin off", the input of resources into the economical system is taken into account, often in a quite incomplete way (limited number of resources, not making a distinction between different resources but using an aggregated measure such as MJ, etc.).

Knowledge gaps, organisational implications and conclusions

One activity that could be useful is to re-analyse the underlying data bases built up in the bottom-up studies available. This would allow to trace back resource uses now often not reported clearly in the reports, and to analyse correlations and causal relations between resource use with emissions and consumption. It is not totally clear how much time such a project would cost, but it is certainly closer to 100,000 Euro than one million Euro.

It is probably not useful from a point of view of resource policy to embark on a *new* extensive

17 N.F. van Maanen, G. Huppes and H.A. Udo de Haes (1990). Straf, beloning of gewetensrust? Over lange-termijn beleidsinstrumenten. In: CLTM, Het Milieu, Denkbeelden voor de 21[ste] eeuw. Kerkebosch, Zeist, Netherlands.

18 Both the word Substance Flow Analysis nor Material Flow Analysis covers in full what is proposed here. We propose to do analysis of flows of relevant substances (e.g. lead, mercury, cadmium), but also relevant materials (such as wood) or even energy carriers (such as oil and gas). We pragmatically called this 'Resource Flow Analysis' here.

EU-wide bottom-up study oriented towards final consumption functions to solve the knowledge gaps on the relation between resource use and environmental impact. The simple fact is that such a study would have too much a focus on final consumption functions, rather than resources. If a bottom-up approach would be used, it is probably better to take the resource perspective as a starting point, and build up the knowledge base from there. This is actually the second strategy that is proposed.

3.3.3 Strategy 2: Bottom-up input-related studies

Main approach

As a second strategy, one would embark on a number of truly resource-related studies. One would select a priori a number of primary resources that in terms of volume, or in terms of known environmental impacts, should be taken into account. Though this in part is a subjective affair, it is likely that Chapter 2, in combination with some additional research and an expert workshop will result in a reasonably robust list of relevant resources. After all, from the evaluation of existing studies it is clear that some resources are seen as relevant repeatedly in most of the studies. It is likely that such a list (at least initially) will consist of the following primary resources:

a) fossil fuels (oil, natural gas, coal)

b) 10-20 different metal ores

c) 5-8 minerals mainly used in the building industry (clay, lime, sand etc.)

d) 3-4 other minerals (phosphate ores, etc.)

e) 2-4 main wood classes

f) water

g) fish (and any other biotic resources)

h) land

In total one would end up with about 40 studies (about the same number of LCAs that bottom-up functional studies take as a basis). At least the studies mentioned under a-f probably can be performed as a kind of hybrid RFA/LCIA, in the following way:

Inventory

- Map the flows of the materials in society, estimate, when relevant, stocks in society, and identify in which processes the material is transformed or used.
- Calculate emissions per step in the chain that directly have to be allocated to this material for causal reasons.
- If there is a process in that chain that for causal reasons uses other inputs related to this materials, estimate the cradle to gate environmental impacts for this input (e.g. LCI databases)[19].

Impact assessment

- Perform an impact assessment making use of epidemiologically-based approaches, as well as well-known approaches such as CML 2001, etc.

The strategic question as of to what extent to include resources that cause mainly toxicity problems and mainly local problems might lead to skipping a few of the resources of the list (e.g. resources like sand mainly create space problems (or better: discussions on how to use scarce land) at a local scale, and it will be difficult to prioritize such issues, let alone solve them at EU level). A drawback of skipping such materials is that all kind of "supply chain" issues (e.g. energy use related to lead production) becomes invisible as well.

Usefulness for resource policy

The advantage of this approach is that there will be a sound, causal relation between the input

19 For instance: according to this logic for steel the energy used in blast furnaces would be allocated to steel used for buildings, but the energy use of the building would not be allocated to the steel used in buildings since there is no causal relationship.

of a primary resource into the EU economy and environmental impacts (in terms of outputs to water, soil and air). Per primary resource, this results in clear understanding of the importance of environmental issues per step in the chain and/or per application, which is essential information for the development/assessment of policy measures. If the different studies for primary resources are set up in a similar way (same LCI databases for supply chains, same LCIA[20] approaches), comparability across studies can be guaranteed.

To some extent, this approach has the same shortcomings as the functional bottom-up approach:

- They are incomplete in terms of allocating the full environmental impact to a resource, mainly due to subsequent cut-offs in the LCIs of other inputs to the substance chain;
- They cannot be easily updated.

Furthermore, due to the focus on input of primary resources, the relation with the final economic driver of environmental problems, final consumption, is lost. This, however, seems less of a problem in view of the goals of the resources policy.

Main knowledge gaps

For many of the resources mentioned, RFAs at country or even EU level are available. However, this knowledge is probably not structured in a comparable way. A main effort hence would be needed to re-organise data into a common format. Apart from this, a number of generic knowledge gaps still would need to be filled:

a) Models for estimating emissions of heavy metals from mining activities and dissipative use are still relatively weak.

b) Methods for impact assessment of toxic releases are improving, but will stay weak in the foreseeable future.

c) The local character of many impacts (e.g. water use, diffuse emissions of heavy metals, direct versus indirect intake routes of e.g. lead emissions from pipes) is difficult to reconcile with the generic nature of assessment methods.

d) The over-exploitation of renewable resources tends to be a weak point in assessment methodologies.

Implications in terms of organisation and budgets

Embarking on a research program that covers the knowledge gaps above will not come with a low investment. During the last few years, the European Commission (DG Environment and DG Enterprise) have commissioned quite a few relatively straightforward and simple SFAs on e.g. lead, mercury, and some chlorinated solvents, and these required a typical budget of 50,000 Euro each. Studies that include the impacts related to causally related inputs into processes in the substance chain typically have a price tag of around 100.000 Euro. If one assumes that some 40 resources have to be covered, and some learning effects will occur across studies, one probably will end up with a budget of some 2 Million Euro for basically the data gathering alone.

Apart from this, one needs a budget for the generic knowledge gaps (a-d under "Main knowledge gaps"). The problem here is that to some extent these knowledge gaps are "transscientific problems" that probably cannot be solved fully by science. It is probably best to set a few 100,000 Euro aside for these issues, and to be pragmatic in the assessment.

As for organisational implications, there is of course a variety of options to organise this research program. One could organise it directly via one or several of the European Commission's DGs (e.g. Joint Research Centre, Environment, EUROSTAT), but also the European Environment Agency with

20 Life Cycle Impact Assessment.

the European Topic Centre on Waste and Material Flows. Budget availability will probably be a major drawback. Another option is to have it put as a priority in the European research framework programmes. The very big disadvantage here is the big distance between executing consortium and the demand side, and the big liberty that a consortium (necessarily) has in executing the work, plus different types of intellectual property issues.

Conclusions with regard to Strategy 2

Organising a string of hybrid RFAs/LCIAs (or similar dedicated studies) with regard to some 40 primary resources, executed via a common format, is a suitable way to alleviate the main knowledge gaps with regard to the resource policy. However, costs in the order of magnitude of 2 Million Euro can probably not be avoided. Furthermore, if one truly tries to gather the data related to the different resources in a coherent database, one actually comes close to building a European NAMEA. This brings us to a discussion of strategy 3.

3.3.4 Strategy 3: Set up the European NAMEA

Main approach

Building a European NAMEA basically follows a top-down approach. Extended input-output analysis is applied to estimate the environmental interventions associated with use of a certain amount of commodities or services. Examples of this approach are the studies by Moll et al. (2004) and Nijdam and Wilting (2003). Both Japan and the United States have rather detailed NAMEA databases (see e.g. Garreth et al. 2004).

When properly designed, an input-output database can support three main functions (Heijungs, 1997). It can be used to produce:

- SFA/RFA (relevant for resource policy),
- LCAs of products or product groupings (relevant for product policy), and
- industrial sectoral analyses (relevant for a ″target group″ policy and IPPC).

As shown by Heijungs (1997), the dataset should consist of a “technology matrix” (representing the commodity inputs and outputs of processes in society) and a “resources and emissions matrix” (representing inputs from the environment and emissions to the environment of processes in society)[21]. Multiplication of the “technology matrix” with a so-called “transmission vector” results in a ″filtered″ matrix only zooming in on the desired resource[22]. If one, furthermore, multiplies with a so-called “final demand vector” (representing the final demand for commodities in society), the flows of the specific resource (and related emissions) in society are made visible.

The description above is provided in somewhat mathematical terms, but is identical to what is done in the individual RFAs in Strategy 2. Take a cadmium RFA as an example. Processes in which cadmium is mined, transformed, put into products, etc. are identified (basically the groundwork for setting up the ″technology matrix″), material flows between these processes are quantified often by first estimating an amount of the integrated product (e.g. an amount of NiCd batteries – an item showing up in the ″technology matrix″; the total mass flow determined by the ″final demand vector″), and then multiplying this by a cadmium content (and item part of the ″transmission vector″). Per process, primary resource use and emissions are estimated (part of the ″resources and emissions matrix″) etc. The clear added value of using such a structural approach over Strategy 2 is that it builds up a database that has a multi-purpose use and that can be improved and detailed over time[23].

21 Processes should be defined at an appropriate level of resolution for a meaningful allocation of inventory data (primary resource input and emissions) and commodity inputs to commodity outputs.

22 An example: the “technology matrix” shows as output from a specific process an amount of batteries. The “transmission vector” gives the percentage cadmium in these batteries. Multiplication gives a cadmium flow.

23 For instance, multiplication of the “final demand vector” with the “technology matrix”/”resources and emissions matrix” gives emissions per consumption domain, an issue relevant in product policy..

NAMEAs and economic input/output tables give exchanges of commodities between processes/sectors in economic terms, and hence are slightly different from the "technology matrix" indicated above. However, in practice they can be related so that the resulting database is expressed in both monetary and physical terms.

In order to set up a European NAMEA, the following approaches can be followed:

a) Use an existing NAMEA from either a member state or another world region that is likely to have a similar economic structure as the EU, and adapt/extrapolate this database for EU use.

b) Building up a European NAMEA (or better: technology and resources and emission matrices) from scratch.

Option a) can be seen as a first step that can prove the value of the approach, but in the end option b) is probably a more productive solution. As already indicated, this approach would include a lot of activities and information gathering that also has to be gathered if Strategy 2) would be followed:

- Stocks in use of specific materials (as a basis for estimating emissions)
- Elaborating dedicated emissions models for specific processes
- Etc.

Indeed, one could state that Strategy 3 is actually a coherent framework to perform the same data-gathering and –analysis as needed via Strategy 2.

Usefulness for resource policy

The advantage of this approach is that there will be an extensive, complete database available at a reasonable level of resolution that tracks material flows through the production and consumption realms (see Figure 1, Chapter 1). It will hence be possible to analyse correlations via various of cross-sections seen as relevant (final consumptions and impacts, final consumption and resource use, resource use and impacts, etc.). Consistency is inherently guaranteed. It will give a new quality to the efforts to identify those types of resource use that cause the important environmental impacts (given the inherent limitations in impact assessment methods, and uncertainties in emission estimations).

The initial price tag will probably be similar as for Strategy 2. However, the big advantage of this approach is that the structure developed can be systematically updated, expanded and detailed. Information about the industry structure and issues such as emission intensities, stocks, etc. can be held constant for a number of years, and be updated by e.g. a revision every 3-5 year. Also causal relations can be properly included, by modelling the Technology and Inventory matrix where relevant to an appropriate level of detail.

Main knowledge gaps

Apart from building the EU's NAMEA/ Technology and Inventory Matrix, a number of knowledge gaps already mentioned under Strategy 2 still would need to be filled:

a) Models for estimating emissions of heavy metals from mining activities and dissipative use are still relatively weak.

b) Methods for impact assessment of toxic releases are improving, but will stay weak in the foreseeable future.

c) The local character of many impacts (e.g. water use, diffuse emissions of heavy metals, direct versus indirect intake routes of e.g. lead emissions from pipes) is difficult to reconcile with the generic nature of assessment methods.

d) The over-exploitation of renewable resources tends to be a weak point in assessment methodologies.

Implications in terms of organisation and budgets

Embarking on a research program that covers the knowledge gaps above will not come with a low investment. It is likely that Strategy 3 needs a similar budget as Strategy 2.

Apart from this, a budget for the generic knowledge gaps (a-d in "Main knowledge gaps"). The problem here is that to some extent these knowledge gaps are "trans-scientific problems" that probably cannot be solved fully by science. It is probably best to set a few 100,000 Euro aside for these issues, and to be pragmatic in the assessment as also suggested for Strategy 2.

As for organisational implications, roughly the same options exist as for Strategy 2. One of the EU-related bodies could take the leading role, e.g. the European Commission (DG Environment, DG Joint Research Centre, Eurostat), the EEA and/or ETC/WMF. It could also be considered as a priority in the research framework programme. More than in the case of Strategy 2, for Strategy 3 hands-on involvement and leadership of one of the Commission's services seems to be preferred.

Conclusions with regard to Strategy 3

Setting up a European NAMEA/Technology and Inventory Matrix would close a knowledge gap with Japan and the US and would allow developing a tool that contributes to support of the different chain-oriented and system-oriented (environmental) policies of the EU, such as the resource policy, the integrated product policy (IPP), and maybe even substance policy[24]. The initial investment will be similar to the one of Strategy 2, but the added value is that a structure is build that lasts. During the last years, a lot of individual RFAs/SFAs have been performed at EU level. However, since they were not performed within a common context, they are not mutually comparable and cannot be connected. At the same time, from the above it is clear that a good European technology and emission matrix can be build for a budget equal to a few dozen RFA/SFA studies and deliver the same information in a structured way. Hence, it is very likely that an investment in Strategy 3 in the end will be more cost-effective than maintaining the current situation, i.e. ad-hoc funding of studies when needed.

3.4 Conclusions

The knowledge base on the environmental questions of the EU's resource policy is incomplete. In particular, there is a lack of understanding concerning the causal relationships between resource use and environmental impacts as the currently available studies in general do not correlate impacts with resource use, let alone to structurally analyse causal relations[25]. They give only a partial picture of the environmental "hot spots" within the uses of one resource, and across different resource types.

There are basically three strategies to overcome such knowledge gaps:

1. Exploit thoroughly the models behind the existing studies with a focus on the relation between resources and environmental impacts.
2. Make a selection of the resources a priori seen as most relevant, and perform for each of them Substance Flow Analyses or other adequate resource-specific analyses.
3. Set up and use for the analysis a detailed European NAMEA, specified from the outset in a way that takes into account the information needs of the EU's resources strategy (European top-down approach).

The first strategy probably can be realised for a limited investment of 100.000+ Euro. It gives, however, not a structural information basis that can be easily updated. The investment in the last two strategies is probably of a similar order of magnitude (some two million Euros each option).

24 The advantage of NAMEA is that a full I/O model of the economic system is build up, with information on resource use and –flows, emissions, in relation to consumption patterns. This allows for analyses via all kinds of cross-sections (individual resources, substances, or final products).

25 As indicated before, such an analysis might be possible by digging deeper in the underlying databases of the studies.

Approach c) actually covers similar research as approach b), but it has the advantage that a structure is build that lasts, and that allows for regular and relatively cost-effective upgrading/ updating. If a major investment will be made, the authors express a clear preference for option c).

It has to be noted, however, that due to "trans-scientific" elements that plague any of these analyses, certain weighting issues probably never can be resolved scientifically. We point particularly on issues related to:

- Toxicity.
- The relation between consumption and production activities and biodiversity loss.
- The damage due to stress on biotic resources and the weighting across such resources.
- Equality between different parts of societies and between different parts of the world.
- The role of precaution.

For an effective political process under such circumstances, any of the proposed research would therefore have to be conducted in close relation to parallel research and dialogue on:

- A precaution-based approach to a resources strategy building on already existing knowledge.
- An approach based on the scarcity of resources in Europe and globally.
- An approach building on equality among the different parts of the world based on concepts like environmental space.
- The requirements of different methods of linking the state of the environment to resource consumption (through materials, product groups, consumption areas etc.).
- The abatement strategies used in cases, where it has been possible to obtain agreement about and implementation of regulation of specific compounds and resources.

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Annex 1: Evaluation reports on the eight considered studies

The present annex provides a summary of information extracted for EU's resources strategy from the eight considered studies. Annex 1.0 provides a brief overview of all studies and Annex 1.1-1.8 cover main characteristics of each study, relevance of each study in an EU resources strategy context, assessment of the completeness and reliability of each study and finally a summary of results applicable for EU's resources policy for each study.

Annex 1.0: Overview of the eight considered studies.

Annex 1.1: Labouze et al. (2003), "Study on external environmental effects related to the life cycle of products and services".

Annex 1.2: Moll et al. (2004), "Study on the environmental implications of resource use – insights from input-output analysis".

Annex 1.3: van der Voet et al. (2004), Dematerialisation: not just a matter of weight - Development and application of a methodology to rank materials based on their environmental impacts.

Annex 1.4: Phylipsen et al. (2002), "Assessing the environmental potential of clean material technologies"

Annex 1.5: Nemry et al. (2002), "Identifying key products for the federal product & environment policy"

Annex 1.6: Dall et al. (2002), "Environmental impacts of Danish households"

Annex 1.7: Nijdam and Wilting (2003), "A view on environmental pressure on consumption"

Annex 1.8: Rixt et al. (2003): Household metabolism in European countries and cities Comparing and evaluating the results of the cities Fredrikstad (Norway), Groningen (The Netherlands), Guildford (UK), and Stockholm (Sweden).

Annex 1.0 Overview of the eight considered studies

A brief schematic overview of methods, scopes and main results of the eight studies is provided next page.

Applied abbreviations are explained below:

gw: global warming potential

od: Stratospheric ozone depletion potential

ac: acidification potential

po: photochemical ozone creation potential

ne: nutrient enrichment

tox: toxcicity (number in brackets refer to the number of toxicity indicators applied).

DALY: Disability Adjusted Life Years

PAF: Potentially Affected Fraction

TMR :Total Material Requirement

Report no and reference	1: Labouze et al. (2003)	2: Moll et al (2004)	3: van der Voet et al. (2004)	4: Phylipsen (2002)	5: Nemry et al. (2002)	6: Dall et al. (2002)	7: Nijdam and Wilting (2003)	8: Rixt et al. (2003)
Method	Bottom up	Top-down	Bottom up	Bottom up	Bottom up	Bottom up	Top-down	Hybrid
Fucus	Products/services	Entire economy	Materials	Materials	Broad selection of products	Household consumption	Entire economy	Household metabolism
Impact assessment	Characterisation	Characterisation	Characterisation	Characterisation and damage assessment	Characterisation	Mixed	Characterisation	Energy
Indicators (environment)	Gw, od, ac, po, tox(3)	Gw, ac, po, waste	Gw, od, ac, po, ne, tox(4), waste, radiation	Gw, od, ac, ne, po, tox(3) / DALY, PAF.	Gw, ac, po, oxygen depletion, waste	Primary energy, waste	Gw, ac, ne, po, noise.	Primary energy consumption
Indicators (resources)	Depletion. of non renewable raw materials	TMR, primary energy, land use	Land use, abiotic raw materials, bio diversity	Land use, fossil fuel and mineral depletion / "Additional energy"	Material intensity, energy intensity, water intensity	Primary energy Weighted resources	Land use, wood, water, fish	Primary energy consumption
Geographic area	EU-15	Germany	Netherlands	EU-15	Belgium	Denmark	Netherlands	Netherlands, Norway, United kingdom Sweden
Data								
Consumption (year)	1999+	1995-2000	2000	Late 1990'ties	2000	2000	1995	1990'ties
Production (year)	1990'ties	1995-2000	Early 1990'ties	Early 1990'ties	1990'ties	Early 1990'ties	1995	mid 1990'ties
Production (technology)	West European	Present	West European	West European	West European	West European	Present	West European
Aggregation								
Principle	Functional	NACE /EPA classification	Data availability	Data availability	Function based	Function based	Function based	Statistical account. principles
numper of products/ materials	13 product families	27-57 product groups	100 materials in 6 material groups	21 materials in four groups	9 function classes	800 products, 7 function classes	7 function classes	31-75 sectors, 14 product groups
Observed main driving forces behind environmental impact and resource use	- Transport - Building ccupancy - Food - Textile	- Construction - Food and agricultural. products - Metal products Electricity, gas, steam and hot water supply - Chemicals and chemical products	- Biomass from agriculture - Iron and steel - Aluminium - Concrete and cement - PVC/PE - Nickel, copper and zinc	- Building construction - Packaging - Consumer non-durables - Machinery and other equipment - Furniture and interior decoration - Infrastructure	- Building structure - Building occupancy - Transportation	- Food - Transportation - Housing	- Food - Housing - Leisure	- Fuels, heat and electricity - Food - Recreation and transportation

Annex 1.1: Labouze et al. (2003)

Main characteristics

Title of the report: Study on external environmental effects related to the life cycle of products and services.

Year of publication: 2003.

Names of authors and institutions: Eric Labouze and Véronique Monier (BIO Intelligence Service) and Jean-Baptiste Puyou (O2 France).

Name of commissioner: European Commission, Directorate General Environment,

Directorate A - Sustainable Development and Policy Support.

Approach: Lifecycle assessment of product systems at a macroeconomic level ("bottom up").

Indicators applied

Impact assessment is partly based on a problem oriented mid-point approach and partly a damage oriented end-point approach. The endpoint assessment includes "Years of life lost" (year). The mid-point assessment includes following indicators.

Depletion of non-renewable raw materials

Greenhouse effect

Stratospheric ozone depletion

Air acidification

Photochemical oxidation

Eutrophication

Human toxicity Aquatic ecotoxicity

Sediment ecotoxicity

Terrestrial ecotoxicity

Normalisation or weighting has not been applied and contributions to impacts are expressed in quantities of relevant equivalents (characterised data).

Focus of the study

The study focuses on products and services consumed by European consumers per year in 1999.

Types of resource use considered

The following raw materials are taken into consideration in the study:

- Oil, natural gas, coal and lignite.
- Bauxite, copper, chromium iron, lead, manganese nickel, silver, uranium and zinc.
- Phosphate, potassium chloride, barium sulphate, sulphur.

Level of aggregation

Products and services have been divided into 34 different categories, which have been classified in 13 product families. The product families include:

- Food and beverage
- Clothing and food wear
- Health and body care
- Transport
- Communication, recreation and culture
- Other products and services
- Electric and electronic products and equipment
- Construction work
- Building occupancy and
- Textile

System boundaries

The study covers the entire lifecycle of products and services consumed in the entire European (EU-15) economy in 1999 produced with mixed West European technology from the past decade.

Key results

Environmental impacts and resources depletion are mostly caused by transport (goods transport and private transport), and building occupancy (mainly due to the energy used to heat domestic and commercial buildings). Food is the largest source of eutrophication (due to fertilizer application) and a large source of global warming and photochemical oxidation (due to enteric fermentation and manure management. Textile is among the largest sources of acidification and photochemical oxidation.

Relevance of the study in an EU resources strategy context

The goal of the study is among other things to identify main driving forces behind raw material consumption and environmental impact associated with products and services consumed in Europe.

The study is general for Europe (EU-15) and the study provides geographically relevant average information for the region. Specific information for sub-regions (e.g. due to specific technology and specific climatic conditions) is not available and differences between regions, which are also relevant for the European resources strategy, do not appear.

Data on product and service consumption are from 1999 or later and process data refer to mixed western technology from the past decade. Thus, the study provides a pretty updated input to the EU resources strategy which is technologically representative for West Europe. The applied impact indicators cover a broad range of environmental impact categories and one indicator for raw material consumption. Environmental impact indicators are all relevant for EU's resources strategy. The applied indicator for raw material consumption (depletion of non-biological raw materials) expresses the contribution to raw material depletion in terms of kg antimony equivalents (Ministerie van Verkeer en Waterstaat, 2002) and the indicator gives an input to the EU resources strategy development in terms of loss of natural capital. The applied midpoint assessment is based on well-established principles, whereas the endpoint assessment is somewhat more experimental.

Completeness of the study

The list of products covered by the study is comprehensive, but some of the European economic sectors such as services and food products are less well represented than others.

The study covers a comprehensive list of non-renewable raw materials but many minerals and rare metals are not taken into account.

Renewable raw materials such as timber, water and wild fish have not been considered and space occupation such as land use for human settlements, infrastructure, industry, raw material extraction, agriculture and forestry has not been considered.

With a few exceptions, the study covers all processes in the economy: raw material extraction, component production, product production, use and end of life for all considered products. The exceptions include product production for buildings, domestic appliances, furniture, cleaning agents and information technology equipment and use of footwear and beverages. This omission is probably unimportant in most cases because of large environmental impacts and resource consumptions in material production phases and use phases, but can be important for products such as furniture where the relative importance of these phases can be of less importance.

The environmental indicators included in the study provide a broad picture of the environmental impacts associated with product and service consumption. However, inventory data and calculation methods for human toxicity and ecotoxicity are considered very uncertain and the results related to these aspects do only provide rough indications.

Indicators for resource consumption are limited to raw material depletion and the study does not provide any input to the resources strategy with respect to overexploitation of renewable raw materials and use of land. The study considers three indicators for waste generation (municipal and industrial waste; hazardous waste; inert waste), which appear as "other environmental indicators".

Impacts provided in the report are basically "impact potentials" (as standard in most LCAs) which refer to "full effects" of all emissions to air and water. The realised environmental impacts will therefore be smaller than the estimated impact potentials. The difference between impacts and impact potentials is determined by local and site-specific conditions.

Reliability of obtained results

As noted in the report, the study has to be seen as a pioneer work in the field of integrated product policy (IPP); an early stage of lifecycle assessment of products and services in the entire European economy. Due to time and resource constraints, the study is based on a considerable amount of uncertain data and methodological simplifications and it is stressed by the authors that the results of the work should be seen as a first step in developing a suitable methodology for future work – not a definitive basis for policy making. The authors recommend review of data and hypotheses and refinement hereof before concrete measures are taken. A number of improvement options are suggested.

Summary of results applicable for EU's resources policy

A link between product and service consumption and environmental impact and resource consumption in Europe has been established and groups of products and product families have been ranked with respect to contributions to various impact categories and raw material consumption. The study is a pioneer work based on quite uncertain data and many rough assumptions and simplifications and the obtained results do in general only provide indications.

It appears, however, from the study that most of the contributions to environmental impacts and raw material consumption are generated by two main categories

- transport (transport of goods and private transport of passengers by car),
- building occupancy (domestic and commercial buildings).

The total contribution to global warming, acidification, photochemical ozone formation, dust emission and depletion of non-renewable resources from the two categories is in the range of 45-65% of the total contributions of products and services in the entire economy and use stage (driving respectively heating) is generally dominating.

It furthermore appears that building occupancy dominates depletion of non-renewable raw material and generation of dust emission and that transportation (particularly by personal car) dominates photochemical oxidation.

Food production appears to be major driving force related to eutrophication (about 80% of contributions from the entire economy, primarily due to fertilizer application) and an important driving force for contributions to global warming and photochemical oxidant formation (due to enteric fermentation and manure management). Textile is among the most important driving forces related to acidification and photochemical oxidation.

The link between resource consumption and environmental impact is established through the product and service consumption and a direct link between resource consumption and environmental impacts has not been revealed. Thus, the resources behind the impacts can only be identified by analysing the model behind the results with this particular aim.

Annex 1.2: Moll et al. (2004)

Main characteristics

Title of the report: Study on the environmental implications of resource use – insights from input-output analysis.

Year of publication: 2004.

Names of authors: Stephan Moll, José Acosta, Alejandro Villanueva.

Institutions: Wuppertal Institute for Climate, Environment and Energy and European Topic Centre on Waste and Material Flows.

Name of commissioner: European Topic Centre on Waste and Material Flows.

Approach: Environmental assessment of product groups at a macroeconomic level (based on input-output analysis with data from National Accounting Matrices extended by Environmental Accounts (NAMEAs); "top-down") with a special focus on identifying correlations or links between resource use and emission/waste indicators.

Indicators applied

Pressures from resource use are assessed as Total Material Requirement (TMR), primary energy supply and land-use of built-up area. Specific environmental impact potentials are expressed as global warming potential, potential acidifying effect, tropospheric ozone formation potential and waste generation.

Normalisation has not been applied and contributions to impacts are expressed in quantities of relevant equivalents (characterised data). Application of TMR as indicator for raw material consumption represents an implicit weighting because all materials are added together and hence weighted equally.

Focus of the study

The study focuses on all products and services in the German economy entering into final demand (which in input-output terminology includes exports) in the period from 1995 to 2000 (for the different indicators data are available for different years within this period).

Types of resources use considered

The following resources are taken into consideration in the study:

- Fossil fuels
- Metals
- Minerals
- Biomass
- Built-up land (for settlements and infrastructure)

Level of aggregation

The level of aggregation is determined by availability of primary data and varies for the different indicators. 57 product groups are considered for total material requirement, primary energy supply, global warming potential, acidification potential and tropospheric ozone formation potential. 55 product groups are considered for land-use and 27 product groups are considered for waste generation. The grouping of products is in accordance with the NACE/CPA classification.

System boundaries

The study covers all products in the German economy (imported and domestically produced) for consumption in Germany or abroad (all categories of final demand according to National Accounting conventions). Production processes from raw material extraction to the point of sale (final demand) in Germany and abroad are included. However, the standard assumption for imported goods is applied, which means that foreign (imported) products are assumed to be produced in the same way as products from the corresponding German industry. This assumption is problematic for imported products that are either not produced in Germany (i.e. steel ore) or produced in very different ways in Germany (e.g. some agricultural products).

Emissions in the use phase are not included.

Recycling is included, in the sense that recycling is one of the 57 industries analysed, and following the standard economic logic of input-output analysis the industries (product groups) that use recycled material will have a smaller resource input and less emissions than if they had not been using recycled material. This is opposite to LCA practice where it is the industry (or product) supplying material to recycling that is to be ascribed the benefits of smaller resource input and less emissions.

Key results

The study identifies eight product groups characterised by high resource uses and high environmental impact potentials. The eight product groups, further aggregated into five clusters, are:

- Construction
- Biomass products (food and agricultural products)
- Metal products (motor vehicles, basic metals and machinery)
- Electricity, gas, steam and hot water supply
- Chemicals and chemical products

Relevance of the study in an EU resources strategy context

The goal of the study (to contribute to find answers to which resource uses are of most concern and should be addressed by a policy of sustainable resource management) relates directly to the European thematic strategy on sustainable use and management of resources.

For feasibility reasons, data are derived from Germany where a good database for resource related indicators (TMR) is available.

The system boundary is functional, i.e. relating to the consumption within the region (Germany), but including exported products (concept of "final demand" following National Accounting conventions).

Data on product volumes, resource use and environmental indicators are from 1995-2000 and represents the German economy. The quality of the data is high, but the assumption that foreign production (of imported products) is identical to German production adds significantly to the uncertainty of the results. The relevance of the results in EU as a whole has not been discussed and the extent that results can be extrapolated to other EU countries depends on how different the EU economy is from the German economy. Especially with respect to agriculture, fisheries and resource extracting industries, significant differences may exist.

Nevertheless, the applied methodology can readily be applied in other countries, and the import assumption could be corrected for by linking to foreign NAMEAs. The implicit recycling credit to industries/products using recycled material could also be corrected for easily. The applied impact assessment covers a broad range of resources pressure indicators and environmental impact indicators. The applied environmental impact indicators are all relevant for EU's resources strategy. The applied indicator for resources consumption covers total material requirement (fossil fuel, metals, minerals and biomass) in terms of mass and land use in terms of area. The study does not provide any input to the resources strategy with respect to scarcity or substitutability of different resources and land types. The applied impact assessment principles are well-established.

Completeness of the study

The study covers the complete volume of products entering into final demand in the German economy.

The degree of aggregation is very important for the ranking of product groups (the environmental impacts are "spread" on many products when a product group is highly disaggregated and vice versa). The degree of disaggregation is determined by the data availability, and other principles of disaggregation or degrees of disaggregation could mean that other product groups could turn out as important.

The study covers all production and recycling/ waste management stages for the products consumed in Germany, but not the emissions during final use, although the latter are undertaken by analyses of the contributions to the indicators from different human activities.

The study covers a comprehensive list of renewable and non-renewable raw materials, but renewable raw materials such as water and wild fish have not been given attention. Land has only been included as built-up land, i.e. excluding land use by agricultural and silvicultural production.

The environmental indicators included in the study provide a broad picture of the environmental impacts associated with product production. However, many toxic substances are not included in inventory data and the study does not provide any input to the strategy in terms of toxicity to humans or ecosystems.

Impacts provided in the report are basically "impact potentials" (as standard in most environmental assessments of products) which refer to "full effects" of all emissions to air and water. The realised environmental impacts will therefore be smaller than the estimated impact potentials. The difference between impacts and impact potentials is determined by local and site-specific conditions.

Reliability of obtained results

The results are based on reliable data sources and recognized methods for input-output analysis. The limitations of traditional input-output analysis (notably the import assumption, the implicit economic allocation and the high aggregation level) may be corrected for by expanding the analysis. It would also be an advantage if the exported products were separated from the consumption in the region. Nevertheless, the product groups identified as important are not likely to be affected by such improvements in methodology and presentation, although the relative order may change.

Summary of results applicable for EU's resources policy

The following product groups characterised by high resource uses and high environmental impact potentials are identified as important:

- Construction
- Biomass products (food and agricultural products)
- Metal products (motor vehicles, basic metals and machinery)
- Electricity, gas, steam and hot water supply
- Chemicals and chemical products

The study shows that the 8 top-ranking product groups score high on both resource use indicators and environmental impact indicators, implying that these product groups are important, disregarding the perspective.

The relationship between the resource use indicators and the environmental impact indicators were further investigated with the help of bi-variate correlation analyses.

Not surprisingly, a strong relationship is detected between the use of fossil fuels and "global warming potential" and "potential acidifying effect". Emissions of CO_2, NO_x, and SO_2, which belong to the groups of greenhouse gases and acidifying substances, are closely linked to the combustion of fossil energy carriers. Also a strong correlation is found between fossil fuels and generation of bulky-like wastes for this resource category. This can be explained by the large waste generation associated with coal and lignite mining, which is a specific German issue.

High correlations are also found between the TMR for metals and the air emission related impact potentials, linked to the large energy consumption in the metal processing industries. Since the processing of construction minerals and the generation of construction and demolition wastes are both linked to the construction industry, it is not surprising that a correlation is found between the TMR for industrial & construction minerals and generation of bulky-like waste.

Finally a correlation is found between land-use in terms of built-up area and "potential acidifying effects" and "global warming potential", which can be explained by the sectors agriculture, construction and transport also contributing significantly to the air emission related impact potentials either due to high indirect energy requirements or due to CH_4, N_2O and NH_3 emissions in the specific case of agriculture.

Although causal explanations could be found for the identified correlations, it cannot be concluded that all environmental impacts can be causally linked to specific resource uses or vice versa. Correlations may hint at causal relationships, but cannot prove them. Some correlations may be accidental rather than causal, and in some cases where a causal relationship exists it may still not turn up as a significant correlation due to "noise" or aggregation uncertainties.

Nevertheless, the study shows that the eight top-ranking product groups score high on both resource use indicators and environmental impact indicators, implying that these product groups are important, disregarding the perspective.

The study does not indicate any specific resource use indicator as more important than others in terms of indicating environmental impact.

Annex 1.3: van der Voet et al. (2003)

Main characteristics

Title of the report: Dematerialisation: not just a matter of weight - Development and application of a methodology to rank materials based on their environmental impacts.

Year of publication: 2003

Names of authors: Ester van der Voet, Lauran van Oers and Igor Nikolic

Name of institution: Centre of Environmental Science (CML), Leiden University.

Name of commissioner: Rijksinstitut voor Volksgezondheid en Milieu (RIVM).

Approach: Environmental assessment of materials at a macroeconomic level (based on LCA principles, "bottom up") by a combination of Material Flow Accounting (MFA) and Lifecycle Assessment (LCA).

Indicators applied

Impact assessment covers following indicators

Global warming*

Ozone layer depletion

Photochemical ozone formation

Acidification

Eutrophication

Aquatic ecotoxicity*

Marine ecotoxicity

Terrestrial ecotoxicity

Human toxicity

Land use competition (space occupation)*

Abiotic resources depletion*

Loss of biodiversity

Solid waste production*

Radiation

Five indicators marked with * are singled out in the report out as examples. Results for other indicators are reported for three different sets of system boundaries in appendices.

Normalisation has not been applied and contributions to impacts are expressed in quantities of relevant equivalents (characterised data) or percent of total impacts.

Focus of the study

The study focuses on yearly impacts of materials applied in the Netherlands in 2000. The impacts are considered from three different perspectives: 1) a "regional approach" where the focus is on processes that occur within the Netherlands, 2) the "consumption approach" where the focus is on processes which are induced worldwide by Dutch consumption and 3) the "production approach" where the focus is on processes worldwide induced by materials produced in the Netherlands for either home market or export markets.

Types of resources use considered

Metals, minerals, biomass and land are considered in the study. Fossil fuels are considered insofar they appear in the chains of the materials.

Level of aggregation

The selection of material categories is based on available data for material flow accounting (primarily "Eurostat database of material flows", 2002) and environmental assessment data (primarily "ETH database", 1996), resulting in approximately 100 different materials belonging to six different groups being considered.

The six groups are:

- Metals
- Chemicals and minerals
- Construction materials
- Plastics

- Biomass and
- Others

Data on environmental impacts and resource consumption are presented for specific materials only.

System boundaries

The study covers the entire lifecycle of materials from raw material extraction through material production to use and waste-management/recycling. Product manufacture is not considered, and use processes are included in terms of emissions from the materials with different applications. The products in which the materials are applied are disregarded. The study covers all major materials used in the Dutch economy in 2000 (Eurostat database of material flows (2002)) produced with mixed West European technology from the early 1990'ies (ETH database).

Key results

When total aggregated impacts are considered in a Dutch consumption perspective, the top-scoring materials in terms of environmental impact and resource consumption are biomass from agriculture (vegetable and animal), iron and steel, aluminium, concrete and cement, some of the plastics (PVC and PE) and some of the more bulky heavy metals (nickel, copper and zinc).

More than half of the total environmental impact caused by human activities in the Netherlands (the Dutch normalisation reference) can be assigned to "materials" as defined in the study (materials production, material emissions during use, material recycling and waste handling).

Relevance of the study in an EU resources strategy context

The overall goal of the study (to develop and apply a methodology to identify the materials that contribute most to environmental problems) is highly relevant to the EU resources strategy although the study is limited to the Netherlands with respect to material flows and West Europe (late 90ties) with respect to environmental data. Several system boundaries are applied, both functional (related to the consumption within the Netherlands) and regional (related to the processes occurring within the Netherlands) and a hybrid (related to the materials produced within the Netherlands), and the results of the study can therefore be related to very different questions.

Data on material consumption are mainly from year 2000, obtained by a mass-balance approach using data from a number of different sources, mainly the Dutch Statistical Bureau. As the data sources, data quality and collection procedures differ across the different materials, this may result in inconsistencies when comparing materials.

The environmental data are bottom-up LCA process data, representative of Western technology in the early 1990'ies, i.e. somewhat outdated.

The total list of indicators considered in the study cover a broad range of environmental impacts, impacts on humans and use of resources. The applied environmental impact indicators are all relevant for EU's resources strategy. The applied indicator for resources consumption expresses depletion of non-biological raw materials and land use competition (space occupation) and provides an input to the EU resources strategy development in terms of loss of natural capital and loss of environmental media. The applied impact assessment method is well-established, but it should be noted that a broad spectrum of different methods are still applied for assessment of contributions to toxicity and that other methods might come up with other priorities.

Completeness of the study

The list of materials covered by the study is comprehensive, but not all materials transferred through the Dutch economy have been included. Materials, which are not considered in the study, are for instance consumer minerals and chemicals such as pharmaceuticals and soaps, a number of "other" minerals (e.g. explosives and pyrite), wild fish and game.

The degree of aggregation is very important for the final ranking of materials (the environmental impacts are "spread" on many products when a product group is highly disaggregated and vice versa). The degree of disaggregation is determined by the data availability during the study and other principles of aggregation or degrees of disaggregation would yield other rankings.

The study covers raw material extraction, material production and recycling/waste management but not product manufacture and application in a product (only direct emissions of the material are considered). The production phase and use phase can be very important when the environmental impacts of the use of resources are considered in a lifecycle perspective and this has to be taken into consideration when the results are considered in the frame of EU's resources strategy.

The environmental indicators included in the study provide a broad picture of the environmental impacts associated with materials.

Indicators for resource consumption covers abiotic raw material depletion in terms of mass and the study does not provide any input to the resources strategy with respect to overexploitation of renewable raw materials such as water, timber and wild fish and game. The study covers land-use competition (space occupation), which is an important indicator for the resources strategy. Fossil fuels are only considered when they provide a direct input to materials (e.g. transportation or as feedstock) and the study only provides limited input to the resources strategy with respect to fossil fuels depletion. Value of different raw materials in terms of substitutability and scarcity are not given attention in the applied impact assessment method.

Impacts provided in the report are basically "impact potentials" (as standard in most LCAs) which refer to "full effects" of all emissions to air and water. The realised environmental impacts will therefore be smaller than the estimated impact potentials. The difference between impacts and impact potentials is determined by local and site-specific conditions.

Reliability of obtained results

The study is a pioneer work with method development as one of its aims and as noted in the report, outcomes of the application of the method are subject to large uncertainties due to data gaps, data uncertainties, methodological choices and simplifications. The results therefore should only be seen as indicative. Further improvements are considered necessary before results can be the basis for policy on materials.

Summary of results applicable for EU's resources policy

A link between material consumption in the Netherlands and impacts on environment and resource consumption has been established, and materials have been ranked with respect to contributions to various impact categories and resource consumption. Some observations applicable for EU's resources policy are provided below:

1) The contributions to environmental problems appear to lie mainly in the production phase. Some, but not many, materials are clear exceptions to this rule.
2) Sometimes, the material itself contributes a lot to the score. In many cases, however, it's the energy and auxiliary materials that determine the score.
3) Top-scoring materials in general both have a relatively high contribution per kilogram, and have a relatively large volume of flows.
4) When products are seen in a regional perspective, a Dutch consumption perspective and a Dutch production perspective, iron/steel seems to be by far the most important materials in terms of raw material use (kg antimony equivalents). Agriculture products

(vegetables and animal products) seem to be by far the most important materials in terms of land use and eutrophication. Agricultural products, iron and steel appear to be the most important products when contributions to global warming are considered. Polyethylene (PE) appears to be the most important source of photochemical oxidant formation.

5) When all considered impacts are weighted equally and materials are considered in a Dutch consumption perspective (including national and abroad impacts), the top-scoring materials in terms of environmental impact and resource consumption appear to be biomass from agriculture (both vegetable and animal), iron and steel, aluminium, concrete and cement, paper and some of the plastics (PVC and PE) and some of the more bulky heavy metals (nickel, copper and zinc).

The link between resource consumption and environmental impact is established through the material consumption and a direct link between resource consumption and environmental impacts has not been revealed. Thus, the resources behind the impacts can only be identified by analysing the model behind the results with this particular aim.

Annex 1.4: Phylipsen et al. (2002)

Main characteristics

Title of the report: Assessing the environmental potential of clean material technologies

Year of publication: 2002

Names of authors: D. Phylipsen, M. Kerssemeeckers, K. Blok, M Patel and J. de Beer.

Name of institution: Ecofys

Name of commissioner: European Commission, Joint Research Centre, Institute for Prospective Technological Studies

Approach: Environmental assessment of materials at a macroeconomic level (based on LCA principles, "bottom up"). Assessment of environmental improvement with three different scenarios of cleaner material technologies implemented.

Indicators applied

Impact assessment is based on the EcoIndicator99 method (Hierarchist perspective) and the study includes the following indicators: carcinogenesis, summer smog, winter smog, climate change, radiation, ozone depletion, ecotoxicity, acidification/eutrophication, land use, minerals depletion and fossil fuel depletion. The impact categories have been aggregated into three damage oriented impact categories: human health, ecosystem quality and resource depletion.

Effects on human health are expressed as Disability Adjusted Life Years (DALY), effects on ecosystems quality are expressed and Potentially Affected Fraction (PAF) and effects on resources is expressed as the additional energy needed for future extraction (MJ).

Focus of the study

The study focuses on widely used bulk materials consumed per year in the European Union (EU-15) in the late 90'ties and in three different future scenarios.

Types of resources use considered

The study includes minerals, fossil fuels and land occupation.

Level of aggregation

The study covers 21 materials: eight polymers, four natural organic materials (paper and boards), four metals (steel, aluminium, copper and zinc) and five other mineral materials (cement, fired clay, glass, gypsum and lime).

As driving forces for the material consumption, four application areas are defined, encompassing 11 sub-areas: construction (residential, non-residential, roads and others), transport (passenger cars and others), packaging, and other manufactured goods (machines, furniture and interior decoration, consumer durables and non-durables).

System boundaries

The study covers production and recycling/waste management of materials for widely used materials consumed in the entire European economy (EU-15) in the late 90ties. Material production is modelled with data from the ETH database (Frischknecht 1996) representing western European technology from early 1990'ties.

Key results

The following materials have been identified as being most important: steel, aluminium, copper, zinc, lead, cement, glass, ceramics, polyethylene, polypropylene, polystyrene, PVC, PET, paper, boards and wood. The largest amounts of these materials are used in building construction and packaging, followed by consumer non-durables, machinery and other equipment, furniture and interior decoration, and other infrastructure.

The material sector accounts for roughly a quarter of the total environmental impact caused by human activities in the EU and there is a substantial potential to reduce these impacts by implementing available new technologies.

Relevance of the study in an EU resources strategy context

The goal of the study (to determine environmental effects related to current and future material production and consumption) is highly relevant to the EU resources strategy.

The system boundary is functional, i.e. relating to the consumption within the region (EU-15) and the study provides geographically relevant average information for this region. Specific information for sub-regions (e.g. due to specific technology and specific climatic conditions) and differences between regions, which is also relevant for the European resources strategy, is not available.

The data on material consumption are from 1997-2000, obtained by interpolation of a number of different sources. This approach is acceptable for the purposes of the study, but can result in inconsistencies when comparing materials, since the data sources and collection procedures may vary for different materials.

The environmental data are bottom-up LCA process data, representative of Western technology in the early 1990'ies, i.e. somewhat outdated.

The impact assessment method (Ecoindicator99) is widely used, and provides a broad and relevant input to EU's resources policy development, but it should be noted that when it comes to impact categories such and toxicity and carcinogenesis other widely used impact assessment methods may give other results. The impact assessment covers a range of human health indicators, ecosystem quality indicators, and resource depletion indicators. The damage model for land occupation expresses problems associated with occupation of land as an impact on ecosystems (disappearance of species). The damage model for resources expresses problems associated with raw material extraction as "surplus energy" for future raw material extraction from decreasing quality ores and provides a relevant input to the resources strategy in terms of dispersion and disappearance of non-renewable raw materials and hence accessibility of natural capital. Endpoint impact assessment is still at a somewhat experimental level.

Completeness of the study

The list of materials covered by the study is comprehensive and mostly quite disaggregated and materials applied in the European economy seem to be well covered when importance of the materials in terms of quantities used is taken into account. The study does not include food and fodder, textiles, and chemicals. It is furthermore noted in the report that the study excludes "a number of rare and heavy metals that probably make an important contribution to the 'Ecotoxicity' and 'Minerals depletion' environmental impact categories".

The degree of aggregation is very important for the final ranking of materials (the environmental impacts are "spread" on many products when a product group is highly disaggregated and vice versa). The degree of disaggregation is determined by the data availability during the study and other principles of disaggregation or degrees of disaggregation would yield other rankings.

The study covers material production and recycling/waste management but not product production and use, except in some accompanying case studies. The production phase and use phase can be very important when the environmental impacts of the use of resources are considered in a lifecycle perspective and this has to be taken into account when the results are considered in the frame of EU's resources strategy.

The indicators applied in the study provide a reasonable picture of impacts in terms of human health and ecosystem quality. The study covers land occupation, minerals and fossil fuels but it should be noted that overexploitation of renewable raw materials such as timber and water are not taken into consideration, and that substitutability of applied natural resources are not given attention in the applied impact assessment method. No indicator for waste generation has been applied.

The study is based on LCA process data which are known to be less complete than comparative input-output based data.

Impacts provided in the report are basically "impact potentials" (as standard in most LCAs) which to full effects of all emissions and resource uses. The realised impacts will therefore be smaller than the impact potentials. The difference between impacts and impact potentials is determined by local and site-specific conditions.

Reliability of obtained results

Reliability of results has not been discussed in the report and the applied LCA modelling and process data have not been described in detail, as this has not been a main focus of the study. An overall judgement of the study suggests, however, that the study provides reasonable indications relevant for EU's resources strategy, but that the indications need to be confirmed by a more detailed analysis of data and applied assumptions before application in policy making can be recommended.

Summary of results applicable for EU's resources policy

A link between material consumption in Europe (EU-15) and damage to human health, damage to ecosystem quality and resource depletion has been established and materials have been ranked with respect to contributions to various impact categories and resource consumption.

Packaging, construction of buildings, machines and domestic paper use appear to be the main driving forces of environmental impacts from the material sector (defined as the material production and recycling/waste management stages).

Steel appears to be a major driving force behind damage to human health in terms of carcinogenics. Paper, steel, cement and aluminium appear to be major drivers of damage to human health in terms of smog formation and climate change and damage to ecosystems in terms of land use and acidification/eutrophication.

Copper appears to be an extremely important material in terms of mineral depletion. Steel, paper and some of the most used plastics (polypropylene and polyethylene) appears to be among the most important materials in terms of fossil fuel depletion.

The study covers raw material extraction/ harvesting, material production and recycling/ waste management but not product production and use. The observations can therefore only be used for prioritising environmental actions related to the individual materials. The results cannot be used for comparison of different materials' environmental properties, as this would require a full lifecycle assessment including product production and use as well as estimates of products lifetimes.

"The material sector" as defined in this study (materials production, recycling and waste handling) accounts for roughly a quarter of the total environmental impact caused by human activities in the EU. In particular, materials have a considerable contribution to the impact categories 'Carcinogenics' (24 %), 'Climate change' (16 %), 'Ecotoxicity' (39 %) and 'Fossil fuel depletion' (28 %). The relative importance of the material sector for radiation, ozone layer depletion, acidification and land occupation is much lower (< 10 %).

The link between resource consumption and environmental impact is established through the material consumption and a direct link between resource consumption and environmental impacts has not been revealed. Thus, the resources behind the impacts can only be identified by analysing the model behind the results with this particular aim.

Annex 1.5: Nemry et al. (2002)

Main characteristics

Title of the report: Identifying Key Products for the Federal Product & Environment Policy.

Year of publication: 2002.

Names of authors: Françoise Nemry, Karine Thollier, Bart Jansen, Jan Theunis.

Name of institution: Institut Wallon de Développement Économique et Social et D'Aménagement Du Territoire ASBL and Vlaamse Instelling Voor Technologisch Onderzoek – Vito.

Name of commissioner: The Federal Services of Environment – Department of Product Policy.

Approach: Lifecycle assessment of selected products at a macroeconomic level ("bottom up").

Indicators applied

Indicators are divided into two main categories: 1) indicators related to input to processing and 2) indicators related to outputs from processing:

Input related indicators include:

- Material intensity (total material, mineral, metal, synthetic respectively natural organic materials)
- Energy intensity (lifecycle perspective, production phase and use phase)
- Water intensity

Output related indicators include:

- Greenhouse effect
- Acidification
- Photochemical pollutants
- Oxygen depletion
- Waste generation

Normalisation/weighting have not been applied and contributions to impacts are expressed in quantities of relevant equivalents (characterised data).

A number of other indicators (release of heavy metals and persistent organic pollutants and eutrophication) are discussed in the report but no results are provided because of modelling difficulties and lack of data.

Focus of the study

The study focuses on a large selection of products consumed in Belgium in one year in 2000.

Types of resources use considered

The study includes minerals, metals, fossil fuels water and natural organic material.

Level of aggregation

The study focuses on a broad spectrum of materials, which have been organised in large number of product categories which have again been organised in nine function classes. Results are provided per product category and per function class.

The function classes are following:

- Building structure
- Building occupancy
- Furniture for interior
- Electric appliances
- Health care and detergent
- Transport
- Information technologies and paper
- Packaging
- Textile and footwear

System boundaries

The study covers products consumed in Belgium economy in year. Production of products is modelled with data from IVAM LCA Data 3.0, Buwal 250, ETH-ESU 96, IDEMAT 2001 Pre4 database, and publicly available industry data and hence represents West European technology from the past decade. The study includes mining of raw materials, manufacturing of materials, use of products and disposal/recycling of used products. Material processing, product assembly and distribution to consumers have not been considered.

Key results

Among the considered function classes building structure appears to be the most important in terms of raw material consumption and waste generation. Building occupancy, transportation and to a more limited extent building structure appears to be among the most important function classes with respect to overall energy consumption and hence contribution to greenhouse effect, acidification and photochemical ozone formation.

Relevance of the study in an EU resources strategy context

The study is specific for Belgium with respect to product consumption, but with respect to process data the study refer to mixed western technology. Data on product consumption refer to 2000 whereas process data during the lifecycle refer to from the past decade.

Thus, the study provides a pretty representative and pretty updated input to the EU resources strategy for West European countries with the same overall consumption pattern as in Belgium. The extent to which results can be extrapolated to other countries is unknown.

The impact assessment covers a range of material consumption indicators (materials, energy and water) and a range of environmental pollution indicators related to air emissions, water emissions and waste generation and the study provides a broad and relevant input to EU's resources policy development.

Data on material consumption are divided between metals, minerals, synthetic and natural organic materials and it is possible to differentiate between main categories of resources. However, the materials are weighted equally and the study does not provide any input to the resources strategy with respect to scarcity of different resources or value in terms of substitutability. Space occupation such as land use for human settlements, infrastructure, industry, raw material extraction, agriculture and forestry has not been considered. The applied impact assessment method is based on well-established principles.

Completeness of the study

The list of materials and products covered by the study is comprehensive and results are provided both at a disaggregated level (products) and a more aggregated level (function classes). The selected products cover a large fraction of products consumed in modern European societies and the importance of different phases in the products' lifecycles (production phase, use phase and disposal phase) can be differentiated. The study includes food storage and cooking but production of food products in agriculture, fishery and food industry has not been included.

The study does not cover product assembly and distribution to consumers. This omission is probably unimportant for most products because of large environmental impacts and resource consumptions in material production phases and use phase, but can be important for products such as furniture where the relative importance of these phases can be of less importance.

The aggregation of materials in products is based on facts and is quite unambiguous. The aggregation of products in function classes is logical but not unambiguous (for instance "washing laundry" which has been put under "electric appliances" could also have been put under "textile" in the use phase. Other aggregation principles and function classes would therefore yield other results.

The indicators applied in the study provide a broad picture of impacts in terms of resource consumption and environmental impact. However, for application of results in EU's resources strategy it should be noted that no data on toxicity to environment and to human beings has been provided (due to lack of data) and that use of renewable raw materials include water but not other renewable raw materials such as timber. Indicators for raw material consumption are limited to mass and the study does not provide any input to the resources strategy with respect to overexploitation of renewable raw materials.

Impacts provided in the report are basically "impact potentials" (as standard in most LCAs) which refer to "full effects" of all emissions to air and water. The realised environmental impacts will therefore be smaller than the estimated impact potentials. The difference between impacts and impact potentials is determined by local and site-specific conditions.

Reliability of obtained results

Uncertainty of results has been analysed for different lifecycle phases. From this analysis it is concluded that the uncertainty is quite large, and that confidence intervals ranging from more than half to twice the estimates can be expected and that results should be interpreted as orders of magnitude.

Summary of results applicable for EU's resources policy

A link between product consumption in Belgium and raw material consumption and environmental impacts has been established and groups of products have been ranked with respect to contributions to various impact categories and raw material consumption. The main findings outlined below are probably relevant for most Western countries in EU.

House construction appears to be among the most important products when metal consumption and particularly mineral consumption and waste generation are considered.

House heating and transport appears to be among the most important functions when energy consumption and air pollutions in terms of acidification, greenhouse effect, photochemical ozone formation is considered.

Personal transportation appears furthermore to be the very most important source of metal consumption and to some extent also synthetic organic material consumption.

Packaging appears to be an important driver for metal and particularly synthetic and natural organic material consumption.

Toilets appear to be the most important product in terms of water usage, but also bathing equipment and washing equipment appear to be important.

All functions considered in the study are needed in a modern society and the results can be used to prioritise improvement actions in terms of raw material saving and reduction of environmental impacts associated with resource use.

The link between resource consumption and environmental impact is established through the product consumption and a direct link between resource consumption and environmental impacts has not been revealed. Thus, the resources behind the impacts can only be identified by analysing the model behind the results with this particular aim.

Annex 1.6: Dall et al. (2002)

Main characteristics

Title of the report: The environmental impact of Danish households (in Danish).

Year of publication: 2002

Names of authors and institutions: Ole Dall (COWI A/S), Jesper Toft (ØkoAnalyse) and Trine Thorup Andersen (DHI Water & Environment)

Name of commissioner: National Consumer Agency's Consumers' Information Service / Danish EPA.

Approach: Environmental assessment of household consumption divided on activities and products. Product streams are based on monetary consumption statistics and price index statistics and environmental impacts are determined by lifecycle assessment (bottom up LCA approach).

Indicators applied

Impact assessment covers following three indicators

- Raw material consumption (divided into "energy raw materials" and "other raw materials")
- Primary energy consumption (as a common indicator for energy related environmental impacts).
- Waste to landfill.

Raw material consumption is normalised with an average person's yearly consumption and weighted according to known reserves of non-renewable raw materials or yearly productivity of renewable raw materials according to the EDIP method (Wenzel et al. 1997 and Hauschild and Wenzel 1998). Renewable raw materials have only been considered when total consumption exceeds replacement. Primary energy consumption and waste to landfill has been normalised with an average person's yearly consumption respectively landfill disposal.

A semi-quantitative toxicity assessment of the most important household chemicals is also included in the study.

Focus of the study

The study focuses on yearly impacts of products purchased and consumed by private households in Denmark in 2000, including products produced abroad.

Types of resources use considered

Fossil fuels, metals, minerals and biomass are considered in the study.

Level of aggregation

Household consumption is represented by approximately 800 products aggregated into 30 major activities and 7 activity groups:

- Food consumption
- Clothing
- Hygiene and health
- Leisure
- House cleaning
- Housing
- Transport

Data on environmental impacts and raw material consumption are presented for the 7 activity groups and the 30 product groups. The data cover 93% of the household consumption, the remainder being public transport, charter travelling and smaller consumption items for which environmental data have not been available.

System boundaries

The study covers the entire lifecycle of products from raw material extraction through material production and product manufacture to use, waste management and recycling. The study covers all major products used by private households in 2000 (Statistics Denmark) produced with Danish and West European technology from the early 1990'ties (EDIP database).

Key results

Food consumption, transport and housing appear to be the most important driving forces for raw material consumption and primary energy use covering about two thirds of the households' total impact. Out of the household chemicals, the most environmental impact is related to textile washing agents.

Relevance of the study in an EU resources strategy context

The overall goal of the study (to assess the possibility of applying the consumption statistics to provide a continuous inventory and assessment of the environmental impacts of households) is highly relevant to the EU resources strategy.

The system boundary is functional, i.e. relating to the consumption within the region (Denmark), but limited to household consumption.

Data on consumption patterns are from 2000. Environmental data are from the early 1990'ies, with the exception of more recent data for electricity and heat, i.e. somewhat outdated.

The applied impact assessment includes one indicator for raw material consumption and two indicators for environmental impacts (waste and primary energy consumption). The applied indicator for raw material consumption differentiates energy carriers and other raw materials and differentiates renewable raw materials and non-renewable materials, taking overexploitation of renewable raw materials into account and the study provides an input to the EU resources strategy development in terms of loss of natural capital.

The impact assessment method of energy consumption and waste generation is specific for Denmark (due to normalisation with Danish average). The impact assessment of raw materials (with weighting based on known reserves) has been widely used in Denmark and elsewhere, but the relevance of the weighting principle can be discussed (Jolliet et al. 2003). Characterisation and normalisation is based on well-established principles.

Completeness of the study

The list of products and activities covered by the study is comprehensive. Missing products are reported and includes for instance tobacco, make up, and small electrical equipment's energy consumption. Modelling of processes behind products and activities is not always complete due to data gaps. House construction and maintenance is for instance left out of consideration and food and beverage production is for instance based on a simple and quite incomplete model.

The aggregation into seven activity groups is function-based and rational. Other function-based aggregation principles at the same aggregation levels would probably yield similar rankings and hence same results of environmental assessment. The aggregation at the 30-product-level is more arbitrary and very important for the final ranking of products (the environmental impacts are "spread" on many products when a product group is highly disaggregated and vice versa). Other principles of aggregation or degrees of disaggregation would yield other rankings.

The study covers raw material extraction, material production, product production, packaging and distribution use and disposal. Data on recycling are very coarse. Incomplete modelling of recycling can be important for results on raw material consumption and energy consumption for products produced from materials with high impact during material production and low impact during re-melting (e.g. steel and particularly aluminium).

Primary energy use and waste generation are the only environmental indicators applied. Primary energy is a quite good single indicator because energy is widely based on fossil fuel combustion in Denmark and one of the most important sources of global warming, acidification, photochemical ozone formation, particulate formation and to some extent nutrient enrichment. But it should be noted that it neglects significant contributions to global warming from methane and laughing gas (mostly from agriculture), contributions to acidification from ammonia (mostly from agriculture) and emissions of volatile organic compounds e.g. from plastic production and paints application. Toxicity aspects are neglected for all products except a selection of chemicals.

The indicator for raw material consumption covers renewable and non-renewable raw materials (normalised and weighted). The applied weighting principle does not take the value of different raw materials into account and non-substitutable raw materials such as phosphate (for fertiliser) is not given more attention than lignite which can be replaced by a wealth of other resources. The coverage of non-renewable raw materials is good but a threatened renewable raw material such as wild fish and specific types of timber has not been considered in the study. Land occupation is left out of consideration.

Impacts provided in the report are basically "impact potentials" (as standard in most LCAs) which refer to "full effects" of all emissions to air and water. The realised environmental impacts will therefore be smaller than the estimated impact potentials. The difference between impacts and impact potentials is determined by local and site-specific conditions.

Reliability of obtained results

The study is a pioneer work with method development as one of its aims and as noted in the report, outcomes of the application of the method are subject to large uncertainties primarily due to data gaps and data uncertainties. The uncertainty is estimated to at least a factor 2 and results therefore should only be treated as indicative. The study concludes that the consumption statistics are inadequate for a detailed assessment of the total household environmental impact, except for food products, and that the environmental product data needs to be updated on a more regular basis.

Summary of results applicable for EU's resources policy

Food consumption, transportation and housing appear to be the most important activities in terms of raw material consumption and primary energy use covering about two thirds of the households' total impact.

Production of food products appears to be the most important driver for resource consumption (particularly energy resources) and the most important driver of primary energy consumption. Other activities related to food consumption (food storage, food preparation and dishwashing) play a role too, but are less important.

Car transportation appears to be an important driver for raw material consumption (both energy and "other resources") and primary energy use, which by far exceeds other drivers such as public transportation.

Room heating appears to be a major driver for raw material consumption (particularly energy resources) and energy consumption.

Activities such as television watching, computer application and application of furniture and light appear to be important drivers for resource consumption and energy usage, contributing significantly to impacts from leisure.

Washing of clothes appear to be the most important source of impacts related to clothing in terms of both raw material consumption and energy consumption exceeding production of clothes by a factor four. Also the toxicity impacts (analysed separately) contribute to the significance of textile washing.

The origins of the environmental impacts (derived from primary energy consumption) have not been revealed in the study, and the raw materials behind the impacts can only be identified by analysing the model behind the results with this particular aim.

Annex 1.7: Nijdam and Wilting (2003)

Main characteristics

Title of the report: Milieudruk consumptie in beeld (A view on Environmental Pressure on Consumption), in Dutch.

Year of publication: 2003.

Names of authors: D.S. Nijdam and H.C. Wilting.

Name of institution: Rijksinstituut voor Volksgezondheid en Milieu (National Institute for Public Health and Environment).

Name of commissioner: Dutch Ministry of Environment.

Approach: Assessing the life-cycle environmental impacts per consumption domain based on annual household expenditures, economic input/output analysis, and environmental pressure per 'cell' in the I/O table ("top-down").

Indicators applied

Two types of indicators are used: 1) indicators related to input to processing and 2) indicators related to outputs from processing. This distinction is, however, not made explicit; the study uses a list of 'Environmental themes' that has been selected from a variety of literature sources,

Based on the CML LCIA methodology (Guineé et al., 2002)

- Greenhouse effect
- Acidification
- Nutrification (or Eutrophication)
- Smog formation

Other sources

- Pesticide use (unweighted aggregation per kg active ingredient)
- Road traffic noise (aggregated to car-kilometres with weighting factors per type of transport means. Distinction is made between car-kilometres in urban and rural areas. Trains and aircraft are not included. See Nijland, 2002).
- Land use (aggregation to type III land use with the help of weighting factors of Auhage (1994), that reflect the extent of affection of natural values)
- Wood extraction (not explained in the report; presumably counting kg of wood used)
- Water usage (not explained in the report; presumably counting m^3 of water used)
- Fish extraction (not explained in the report, presumably counting the kg of fish consumed)

Due to the high uncertainty in emission data and equivalency factors for PAHs, heavy metals and pesticides these have not been inventoried nor aggregated to a single indicator for toxic emissions. Energy use was also covered as a means for validation.

Normalisation or weighting has not been applied and contributions to impacts are expressed in quantities of relevant equivalents (characterised data).

Focus of the study

The study focuses on the total consumption in the Netherlands in one year. As far as possible data were gathered for 1995 as base year.

Types of resources use considered

The study focuses mainly on environmental pressure per consumption domain (hence end-use and product oriented). The study was not primarily focused at identifying resource use. The chosen pressure indicators, however, allow for an analysis of the following resource categories:

- Land use
- Wood extraction
- Water usage
- Fish extraction

Contributions to greenhouse effect are to a large extent related to use of fossil fuels. The study also covered energy use for validation purposes but was not included in the main analysis.

Level of aggregation

The study uses final consumer expenditures as a starting point for aggregation. On the basis of earlier classifications and some adaptations, the following sub-categories or function-classes have been used:

- Housing (the building plus heating and electricity usage)
- Furnishing (including plants, garden, and "light" it is unclear how electricity use has been split between furnishing and housing)
- Food (all activities related to food consumption
- Leisure (including holidays related transport)
- Hygiene
- Labour (e.g. traffic to/from labour)
- Clothing (including washing of clothing)

System boundaries

The functional unit of the study are the products and services consumed by final consumers in the Dutch economy in one year, with 1995 as base year. For a full description of the data gathering reference is made to Goedkoop et al. (2003). The environmental pressures per industry branch have been inventoried per economic region (the Netherlands: 105 sectors; OECD: 30 sectors; non-OECD: 30 sectors) and translated into environmental pressures per Euro turnover. Via input/output modelling the life-cycle environmental pressures per Euro for 350 categories of products/ services that are covered in the Dutch consumer budget survey are determined. The economic I/O data were gathered from the Central Statistic Bureau (CBS) for the Netherlands and GTAP [26]for other world regions. The main sources for determining environmental pressures were:

- The 105 sectors in the Netherlands: the Dutch Emission Registration system
- The 30 OECD and 30 non-OECD sectors:
  - The Edgar Database (reflecting emissions of CO_2, methane, N_2O, NO_x, SO_x and VOC per sector and world region in 1995); see www.rivm.nl
  - The GEIA Database (reflecting a.o. NH_3 emissions per sector and world region for the early 1990s); see www.rivm.nl
  - The FAOSTAT database was used to obtain data on land use, manure, pesticide use, irrigation, wood production and fishery.
  - For water usage the WRI (www.wri.org) data per sector and country were used
  - Various others.

Hence, in principle this study tried to model local technology as present in 1995. Due to the I/O approach no sectors have been 'forgotten'; the main problem is of course the level of aggregation used when defining sectors and product categories. For instance, since the food industry is seen as one category no distinction is possible in deliveries to other sectors that include only fish, and only other products such as leather (relevant for the pressure indicator fish consumption).

Key results

Concerning the resource-oriented impact categories, the study comes up with the following priorities:

- Land use: Food (56%), Leisure (14%), Clothing (9%), Furnishing (9%) and Housing (8%)
- Water usage: Food (53%), Leisure (14%), Clothing (9%), Furniture (8%), Personal care (7%)

26 www.gtap.agccom.purdue.edu.

- Wood extraction: Leisure (27%), Food (24%), Furniture (19%) and Housing (13%).
- Fish extraction: Food (72%), Leisure (12%) and Clothing (8%; probably an artefact in the I/O methodology since this should only be leather).
- Energy use: Housing (29%), Food (20%), Leisure (19%), Hygiene, Furniture and Labour each around 8%.

Contributions to greenhouse effect is dominated by Food (30%), followed by Leisure (22%, mainly due to transport for holidays), and Housing (17%; mainly for heating and electricity).

Relevance of the study in an EU resources strategy context

The study is specific for the Netherlands with respect to consumption of products and services, but with respect to process data the study refer to actual processes applied in the base year 1995 in the different regions where these processes take place. This is also the base year for data on product consumption.

Thus, the study provides a pretty representative and pretty updated input to the EU resources strategy for West European countries with the same overall consumption pattern as in the Netherlands. The extent to which results can be extrapolated to other countries is unknown.

The impact assessment covers a range of material consumption indicators (land use, water, fish extraction, wood extraction) and a range of environmental pollution indicators related to air emissions and water emissions.

Since the study was mainly developed with the idea of determining environmental pressure related to consumption in mind, it lacks the focus that one would have applied if one had done this study in view of development of a resource policy. Apart from the four categories mentioned (five including energy use), the study gives little information on resource use. Important categories such as metals, minerals etc. are lacking. It is not possible to distinguish between fish species, water sources, energy carriers nor wood types.

Environmental impacts are provided at characterisation level, which is generally accepted in LCA. However, importance of different types of environmental impacts cannot be differentiated. Toxic impacts (relevant for specific metals) have been excluded.

Completeness of the study

The list of functional classes is comprehensive and results are provided both at a disaggregated level (sub-categories of function classes) and a more aggregated level (function classes). In principle the applied I/O methodology and the use of the consumer budget survey implies that all final consumption in the Netherlands has been covered.

The study does not make a distinction between different phases in the product's lifecycle (production phase, use phase and disposal phase), though does differentiate between direct/indirect impacts, and for the indirect impacts in which regions this takes place (Netherlands, OECD, or Non-OECD). It is doubtful if diffuse emissions related to resource use in the use stage (see e.g. van der Voet et al. 2003) have been covered. This is particularly relevant for e.g. diffuse emissions of metals or toxic chemicals, but as stated above emissions of toxic substances have not been covered in the study.

The choice of functional areas and the allocation of activities to function areas is logical but not unambiguous. For instance, transport is divided over 'Labour', 'Leisure' and 'Food (shopping)', whereas other studies use 'Transport' as a functional area in itself. Some studies group 'Housing' and 'Furniture' (that here encompasses furniture, the garden, etc.) into one category.

The indicators applied in the study provide a broad picture of impacts in terms of resource consumption and environment. However, for application of results in EU's resources strategy it should be noted that no data on toxicity to environment and to human beings has been provided (due to lack of data) and that due to the focus of the study (final consumption), the focus on resource categories has been limited to water, fish, wood, land use, and to some extent energy use. Indicators for resource consumption are limited to mass and the study does not provide clear input to the resources strategy with respect to potential overexploitation of the resources covered. Impact assessment is mostly based on well-established principles.

Impacts provided in the report are basically "impact potentials" (as standard in most LCAs) which refer to "full effects" of all emissions to air and water. The realised environmental impacts will therefore be smaller than the estimated impact potentials. The difference between impacts and impact potentials is determined by local and site-specific conditions.

Reliability of obtained results

The study includes a validation that consists of a comparison with other studies at functional area level. The total impacts related to Dutch consumption in this study are in the same order of magnitude as calculated earlier by Blonk (1997). The same applies for energy use calculated by Vringer (2002).

Yet, the relatively important role of food, instead of housing, what comes out of many other studies as the main priority, is surprising. Furthermore, at detailed level there might be irregularities that might be inherently related to the "top-down" approached followed in this study. We refer to the example that fish extraction in part is allocated to clothing (probably an artefact since clothing is related to fur use from the food industry). What is also a bit surprising is that in the function area 'Clothing', the production of clothing is for most impact categories a factor 5-6 more important than washing and drying. Detailed clothing LCAs show the opposite (i.e. washing and drying is typically a factor 2 or higher more important than clothing production). This might point at irregularities concerning allocation of activities in the household at a deeper level.

Summary of results applicable for EU's resources policy

A link between product consumption in the Netherlands and environmental impacts and a limited number of resource categories has been established. Functional groups of consumption activities have been ranked with respect to contributions to various impact categories and resource consumption. The main drawback with regard to the EU's resource policy is that due to the final consumption focus the study focuses only on a limited number of resource categories (water extraction, wood extraction, fish extraction, land use, and total energy use). Important categories like metal and mineral use are not included. Also, priorities with regard to toxic impacts related to resource use were not included in the study. The study indicates the following priorities with regard to resource use:

- Land use: Food (56%), Leisure (14%), Clothing (9%), Furniture (9%) and Housing (8%)
- Water usage: Food (53%), Leisure (14%), Clothing (9%), Furniture (8%), Hygiene (7%)
- Wood extraction: Leisure (27%), Food (24%), Furniture (19%) and Housing (13%).
- Fish extraction: Food (72%), Leisure (12%) and Clothing (8%; as said probably an artefact).
- Energy use: Housing (29%), Food (20%), Leisure (19%), Hygiene, Furniture and Labour each around 8%.

All functions considered in the study are needed in a modern society and the results can be used to prioritise improvement actions in terms of raw material saving and reduction of environmental impacts associated with resource use.

The link between resource consumption and environmental impact is established through the product consumption and a direct link between resource consumption and environmental impacts has not been revealed. Thus, the resources behind the impacts can only be identified by analysing the model behind the results with this particular aim.

Annex 1.8: Rixt et al. (2003)

Main characteristics

Title of the report: Household metabolism in European countries and cities - Comparing and evaluating the results of the cities Fredrikstad (Norway), Groningen (The Netherlands),

Guildford (UK) and Stockholm (Sweden). "Toolsust project".

Year of publication: 2003

Names of authors and institutions: Rixt Kok, Henk-Jan Falkena, René Benders, Henri C. Moll, Klaas Jan Noorman.

Name of institution: Center for Energy and Environmental Studies. University of Groningen

Name of commissioner: European Union under the Fifth Framework Programme (Energy, Environment and Sustainable Development).

Approach: Assessment of energy consumption (direct and indirect) of products and services applied in households. Product and material streams are determined from monetary input/output tables containing economic transactions between sectors. Energy use is determined by energy analysis "Energy Analysis Program", EAP based on simplified lifecycle assessment principles. Hybrid analysis combining input/output study and LCA.

Indicators applied

Impact is expressed in terms of primary energy consumption and in a few cases CO_2 emissions.

Focus of the study

The study focuses on yearly energy requirements of households in four Northern and Western European countries at national level, city level and regional level and at different household size and income level in the 90'ties.

Types of resources use considered

Following energy carriers have been considered in the study: coal, oil, natural gas, uranium, water for hydropower and wood. Specific data have, however, not been reported.

Level of aggregation

The number of sectors included in the study range between 31 and 75 depending on statistical accounting principles in the four considered countries. The results have been aggregated into following categories:

- Food (including outdoor consumption)
- House rent or mortgage repayments, including maintenance of the house
- Household effects furniture, household appliances etc.
- Clothing and footwear purchase and repair
- Hygiene household services, nursery, cleaning equipment, personal care
- Education tuition, computers, books, and other reading material
- Recreation holidays, sports, games, toys, cultural activities, audio visual equipment, CDs etc., smoking
- Transportation; public transport, purchase and insurance of vehicles, parking, driving lessons, telephone, and postage
- Natural gas
- District heating
- Electricity
- Solid and liquid fuel
- Motor fuels
- Other consumption; insurance premiums, contributions, donations, and family festivities

System boundaries

The study considers the use of energy along the entire production and consumption chain of products and services from raw material extraction through material production, product production to use and waste management and eventual recycling.

The study covers all major goods used by households in four Northern and Western European countries/cities/regions in the 1990'ties produced with Western European technology (EAP database). The original EAP model was developed for the Netherlands. The latest update is from 2001 and contains 1996 data. The EAP model has been converted in a country-specific model by use of country specific energy-data.

Key results

Direct energy consumption (fuels, heat and electricity) make up about fifty percent of households energy consumption. Other fifty percent of household's energy is indirect and due to consumption of products (particularly food), and services (particularly recreation and transportation). The average energy requirement of households in different countries and in different regions and cities varies considerably.

Relevance of the study in an EU resources strategy context

The overall goal of the study is to rank and compare households' activities with respect to environmental impacts (in terms of energy use) in a lifecycle perspective and the study establishes an insight into households influence on EU's metabolism in terms of fuel consumption and associated environmental impact. The study is specific for Fredrikstad (Norway), Groningen (The Netherlands), Guildford (UK), and Stockholm (Sweden) with respect to consumption patterns, energy supply systems and processing systems during the 1990ties and the study provides a pretty updated input to the strategy which is geographically and technologically relevant for EU's resources strategy although Norway is not an EU member.

Considerable variation in households' energy consumption 1) between different types of households (income and size) and 2) between households located in different countries and settings (urban or rural) have been observed. This suggests that information derived from one situation in European Union should be transferred to another only with caution and that advice which is relevant and useful for one group of the population may not be as relevant for another. This is relevant for interpretation of the present study as well as for other studies in EU made for only one geographic unit.

Energy use is applied as a single impact indicator representing resource consumption (fuels, biomass and hydropower) and environmental impacts and the study provides an indirect input to the EU resources strategy development in terms of loss of natural capital (fossil fuels) application of renewable resources (hydropower and wood) and air pollution from fuel combustion. Most energy resources substitute each other and the environmental impacts associated with each are well known and the indicator provides a simple and useful input to the resources strategy.

Completeness of the study

The study covers a very complete list of products and services consumed in households in the Norwegian, British, Swedish and Dutch economy. Exceptions are, however, for instance taxation and expenditure on medical care since these costs are spread between households, employers and the government, making it difficult to ascertain how much each party contributes. It is informed in the study that previous investigations have shown that households' consumption is responsible for 60-70 percent of total energy consumption.

The aggregation of all products and services consumed by households is function based and rational. Aggregation level is quite high and mostly commonsense and other function based aggregation principles at the same level of aggregation would probably yield similar rankings and although some aggregation principles can be discussed (for instance whether computers and books belongs to "household effects", "education" or "recreation").

The study covers raw material extraction, material production, product production, packaging and distribution, use and disposal and/or recycling and appears complete with respect to inclusion of the entire product chain. Since the final energy use is related to actual budget expenditures, products produced for export are excluded and imported products used are included. However, it is unclear if energy intensities are differentiated per sector to region.

The only indicator applied in the study is primary energy (direct and indirect). Primary energy is a quite good single indicator representing environmental impacts and raw material consumption because energy is largely based on fossil fuel combustion and one of the most important origins of fossil fuel consumption and contributions to global warming, acidification, photochemical ozone formation, particulate formation and to some extent nutrient enrichment. Application of energy as indicator is well-established, but it should be noted that 1) it neglects significant contributions to global warming from methane and laughing gas (mostly from food production in agriculture), contributions to acidification from ammonia (mostly from agriculture) and emissions of volatile organic compounds e.g. from plastic production and paints application and 2) it neglects all other resource consumptions such as metals, minerals, wood, water, land etc.

Reliability of obtained results

The applied methodology brings about several uncertainties and four levels of uncertainty have been analysed and discussed: 1) uncertainties directly related to methodology, 2) uncertainties in the applied national databases, 3) uncertainties regarding the analyses of consumption items and 4) uncertainties at the level of budget expenditures and household characteristics. Thus, as noted in the report, most of the results have a considerable margin of error and results shall therefore only be treated as indicative. It is somewhat surprising that the study indicates that in the OECD direct energy consumption by households is around 15-20% of the total energy use in a typical OECD country, i.e. 15-20% of the energy consumed in a region. It is suggest in the report that if one uses a functional approach, i.e. takes the full final consumption of households, that then 40-50% of the related energy use is direct. Structural difference in economic systems between regions (which is unlikely if the 15-20% apparently is valid for the whole OECD) and time-lags apart, one would think that these values should be much closer (for the world as a whole, the percentage direct energy use measured over a number of years should in principle be *equal* to the percentage direct energy use from a functional perspective, unless important time-lags are at stake). It hence seems likely that the calculated indirect energy usage is under-estimated.

Summary of results applicable for EU's resources policy

The study establishes an insight into households influence on EU's metabolism of energy and related environmental impacts and household activities and products have been ranked with respect to contributions. Some observations applicable for EU's resources policy are provided below.

The average energy requirement of households in different countries varies considerably. In general, it is observed that households in countries with high expenditures have also high energy requirements.

Large variations in energy use are also observed in individual countries and different explanations apply to different countries, for instance household size, type and income, setting type (urban or rural), transportation needs, infrastructure and climate.

Direct energy consumption (fuels, heat and electricity) is responsible for about 40-50% percent of households' energy consumption. Direct energy consumption is due to house heating, motor driving and use of electrical appliances. Applied energy sources for house heating vary from country to country (natural gas is dominating in the Netherlands, district heating electricity and oil are dominating in Sweden, and electricity is dominating in Norway) but appears to be a major source of energy use and hence energy carrier consumption and environmental impact in all considered cases. Motor driving is another major source of energy use. Electricity use for household application cannot be distinguished from heating and no conclusions related to the specific importance of household applications can be made.

Indirect energy consumption is responsible for 50-60% of households' energy consumption.

Indirect energy consumption varies considerable between countries and the share of indirect energy use is the highest in countries with the highest expenditures. The importance of different activities and products is quite uniform and food, recreation and transport (public transport, purchase of vehicles, telephone and postage etc.) appear to be major driving forces behind energy consumption and hence energy carrier consumption and environmental impact in all studied countries and cases, although the rank of transport and recreation vary in specific cases.

The link between resource consumption (energy carrier consumption) and environmental impact is established through the product and service consumption and a direct link between resource consumption and environmental impacts has not been revealed. Thus, the resources behind the impacts can only be identified by analysing the model behind the results with this particular aim.

About ESTO

The European Science and Technology Observatory (ESTO) is a network of organisations operating as a virtual institute under the European Commission's – Joint Research Centre's (JRC's) Institute for Prospective Technological Studies (IPTS) - leadership and funding. The European Commission JRC-IPTS formally constituted, following a brief pilot period, the European Science and Technology Observatory (ESTO) in 1997. After a call for tender, the second formal contract for ESTO started on May 1st 2001 for a period of 5 years.

Today, **ESTO is presently composed of a core of twenty European institutions**, all with experience in the field of scientific and technological foresight, forecasting or assessment at the national level. These nineteen organisations have a formal obligation towards the IPTS and are the nucleus of a far larger network. Membership is being continuously reviewed and expanded with a view to match the evolving needs of the IPTS and to incorporate new competent organisations from both inside and outside of the EU. This includes the objective to broaden the operation of the ESTO network to include relevant partners from EU Candidate Countries.
In line with the objective of supporting the JRC-IPTS work, ESTO **aims** at detecting, at an early stage, scientific or technological breakthroughs, trends and events of potential socio-economic importance, which may require action at a European decision-making level.

The ESTO **core-competence** therefore resides in prospective analysis and advice on S&T changes relevant to EU society, economy and policy.

The **main customers** for these activities is the JRC-IPTS, and through it, the European policy-makers, in particular within the European Commission and Parliament. ESTO also recognises and addresses the role of a much wider community, such as policy-making circles in the Member States and decision-makers in both non-governmental organisations and industry.

ESTO members, therefore, **share the responsibility** of supplying IPTS with up-to-date and high quality scientific and technological information drawn from all over the world, facilitated by the network's broad presence and linkages, including access to relevant knowledge within the JRC' Institutes.

Currently, ESTO is engaged in the following **main activities:**

- A series of **Specific Studies**, These studies, usually consist in comparing the situation, practices and/or experiences in various member states, and can be of a different nature a) *Anticipation/Prospective analysis*, intended to act as a trigger for in-depth studies of European foresight nature, aiming at the identification and description of trends rather than static situations; b) *Direct support of policies in preparation* (ex-ante analysis); and c) *Direct support of policies in action* (ex-post analysis, anticipating future developments).
- Implementation of **Fast-Track** actions to provide quick responses to specific S&T assessment queries. On the other hand, they can precede or complement the above mentioned Specific Studies.
- To produce input to **Monitoring Prospective S&T Activities** that serves as a basis of experience and information for all other tasks.
- ESTO develops a "**Alert/Early Warning**" function by means of Technology Watch/Thematic Platforms activities. These actions are putting ESTO and JRC-IPTS in the position to be able to provide rapid responses to specific requests from European decision-makers.
- Support the production of **"The IPTS Report"**, a monthly journal targeted at European policy-makers and containing articles on science and technology developments, either not yet on the policy-makers' agenda, but likely to emerge there sooner or later.

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